Exercise walk-through

Light ▪ 3.2

eXercise

You must be able to

- use the law of reflection and describe the image in a plane mirror
- describe the glass-block experiment and use $n = \dfrac{\sin i}{\sin r}$
- use $n = \dfrac{1}{\sin c}$ and describe total internal reflection and its uses
- draw ray diagrams for a converging lens and describe the image with the right words
- explain how lenses correct short sight and long sight
- describe dispersion and the order of the colours

Method — Reflection in a plane mirror

The **normal 法线** is the line at 90° to the mirror. The **angle of incidence 入射角** equals the **angle of reflection 反射角**, both measured from the normal. The image in a plane mirror is the same size as the object, the same distance behind the mirror as the object is in front, and **virtual 虚像** (the rays only seem to come from it, so it cannot be shown on a screen). It is also laterally inverted: left and right are swapped.

Worked example 1. A point object is 3.0 cm in front of a mirror. Where is the image? To draw a ray from the object to an eye, first mark the image 3.0 cm behind the mirror, on the normal through the object. Draw a straight line from the image to the eye; where it crosses the mirror is the reflection point. The real ray goes from the object to that point and then to the eye. Check: the two angles at the mirror are equal.

Method — Refraction and the glass-block experiment

Shine a narrow ray from a **ray box** 光线盒 into a rectangular glass block. Mark the ray in and the ray out, remove the block, and draw the ray inside. Draw the normal where the ray enters and measure i and r with a protractor. Entering glass, light slows down and bends **towards** the normal; leaving, it speeds up and bends **away** from the normal, so the ray comes out parallel to the way it went in.

$$n = \frac{\sin i}{\sin r}$$

Worked example 2. $i = 60^\circ$ and $r = 35^\circ$ $(\sin 60^\circ = 0.87,\ \sin 35^\circ = 0.57)$. Then $n = \dfrac{0.87}{0.57} = 1.5$.

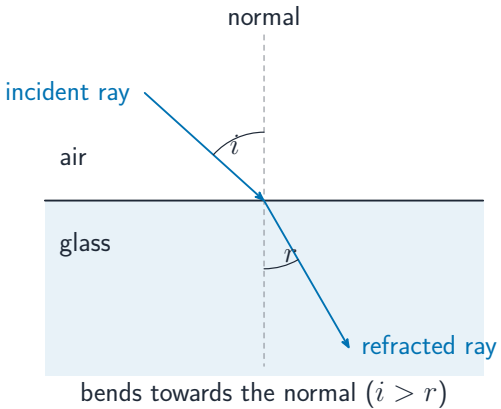
Worked example 3. Light enters water $(n = 1.33)$ at $i = 40^\circ$. Find r.

1. Rearrange: $\sin r = \dfrac{\sin i}{n}$.

Method — Refraction and the glass-block experiment

2. Substitute: $\sin r = \dfrac{0.643}{1.33} = 0.483.$
3. Answer: $r = \sin^{-1}(0.483) = 29^\circ.$

Method — Refraction and the glass-block experiment



A ray bending towards the normal as it enters glass

Method — Total internal reflection

When light tries to leave glass, the angle of refraction is bigger than the angle inside. At the **critical angle 临界角** c the refracted ray runs along the surface; above c no light gets out and it is all reflected inside:

$$n = \frac{1}{\sin c}$$

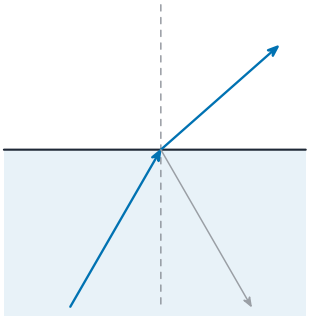
Worked example 4. Glass has $n = 1.5$. Find its critical angle. $\sin c = \dfrac{1}{1.5} = 0.667$, so $c = \sin^{-1}(0.667) = 42°$.

A ray aimed at the centre of a **semicircular block 半圆形玻璃块** meets the curved surface along the normal, so it does not bend there; whether it escapes at the flat face depends only on the angle at that face. Total internal reflection is used in **optical**

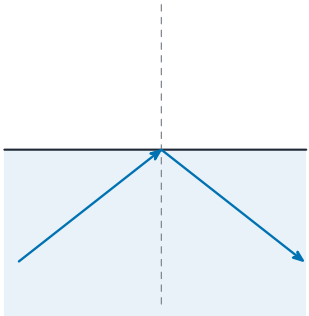
Method — Total internal reflection

fibres 光纤 (telephone and internet signals), in prisms in binoculars, and in reflectors on bicycles and roads.

Method — Total internal reflection



angle $<$ critical:
light refracts out



angle $>$ critical:
total internal reflection

Two blocks: one ray refracts out, the other is totally internally reflected

Method — Lenses and ray diagrams

A **converging lens** 凸透镜 brings parallel rays to the **principal focus** 焦点 F; the **focal length** 焦距 is the distance from the centre of the lens to F, and the **principal axis** 主光轴 is the line through the centre of the lens at right angles to it. A **diverging lens** 凹透镜 spreads parallel rays out.

To find an image, draw any two of the three standard rays from the top of the object:

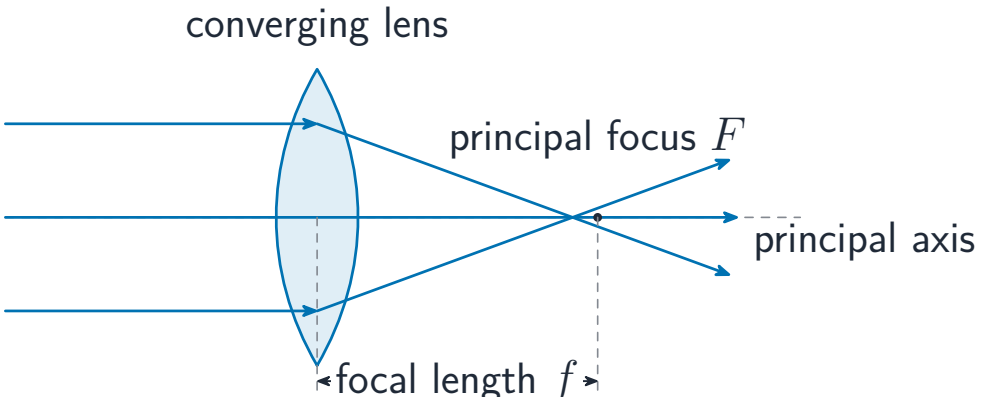
1. a ray parallel to the axis, which refracts through F on the far side;
2. a ray through the centre of the lens, which does not bend;
3. a ray through F on the near side, which refracts parallel to the axis.

Method — Lenses and ray diagrams

Where the two rays cross is the top of the image. If the rays cross on the far side, the image is **real 实像** (it can be shown on a screen) and **inverted 倒立**. If the object is inside F, the rays spread out; extend them backwards and they meet on the same side as the object, giving a **virtual** image that is **upright 正立** and **enlarged 放大的**: a **magnifying glass 放大镜**. Describe every image with three pairs of words: enlarged / same size / **diminished 缩小的**; upright / inverted; real / virtual.

Worked example 5. A ray diagram shows an object 6.0 cm from a lens and F marked 4.0 cm from it. The parallel ray from the top of the object refracts through F; the ray through the centre goes straight on; they cross 12 cm beyond the lens, below the axis. So the image is real, inverted and enlarged, 12 cm from the lens. Reading the focal length off a finished diagram works the same way backwards: the parallel ray crosses the axis at F, so measure the distance from the lens to that crossing.

Method — Lenses and ray diagrams



Parallel rays passing through a converging lens and meeting at the principal focus

Method — Correcting sight

Short-sightedness 近视: distant objects are blurred because the eye focuses the light in front of the **retina** 视网膜. A diverging lens in front of the eye spreads the rays first, so they meet on the retina. **Long-sightedness** 远视: near objects are blurred because the light would focus behind the retina; a converging lens brings the rays together a little first.

Method — Dispersion

A **prism** 棱镜 splits white light into a **spectrum** 光谱: red, orange, yellow, green, blue, indigo, violet. Red has the longest wavelength and the lowest frequency and is refracted least; violet is the opposite. Light of one frequency is **monochromatic** 单色.

Practice 2.1 ▪ 1 mark

State the law of reflection.

Solution 2.1

Worked steps

The angle of incidence equals the angle of reflection, both measured from the normal B1.

Practice 2.2 ▪ 3 marks

An object is 5 cm in front of a plane mirror. State three characteristics of its image.

Solution 2.2

Method: Reflection in a plane mirror

Worked steps

Any three of: virtual; the same size as the object; 5 cm behind the mirror (the same distance as the object is in front); laterally inverted B3.

Practice 2.3 ▪ 2 marks

Light enters glass with $\sin i = 0.80$ and $\sin r = 0.50$. Find the refractive index.

Solution 2.3

Method: Refraction and the glass-block experiment

Worked steps

$$n = \frac{\sin i}{\sin r} = \frac{0.80}{0.50} = 1.6$$ M1 A1.

Practice 2.4 ▪ 3 marks

Light enters a plastic block of refractive index 1.4 at an angle of incidence of $50°$. Calculate the angle of refraction. ($\sin 50° = 0.766$)

Solution 2.4

Worked steps

$$\sin r = \frac{\sin i}{n} \quad \text{M1} \quad = \frac{0.766}{1.4} = 0.547 \quad \text{M1}; \; r = 33^\circ \quad \text{A1}.$$

Practice 2.5 ▪ 2 marks

Diamond has a refractive index of 2.4. Calculate its critical angle.

Solution 2.5

Method: Total internal reflection

Worked steps

$\sin c = \dfrac{1}{n} = \dfrac{1}{2.4} = 0.417$ M1; $c = 25^\circ$ A1.

Practice 2.6 ▪ 2 marks

Describe what happens to a ray inside glass that meets the surface at an angle greater than the critical angle, and give one use of this effect.

Solution 2.6

Method: Total internal reflection

Worked steps

It is totally internally reflected: none of the light leaves the glass and the angle of reflection equals the angle of incidence B1. Use: optical fibres (or prisms in binoculars, or road and bicycle reflectors) B1.

Practice 2.7 ▪ 2 marks

Define the terms focal length and principal focus of a converging lens.

Solution 2.7

Method: Lenses and ray diagrams

Worked steps

Focal length: the distance from the centre of the lens to the principal focus B1.
Principal focus: the point on the principal axis where rays parallel to the axis meet after passing through the lens B1.

Practice 2.8 ▪ 3 marks

A converging lens is used as a magnifying glass. State where the object must be placed, and describe the image using three words.

Solution 2.8

Method: Lenses and ray diagrams

Worked steps

Between the lens and its principal focus (closer to the lens than F) B1; the image is enlarged, upright and virtual B2 *one mark for two correct words.*

Practice 2.9 ▪ 2 marks

State the order of the colours of the spectrum, starting with the one of highest frequency, and state what monochromatic light is.

Solution 2.9

Method: Dispersion

Worked steps

Violet, indigo, blue, green, yellow, orange, red B1. Monochromatic light is light of a single frequency (a single colour) B1.

Exam-style 3.1 ▪ 1 mark

A ray of light travelling in glass ($n = 1.5$) meets a glass–air surface at an angle of incidence of 45°. What happens to the ray?

A It refracts into the air, bending towards the normal.

B It refracts into the air, bending away from the normal.

C It travels along the surface.

D It is totally internally reflected.

Solution 3.1

Method: Total internal reflection

A It refracts into the air, bending towards the normal.

B It refracts into the air, bending away from the normal.

C It travels along the surface.

D It is totally internally reflected. ✓

Worked steps

D. The critical angle is $\sin^{-1}(1/1.5) = 42°$, and $45°$ is larger, so the ray cannot escape. A describes light entering glass, B describes refraction below the critical angle, and C happens only exactly at $42°$.

Exam-style 3.2 ▪ 1 mark

Which row describes the image of a person standing in front of a plane mirror?

A virtual, same size, laterally inverted

B real, same size, upright

C virtual, diminished, upright

D real, enlarged, laterally inverted

Solution 3.2

Method: Reflection in a plane mirror

A virtual, same size, laterally inverted ✓

B real, same size, upright

C virtual, diminished, upright

D real, enlarged, laterally inverted

Worked steps

A. A plane mirror image is virtual, the same size, and laterally inverted; it is never real (B, D) and never diminished (C).

Exam-style 3.3 ▪ 2 marks

A semicircular block of plastic has a refractive index of 1.5. A ray of light travelling inside the block, along a radius, reaches the centre of the flat face.
(a) Calculate the critical angle for the plastic.
(b) The ray meets the flat face at an angle of incidence of $50°$. State and explain what happens to the ray.
(c) A different ray, in the air, meets the flat face at an angle of incidence of $40°$. Calculate the angle of refraction inside the plastic. ($\sin 40° = 0.643$)
(d) State two uses of total internal reflection.
(e) State what happens to the speed of the light as it passes from the air into the plastic.

Solution 3.3

Method: Total internal reflection

Worked steps

(a) $\sin c = \dfrac{1}{1.5} = 0.667$ M1; $c = 42^\circ$ A1.

(b) The ray is totally internally reflected at the flat face B1, because 50° is greater than the critical angle of 42° B1.

(c) $\sin r = \dfrac{\sin i}{n}$ M1 $= \dfrac{0.643}{1.5} = 0.429$ M1; $r = 25^\circ$ A1.

(d) Any two of: optical fibres for telephone and internet signals; prisms in binoculars or periscopes; reflectors on bicycles and roads; endoscopes in medicine B2.

(e) It slows down B1.

Exam-style 3.4 ▪ 3 marks

Fig. 3.1 shows an object 2.0 cm tall placed 6.0 cm from a converging lens. The two principal foci are marked F.

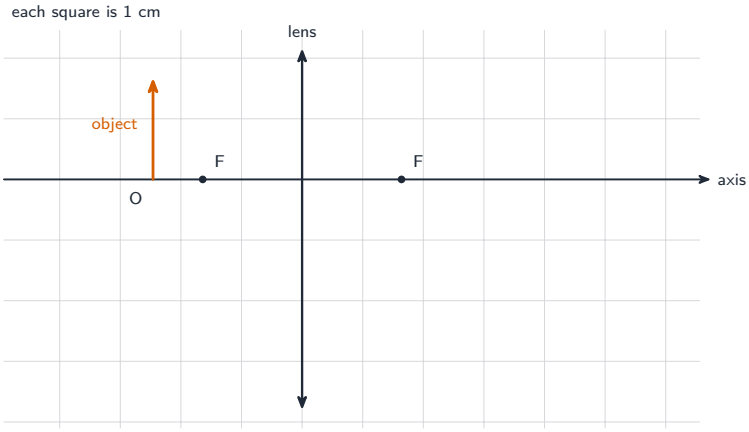
(a) On Fig. 3.1, draw two rays from the top of the object to locate the image. Label the image I, and determine the distance of the image from the lens.

(b) Describe the image using three words.

(c) The object is moved to 3.0 cm from the lens. State two ways in which the image changes.

(d) Explain how a diverging lens placed in front of an eye corrects short-sightedness.

Exam-style 3.4 ▪ 3 marks



Solution 3.4

Method: Lenses and ray diagrams

Worked steps

(a) Ray from the top of the object parallel to the axis, refracting at the lens through the far F M1; ray from the top of the object through the centre of the lens, undeviated M1; the two rays cross 12 cm beyond the lens, 4 cm below the axis, so the image I is drawn from the axis to that point and is 12 cm from the lens A1.
(b) Real, inverted and enlarged B2 *one mark for two correct words.*
(c) The object is now inside F, so the image becomes virtual and upright, on the same side of the lens as the object B1; it is still enlarged B1. (Any two correct changes.)
(d) The eye focuses light from a distant object in front of the retina B1; the

Solution 3.4

diverging lens spreads the rays out before they enter the eye, so they now meet on the retina B1.

Exam-style 3.5 ▪ 2 marks

A narrow beam of white light enters a glass prism.
(a) Describe what is seen on a screen placed after the prism, and name this effect.
(b) State which colour is refracted the most, and explain why in terms of frequency.
(c) A student says that the image in a plane mirror can be shown on a screen. Explain why the student is wrong.

Solution 3.5

Worked steps

(a) A band of colours (a spectrum) from red to violet B1; the effect is dispersion B1.

(b) Violet B1; it has the highest frequency (shortest wavelength), and the glass slows and bends higher-frequency light more B1.

(c) The image is virtual B1: the reflected rays only appear to come from behind the mirror, so no light actually passes through the image position and none can fall on a screen there B1.