IGCSE PHYSICS • EXERCISE SHEET

3.2 Light

Name: ______________ Class: __________ Date: ____________ **Total: 47 marks**

KEY WORDS refractive index 折射率 • plane mirror 平面镜 • critical angle 临界角 • focal length 焦距 • normal 法线 • reflection 反射 • normal 法线 • total internal reflection 全反射 • refractive index 折射率 • converging lens 凸透镜

Objective

Build the skills to answer exam questions on **light 光**: images in a **plane mirror 平面镜**, **refraction 折射** and the **refractive index 折射率**, **total internal reflection 全反射**, ray diagrams for lenses, and **dispersion 色散**.

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

1 Worked examples

■ Reflection in a plane mirror

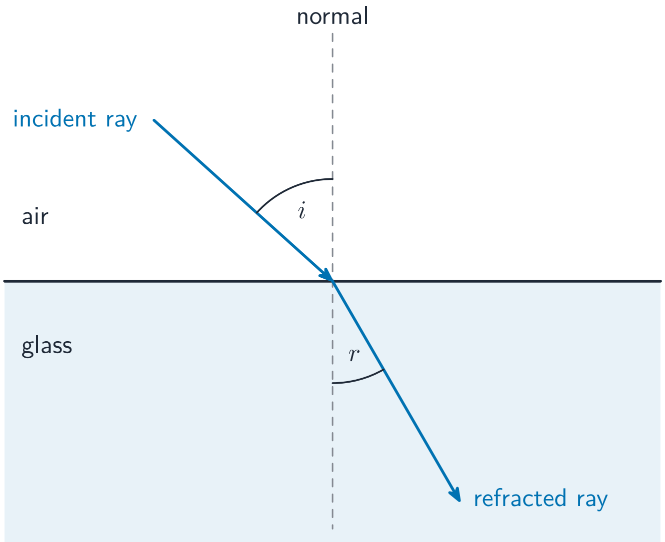
The **normal 法线** is the line at 90° to the mirror. The **angle of incidence 入射角** equals the **angle of reflection 反射角**, both measured from the normal. The image in a plane mirror is the same size as the object, the same distance behind the mirror as the object is in front, and **virtual 虚像** (the 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.

■ 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.

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



Entering glass the light slows and bends towards the normal, so $i > r$

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

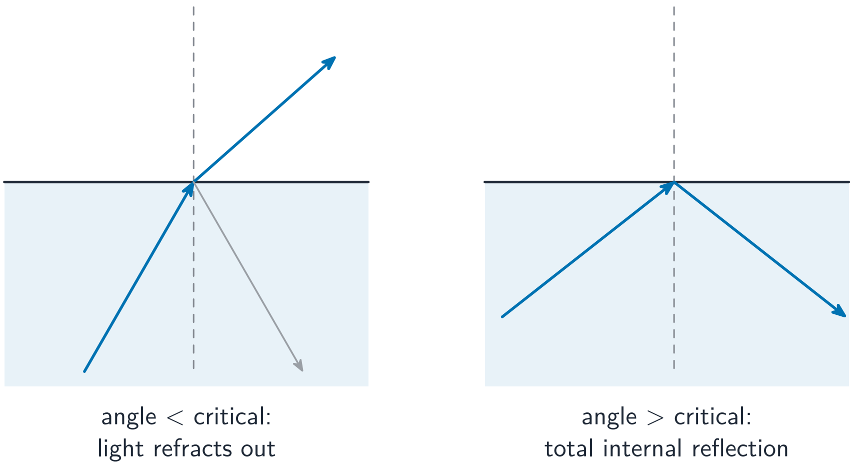
Worked example 3. Light enters water ($n = 1.33$) at $i = 40°$. Find r.

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

■ 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:

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



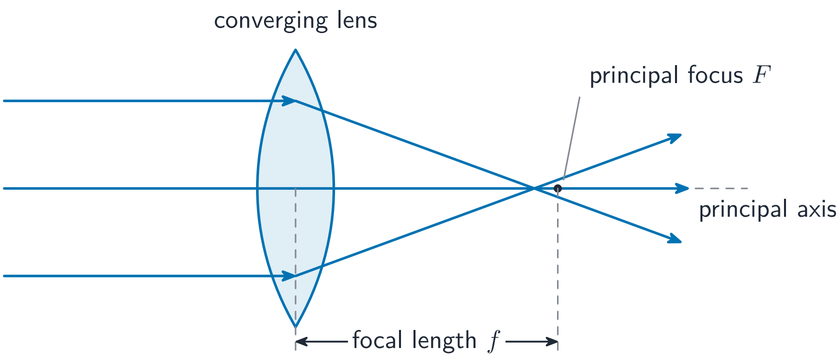
Above the critical angle the light is totally internally reflected

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

■ 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.



Parallel rays meet at the principal focus; the focal length is measured from the centre of the lens

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.

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.

■ 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.

■ 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.

2 Practice

2.1 State the law of reflection. [1]

2.2 An object is 5 cm in front of a plane mirror. State three characteristics of its image. [3]

2.3 Light enters glass with $\sin i = 0.80$ and $\sin r = 0.50$. Find the refractive index. [2]

2.4 Light enters a plastic block of refractive index 1.4 at an angle of incidence of 50°. Calculate the angle of refraction. ($\sin 50° = 0.766$) [3]

2.5 Diamond has a refractive index of 2.4. Calculate its critical angle. [2]

2.6 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. [2]

2.7 Define the terms focal length and principal focus of a converging lens. [2]

2.8 A converging lens is used as a magnifying glass. State where the object must be placed, and describe the image using three words. [3]

2.9 State the order of the colours of the spectrum, starting with the one of highest frequency, and state what monochromatic light is. [2]

3 Exam-style questions

3.1 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? [1]

- **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.

3.2 Which row describes the image of a person standing in front of a plane mirror? [1]

- **A** virtual, same size, laterally inverted
- **B** real, same size, upright
- **C** virtual, diminished, upright
- **D** real, enlarged, laterally inverted

3.3 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. [2]

(b) The ray meets the flat face at an angle of incidence of 50°. State and explain what happens to the ray. [2]

(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. ($\sin 40° = 0.643$) [3]

(d) State two uses of total internal reflection. [2]

(e) State what happens to the speed of the light as it passes from the air into the plastic. [1]

3.4 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.

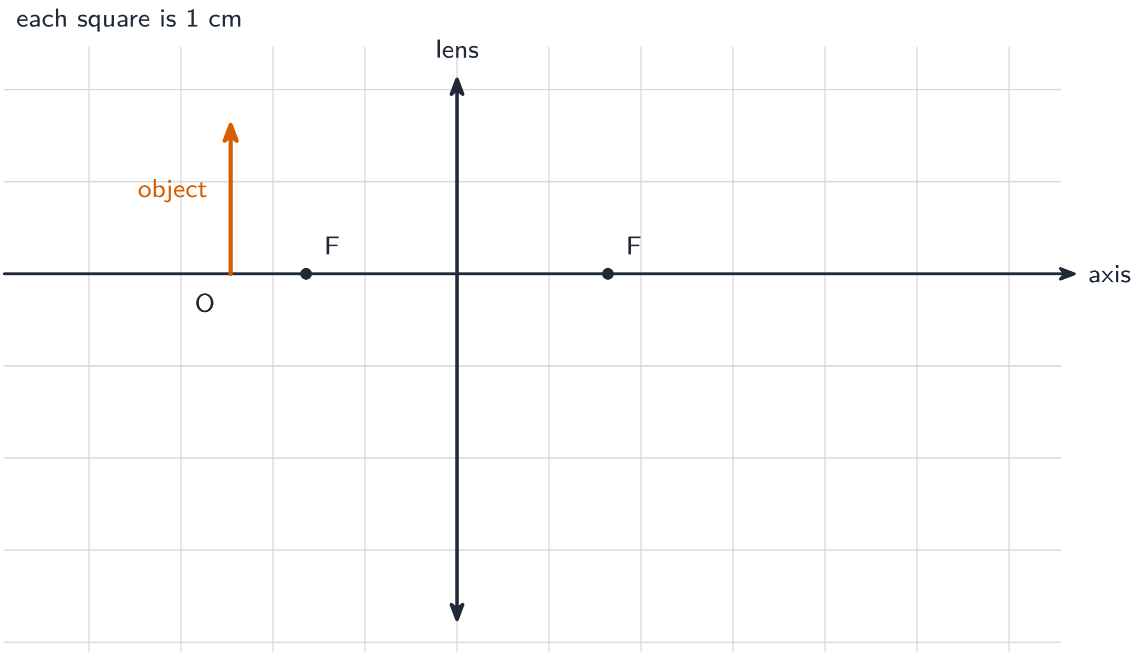


Fig. 3.1 (each square is 1 cm)

(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. [3]

(b) Describe the image using three words. [2]

(c) The object is moved to 3.0 cm from the lens. State two ways in which the image changes. [2]

(d) Explain how a diverging lens placed in front of an eye corrects short-sightedness. [2]

3.5 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. [2]

(b) State which colour is refracted the most, and explain why in terms of frequency. [2]

(c) A student says that the image in a plane mirror can be shown on a screen. Explain why the student is wrong. [2]

Solutions

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

2.2 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.

2.3 $n = \dfrac{\sin i}{\sin r} = \dfrac{0.80}{0.50} = 1.6$.

2.4 $\sin r = \dfrac{\sin i}{n} = \dfrac{0.766}{1.4} = 0.547$; $r = 33°$.

2.5 $\sin c = \dfrac{1}{n} = \dfrac{1}{2.4} = 0.417$; $c = 25°$.

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

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

2.8 Between the lens and its principal focus (closer to the lens than F); the image is enlarged, upright and virtual.

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

3.1 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°.

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

3.3 (a) $\sin c = \dfrac{1}{1.5} = 0.667$; $c = 42°$.
(b) The ray is totally internally reflected at the flat face, because 50° is greater than the critical angle of 42°.
(c) $\sin r = \dfrac{\sin i}{n} = \dfrac{0.643}{1.5} = 0.429$; $r = 25°$.
(d) Any two of: optical fibres for telephone and internet signals; prisms in binoculars or periscopes; reflectors on bicycles and roads; endoscopes in medicine.
(e) It slows down.

3.4 (a) Ray from the top of the object parallel to the axis, refracting at the lens through the far F; ray from the top of the object through the centre of the lens, undeviated; 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.
(b) Real, inverted and enlarged.
(c) The object is now inside F, so the image becomes virtual and upright, on the same side of the lens as the object; it is still enlarged. (Any two correct changes.)
(d) The eye focuses light from a distant object in front of the retina; the diverging lens spreads the rays out before they enter the eye, so they now meet on the retina.

3.5 (a) A band of colours (a spectrum) from red to violet; the effect is dispersion.
(b) Violet; it has the highest frequency (shortest wavelength), and the glass slows and bends higher-frequency light more.
(c) The image is virtual: 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.