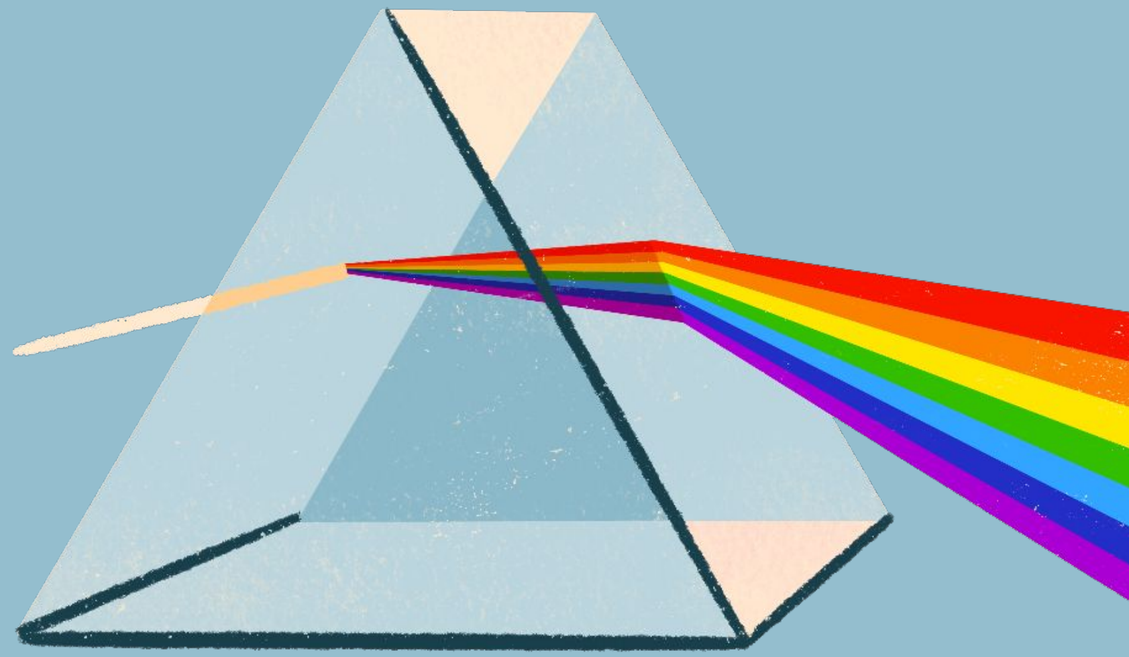
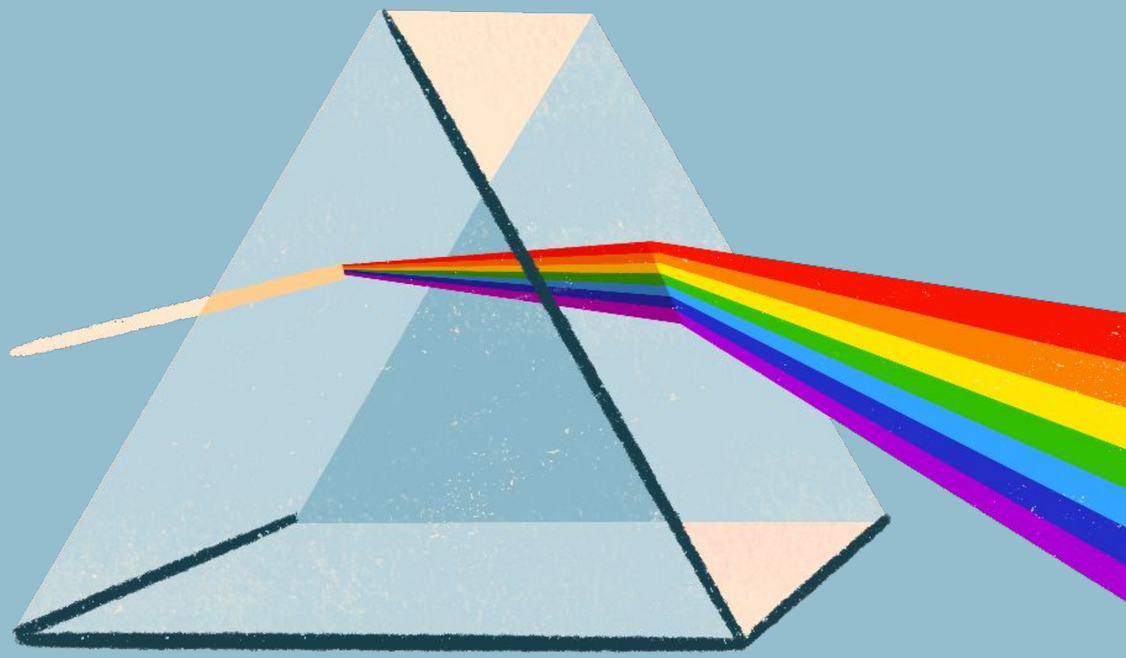
13 Light

Mr Hazhi Rozh



- use the law of reflection of light to explain how an image is formed in a plane mirror
- construct ray diagrams for reflection
- investigate the refraction of light
- draw ray diagrams to show how lenses form images
- describe the difference between real and virtual images
- describe total internal reflection and how it is used
- describe how the visible spectrum is formed.



13.1 Reflection of light

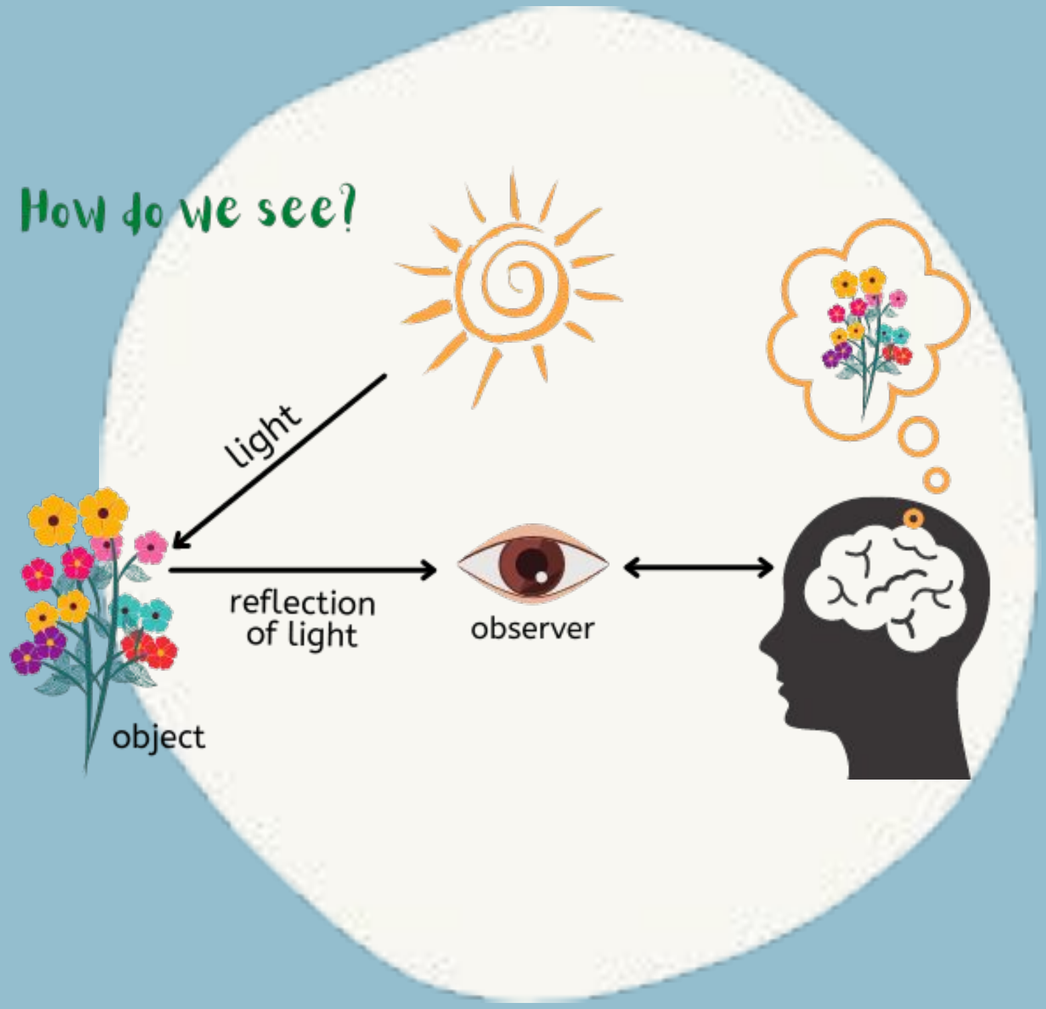
You can see an object only if light from it enters your eyes. Some objects such as the Sun, electric lamps and candles make their own light. We call these luminous sources.

Most things you see do not make their own light but reflect it from a luminous source. They are non-luminous objects.

13.1 Reflection of light

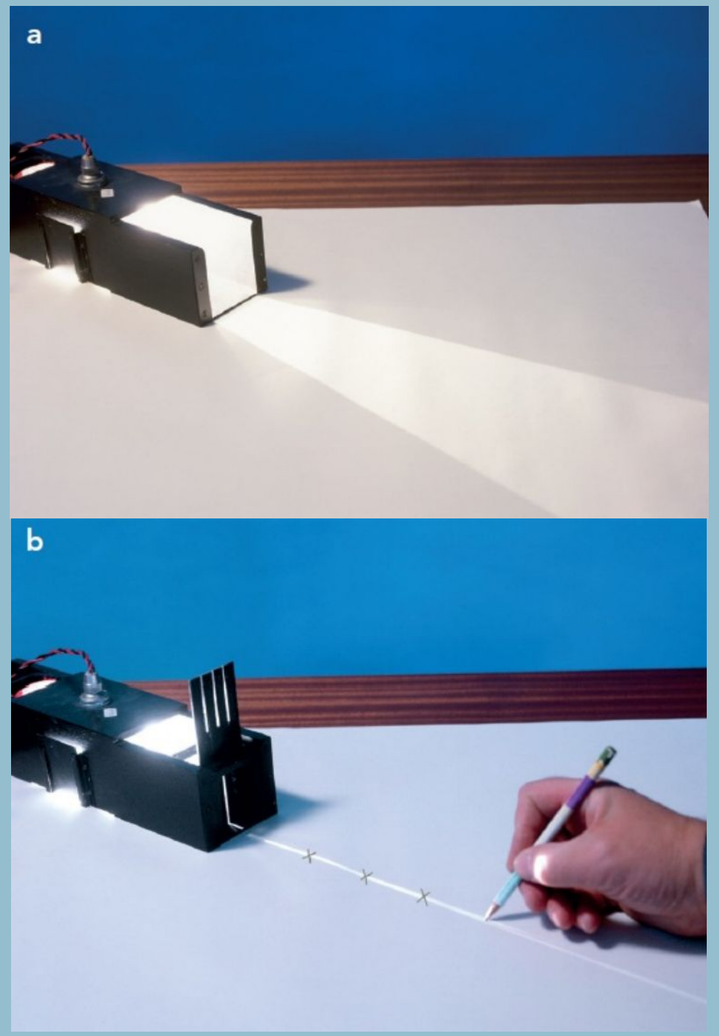
Light usually travels in straight lines. It changes direction if it hits a shiny surface.

This change in direction at a shiny surface such as a mirror is called reflection. We will look at reflection in this section.



13.1 Reflection of light

You can see that light travels in a straight line using a ray box A light bulb produces light, which spreads out in all directions. A ray box produces a broad beam. By placing a narrow slit in the path of the beam, you can see a single narrow beam or ray of light.



Rays and beams

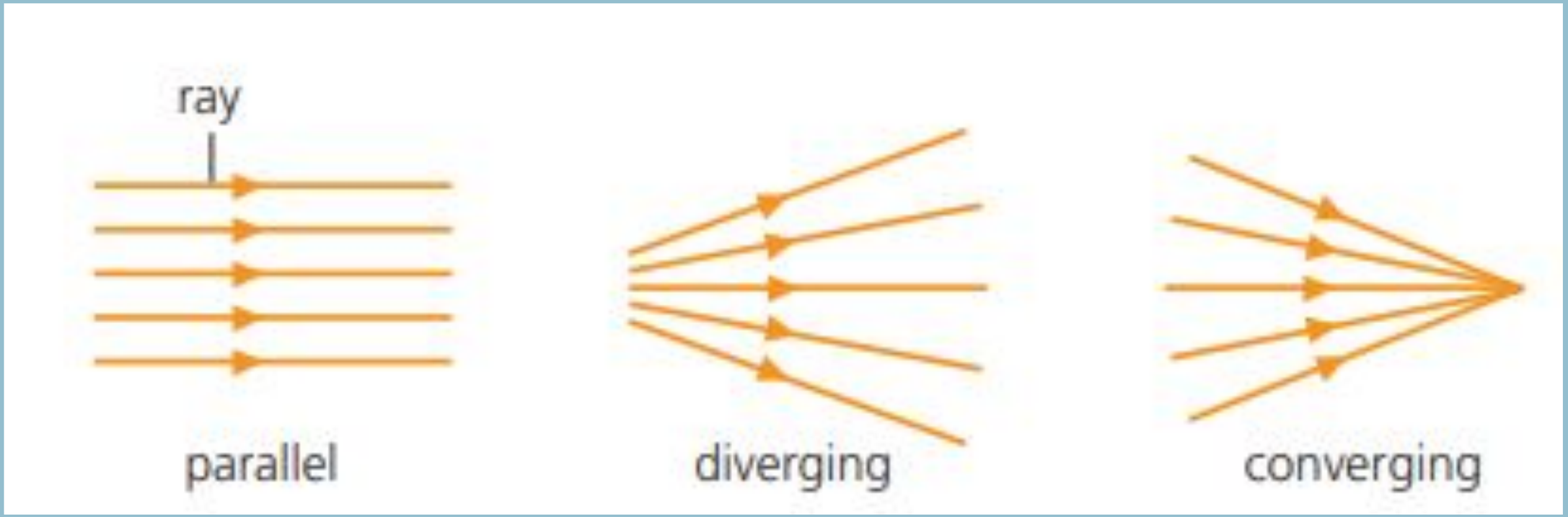
Ray

The direction of the path in which light is travelling is called a ray and is represented in diagrams by a straight line with an arrow on it.

Beams

A beam is a stream of light and is shown by a number of rays.A beam may be parallel, diverging (spreading out) or converging (getting narrower).

Rays and beams

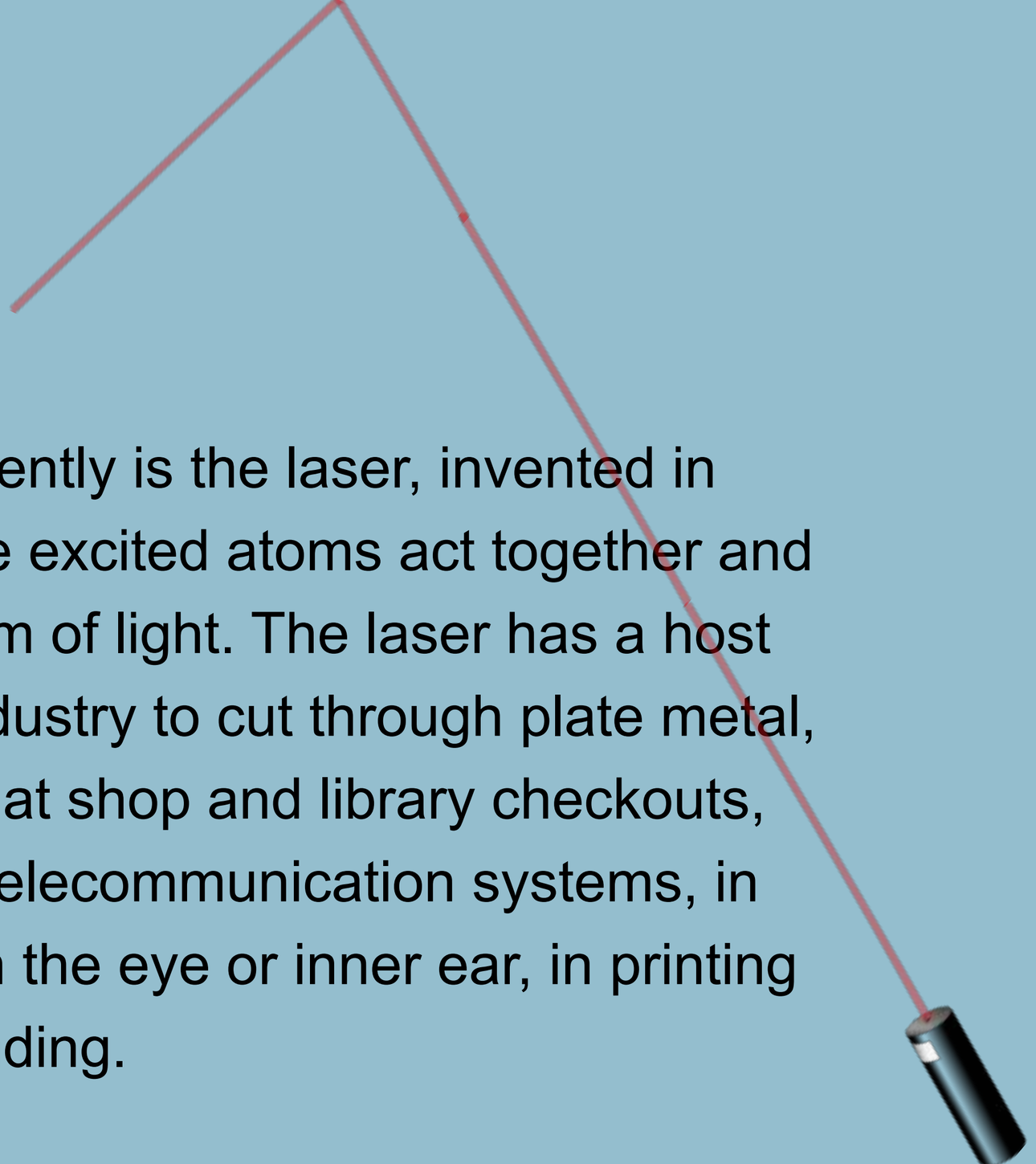


How light is produced?

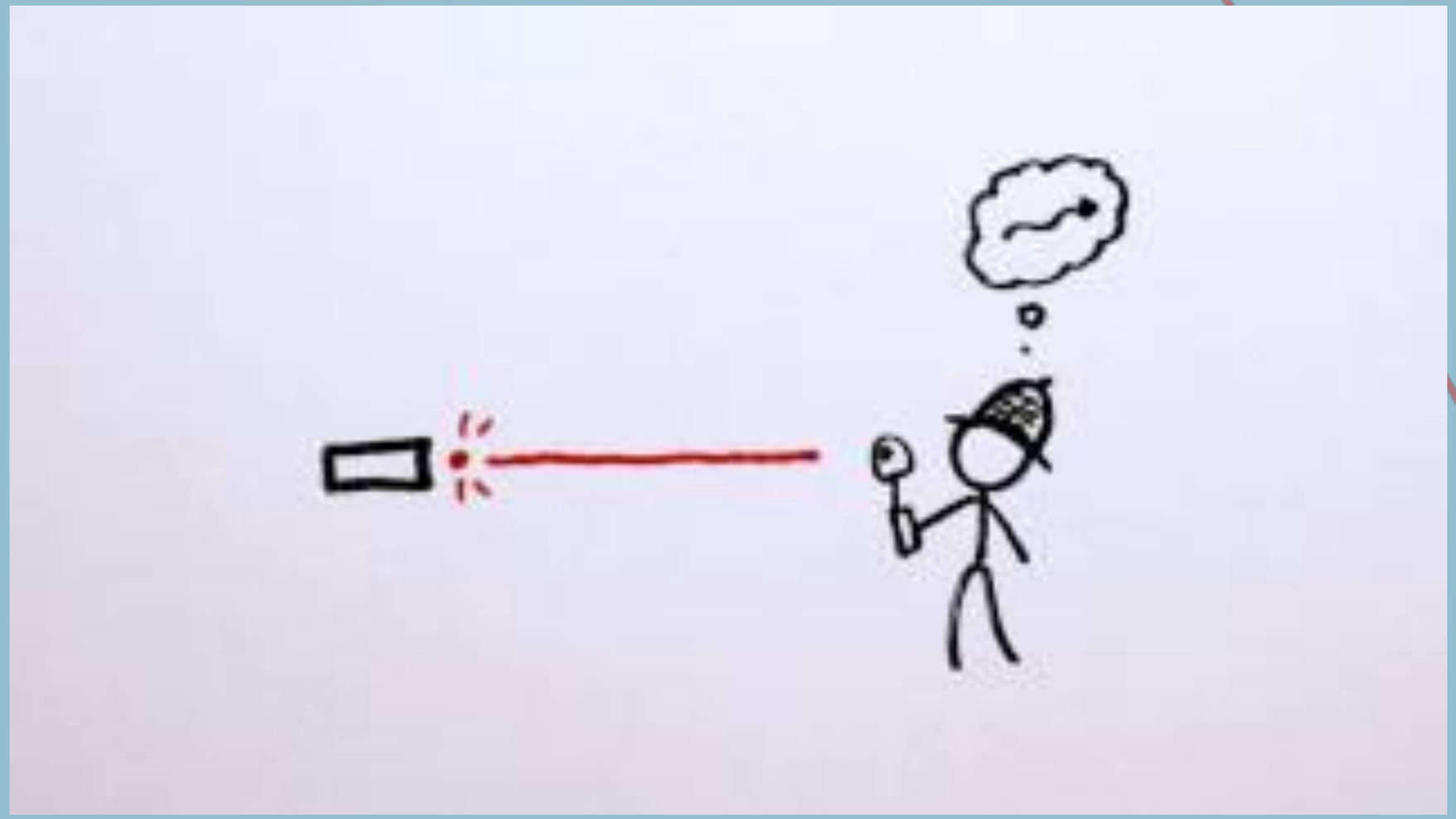
Luminous sources radiate light when their atoms become ‘excited’ as a result of receiving energy. In a light bulb, for example, the energy comes from electricity. The ‘excited’ atoms give off their light haphazardly in most luminous sources.

How Laser words?

A light source that works differently is the laser, invented in 1960. In laser light sources the excited atoms act together and emit a narrow, very bright beam of light. The laser has a host of applications. It is used in industry to cut through plate metal, in scanners to read bar codes at shop and library checkouts, in CD players, in optical fibre telecommunication systems, in delicate medical operations on the eye or inner ear, in printing and in surveying and range-finding.



How Laser words?



Looking in the mirror

An ordinary mirror is made by depositing a thin layer of silver on one side of a piece of glass and protecting it with paint. The silver – at the back of the glass – acts as the reflecting surface. A plane mirror is produced when the reflecting surface is flat.

Looking in the mirror

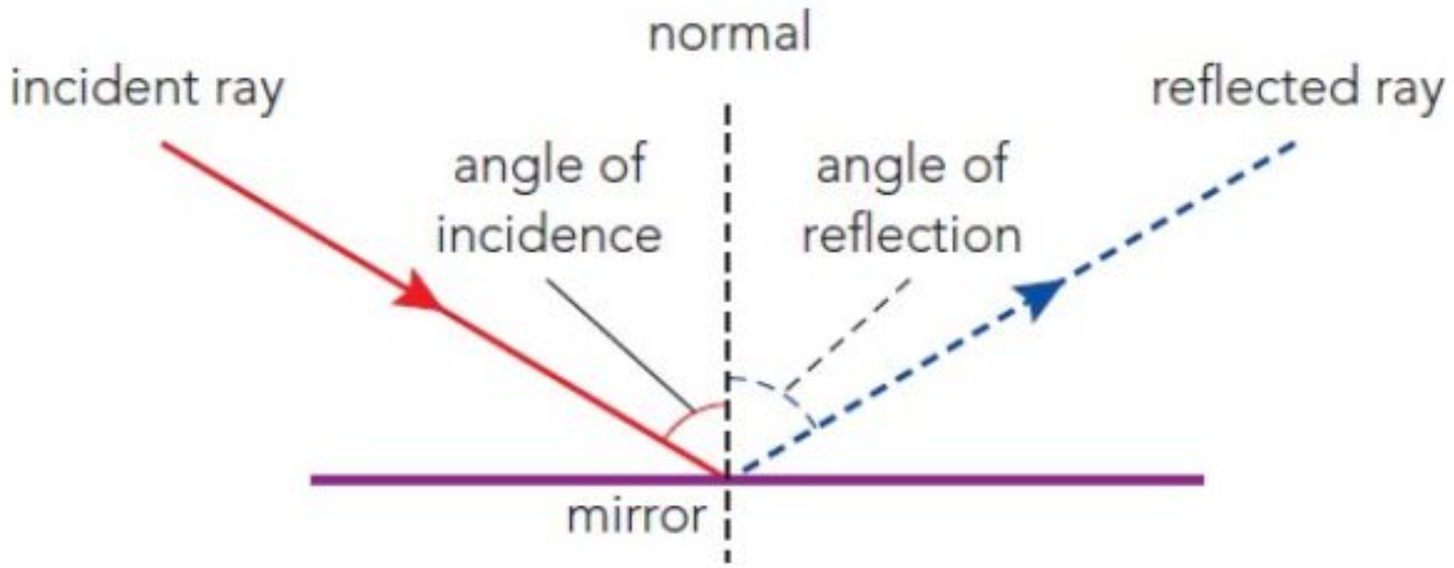


Figure 13.5: This **ray diagram** shows the reflection of light. The normal is drawn at 90° to the mirror. Then the angles are measured between the rays and the normal. The angle of incidence and the angle of reflection are equal: $i = r$.

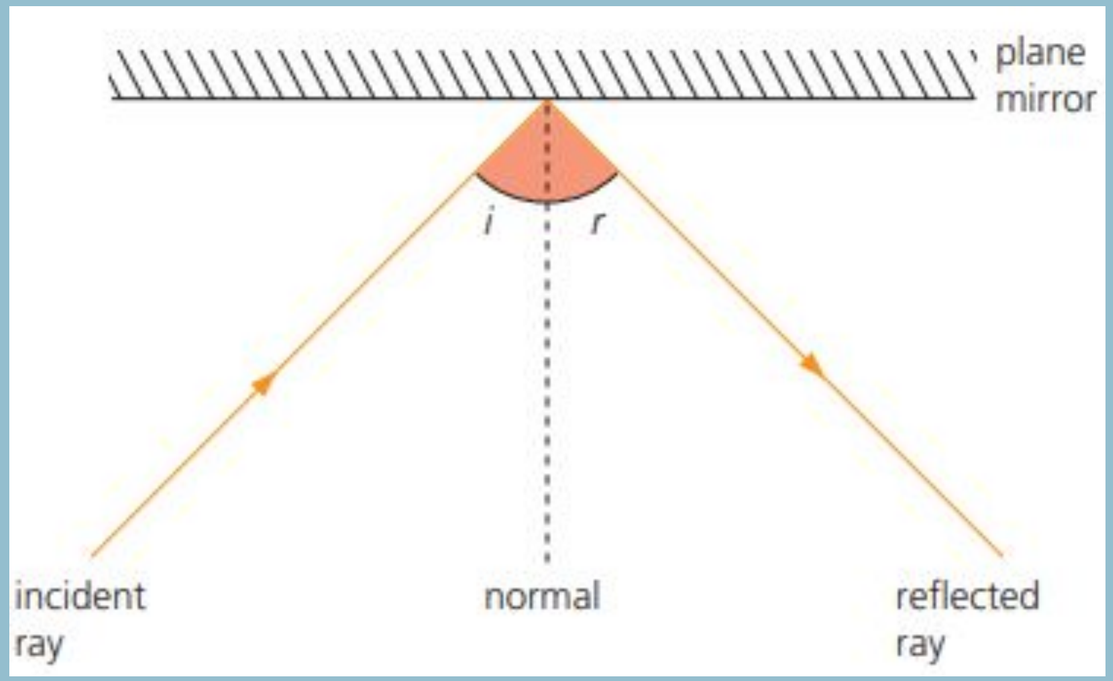
Looking in the mirror

The angle of incidence, i, and the angle of reflection, r, are found to be equal to each other. This is the law of reflection:

angle of incidence = angle of reflection

i = r

Angles of incidence and reflection are always measured between the ray and the normal to the surface.



Looking in the mirror

Key definitions

Normal line which is perpendicular to a surface

Angle of incidence angle between incident ray and the normal to a surface

Angle of reflection angle between reflected ray and the normal to a surface

Law of reflection the angle of incidence is equal to the angle of reflection

Shadows

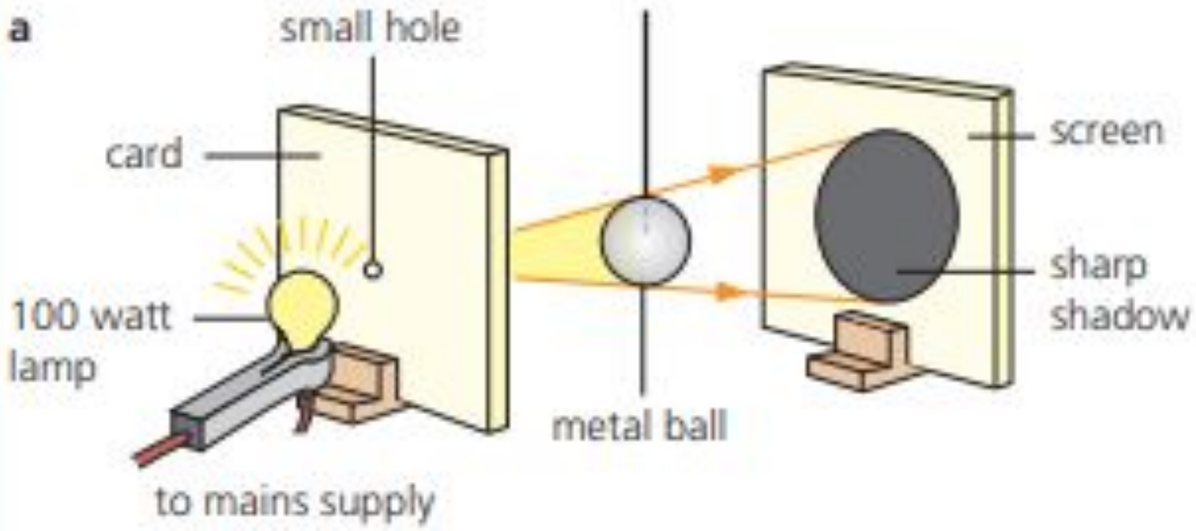
The sharpness of the shadow depends on the size of the light source. A very small source of light, called a point source, gives a sharp shadow which is equally dark all over.

Going further

Shadows

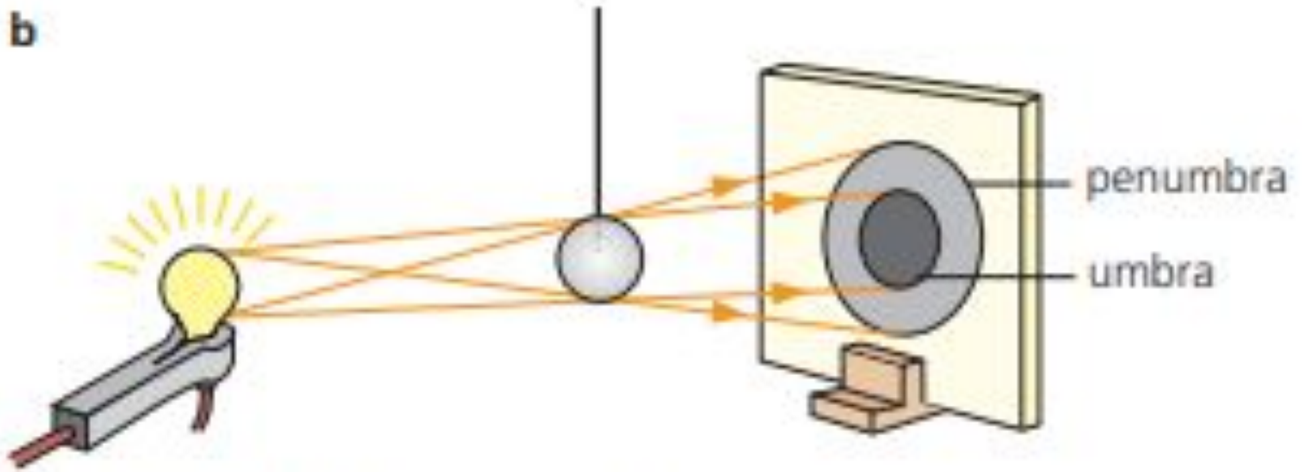
Shadows are formed for two reasons. First, because some objects, which are said to be opaque, do not allow light to pass through them. Secondly, light travels in straight lines.

The sharpness of the shadow depends on the size of the light source. A very small source of light, called a point source, gives a sharp shadow which is equally dark all over. This may be shown as in Figure 3.2.7a where the small hole in the card acts as a point source.



Shadows

The shadow is then larger and has a central dark region, the umbra, surrounded by a ring of partial shadow, the penumbra.

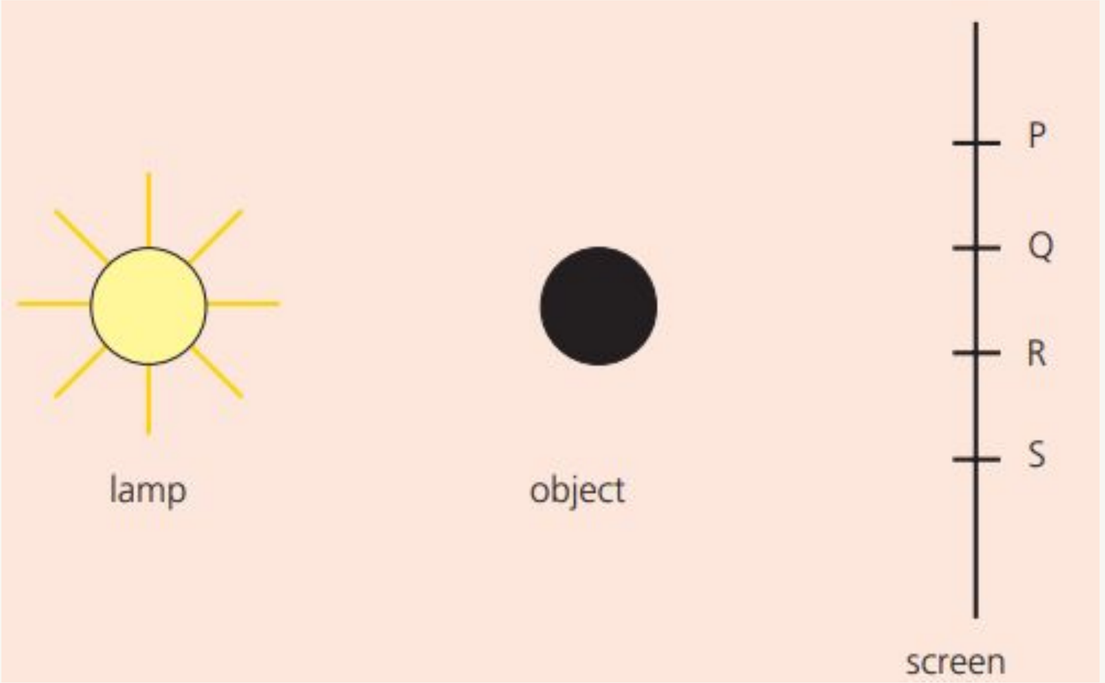


▲ **Figure 3.2.7** Forming a shadow

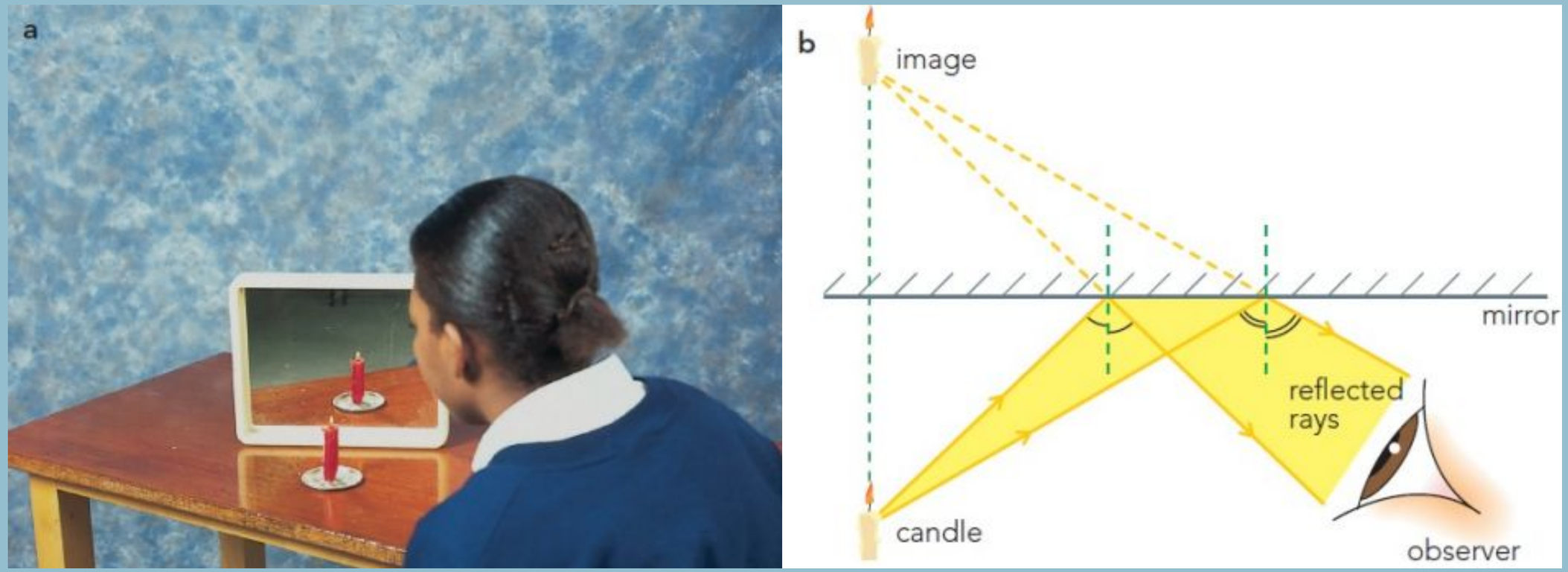
If the card is removed the lamp acts as a large or extended source (Figure 3.2.7b). The shadow is then larger and has a central dark region, the umbra, surrounded by a ring of partial shadow, the penumbra. You can see by the rays that some light reaches the penumbra, but none reaches the umbra.

Question

In the figure the completely dark region on the screen is

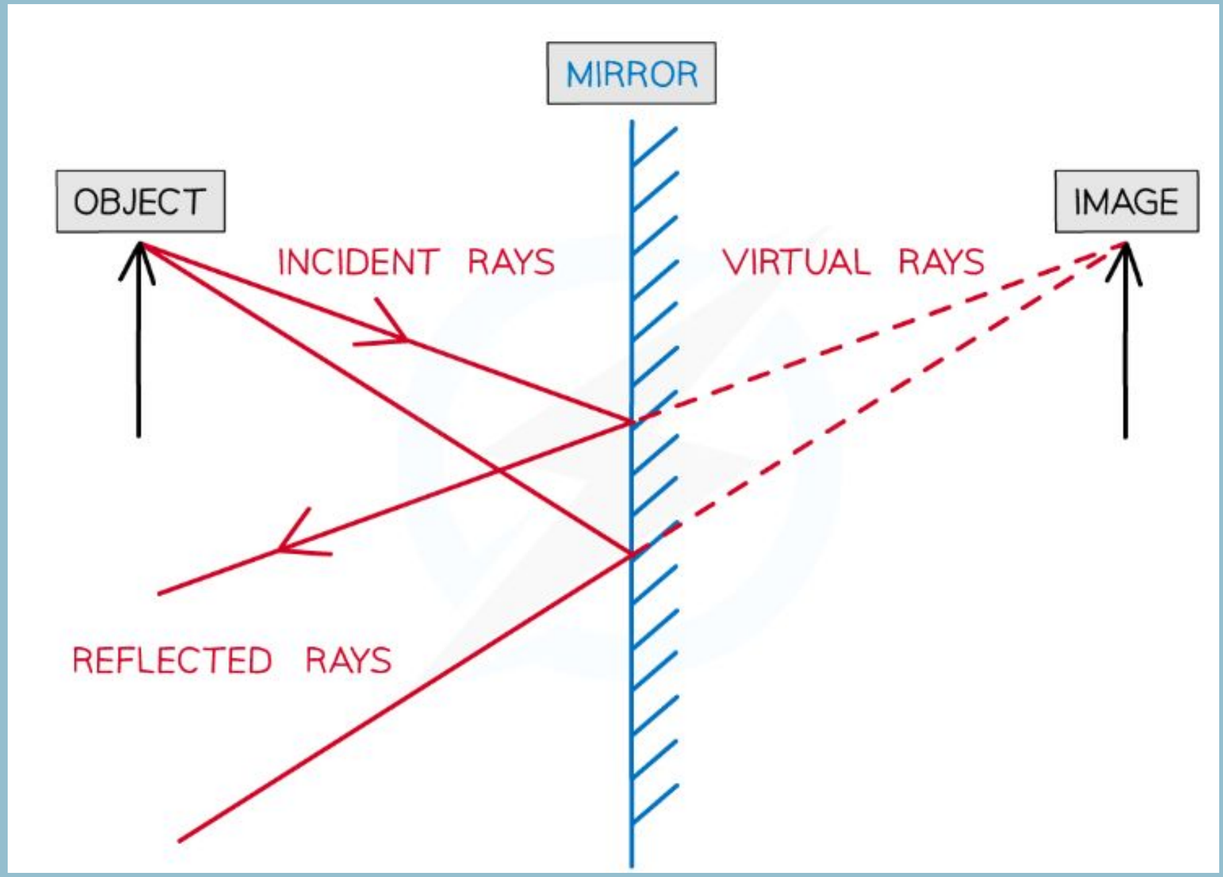


Looking in the mirror



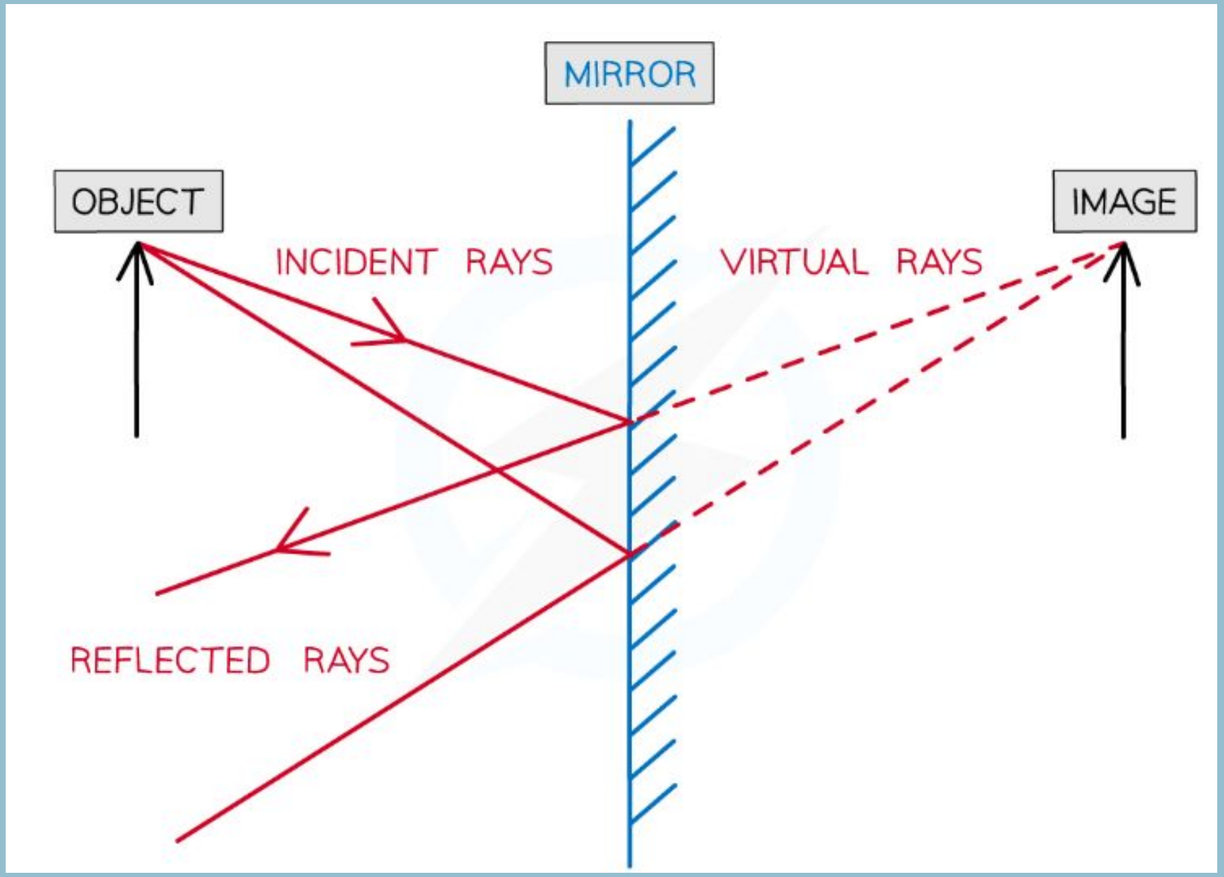
Reflection in a plane mirror

A plane mirror defines a flat, smooth and polished surface. When an object is placed in front of a plane mirror, an image of that object can be seen in the mirror

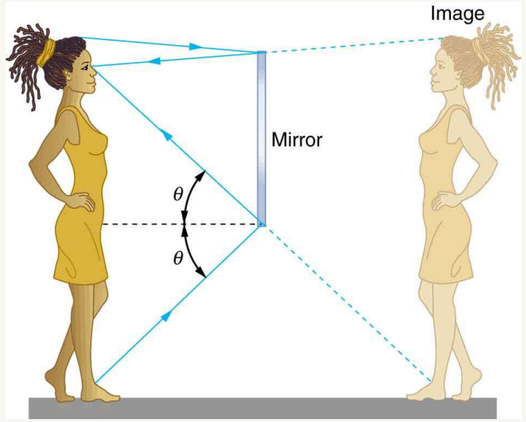


Light from the object hits the mirror, reflecting from it (i=r). To an observer, the reflected ray appears to have come from behind the mirror

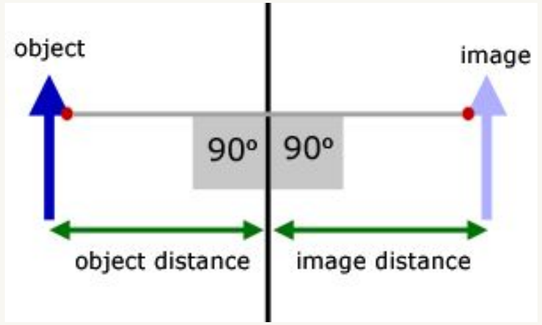
The reflected ray can be traced back in this same direction behind the mirror, forming a virtual ray. This process is repeated for another ray travelling in a slightly different direction



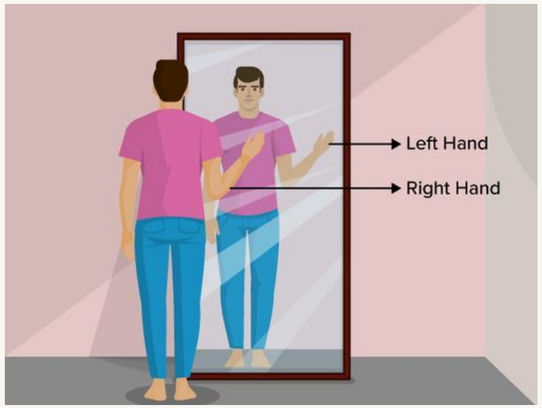
When an object is reflected:



the same size as the object



the same distance behind the mirror as the object is in front of it



laterally inverted and virtual

Each incident ray can be drawn by

- Light from the object hits the mirror, reflecting from it (i=r)
- To an observer, the reflected ray appears to have come from behind the mirror
- The reflected ray can be traced back in this same direction behind the mirror, forming a virtual ray
- This process is repeated for another ray travelling in a slightly different direction

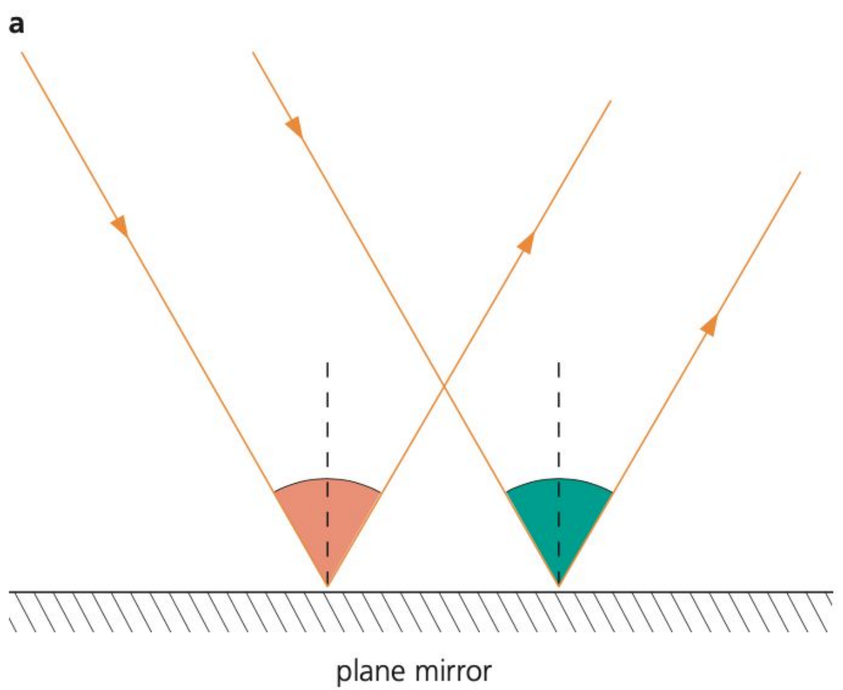
Note

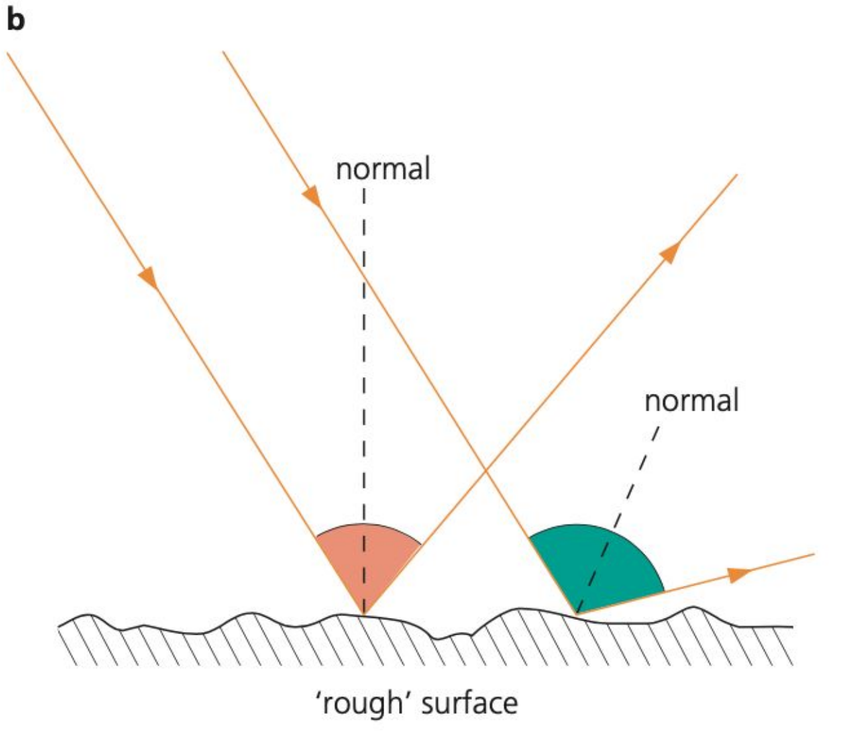
An image of the object will appear where these two virtual rays cross

Also

The type of image formed in the mirror is called a virtual image because of the divergence of the rays from the image

Note that the normal is based on the orientation of the surface. If a ray hits a point that is not horizontal or vertical, the normal has to be according to how the surface is placed. If you look at the image on the right, the normal changes at different points on the water waves.





The law of reflection

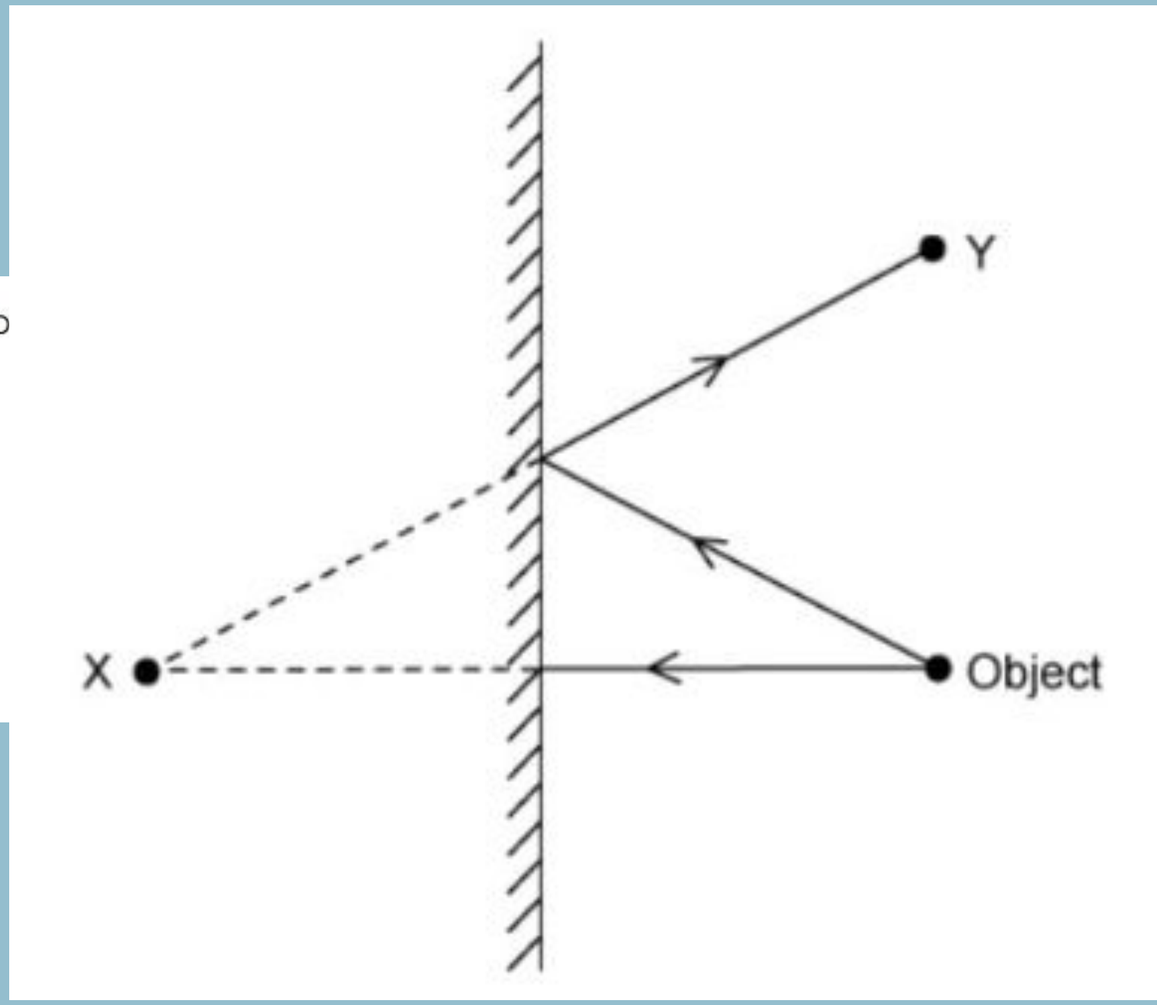
This law of reflection is used in many devices such as:

- mirrors
- cameras
- optical fibres
- periscopes

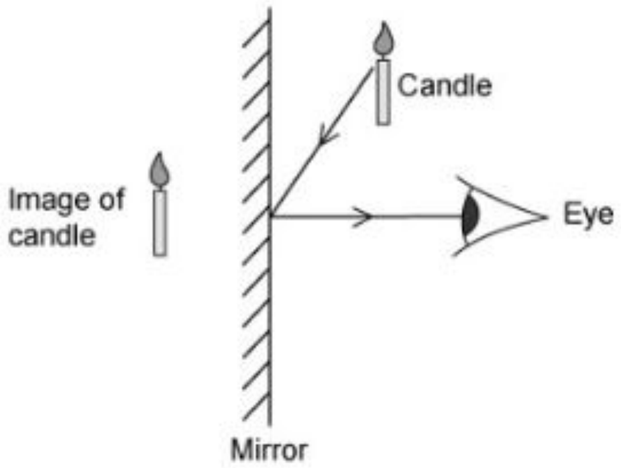
Question

An object is placed in front of a mirror. Where is the image formed, and is the image real o virtual?

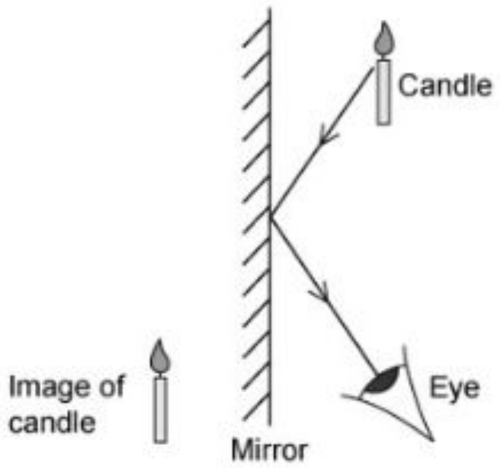
	Image location	Image type
A	X	real
B	X	virtual
C	Y	real
D	Y	virtual



A


Candle
Image of candle
Eye
Mirror

B


Candle
Image of candle
Eye
Mirror

C

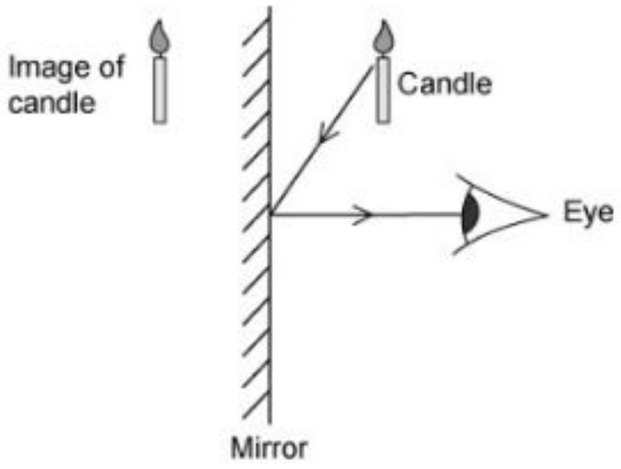


Image of candle
Candle
Eye
Mirror

D

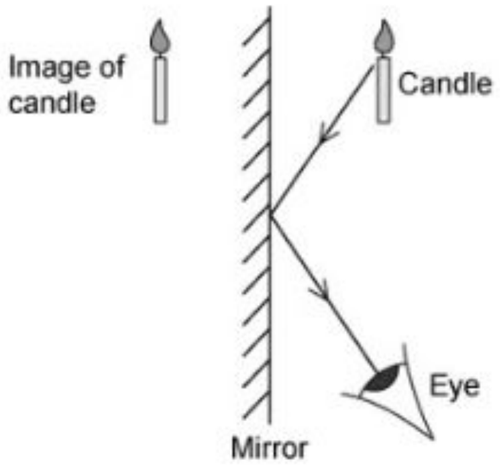


Image of candle
Candle
Eye
Mirror

Question

17 The angle of incidence of a ray of light incident on a plane mirror is gradually increased.

To the nearest degree, what is the maximum possible angle between the incident and reflected rays?

A 0° **B** 45° **C** 90° **D** 180°

Fig. 9.1 shows two rays of light X and Y leaving an object O. The rays strike a plane mirror.

Ray X is reflected as shown.

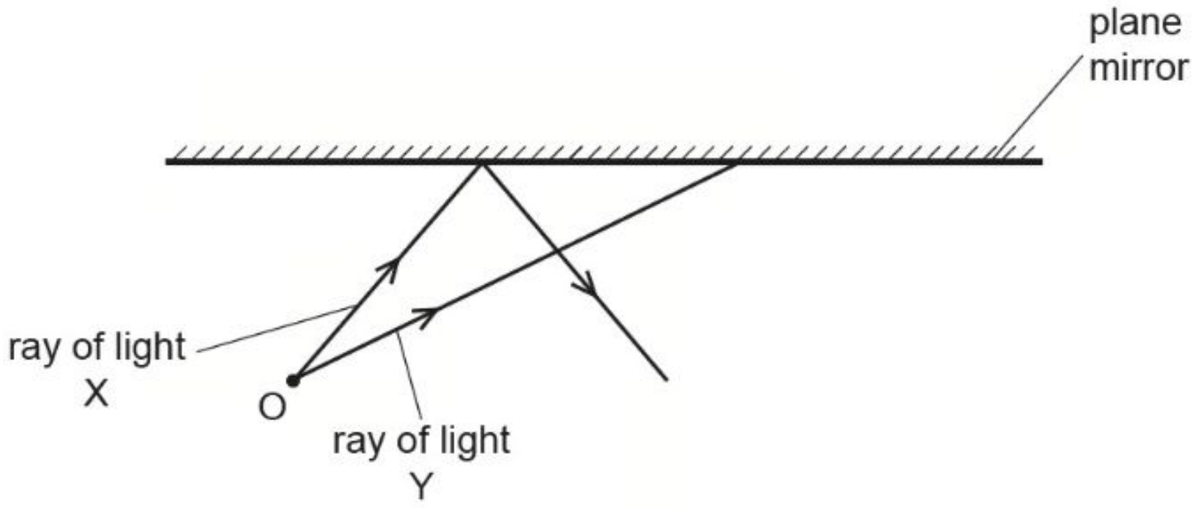


Fig. 9.1

(i) On Fig. 9.1, draw the normal at the point where ray X strikes the mirror.

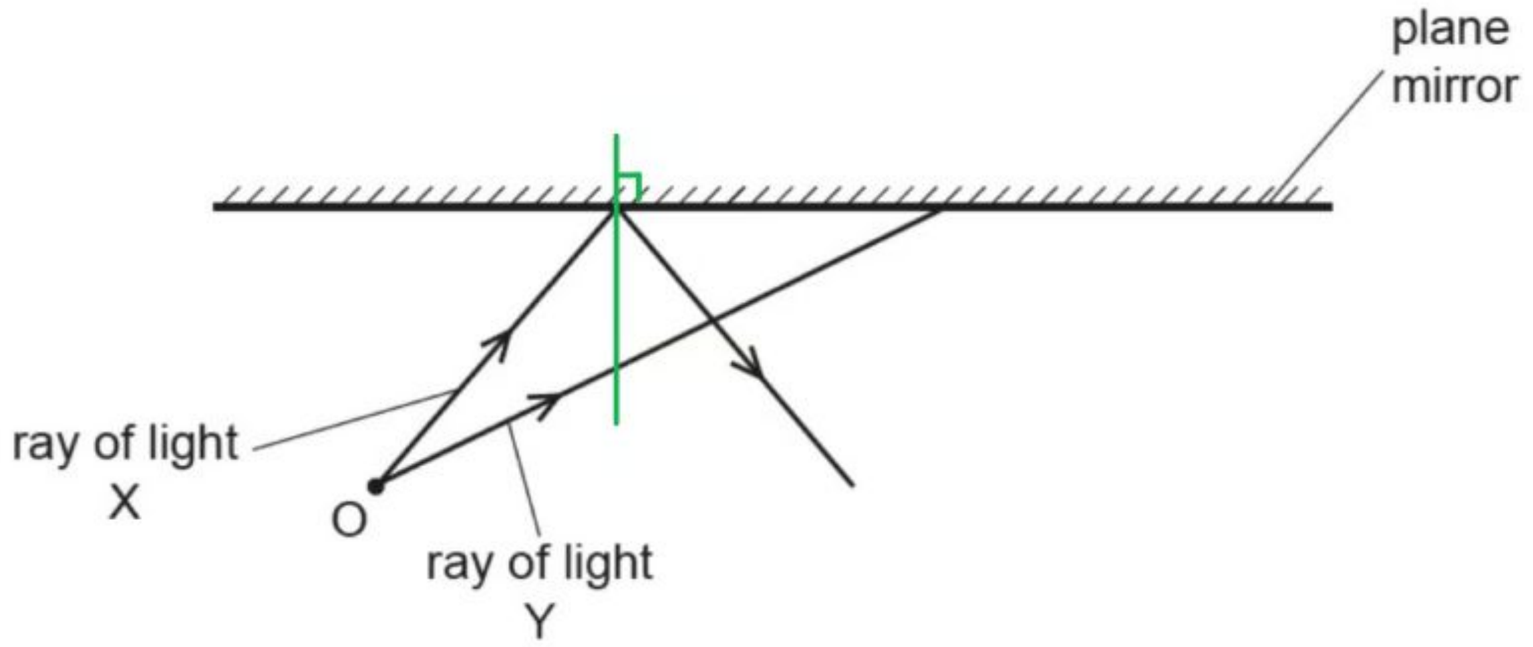
[1]

(ii) On Fig. 9.1, draw the path of ray Y after it strikes the mirror.

[1]

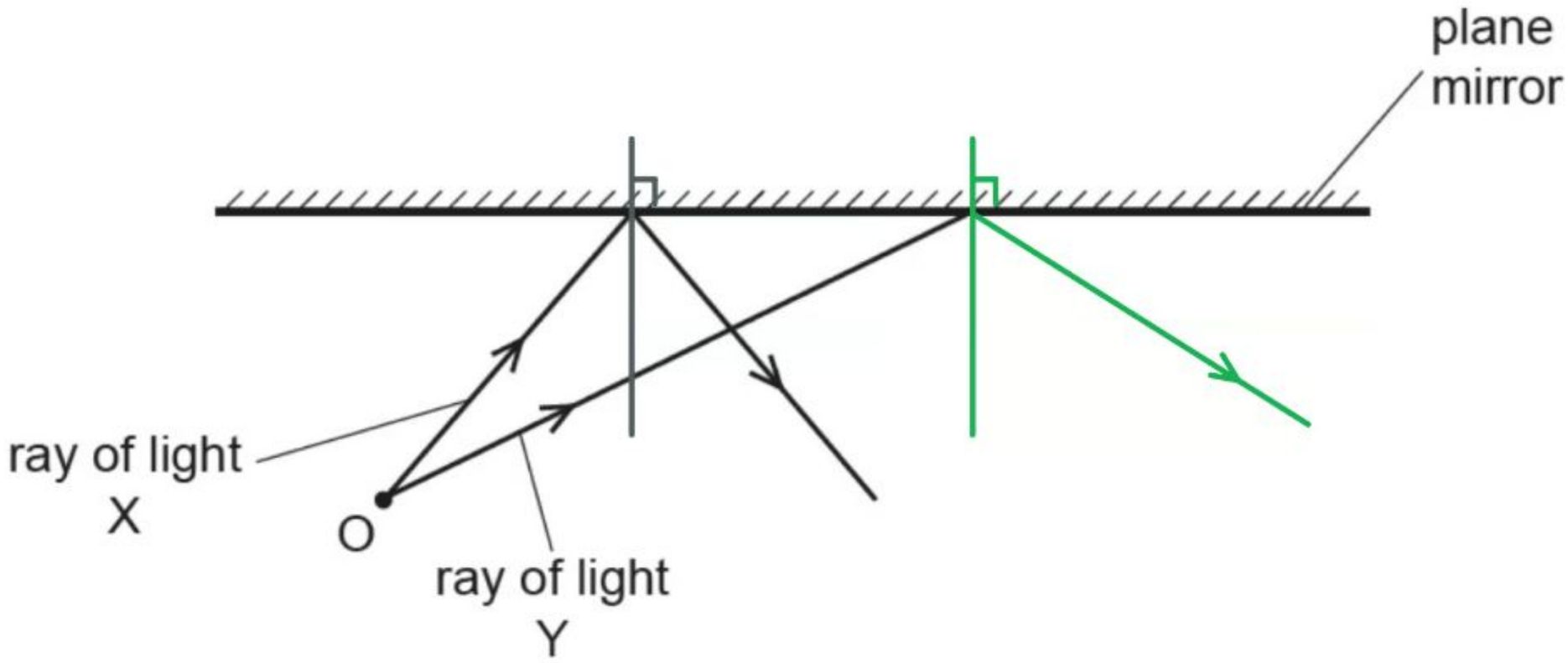
(a)

(i) The normal for ray X looks like:



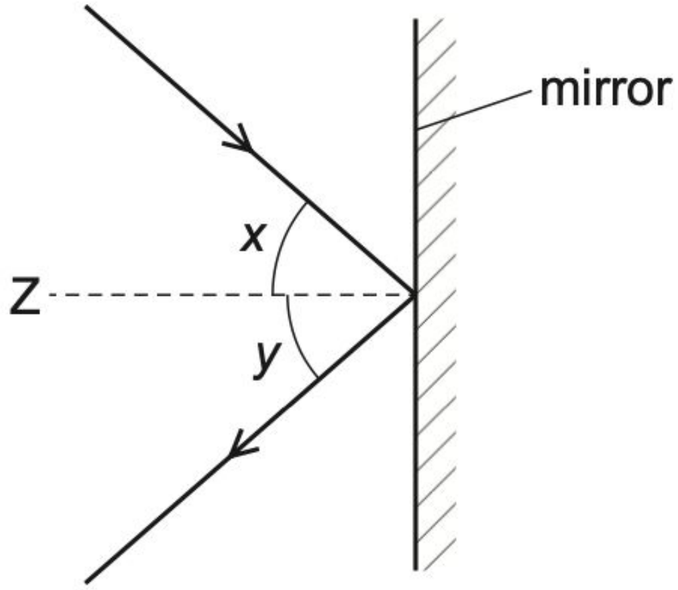
- The normal crosses the point where ray X meets the mirror, and is at 90° to it (by eye); [1 mark]

(ii) The path of ray Y looks like:



- The reflected ray for Y has angle of incidence = angle of reflection (by eye); [1 mark]

18 The diagram shows a ray of light reflecting from a mirror.



Which row shows the correct names for *x*, *y* and Z?

	x	*y*	Z
A	angle of incidence	angle of reflection	normal
B	angle of incidence	angle of reflection	principal focus
C	angle of reflection	angle of refraction	normal
D	angle of reflection	angle of refraction	principal focus

19 A student reads the following relationship in his physics book.

$$i = r$$

What is the student reading about?

A diffraction due to a gap

B dispersion of light by a prism

C reflection in a plane mirror

D refraction as light enters glass

19 Diagram 1 shows the page of a book in front of a plane mirror.

An eye is looking at the image of the page.

Diagram 2 shows a large letter G on the page facing the mirror.

diagram 1

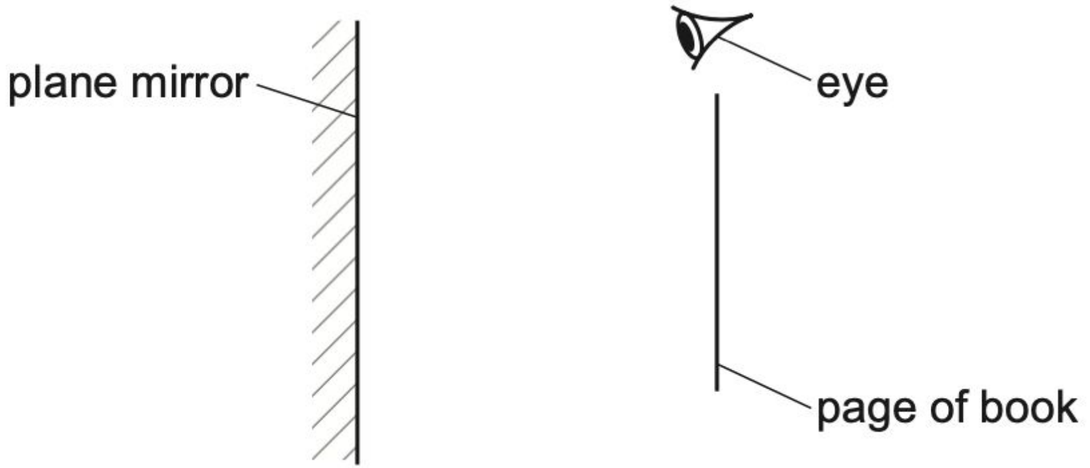


diagram 2

What is the appearance of the image of G seen by the eye?

A

B

C

D

7 **(a)** Fig. 7.1 shows a ray of light striking a plane mirror. The ray is reflected as shown.

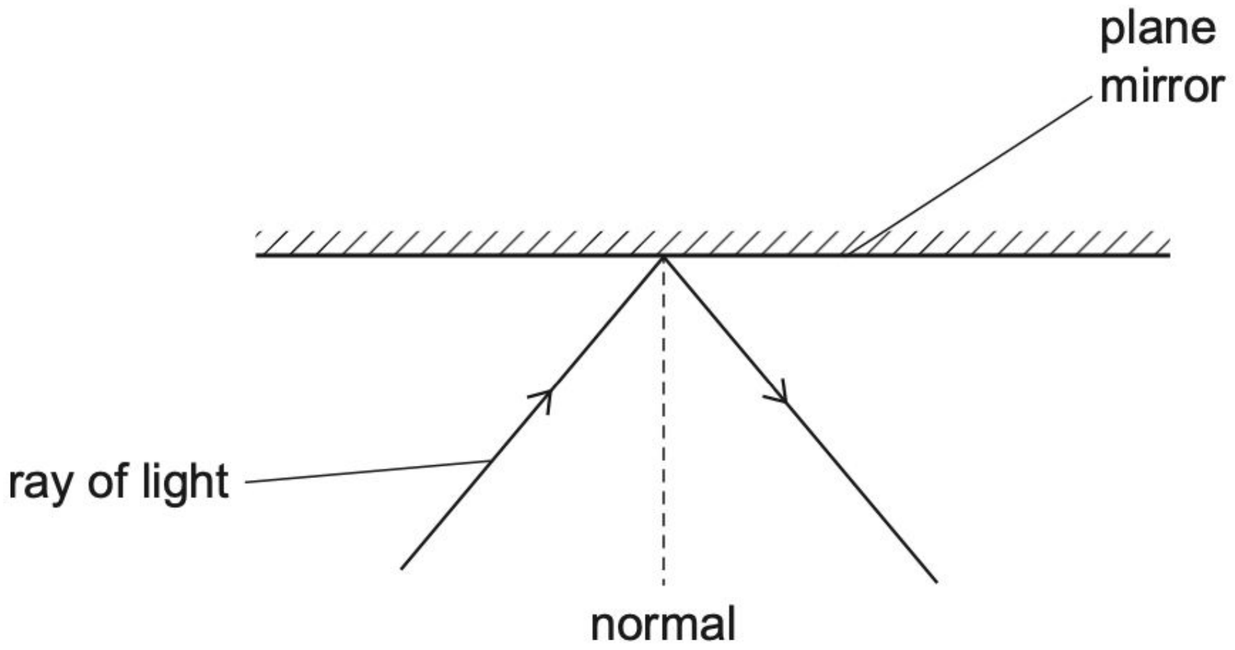


Fig. 7.1

The angle of incidence for the ray of light is 40°.

(i) Indicate the angle of reflection by drawing a letter R on Fig. 7.1. [1]

(ii) State the size of the angle of reflection in Fig. 7.1.

angle of reflection = ...° [1]

Question

Why the word ambulance written in reverse on the front of the vehicle?

Question

A student investigated the law of reflection. She increased her angle of incidence by 20° each time. Which angle of reflection did she measure incorrectly? Suggest what she may have done wrong?

Angle of incidence	Angle of reflection
20	20°
40°	39°
60°	30°

Question

What angle must ray hit a mirror at for the direction of the ray to be turned through 90°? Draw a diagram to illustrate your answer.

45°. Diagram should show a ray hitting a mirror at 45° and therefore being turned through 90°.

Remember

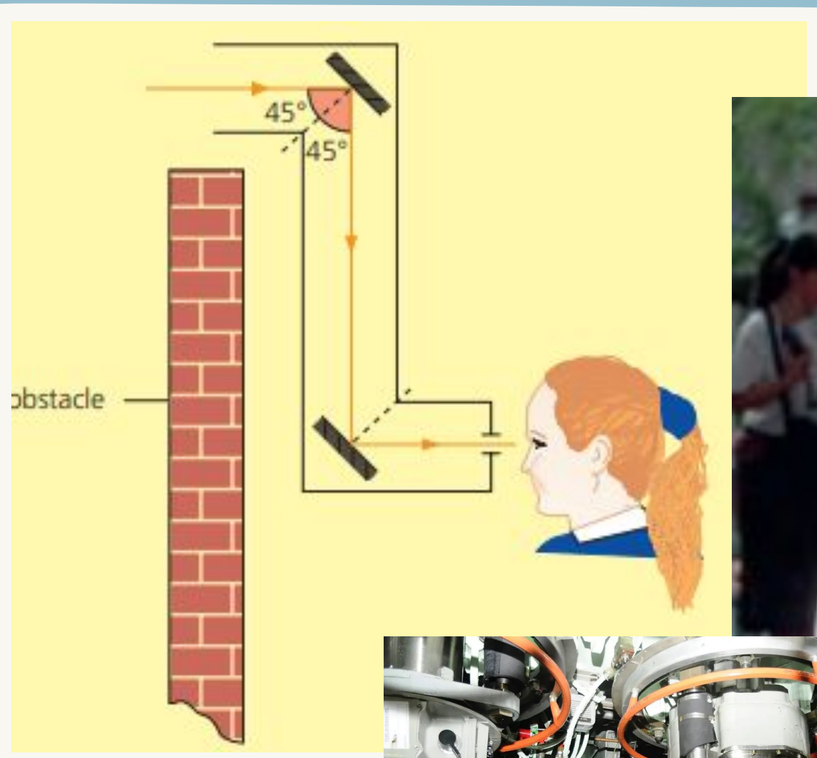
Ray diagrams

- In optics, a **normal line** is drawn at **right angles** to the **boundary** between two **media**
- In reflection, angles are measured between the ray (showing the wave direction) and the normal line
  - The angle of the wave approaching the boundary is called the **angle of incidence *(i)***
  - The angle of the wave leaving the boundary is called the **angle of reflection *(r)***

- When drawing a ray diagram an arrow is used to show the direction the wave is travelling
  - An **incident** ray has an arrow pointing **towards** the boundary
  - A **reflected** ray has an arrow pointing **away** from the boundary

Periscope

A simple periscope consists of a tube containing two plane mirrors, fixed parallel to and facing each other. Each makes an angle of 45° with the line joining them. Light from the object is turned through 90° at each reflection and an observer is able to see over a crowd.



Remember

Exam Tip

When drawing light waves being reflected **take care to get the angle about right.**

If they are slightly out it won't be a problem, but if there is an obvious difference between the angle of incidence and the angle of reflection then you will probably lose a mark.

13.2 Refraction of light

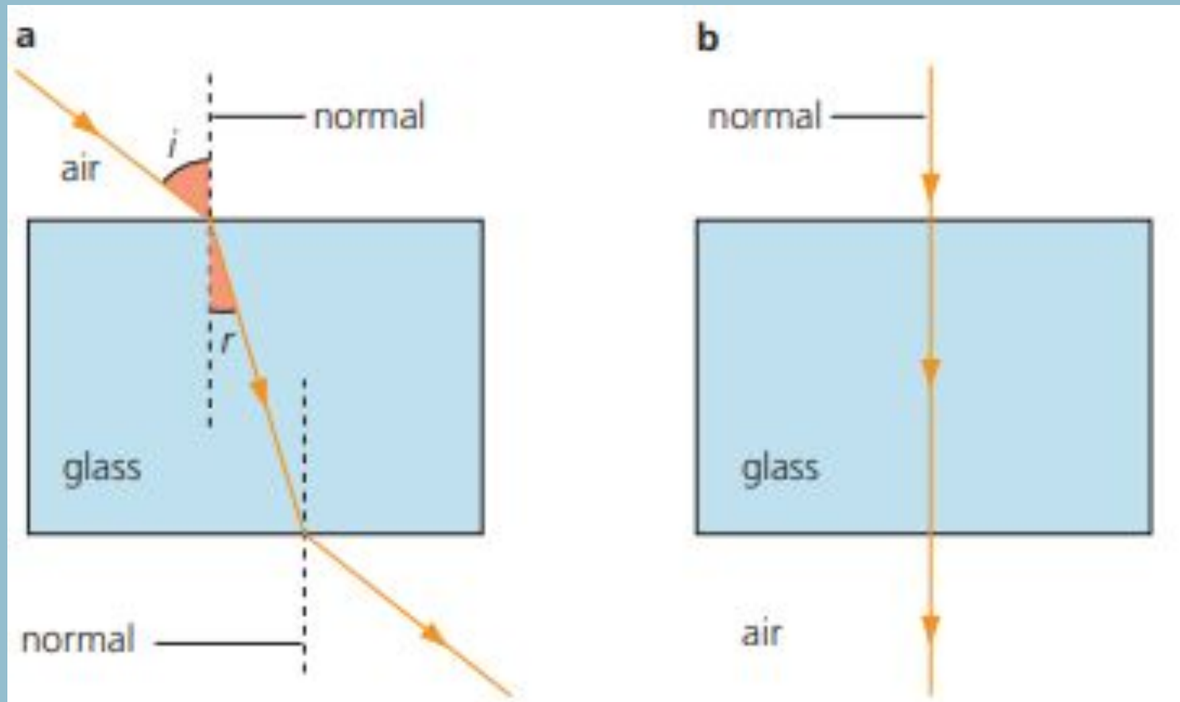
Although light travels in straight lines in a transparent material, such as air, if it passes into a different material, such as water, it changes direction at the boundary between the two, i.e. it is bent. The bending of light when it passes from one material (called a medium) to another is called refraction.

13.2 Refraction of light

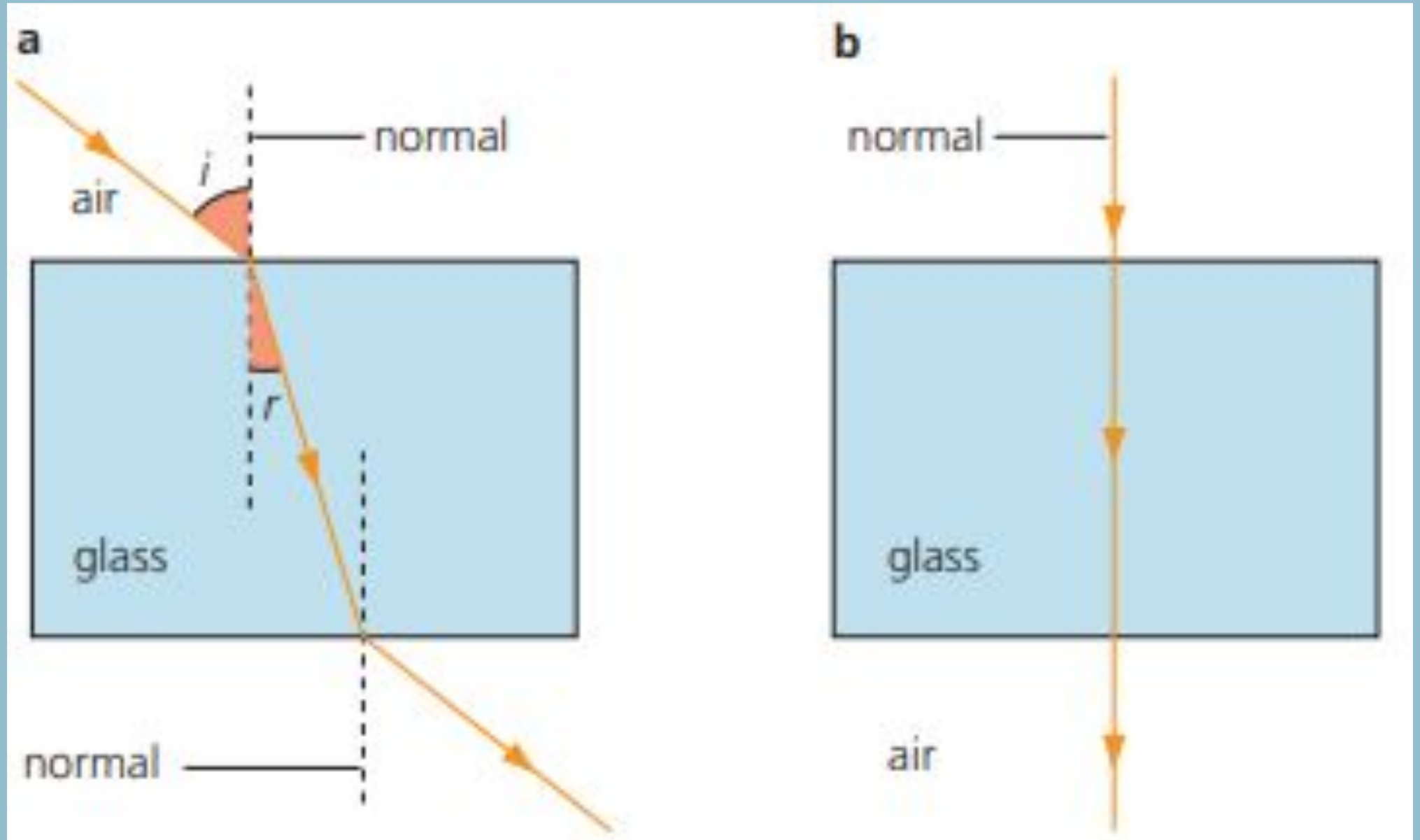
The bending of the straw is another consequence of refraction. The light hits the red object from two different materials. This effect distorts the light and we think they are disconnected.

13.2 Refraction of light

Refraction happens at the boundary between the two materials. The ray approaching the boundary is called the incident ray and the ray leaving the boundary is called the refracted ray. The angle of incidence, i, and angle of refraction, r, are measured to the normal drawn at the point where the ray hits the boundary

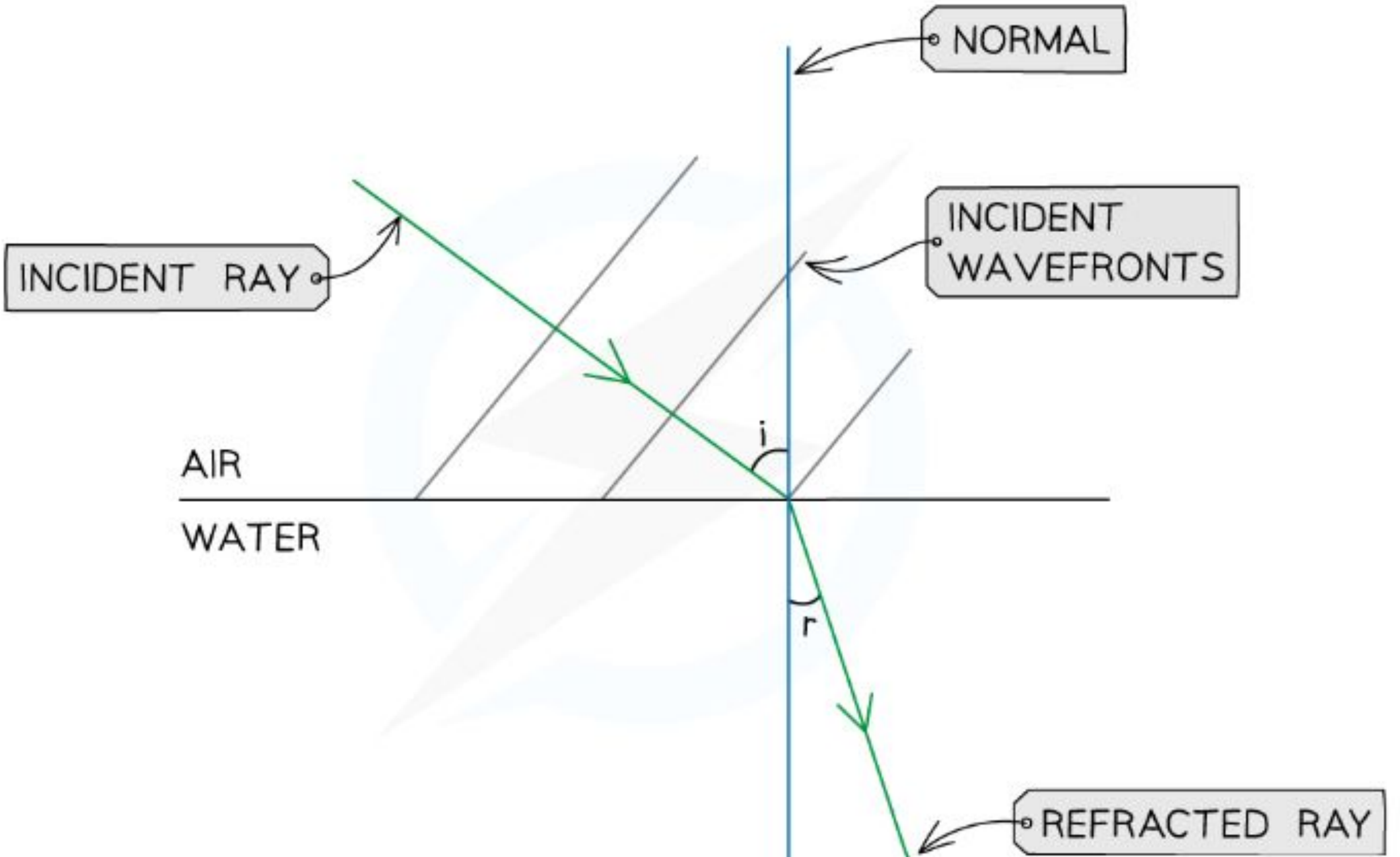


▲ **Figure 3.2.21** Refraction of light in glass



▲ **Figure 3.2.21** Refraction of light in glass

Refraction ray diagram



Facts about refraction

A ray of light is bent towards the normal when it enters an optically denser medium at an angle, for example from air to glass. So the angle of refraction r is smaller than the angle of incidence i.

A ray of light is bent away from the normal when it enters an optically less dense medium, for example from glass to air.

A ray travelling along the normal direction at a boundary is not refracted

Explaining refraction

Light is refracted because it travels at different speeds in different materials. Light travels fastest in a vacuum (empty space) and almost as fast in air. It travels more slowly in glass, water and other transparent substances.

Question

Describe what happens to a ray of light that passes from:

a air to glass

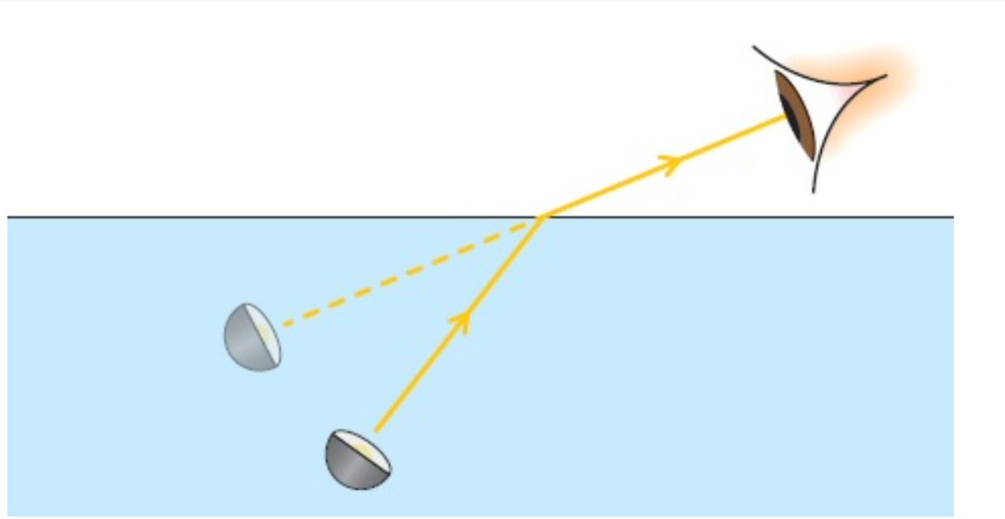
b glass to air.

a. the speed of light decreases and the ray bends toward the normal

b. the speed of light increases and the ray bends away from the normal.

Question

explain why the swimming pool appears to be shallower than it is?



a. **The light is refracted when it leaves the water. It bends away from the normal. The observer assumes that the light travelled in a straight line, and therefore sees the lamp higher – shown by the dashed ray and lamp.**

Speed of light

Light travels very fast. As far as we know, nothing can travel any faster than light. The speed of light as it travels through empty space is exactly 299 792 458 m/s. This is usually rounded to
300 000 000 m/s or 3×10^8 m/s.

Refractive index

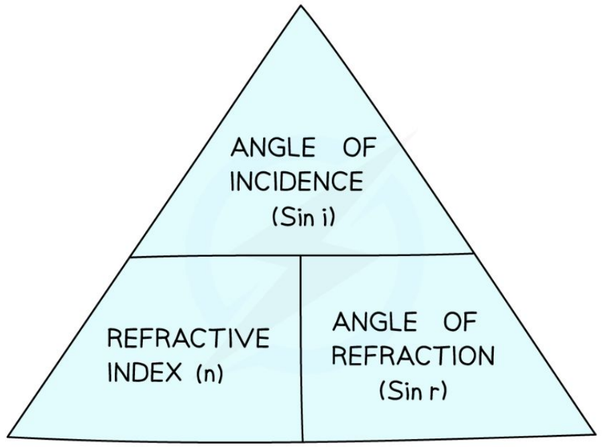
The refractive index of a material is a measure of how much the light slows, or how much it is bent. If the speed of light is halved when it enters a material, the refractive index is 2, and so on. The refractive index is the ratio of the speeds of light in two different media or different regions. We define the refractive index, n, as the ratio of the speeds of a wave in two different regions.

$$\text{refractive index, } n = \frac{\text{speed of light in air (or a vacuum)}}{\text{speed of light in medium}}$$

Refractive index is also

The refractive index, n, for the ratio of angles, is defined as: The ratio of the sine of the angle of incidence and the sine of the angle of refraction of a wave in two different regions.

$$\text{refractive index, } n = \frac{\text{sine of angle between ray in air and normal}}{\text{sine of angle between ray in material and normal}} = \frac{\sin i}{\sin r}$$



Remember

Exam Tip

$n = \frac{\sin i}{\sin r}$ is also known as Snell's law but you do not need to know this for your exam.

Important: $(\frac{\sin i}{\sin r})$ is not the same as $(\frac{i}{r})$. Incorrectly cancelling the sin terms is a very common mistake!

When calculating the value of *i* or *r* start by calculating the value of sin *i* or sin *r*.

You can then use the **inverse sin** function ($\sin^{-1}$ on most calculators by pressing 'shift' then 'sine') to find the angle.

One way to remember which way around *i* and *r* are in the fraction is remembering that '*i*' comes before '*r*' in the alphabet, and therefore is on the top of the fraction (whilst *r* is on the bottom).

Facts about refraction

The more light is slowed down when it enters a medium from air, the greater is the refractive index of the medium and the more the light is bent.

The mediums can be any two different materials. It does not necessarily need to be air and glass!

The change in the direction of travel of a light ray when its speed changes on entering another medium suggests that light may also be a type of wave motion.

Refractive index table

Material	Speed of light / m/s	$\frac{\text{speed in vacuum}}{\text{speed in material}}$
vacuum	2.998×10^8	1 exactly
air	2.997×10^8	1.0003
water	2.308×10^8	1.33
Perspex®	2.000×10^8	1.5
glass	$(1.800 – 2.000) \times 10^8$	1.5 – 1.7
diamond	1.250×10^8	2.4

Question

A ray of light hits the surface of water at an angle of incident of 30°. It is refracted at an angle of 22°. Find the refractive index, n, of water

n = 1.33

Question

A ray of light enters a block of glass at an angle of incidence of 0.698 rad. The angle of refraction in the glass is 25°. Calculate the refractive index of the glass.

n = 1.52

Remember from math class

Radians to Degrees

$$\text{Radians} = \left\{\frac{\pi}{180^o}\right\} \times \text{Degrees}$$

$$\text{Degrees} = \left\{\frac{180^o}{\pi}\right\} \times \text{Radians}$$

Question

A ray of light enters glass with a refractive index of 1.52 at an angle of incidence of 60°.

- Calculate the angle of refraction.
- Calculate the speed of light in the glass.

- **r = 34.7°**

Answer

To calculate the speed of light in glass, we use the formula:

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

v is the speed of light in the medium,

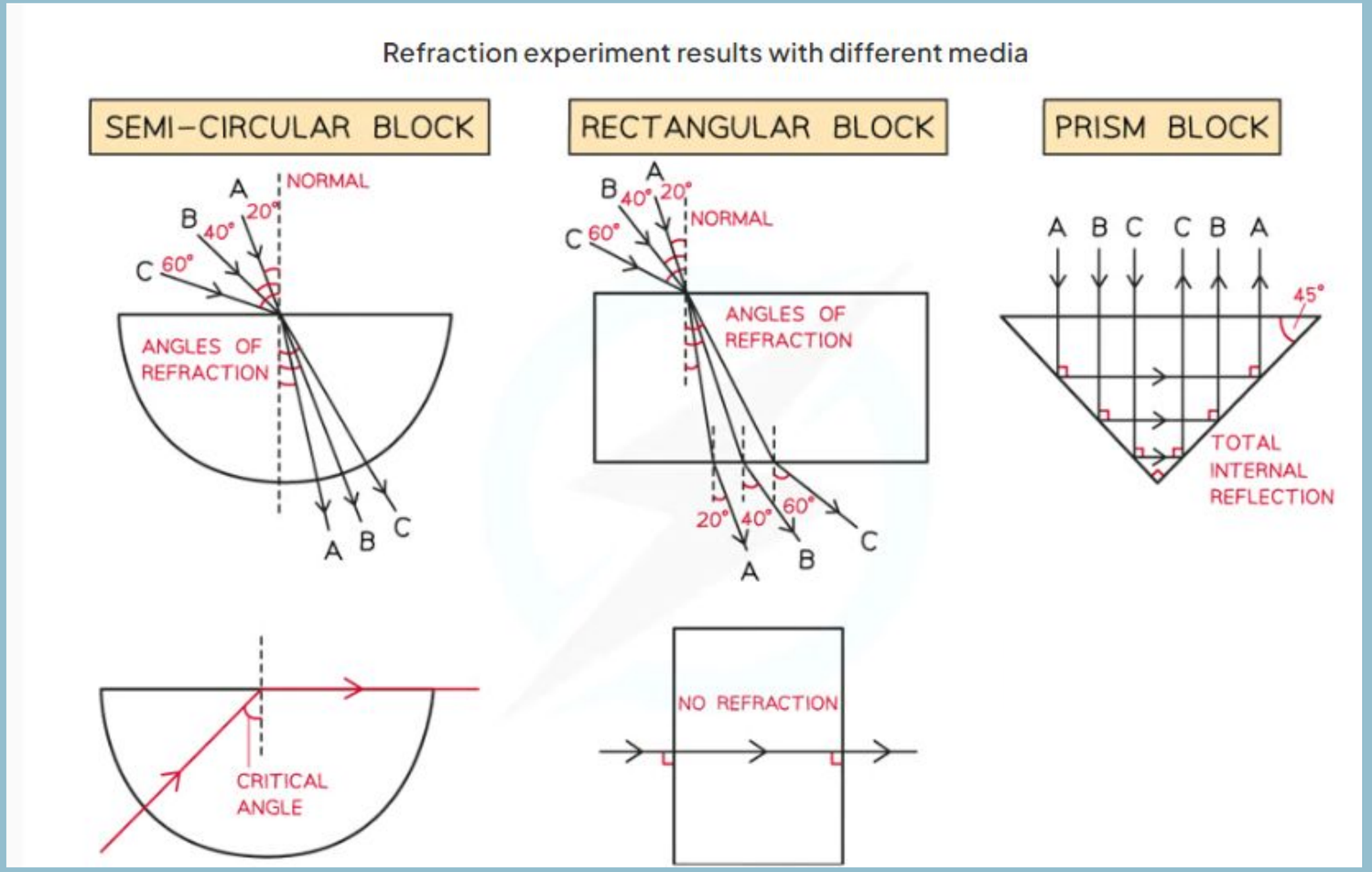
c is the speed of light in a vacuum (3.00×10^8 m/s),

n is the refractive index of the medium

- **the speed of light in the glass is approximately 1.97×10^8 m/s.**

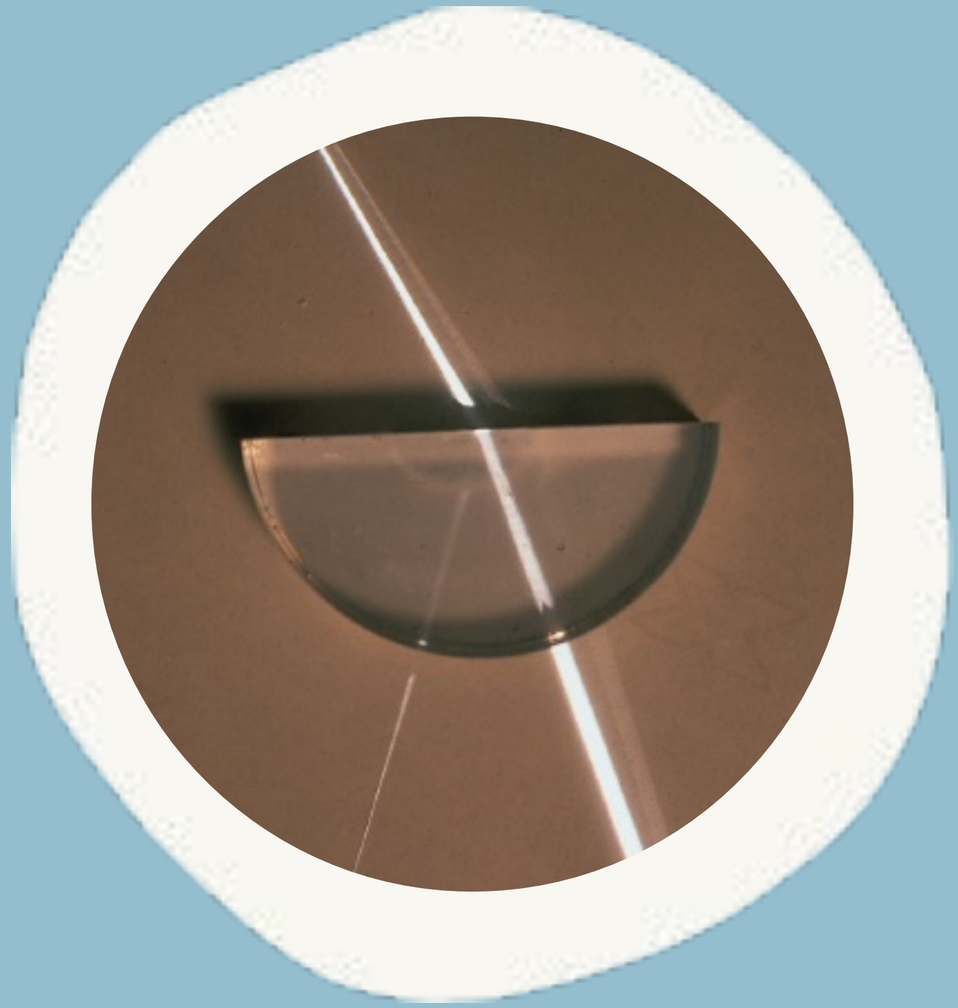
Changing direction

Usually we say that refraction is the bending of light when it passes from one medium to another. However, we should bear in mind that, when the light is perpendicular to the boundary between the two materials, there is no bending.



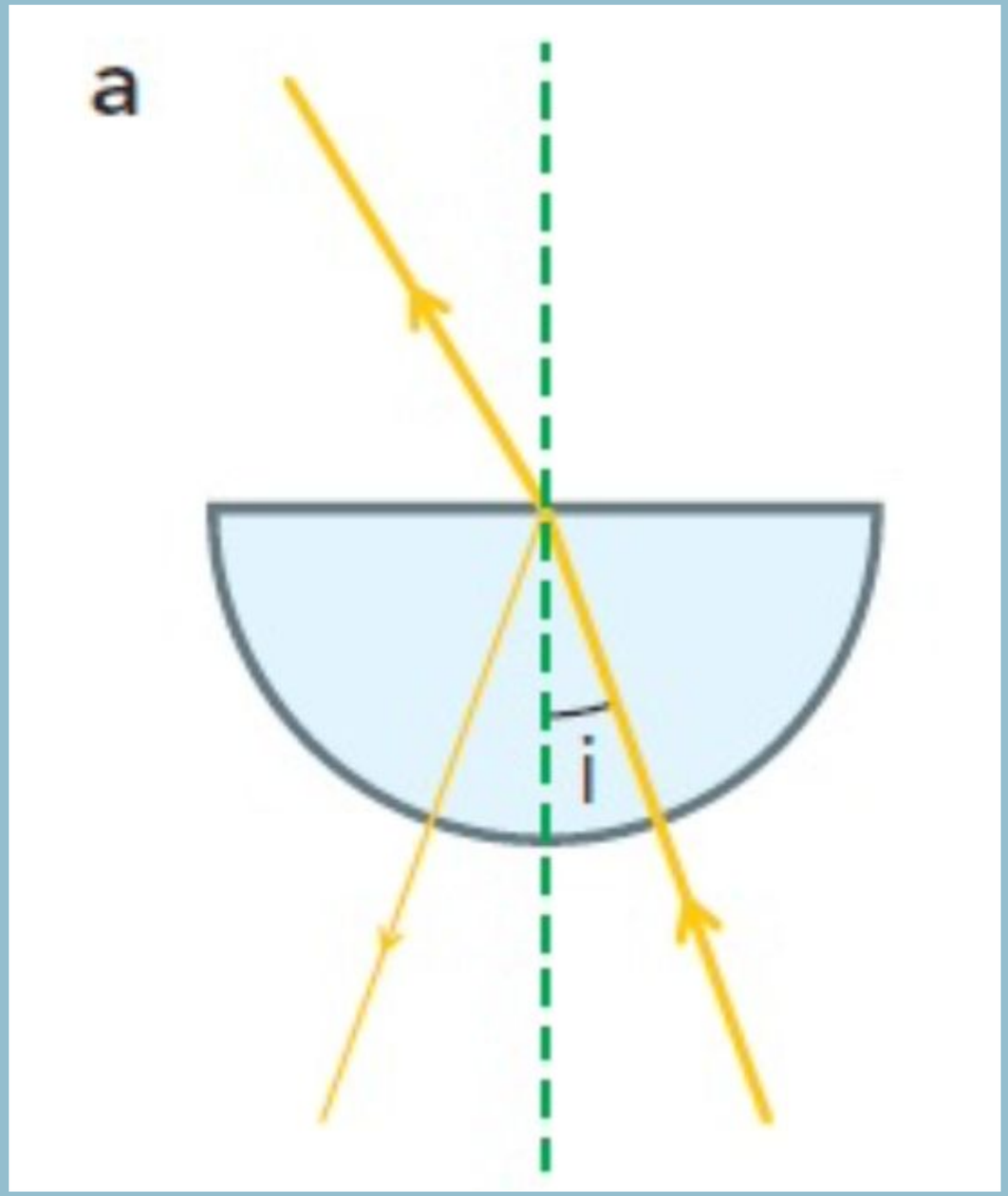
13.3 Total internal reflection

When you investigated refraction you may have noticed that not all the light is refracted. Some is reflected back from the surface. You can also see that as the light emerges from the glass, some light is reflected back inside the glass. This is called internal reflection.



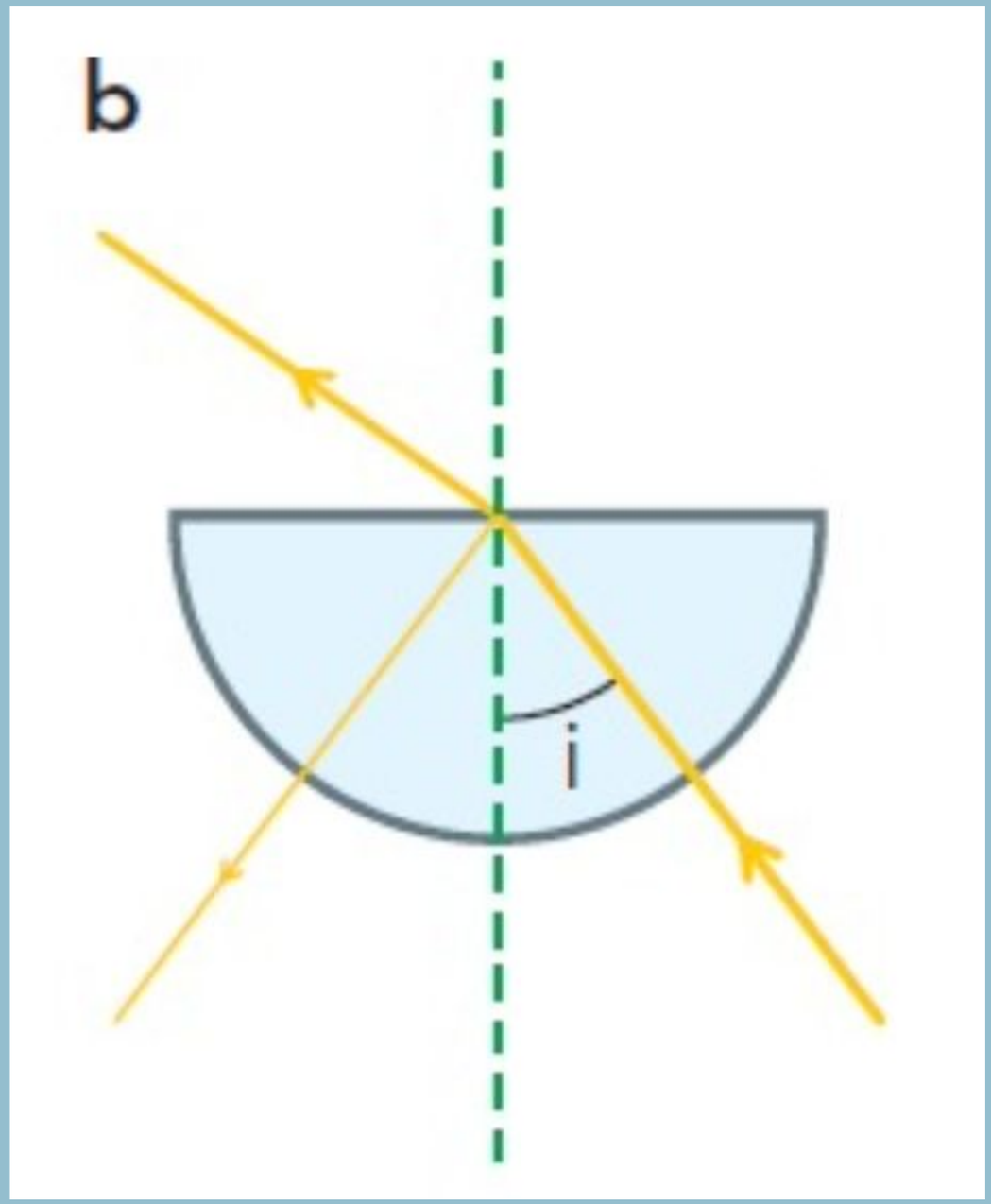
Critical angle

The angle of incidence is small, so most of the light emerges from the block. There is a faint reflected ray inside the glass block. The refracted ray bends away from the normal. What happens next depends on the angle of incidence of the ray at the midpoint.



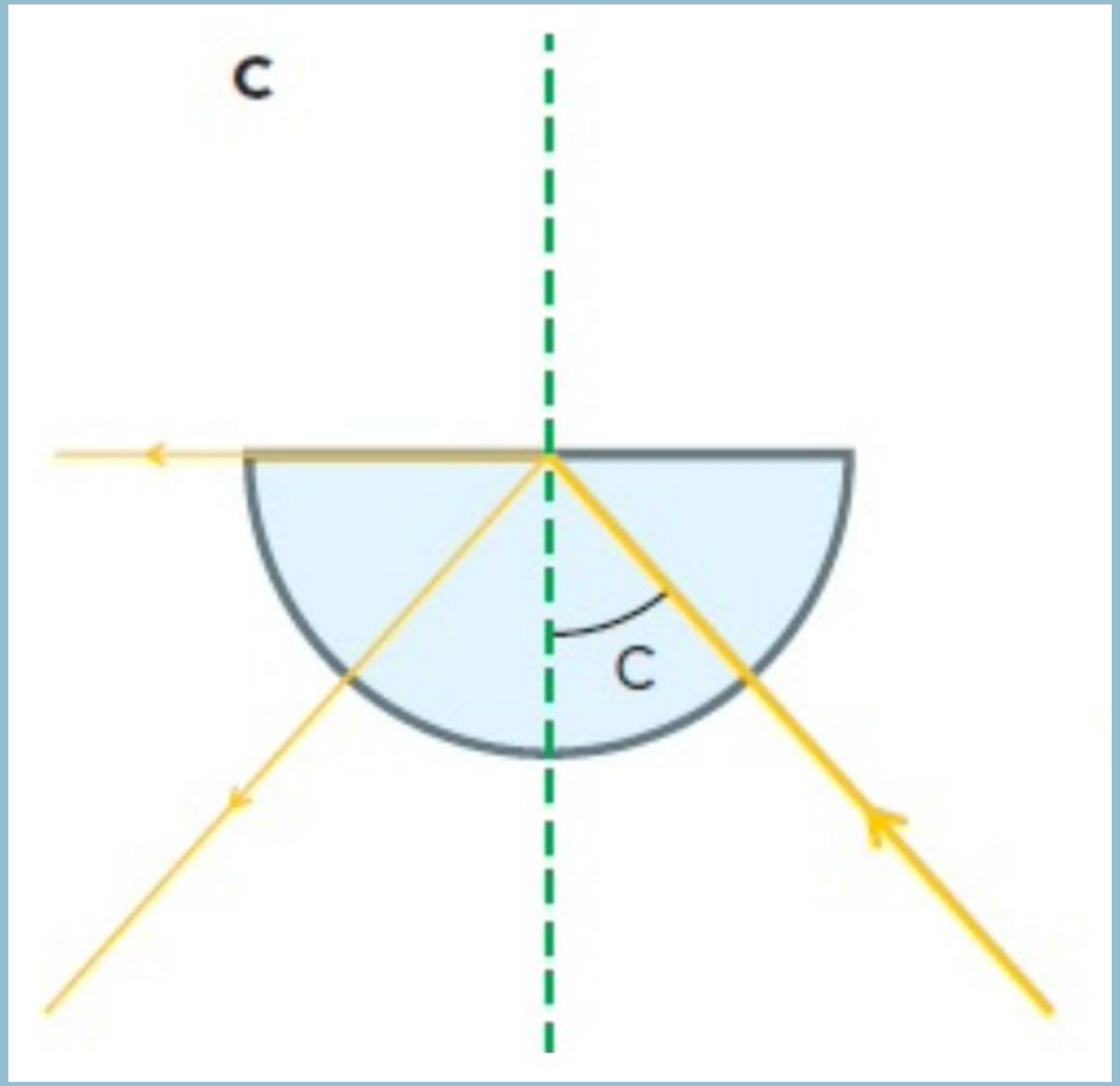
Critical angle

The angle of incidence has increased, so more light is reflected inside the block. The refracted ray bends even further away from the normal.



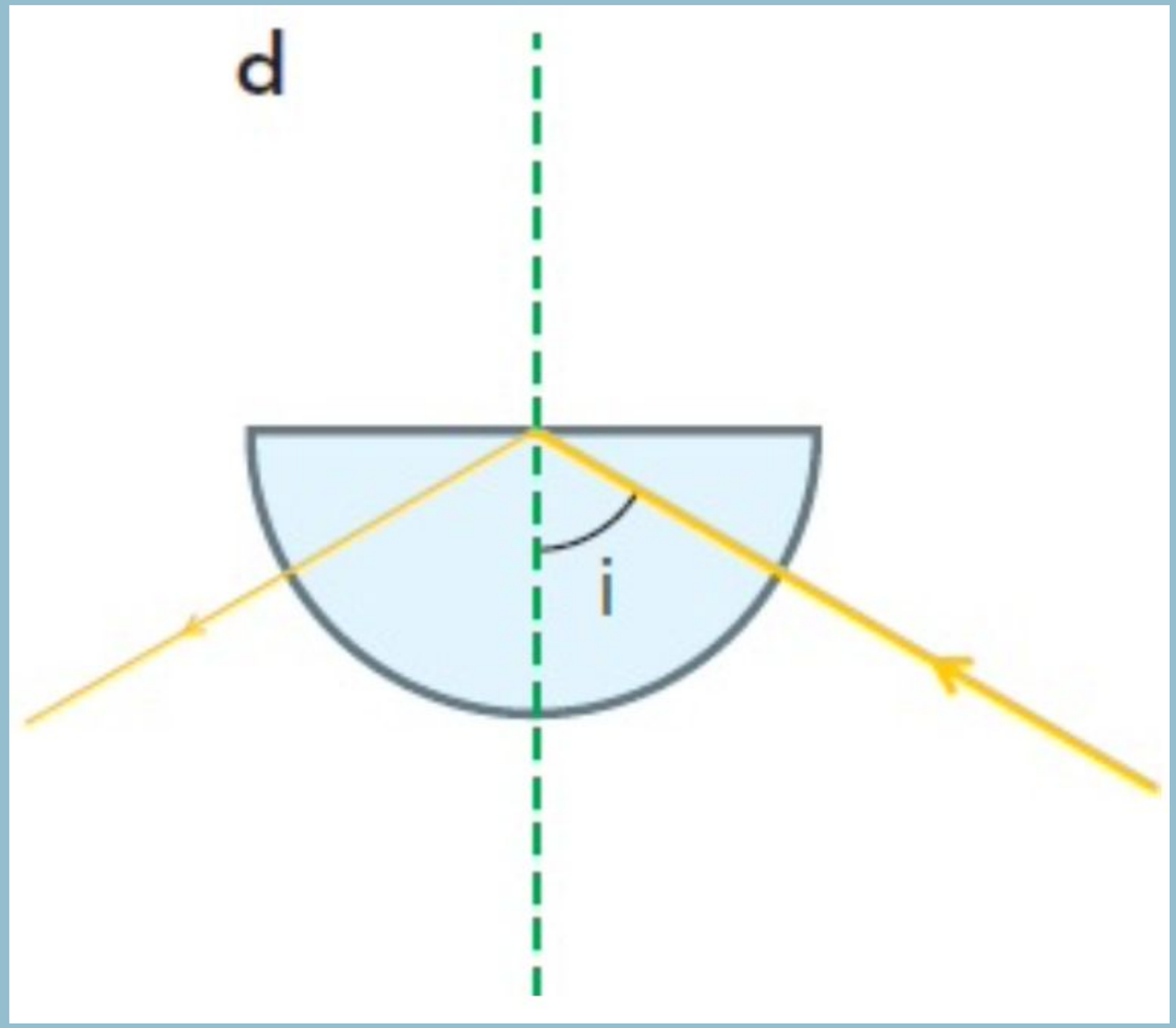
Critical angle

The refracted ray emerges along and parallel to the surface of the block for a particular angle of incidence. This angle is called the critical angle. Most of the light is reflected inside the block. At a certain angle of incidence, called the critical angle, c, the angle of refraction is 90°



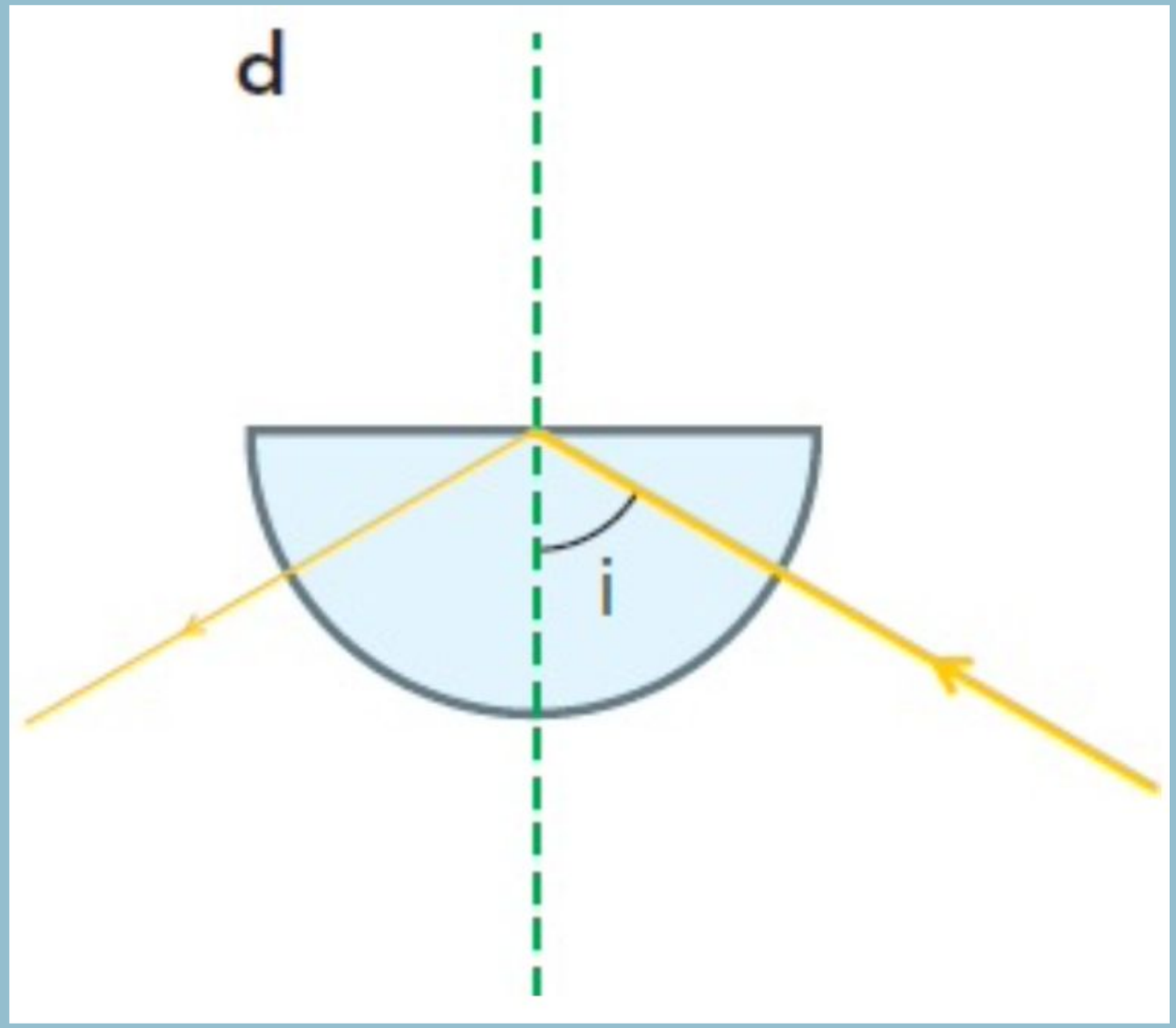
Critical angle

The angle of incidence is even greater and all of the light is reflected inside the block. No refracted ray emerges from the block.

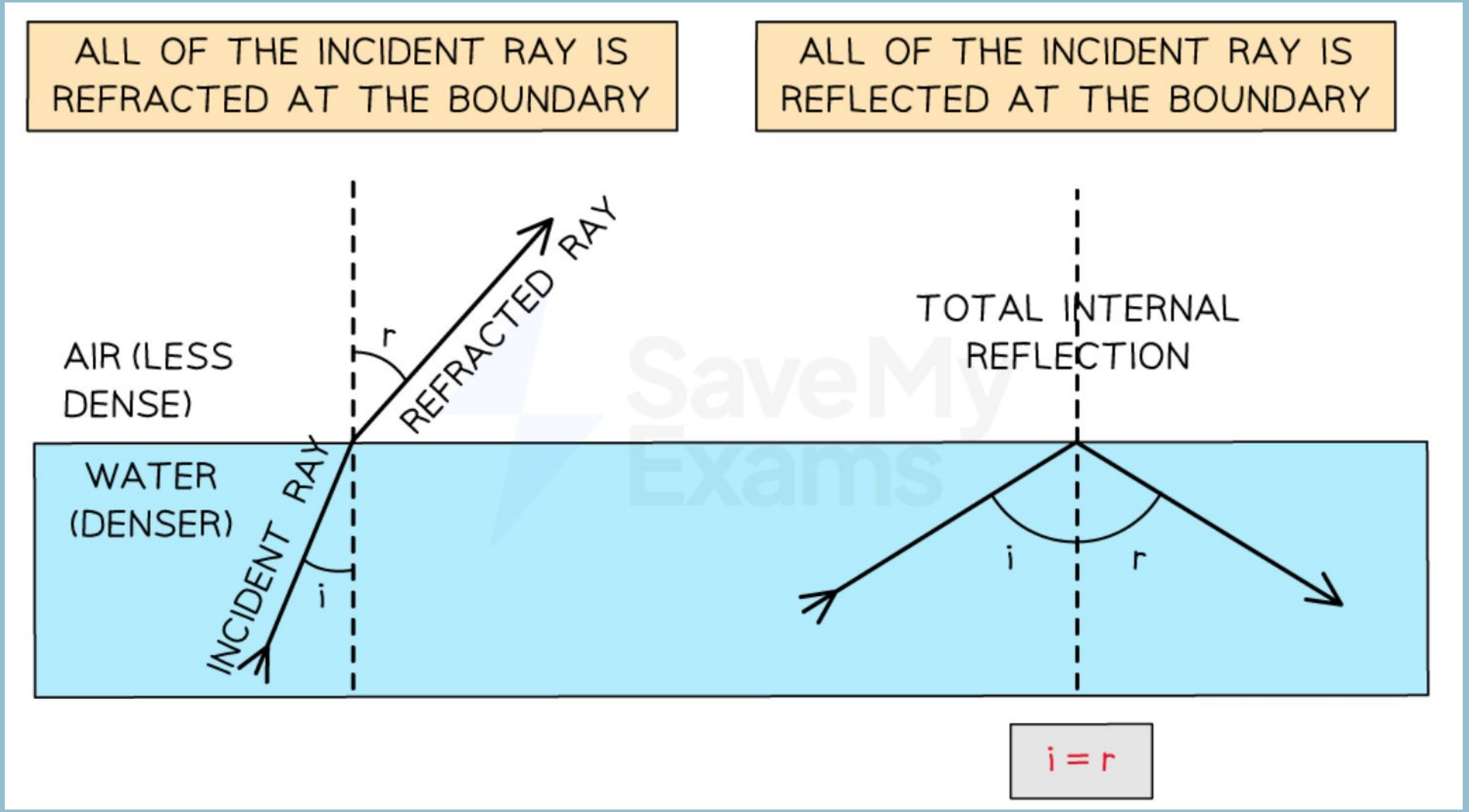


Critical angle

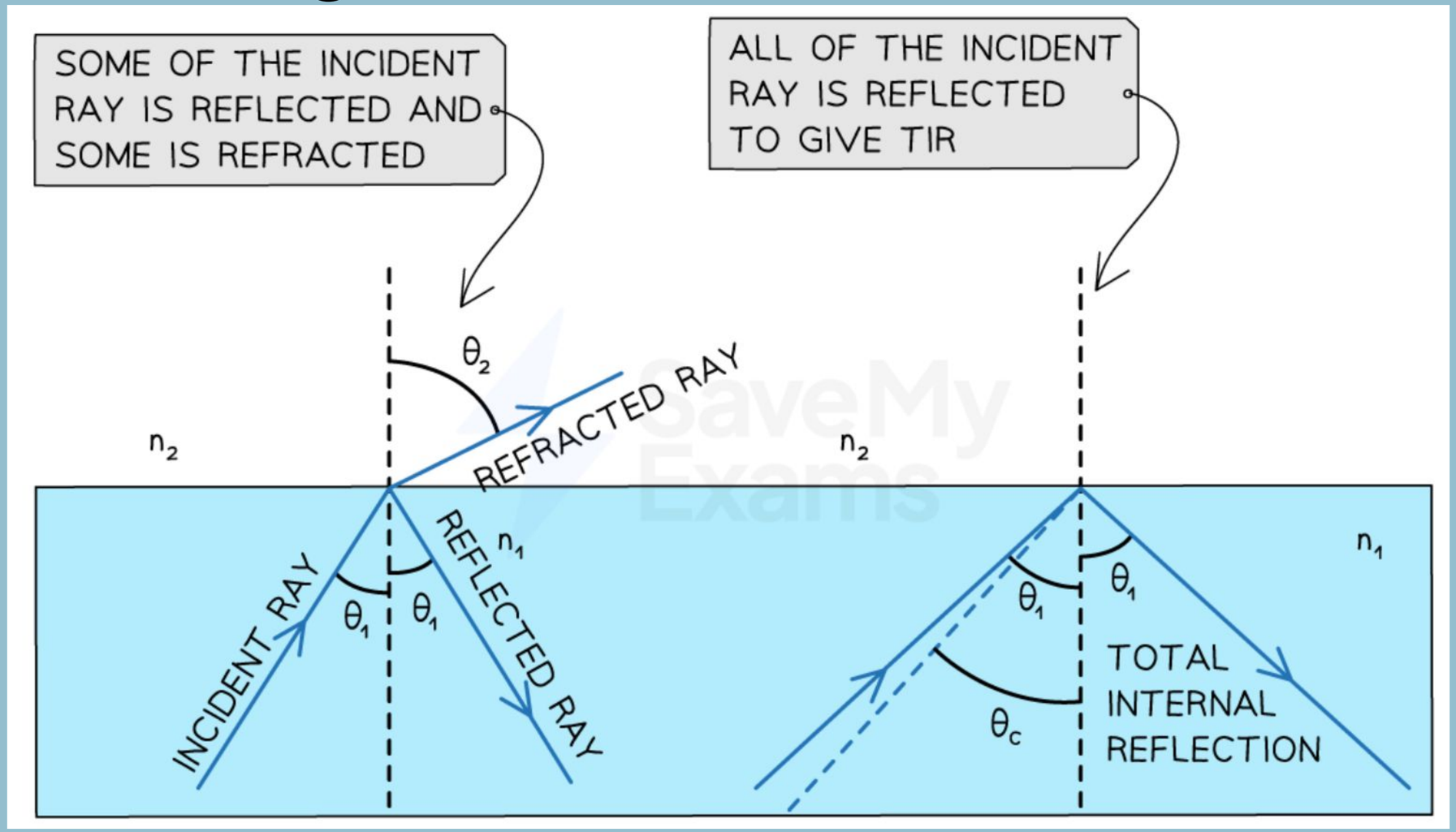
For angles of incidence greater than c, the refracted ray disappears and all the incident light is reflected inside the denser medium. The light does not cross the boundary and is said to undergo total internal reflection.



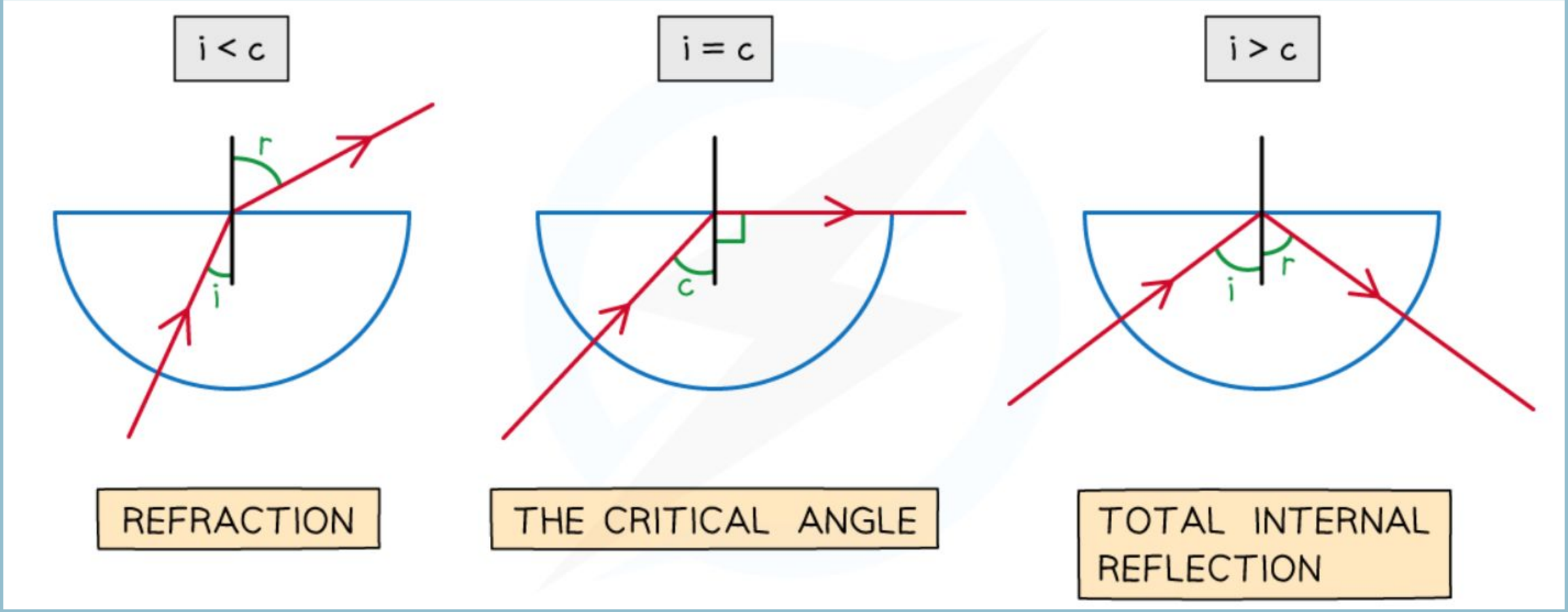
Critical angle



Critical angle



Critical angle



Total Internal Reflection (TIR)

total, because 100% of the light is reflected

internal, because it happens inside the glass

reflection, because the ray is entirely reflected.

Total Internal Reflection (TIR)

For total internal reflection to happen, the angle of incidence of the ray must be greater than the critical angle c. The critical angle depends on the material being used. For glass, it is about 42°, depending on the type of glass. For water, the critical angle is greater, about 49°. For diamond, the critical angle is small, about 25°.

Critical angle

On a hot day the road ahead may appear to shimmer with water. The layers of air close to the surface of the road are hotter and less dense than those above and refraction of sunlight occurs. When the critical angle of incidence is reached, the light undergoes total internal reflection, resulting in a mirage which disappears as you move towards it.

Critical angle

Critical angle and refractive index

As we have seen, the critical angle depends on the material through which a ray is travelling. The greater the refractive index of the material, the smaller the critical angle. The relationship between the critical angle and the refractive index is

KEY EQUATION

critical angle:

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

Question

Find the critical angle, c, for diamond. Assume that refractive index n = 2.40

c = 24.6°

Question

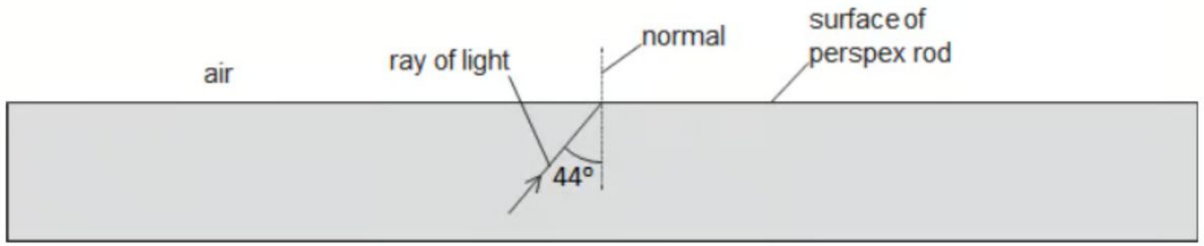
The critical angle for a material is 38°. Calculate its refractive index.

n = 1.62

Question

The diagram shows a ray of light inside a perspex rod.

Perspex has a critical angle of 42°.

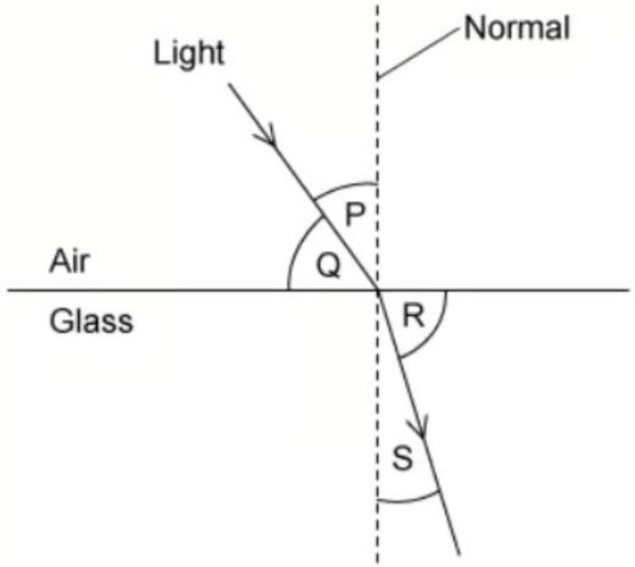


Which row in the table correctly states whether there is any light reflected from the surface, and whether there is any light refracted out of the perspex rod?

	Light reflected?	Light refracted?
A	yes	yes
B	yes	no
C	no	yes
D	no	no

If the angle of incidence is greater than the critical angle, 42 degrees in this case, the light will be totally internally reflected, and no light will escape the rod

The diagram shows light passing from air into glass. A number of angles have been labelled on the diagram.



Which of the equations could be used to correctly calculate the refractive index, *n*, of the glass?

A. $\frac{\sin P}{\sin S}$

B. $\frac{\sin Q}{\sin R}$

C. $\frac{\sin P}{\sin R}$

D. $\frac{\sin Q}{\sin S}$

- $n = . \frac{\sin(angle\ of\ incidence)}{\sin(angle\ of\ refraction)}$
- P is the correct angle of incidence
- S is the correct angle of refraction

Question

Light enters a flat water surface at an angle of 27°.

The refractive index of water is 1.33.

At what angle does the light ray refract?

A. 0.34°

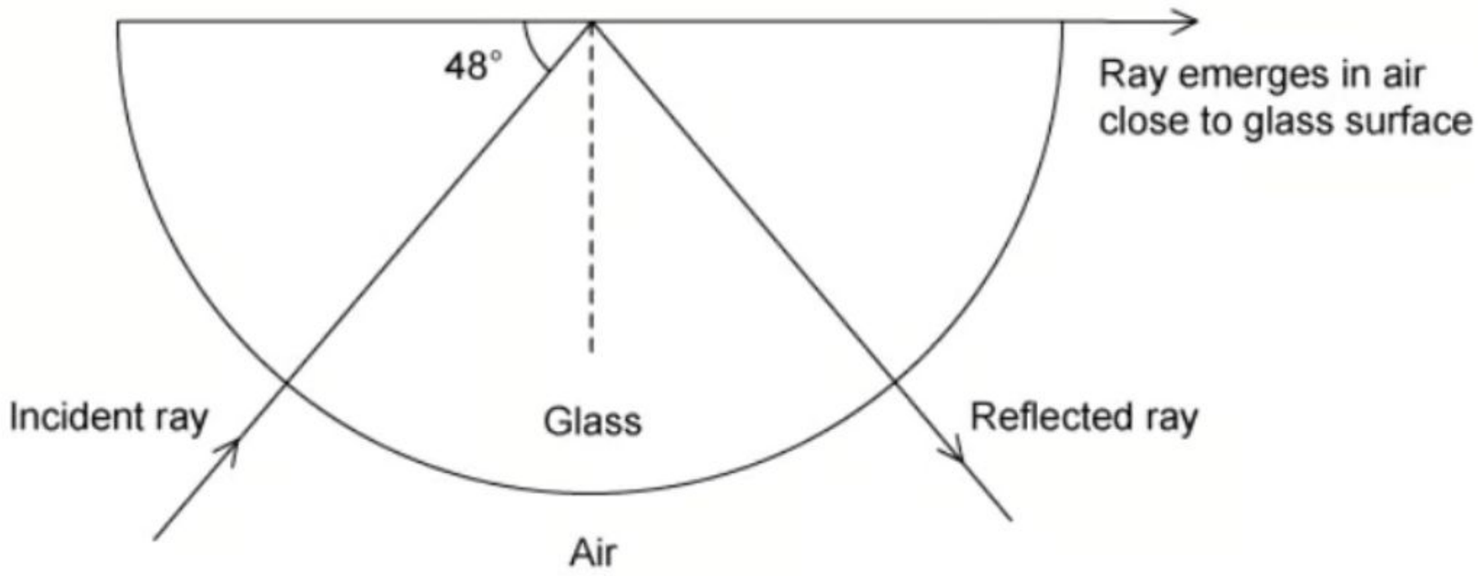
B. 20.3°

C. 20.0°

D. 37.0°

- $n = \frac{\sin i}{\sin r}$
- $\sin r = \frac{\sin i}{n}$
- $r = \sin^{-1}\left(\frac{\sin i}{n}\right)$
- $r = \sin^{-1}\left(\frac{\sin 27}{1.33}\right)$
- $r = 19.95°$

A ray of light is shone into a semi-circular glass block so that it makes an angle of 48° with the rear, flat edge of the block as shown.



Calculate the refractive index of the glass.

A. 0.023

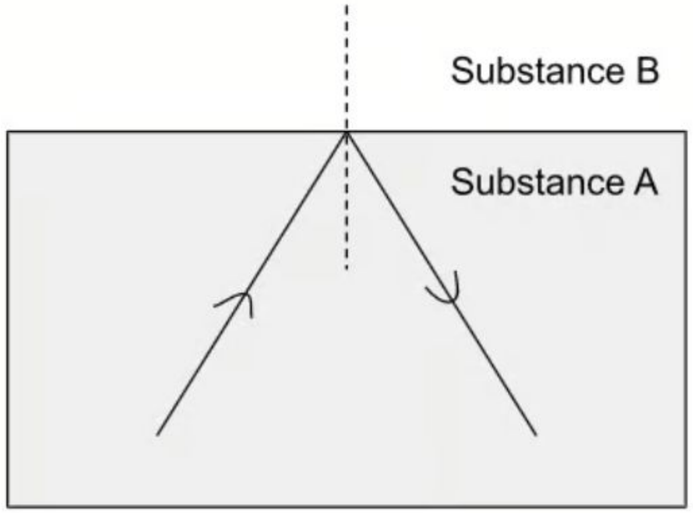
B. 1.49

C. 2.38

D. 1.35

- This is a question about total internal reflection and the critical angle. We know this because light is being reflected **inside** a material, rather than from its surface.
- $n = \frac{1}{\sin c}$
- The angle of incidence (in this case, the critical angle, c) is the angle **between the normal and the incident ray**. We are given the other angle. Therefore:
- $c = 90 - 48 = 42°$
- $n = \frac{1}{\sin 42}$
- $n = 1.494$

The diagram shows a ray of light being totally internally reflected at the boundary between substances A and B.



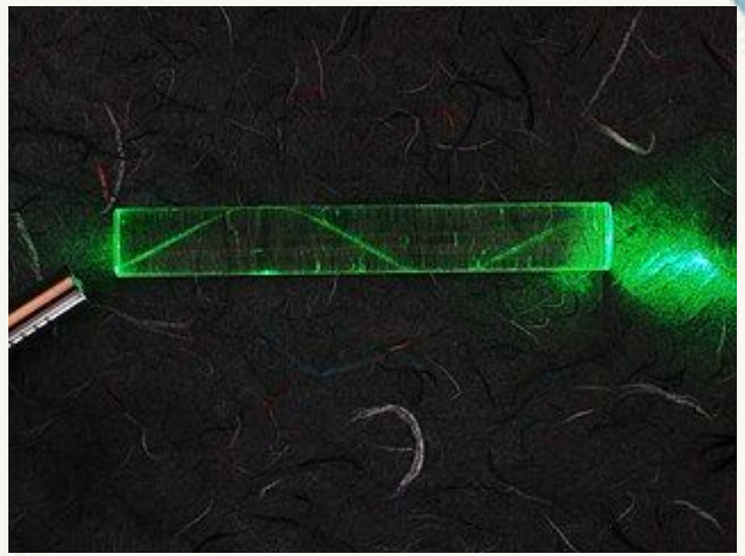
- This question is about total internal reflection.
- If the angle of incidence is greater than the critical angle, the light will be totally internally reflected.
- Total internal reflection only works when the substance the light is going from has a higher refractive index than the substance it is going to, from glass to air for example.

Which row in the table must be true?

	Angle of incidence	Substance A
A	greater than critical angle	greater refractive index than B
B	greater than critical angle	smaller refractive index than B
C	less than critical angle	greater refractive index than B
D	less than critical angle	smaller refractive index than B

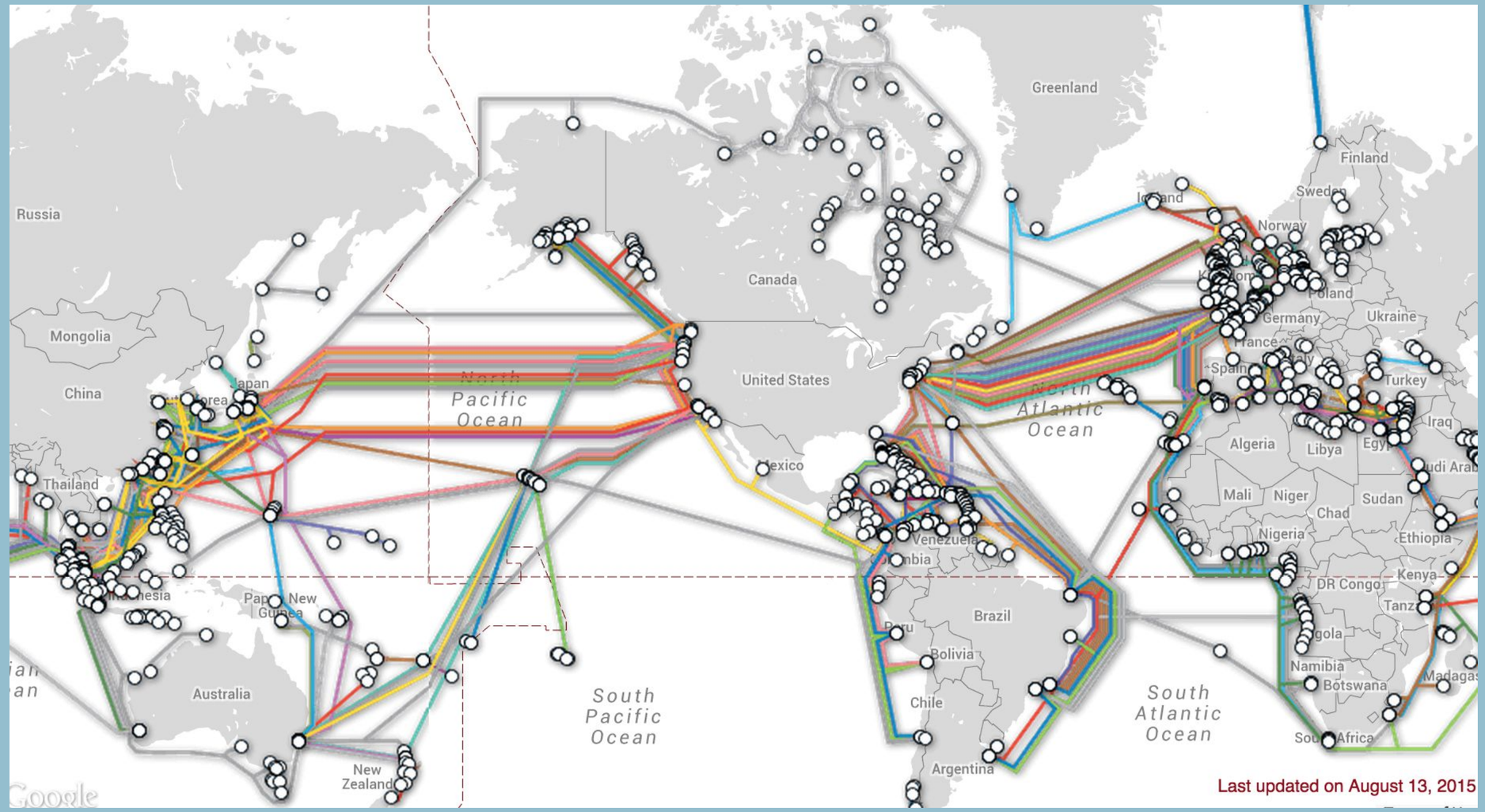
Optical fibers

A revolution in telecommunications has been made possible by the invention of fibre optics. Telephone messages and other electronic signals such as internet computer messages or cable television signals are passed along fine glass fibres in the form of flashing laser light, which is a digital signal.

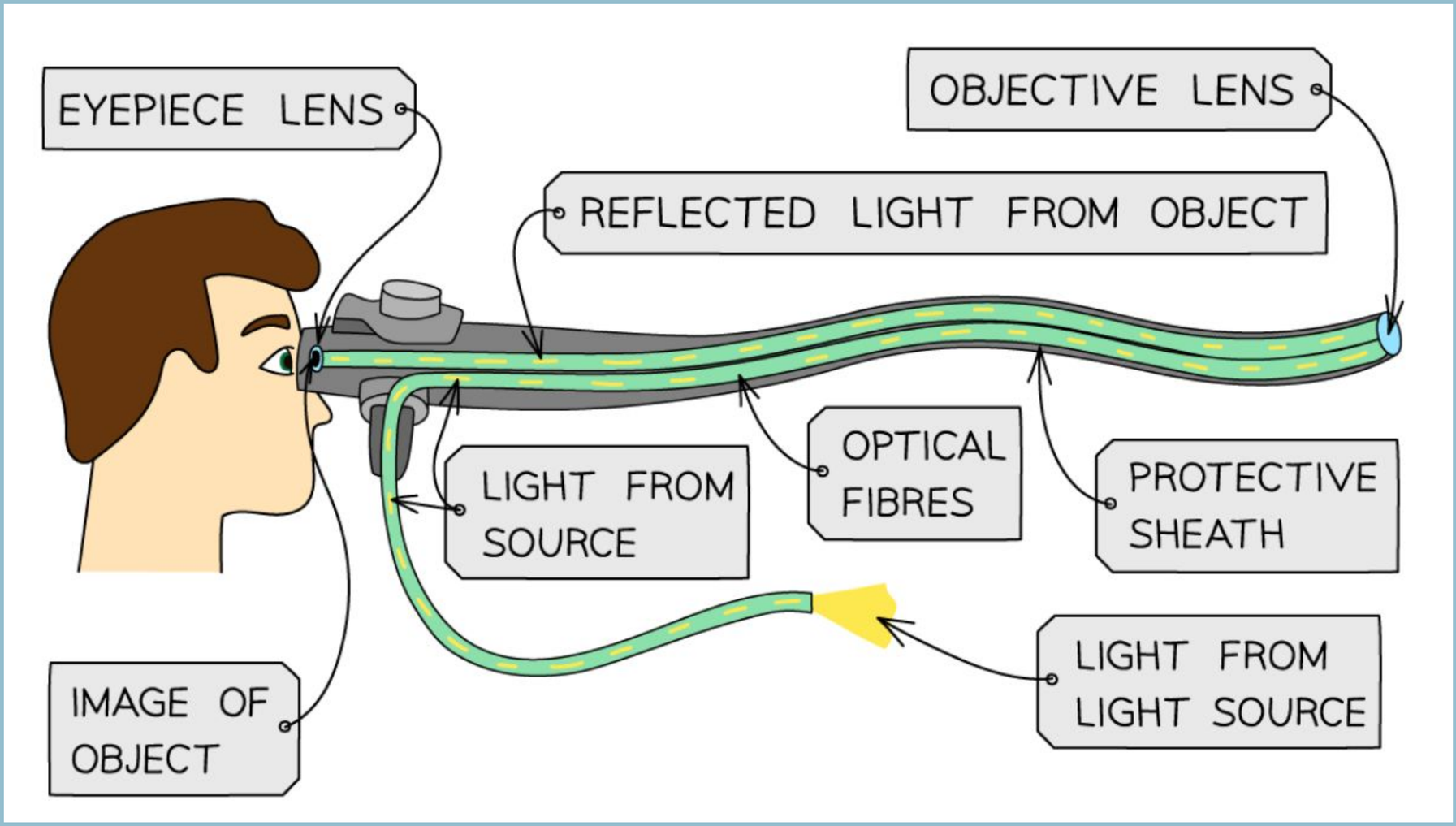


Optical fibers

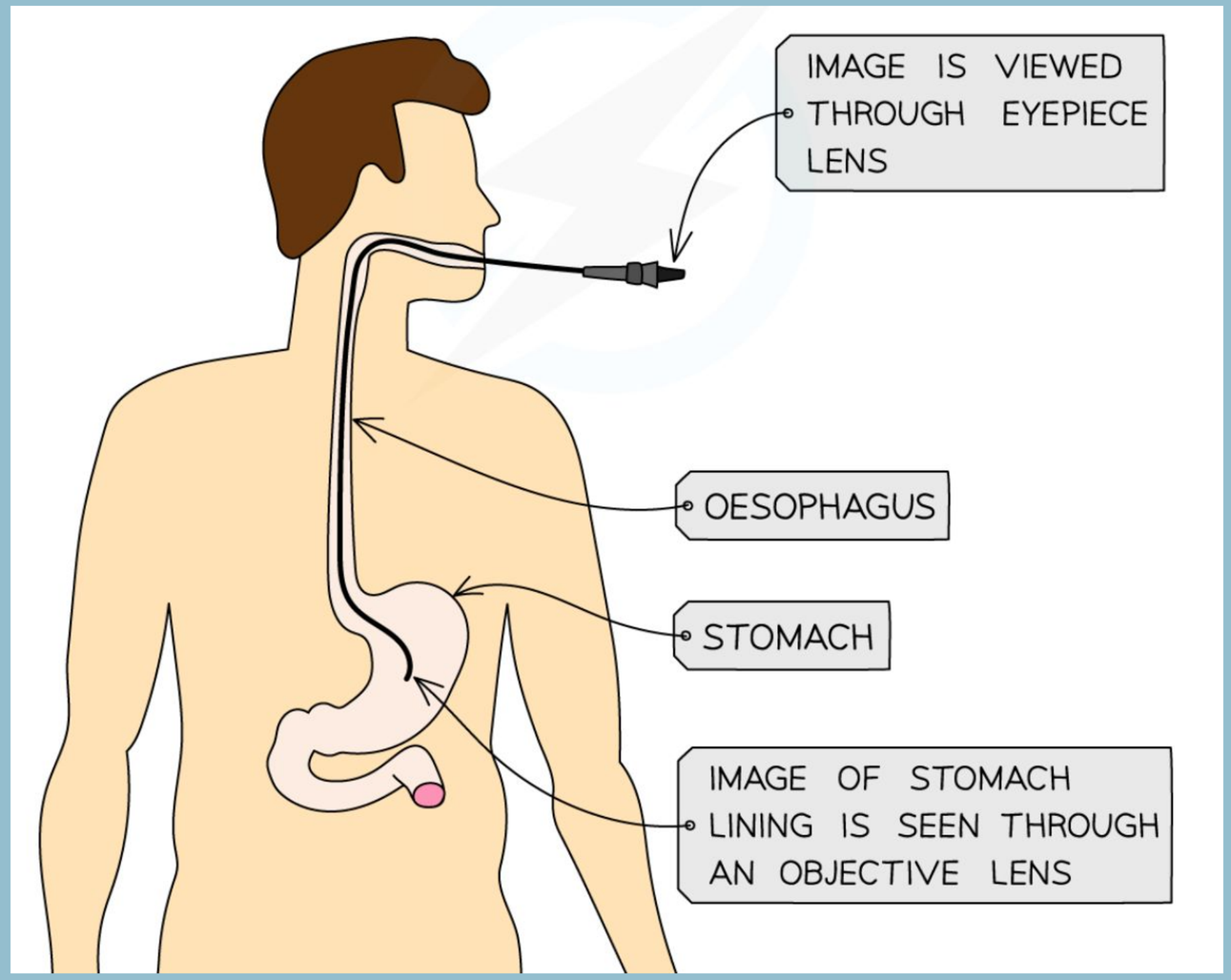
Optical fibers usage for internet



Optical fibers in medicine

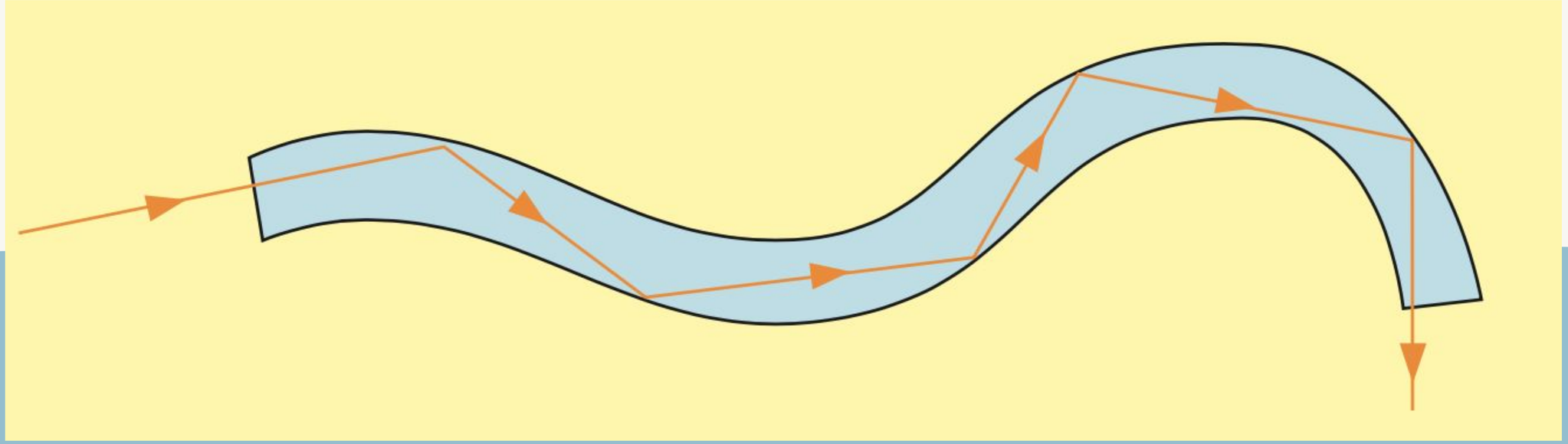


Optical fibers in medicine



Question

Sketch a diagram to show how a ray of light can travel along a curved glass fibre. Indicate the points where total internal reflection occurs.



An endoscope is a piece of medical equipment used to see inside a person's body. Endoscopes use optical fibres within a long tube which reflects light from inside the patient to an eye piece lens or camera.

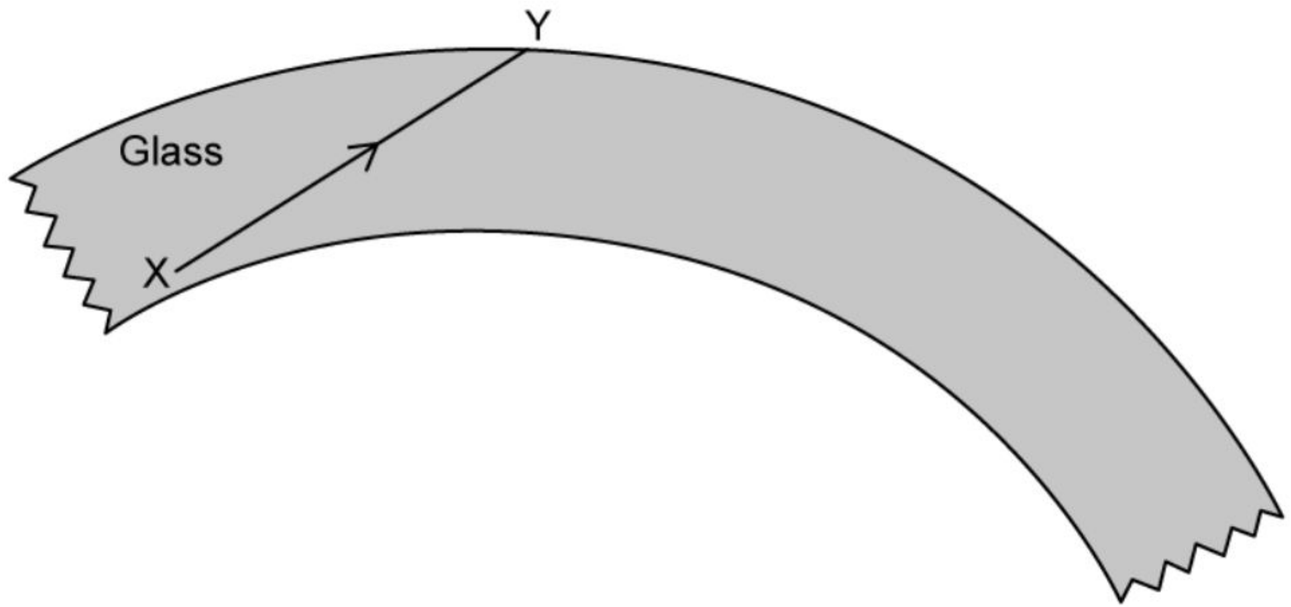
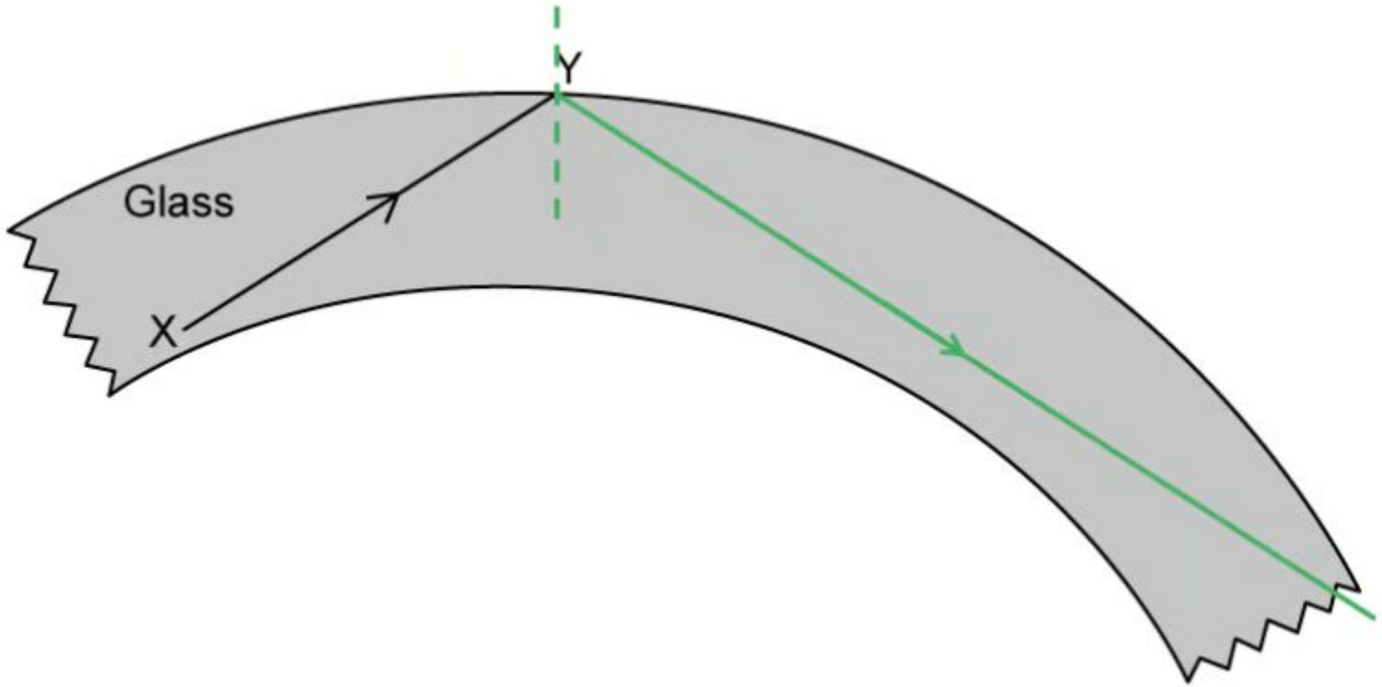


Fig. 1.1

Fig. 1.1 shows a section of optical fibre. Light travels from X to Y.

On Fig. 1.1, complete the path of the light ray until it leaves the section of optical fibre.

A diagram scoring 2 marks:



- Internal reflection drawn **AND** $i = r$ for the first reflection; [1 mark]

  Mark is not awarded if the ray emerges from the sides of the optical fibre

- The ray reaches the end of the tube after 1 or 2 reflections; [1 mark]

Question

State the type of reflection that occurs within an optical fibre.

→ **Internal reflection**

Calculate the critical angle.

Glass has a refractive index of 1.52.

critical angle =

Using Snell's law:

- $\sin c = \frac{1}{n}$ [1 mark]
- $c = \sin^{-1}\left(\frac{1}{1.52}\right)$ [1 mark]
- $c = 41°$ [1 mark]

Question

When the light ray exits the optical fibre it passes into air.

Calculate the speed of light in glass.

speed of light in glass = ...

Using the equation for refractive index:

- $n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ glass}$ [1 mark]
- $speed\ of\ light\ in\ glass = \frac{speed\ of\ light\ in\ vacuum}{n} = \frac{3.00 \times 10^8}{1.52}$ [1 mark]
- $speed\ of\ light\ in\ glass = 1.97 \times 10^8\ \mathrm{m/s}$ [1 mark]

Fig. 1.1 shows a light ray passing though a block of ice.

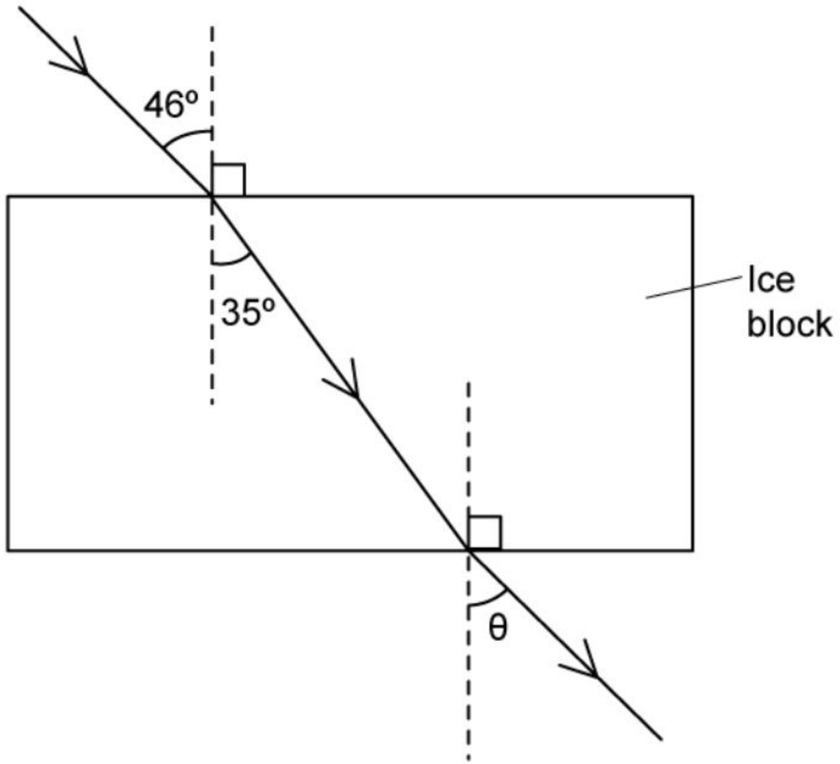


Fig. 1.1

(not to scale)

Determine the refractive index of ice.

refractive index = ...

Using Snell's law:

- $n = \frac{\sin i}{\sin r}$ [1 mark]
- $n = \frac{\sin(46)}{\sin(35)}$ [1 mark]
- $n = 1.25$ [1 mark]

Question

Explain why the angle of refraction is smaller than the incident angle for the boundary from air to ice.

- Ice is denser than air **OR** air is less dense than ice; [1 mark]
- Light slows down as it passes from a less dense medium (air) to a denser medium (ice); [1 mark]
- So the light (changes direction and) bends toward the normal; [1 mark]

Question

State the correct value of angle θ on Fig. 1.1.

angle θ = ...

- The light ray will leave the ice block parallel to its incident pathway, therefore $\theta = i$
- 46° [1 mark]

Question

Complete Table 1.2 by drawing a tick to show which properties of light change during refraction.

One mark for each correct tick:

Property	Does change	Does not change
speed	✓	
wavelength	✓	
frequency		✓

Question

The speed of a light wave in air is 3.00×10^8 m / s. The refractive index of water is 1.33.

Calculate the speed of the light wave in water.

speed = ...

(a) To calculate the speed of light in water

List the known quantities:

- Speed of light in air = 3.00×10^8 m / s
- Refractive index of water, $n = 1.33$

Recall the equation for the refractive index and speed of wave:

- $refractive\ index, n = \frac{speed\ in\ air}{speed\ in\ water}$ [1 mark]

OR

Rearrange the equation and substitute the known quantities:

- $speed\ in\ water = \frac{speed\ in\ air}{n}$
- $speed\ in\ water = \frac{3 \times 10^8}{1.33}$ [1 mark]

Calculate the speed of the wave in water:

- Speed in water = 2.3×10^8 m / s [1 mark]

Fig. 6.1 shows a mirror periscope. The periscope is used to view a golfer over the heads of other people. The periscope has two plane mirrors each at an angle of 45° to the vertical.

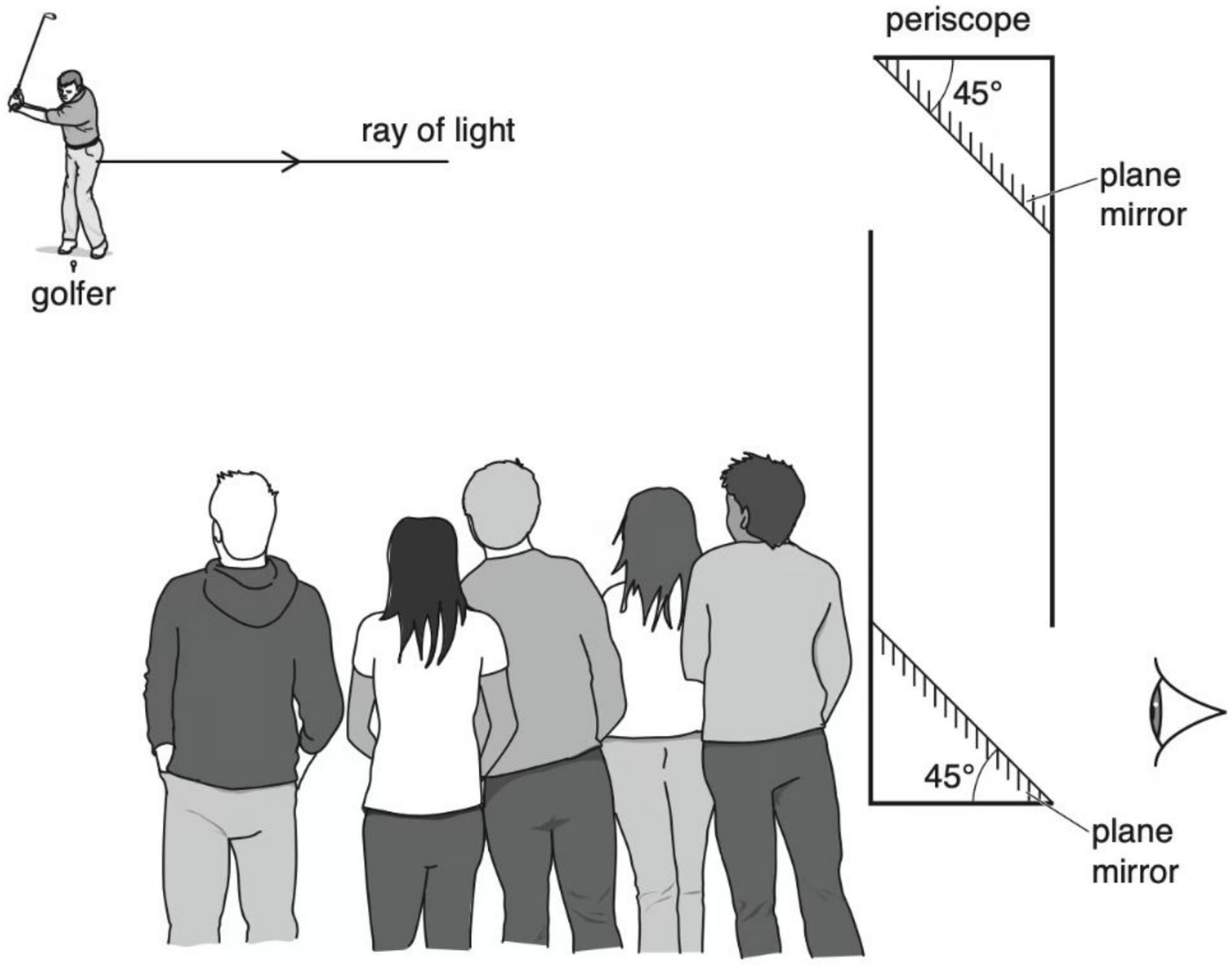
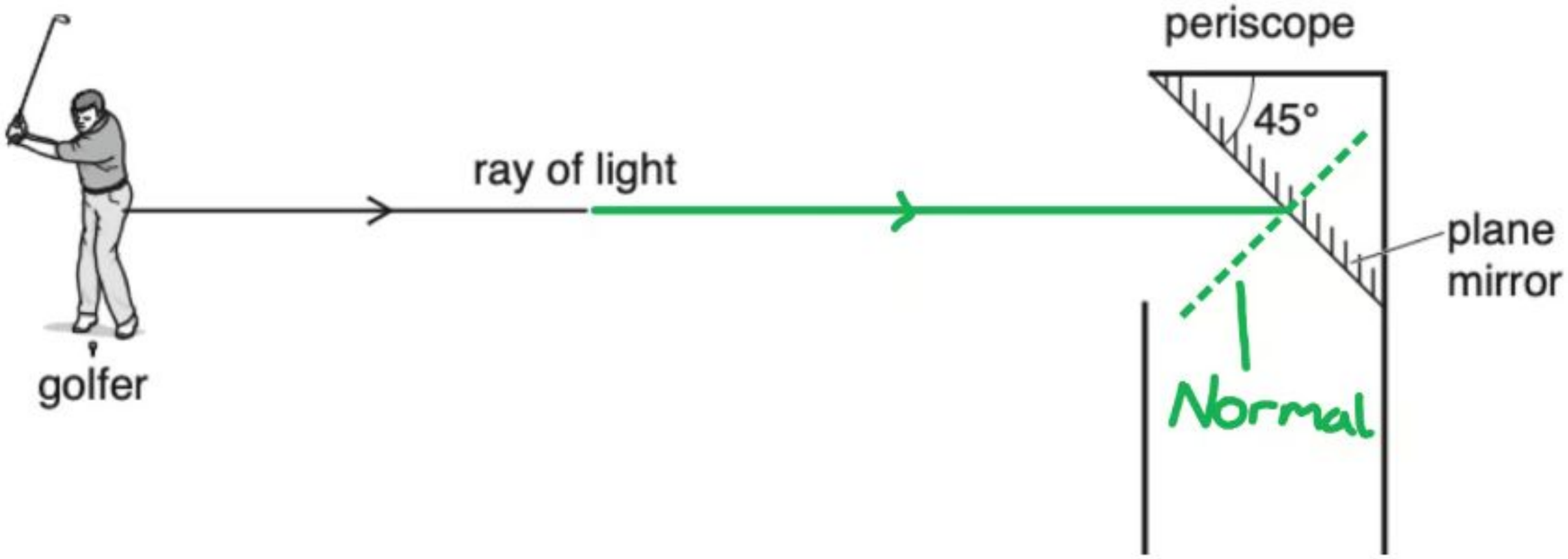


Fig. 6.1 (not to scale)

(i) 1. Continue the ray of light from the golfer towards the upper mirror of the periscope

2. Draw and label the normal at the point where the ray strikes the mirror:



- Ray of light is a straight line to the mirror **AND** the normal is perpendicular to the plane of the mirror (45° to the ray of light); [1 mark]

(ii) Continue the ray of light after reflection at the upper mirror until it leaves the periscope:

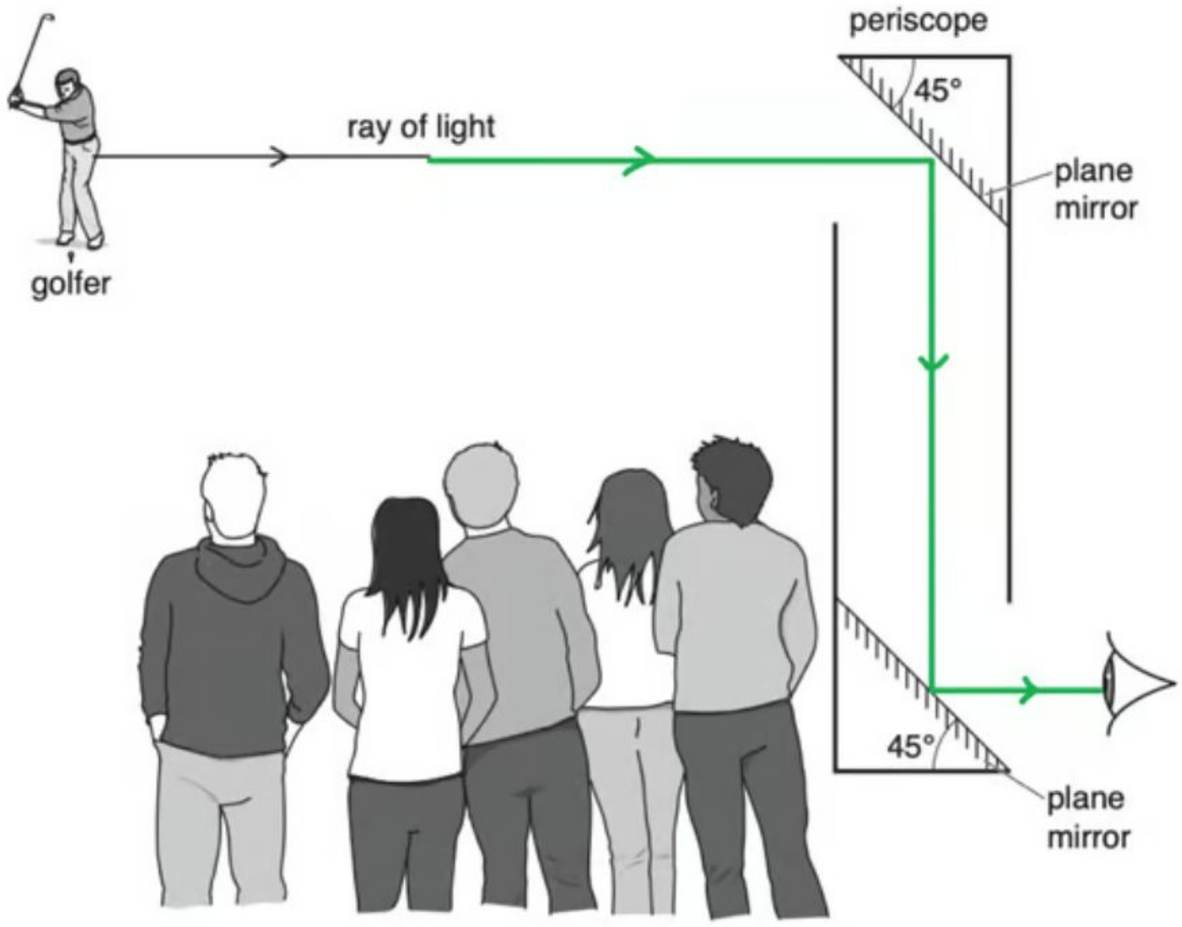


Fig. 6.1 (not to scale)

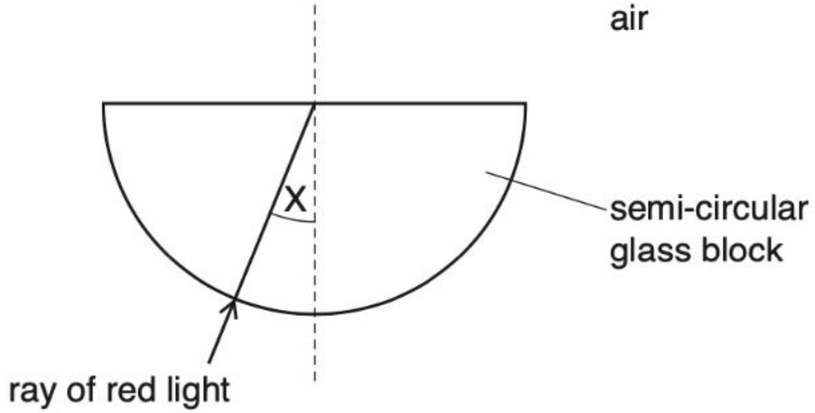
- First reflection is a 90° turn in the ray of light down the periscope **AND** second reflection is a 90° turn in the ray of light towards the eye; [1 mark]

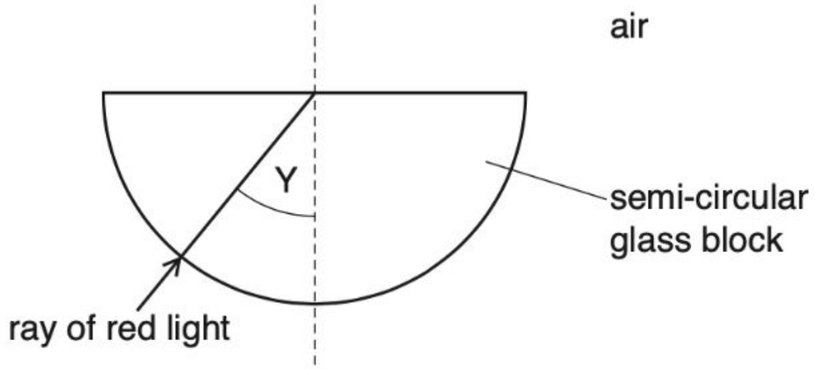
Answer

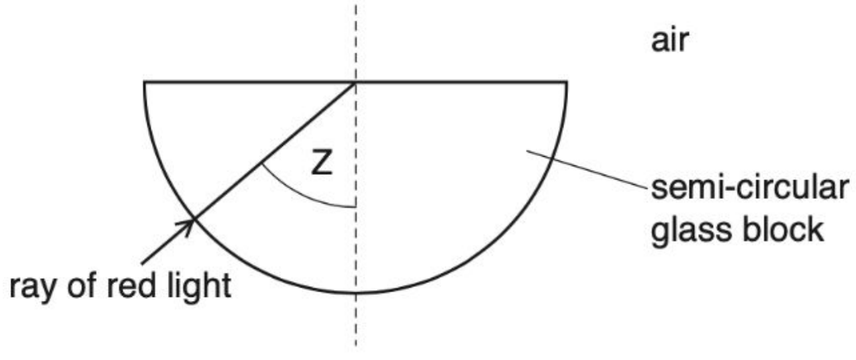
(iii) State the law of reflection used to deduce the position of the ray of light after striking the mirrors:

- The angle of incidence is equal to the angle of reflection; [1 mark]

Fig. 6.2 shows three rays of red light each entering a semi-circular glass block.





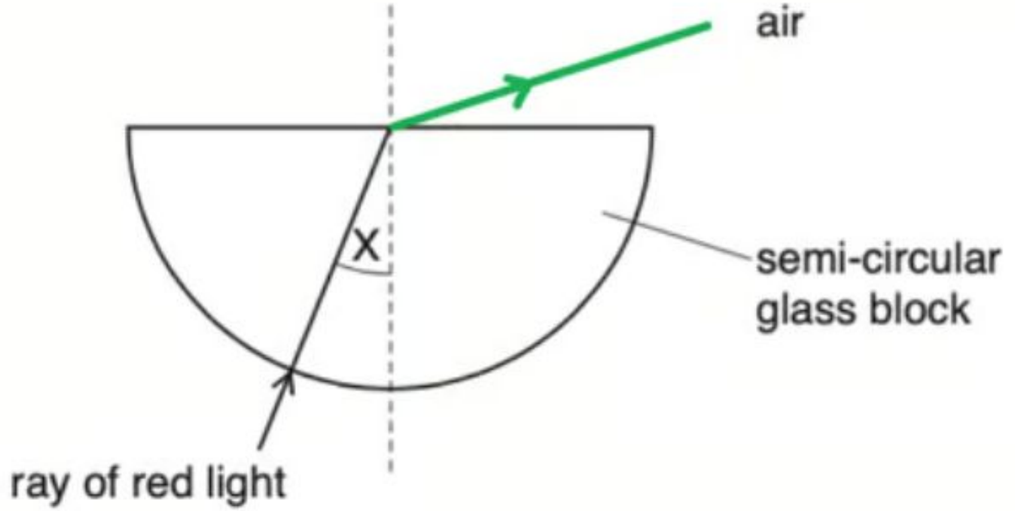


angle of incidence	description
X	less than the critical angle
Y	equal to the critical angle
Z	greater than the critical angle

Answer

Complete the path of the ray for angle of incidence X:

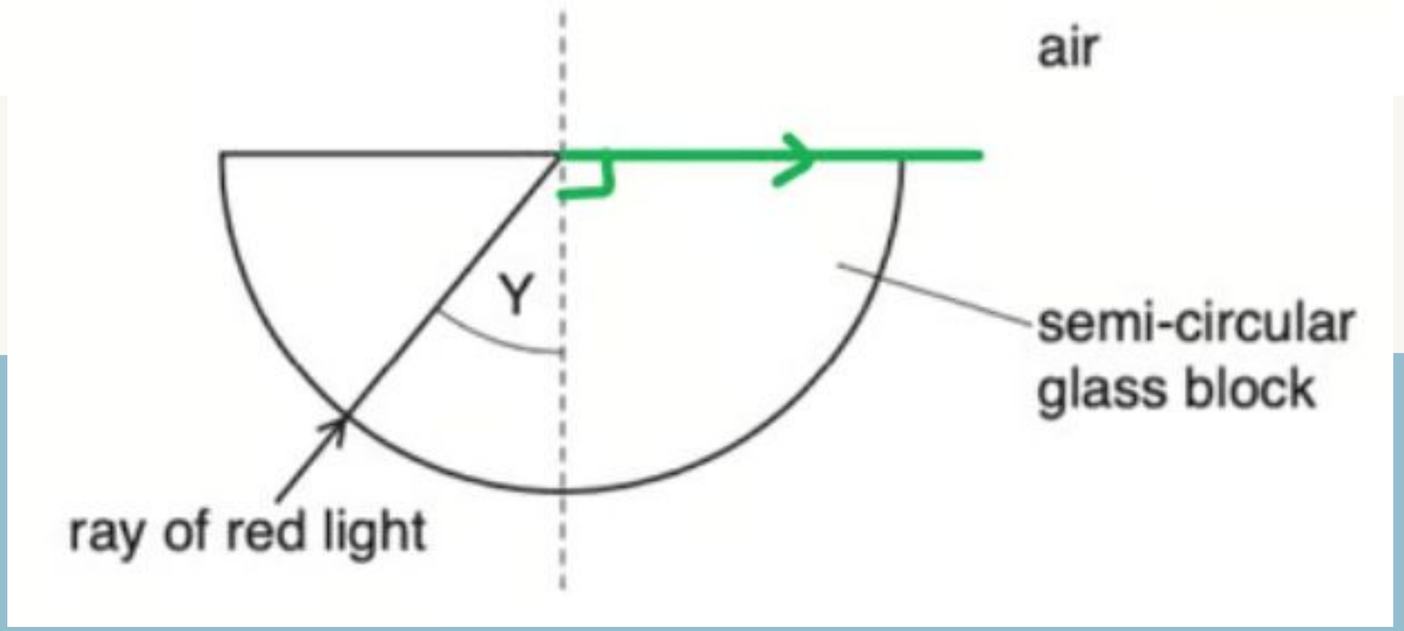
- X is less than the critical angle
- The ray leaves the block and is refracted
- It moves from a more dense medium to a less dense medium so it bends away from the normal (i < r)



Answer

Complete the path of the ray for angle of incidence Y:

- Y is equal to the critical angle
- The ray leaves the block and is refracted 90°
- This means the beam of light travels along the boundary between the glass block and the air



Answer

Complete the path of the ray for angle of incidence Z:

- Z is greater than the critical angle
- The ray does not leave the block and it is totally internally reflected
- This means the beam of light is reflected back inside the block at the same angle as the angle of incidence

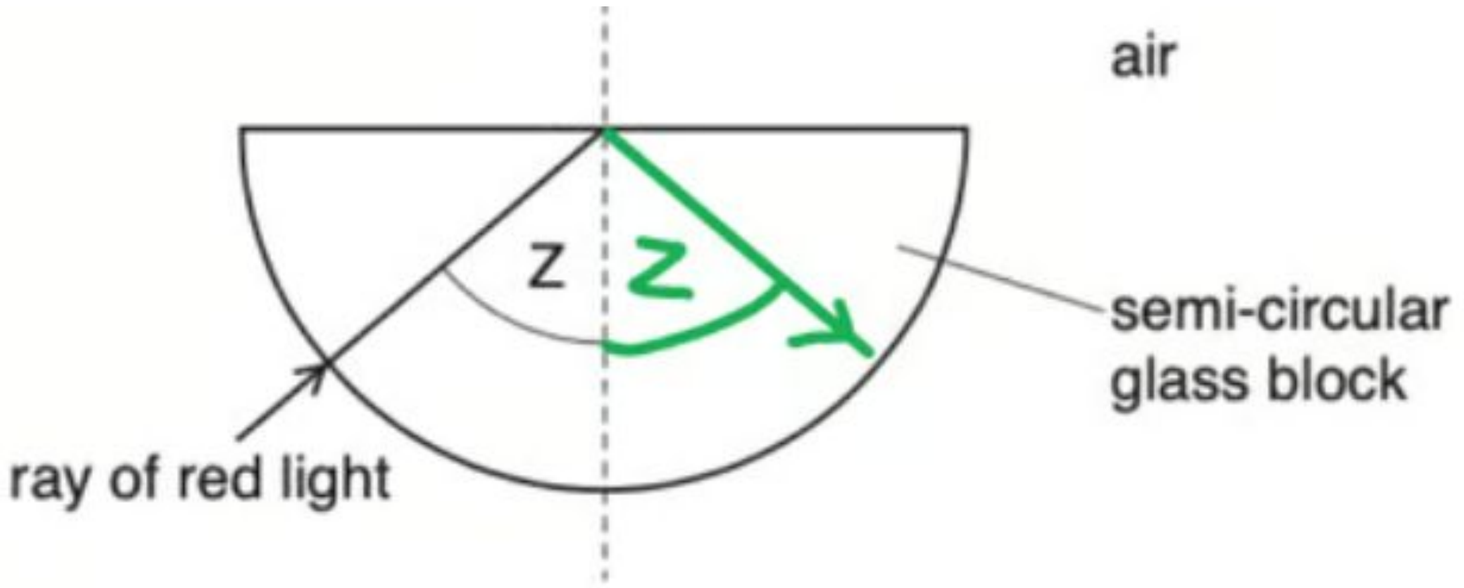


Fig. 8.1 shows a ray of light travelling through a glass block and then reflecting from a mirror.

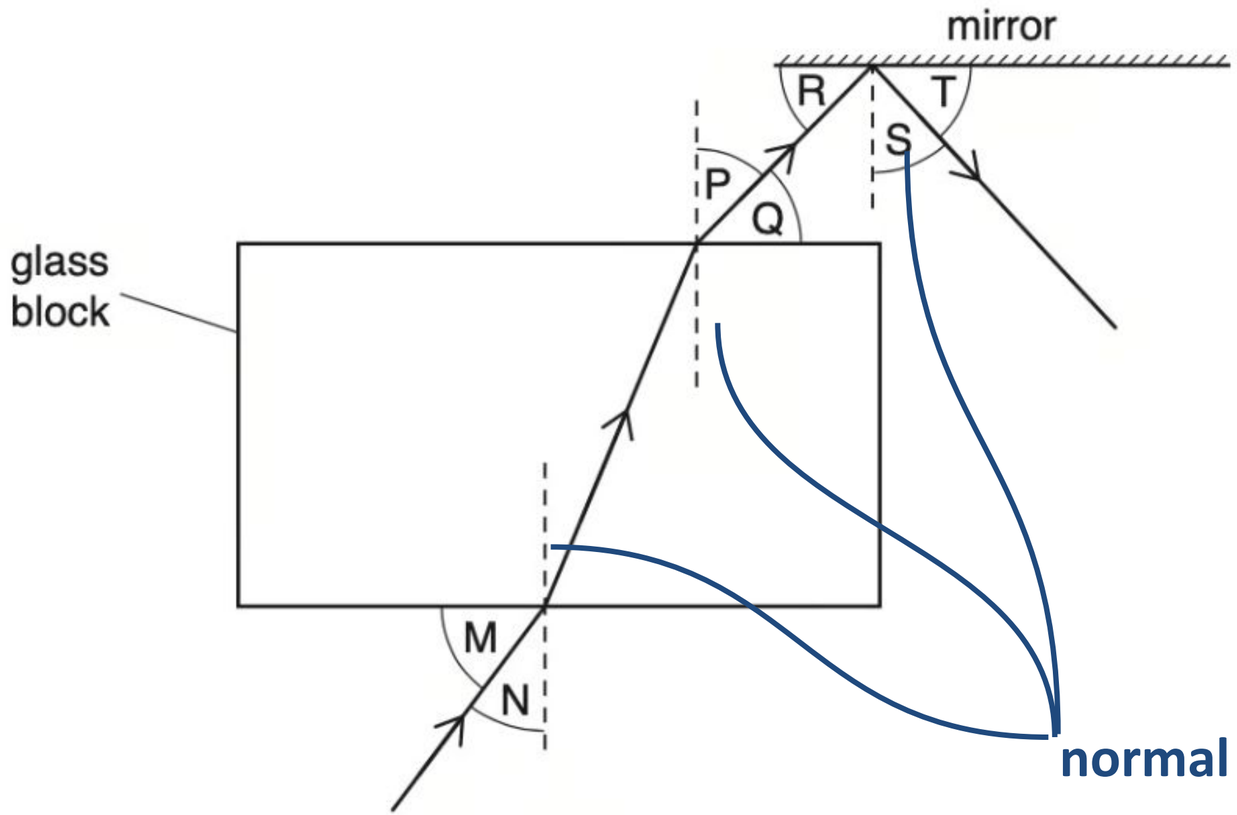
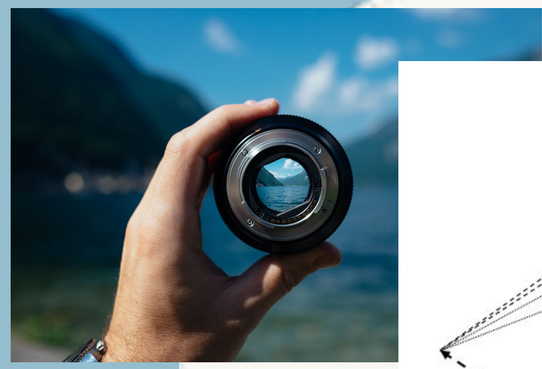


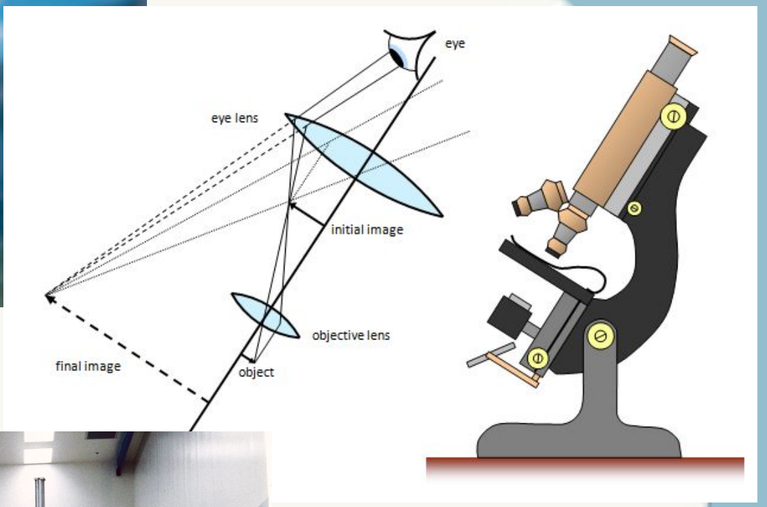
Fig. 8.1

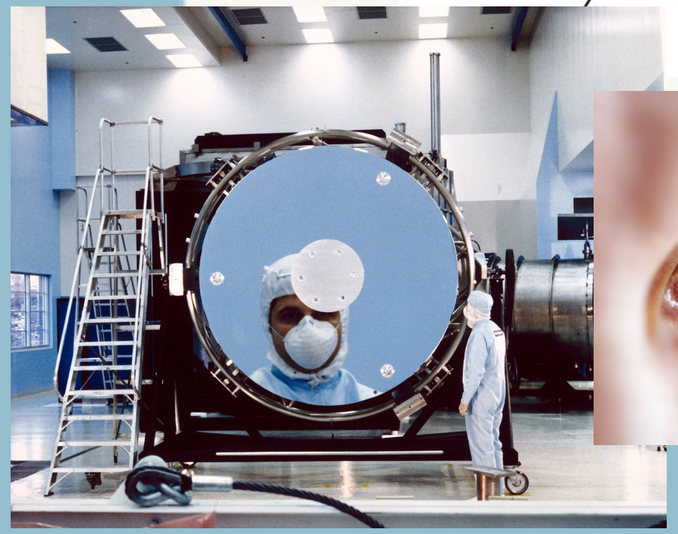
State the term used for the dashed lines drawn in Fig. 8.1.

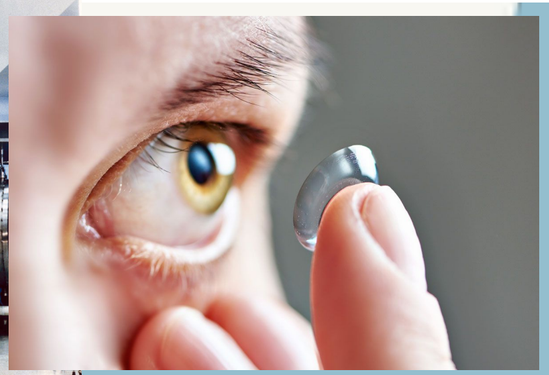
13.4 Lenses

A lens is a transmissive optical device that focuses or disperses a light beam by means of refraction. A lens is a piece of transparent material, usually circular in shape, with two polished surfaces, either or both of which is curved and may be either convex (bulging) or concave (depressed). Lenses are all around us, for example in spectacles and cameras. Lenses are particularly important to scientists in instruments including microscopes and telescopes.





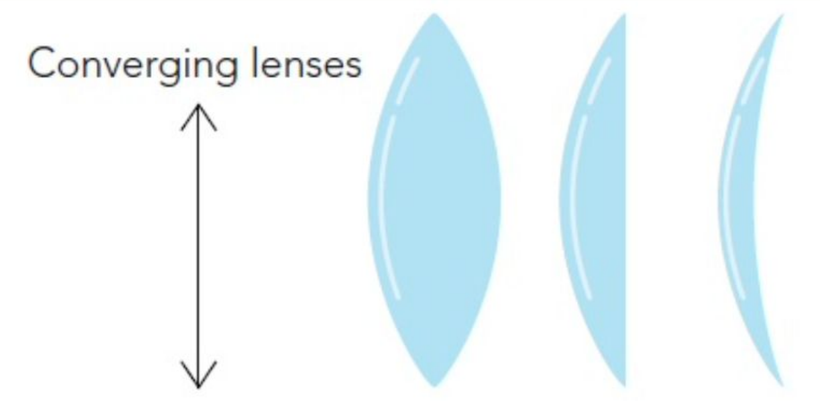




Converging and diverging lenses

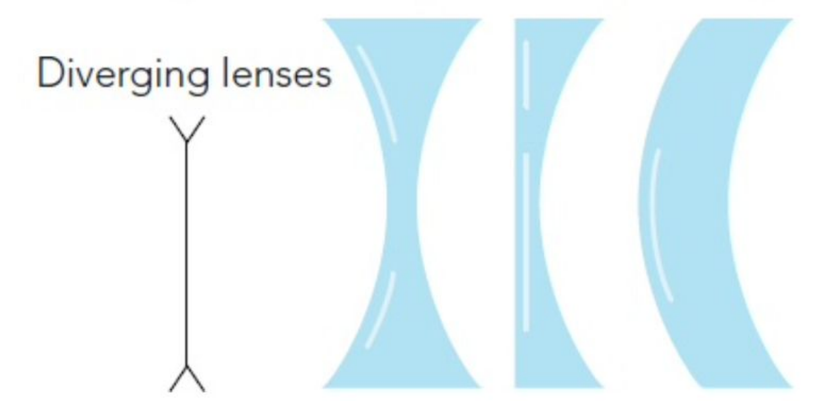
converging lenses

A converging (or convex) lens is thickest in the centre and bends light inwards



diverging lenses

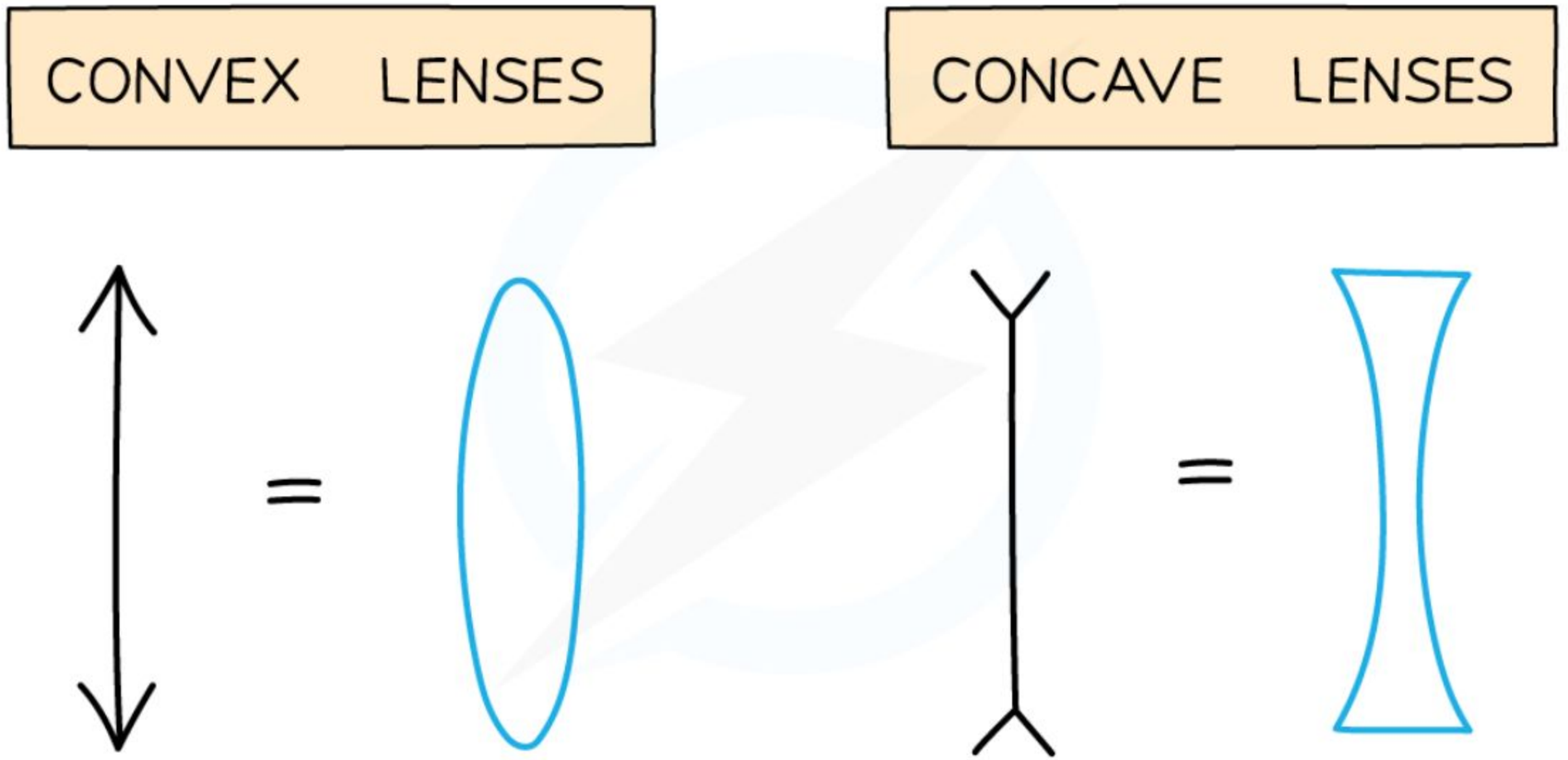
A diverging (or concave) lens is thinnest in the centre and spreads light out



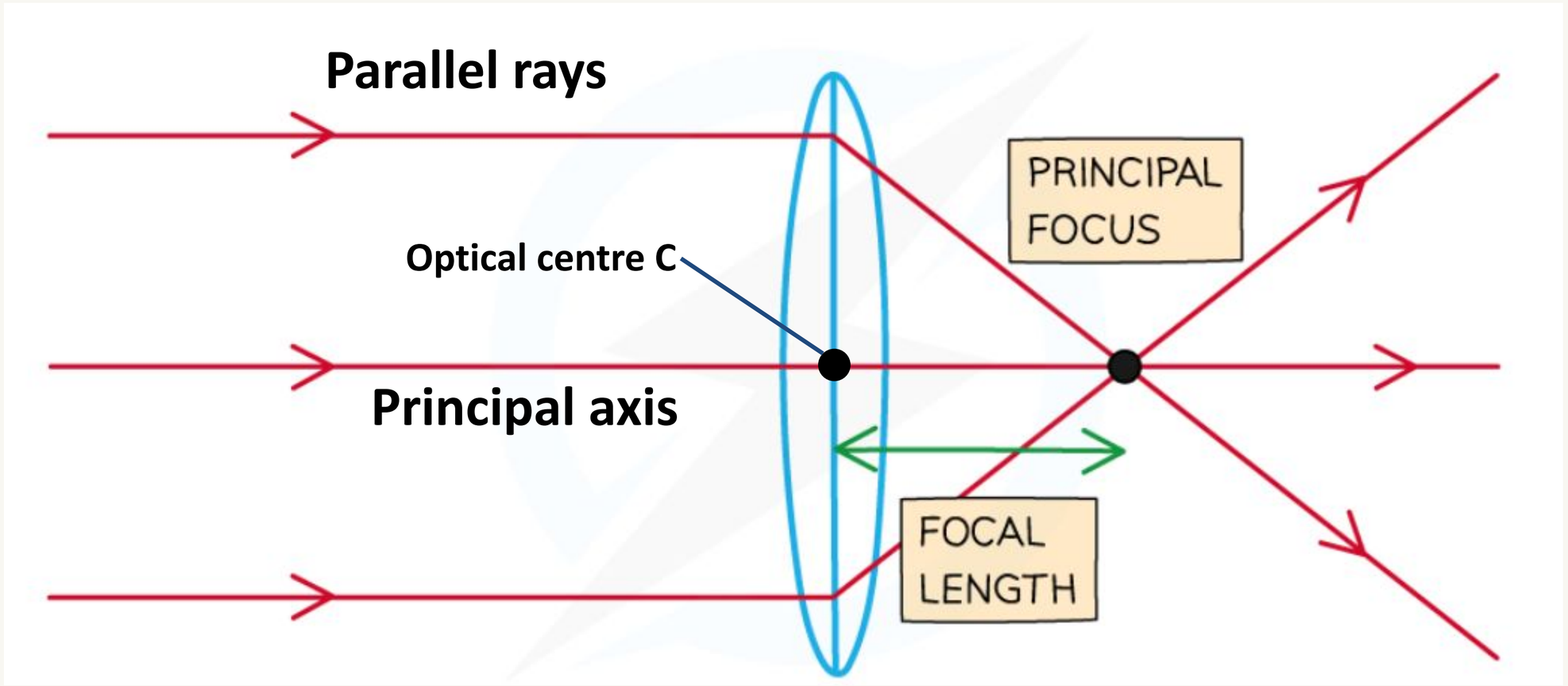
Representing lenses

- In diagrams, the following symbols are often used to represent each type of lens:

Converging and diverging lens symbols



converging lenses



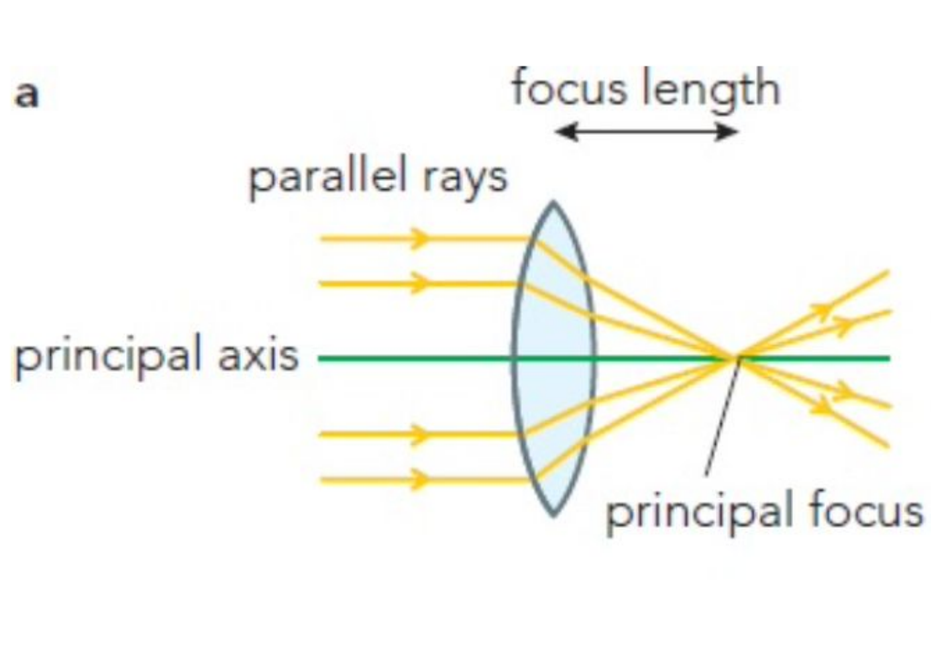
converging lenses

Key definitions

Principal focus (focal point) point on the principal axis of a lens to which light rays parallel to the principal axis converge, or appear to diverge from

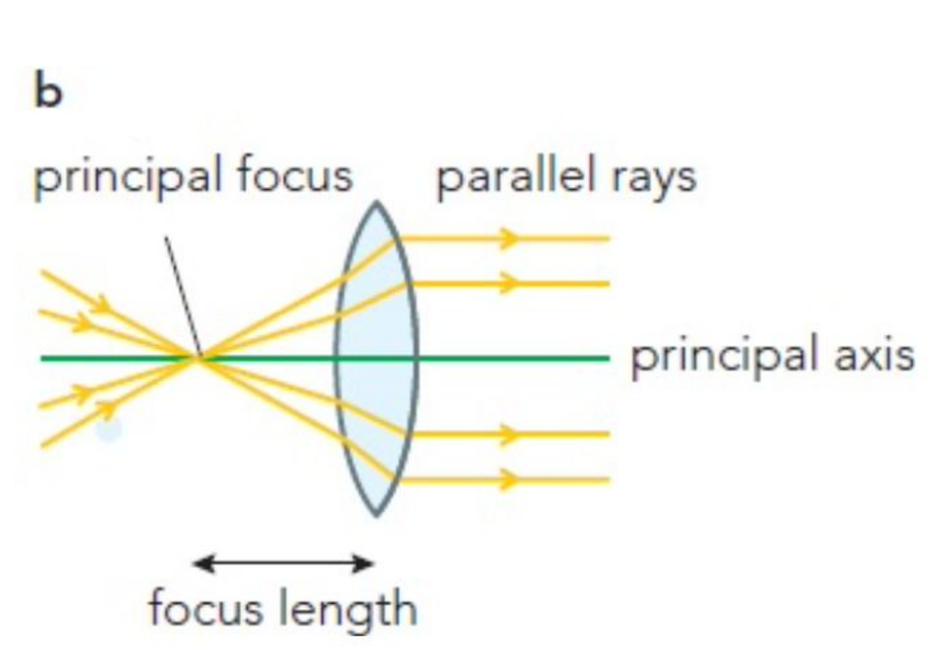
Focal length distance between the optical centre and the principal focus of a lens

converging lenses



On one side of the lens, the rays are parallel to the principal axis of the lens. After they pass through the lens, they converge on a single point: the **principal focus (or focal point)**. After they have passed through the principal focus, they spread out again.

converging lenses



The process can be reversed if the incident rays are not parallel to the principal axis. In this figure it can be seen as a reverse of A in the previous slide.

Drawing ray diagrams for lenses

We can explain how this real image is formed using a ray diagram. These ray diagrams are drawn to scale and show the path of two particular rays. In diagrams a thin lens is represented by a straight line at which all the refraction is considered to occur.

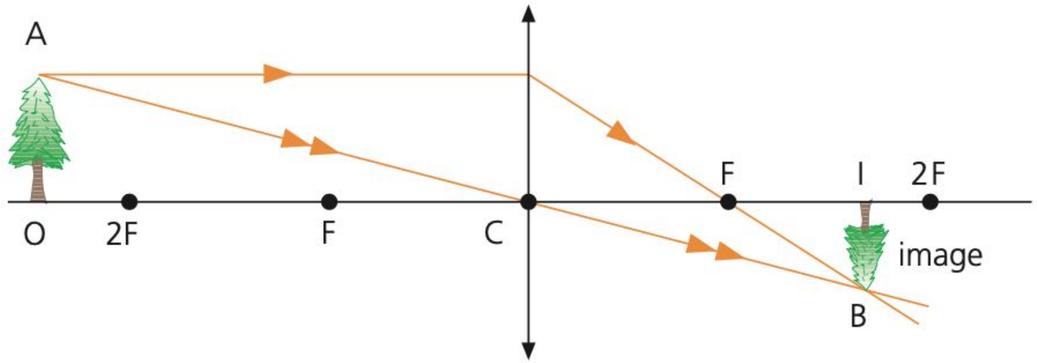
Ray diagrams

Information about the images formed by a lens can be obtained by drawing two of the following rays.

(i) A ray parallel to the principal axis which is refracted through the principal focus, F.

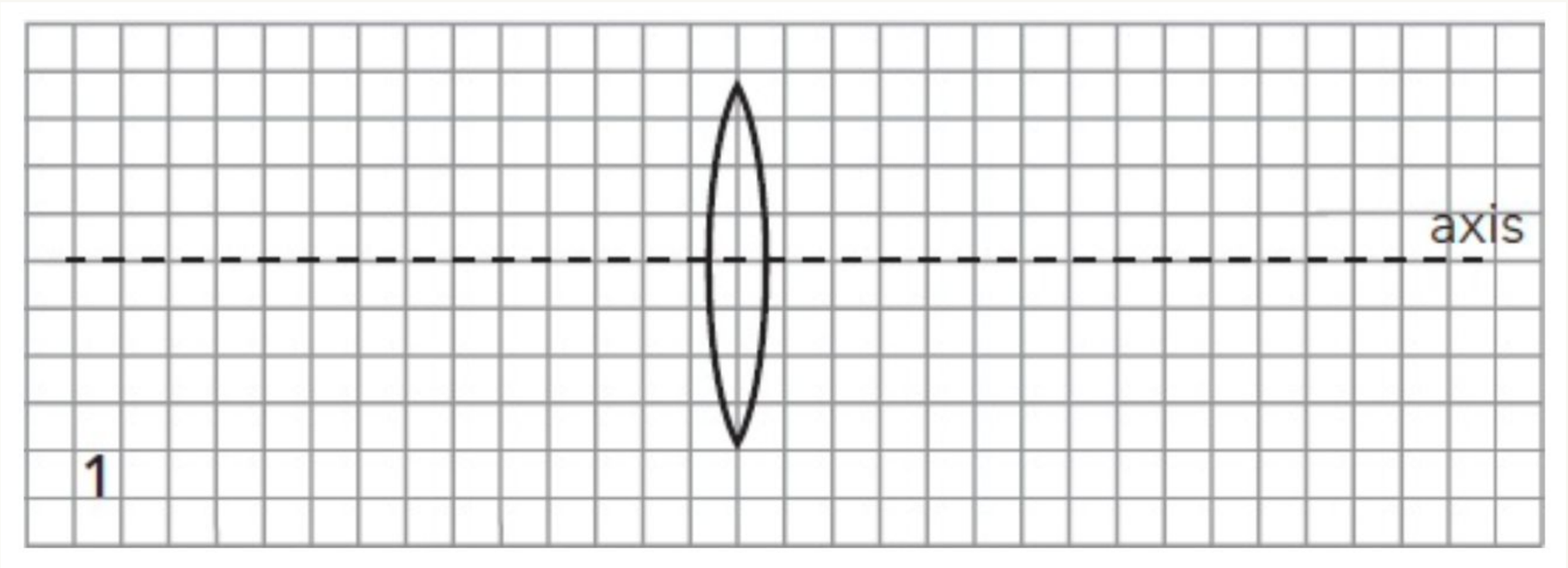
(ii) A ray through the optical centre, C, which is undeviated for a thin lens.

(iii) A ray through the principal focus, F, which is refracted parallel to the principal axis.



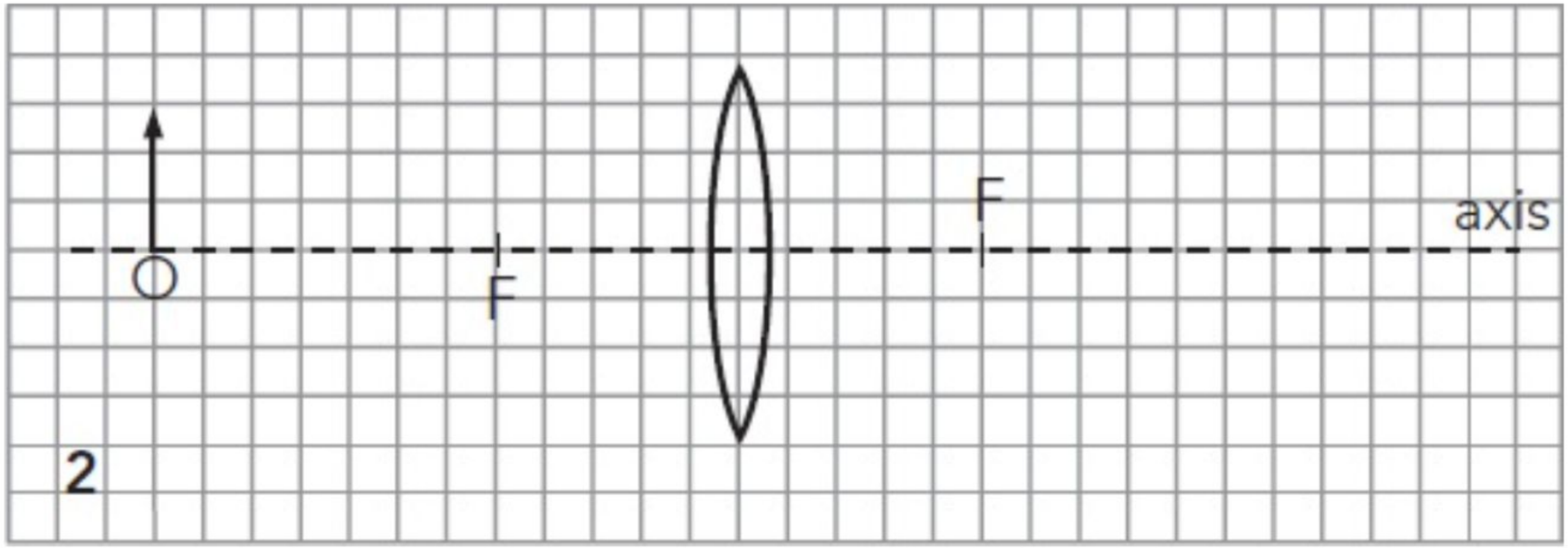
Step 01

Draw the lens (a simple outline shape will do) with a horizontal axis through the middle of it.



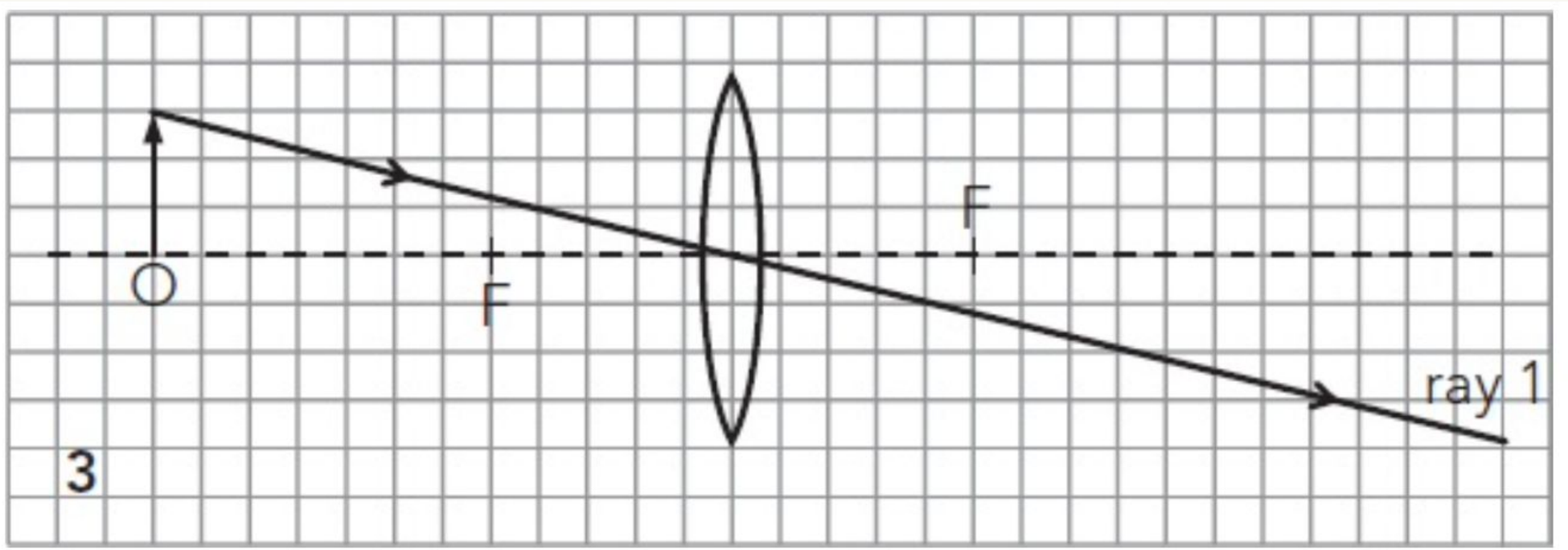
Step 02

Mark the positions of the principal focus (F) on either side, at the given distance from the centre of the lens. Mark the position of the object, O, along with at the given position arrow standing on the axis. Place the arrow with the given height from the lens.



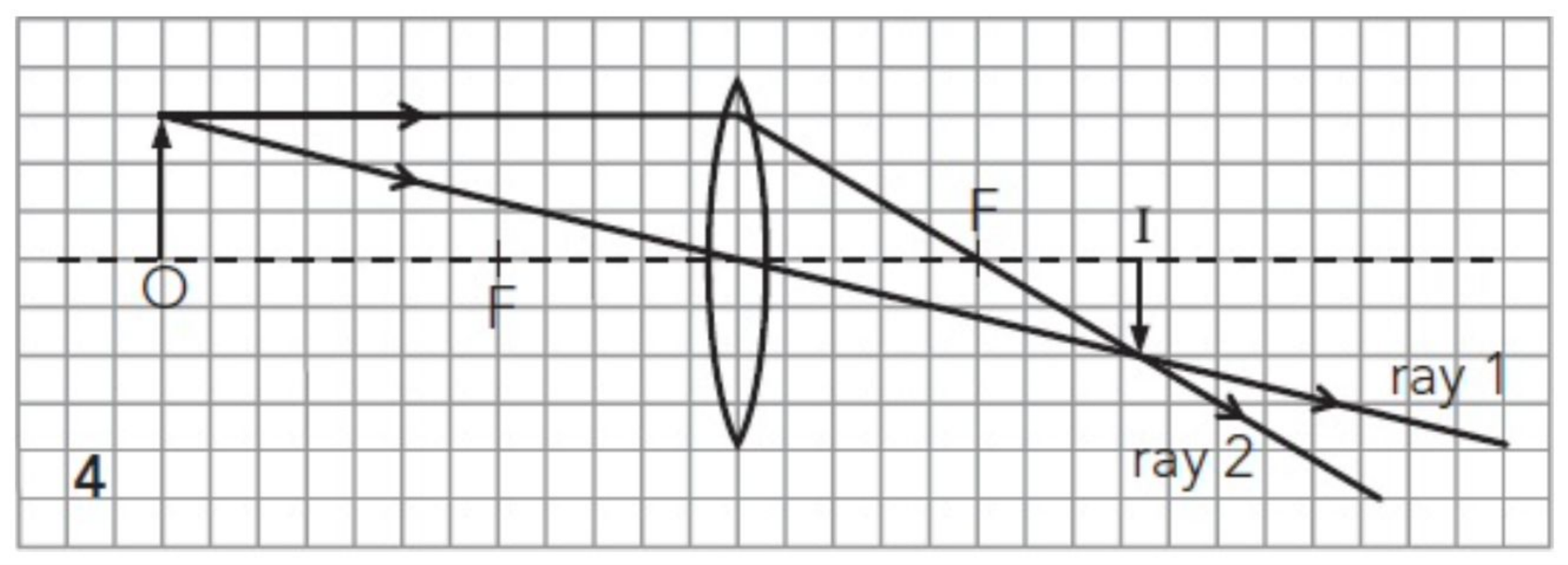
Step 03

Draw ray 1, a straight line from the top of the object arrow which passes undeflected through the middle of the lens.



Step 04

Draw ray 2 from the top of the object arrow parallel to the principal axis. As it passes through the lens, it is refracted through the principal focus. To make things easier when we draw ray diagrams, we only show rays bending once, at the centre of the lens.

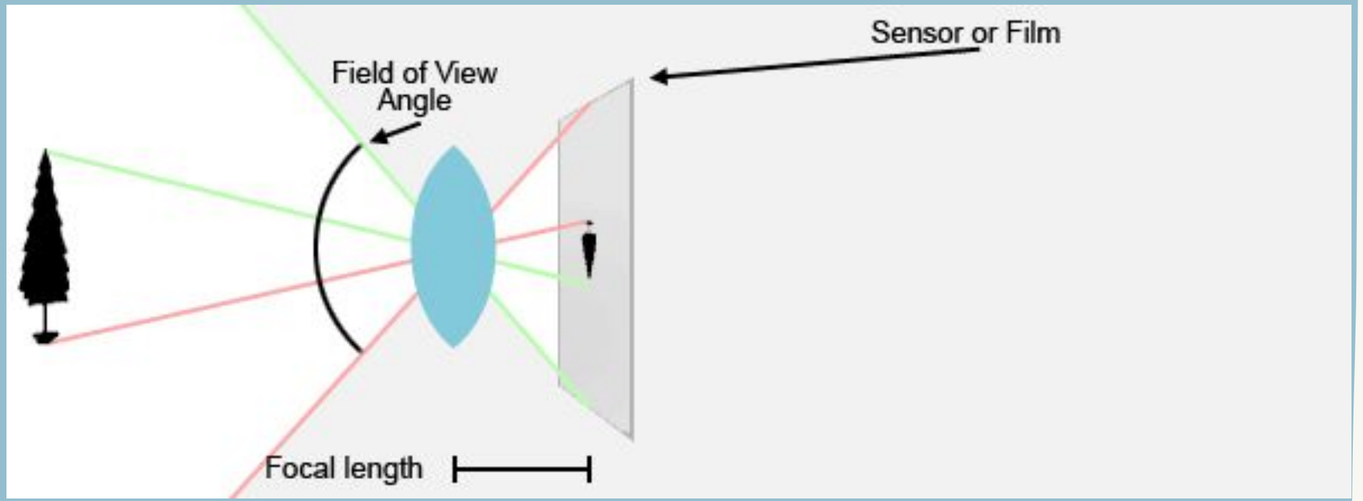


Forming a real image

Images can be described in terms of their size (enlarged, the same size, or diminished), which way up they are (inverted or upright), and where they are formed. We say that the image is real, because light really does fall on the screen to make the image.

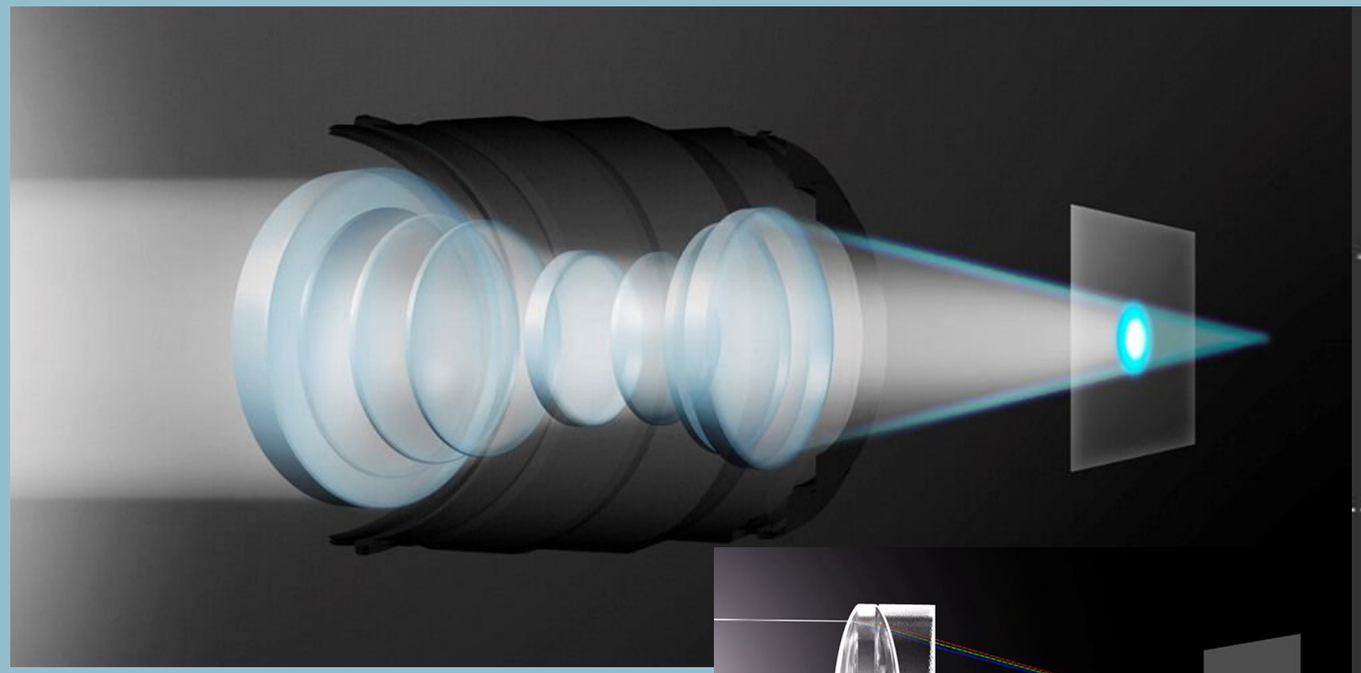
- **enlarged**: used to describe an image which is bigger than the object
- **diminished**: use to describe an image which is smaller than the object
- **inverted**: used to describe an image which is upside down compared to the object
- **upright**: used to describe an image which is the same way up as the object

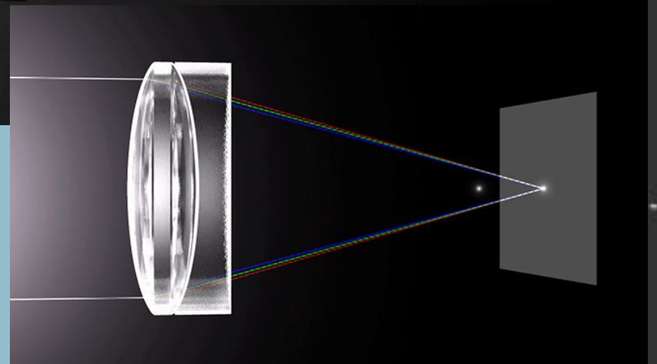
Forming a real image

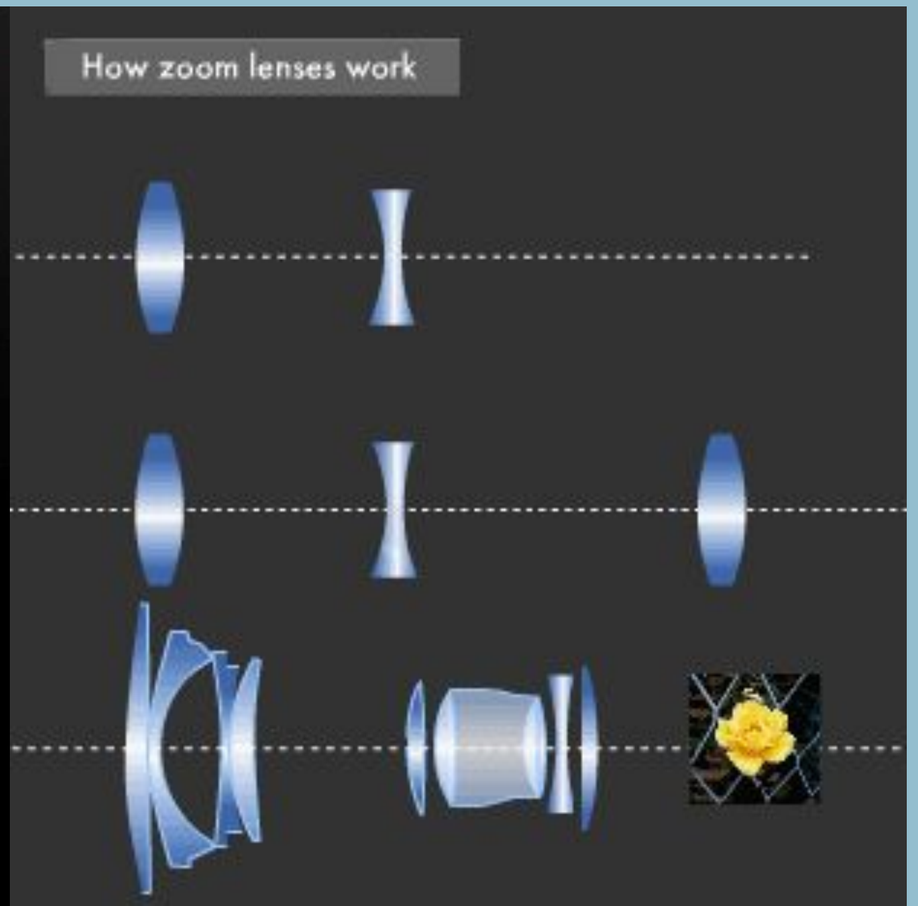


- **enlarged**: used to describe an image which is bigger than the object
- **diminished**: use to describe an image which is smaller than the object
- **inverted**: used to describe an image which is upside down compared to the object
- **upright**: used to describe an image which is the same way up as the object

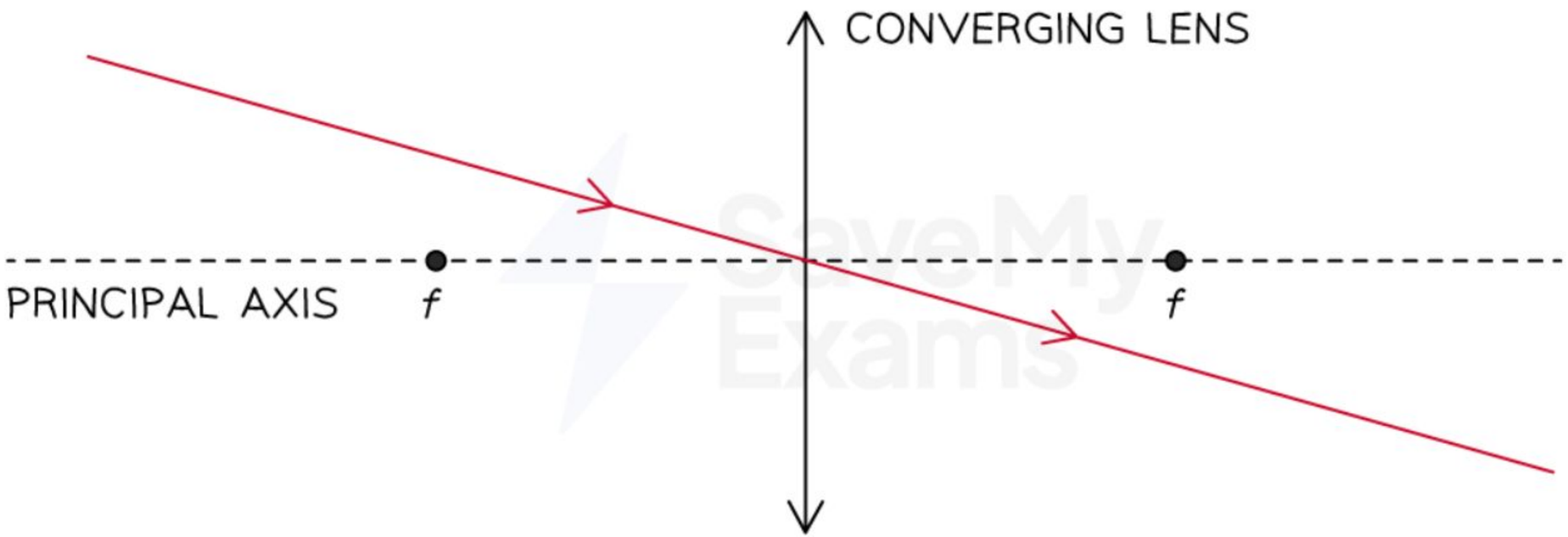
How camera lenses work?



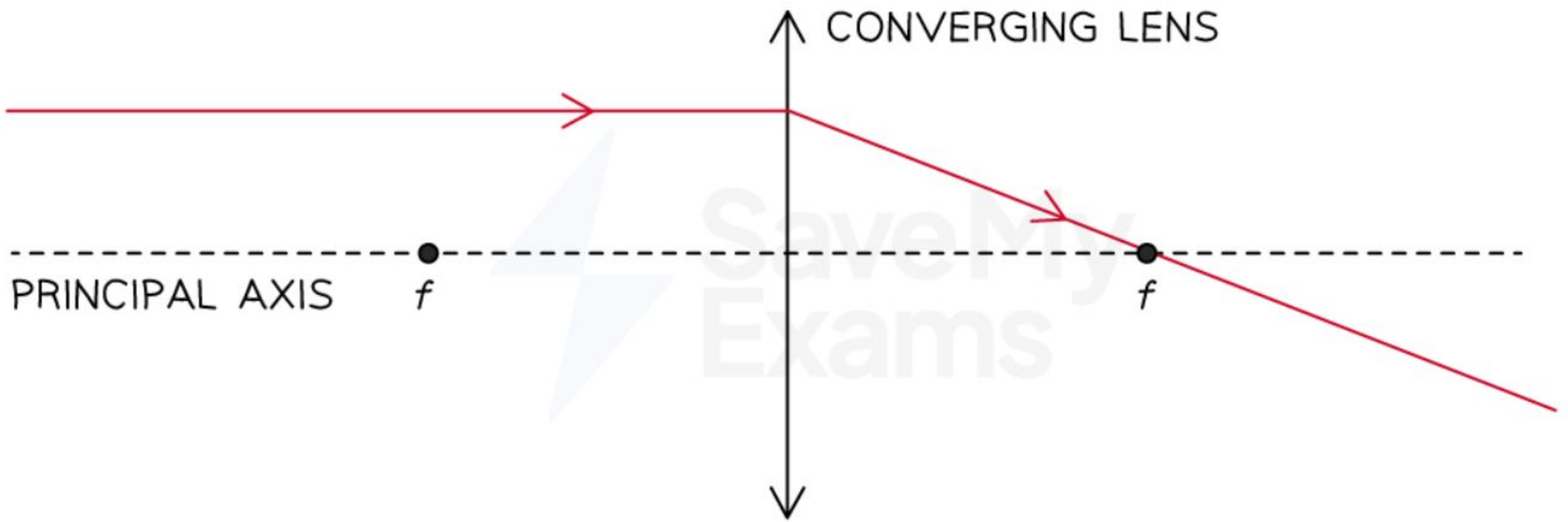




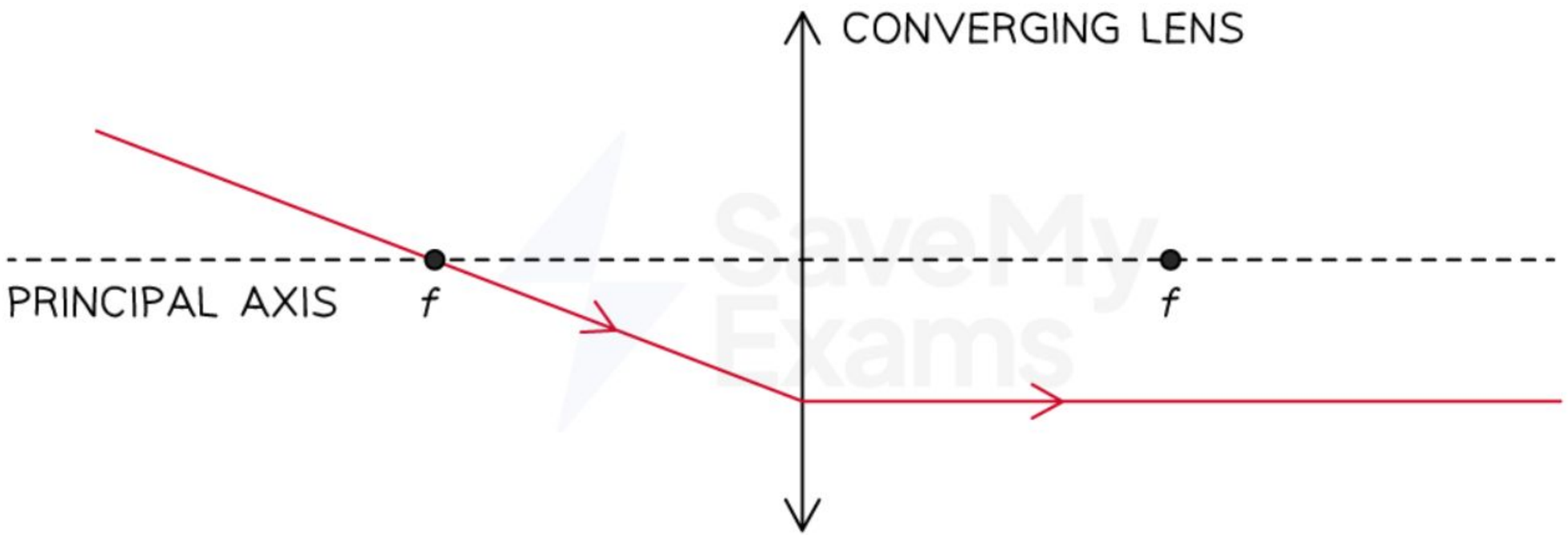
1. Rays passing through the principal axis will pass through the optical centre of the lens undeviated



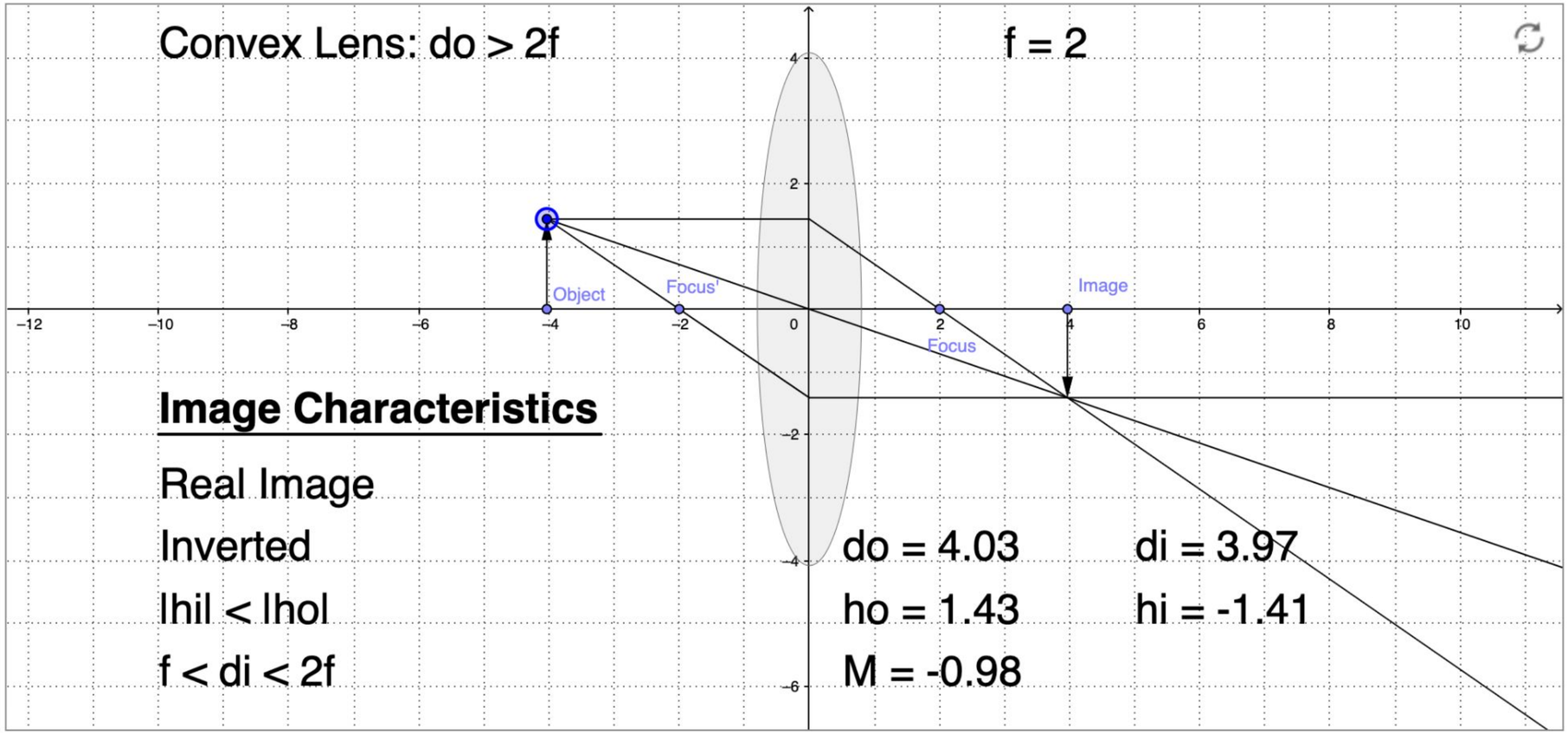
2. Rays that are parallel to the principal axis will be refracted and pass through the focal point *f*



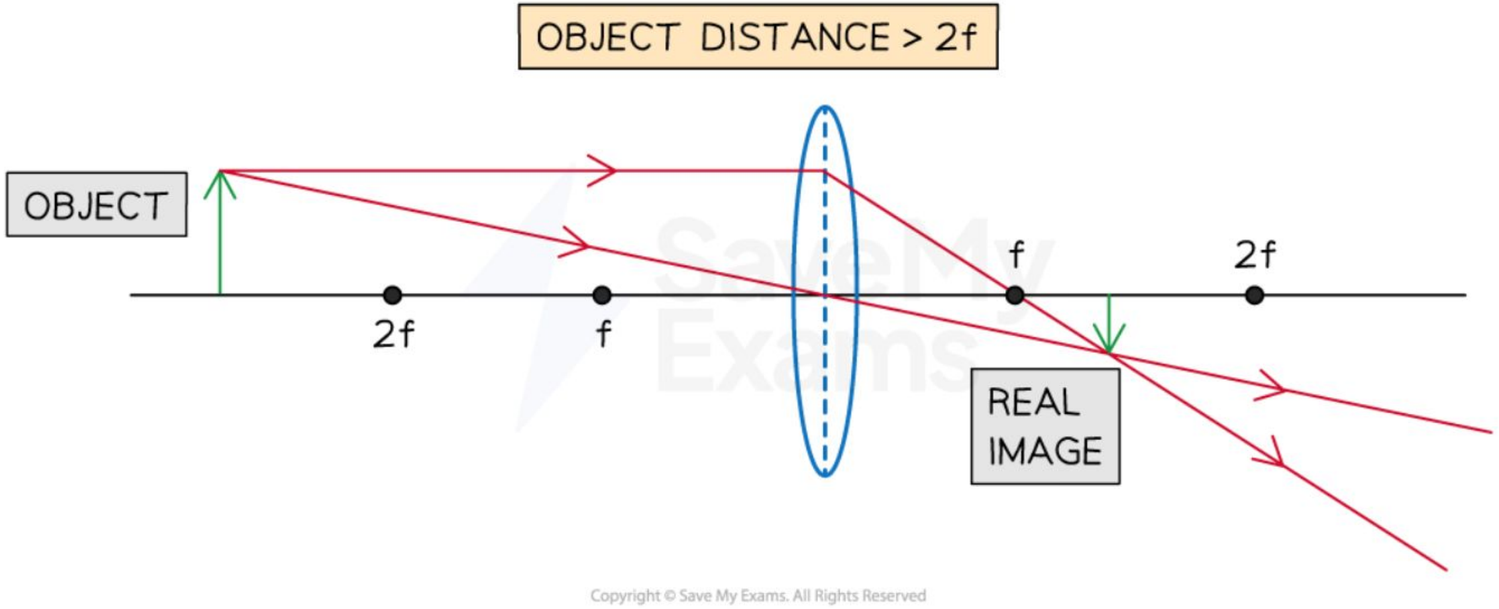
3. Rays passing through the focal point *f* will emerge parallel to the principal axis



Concave and Convex Lenses



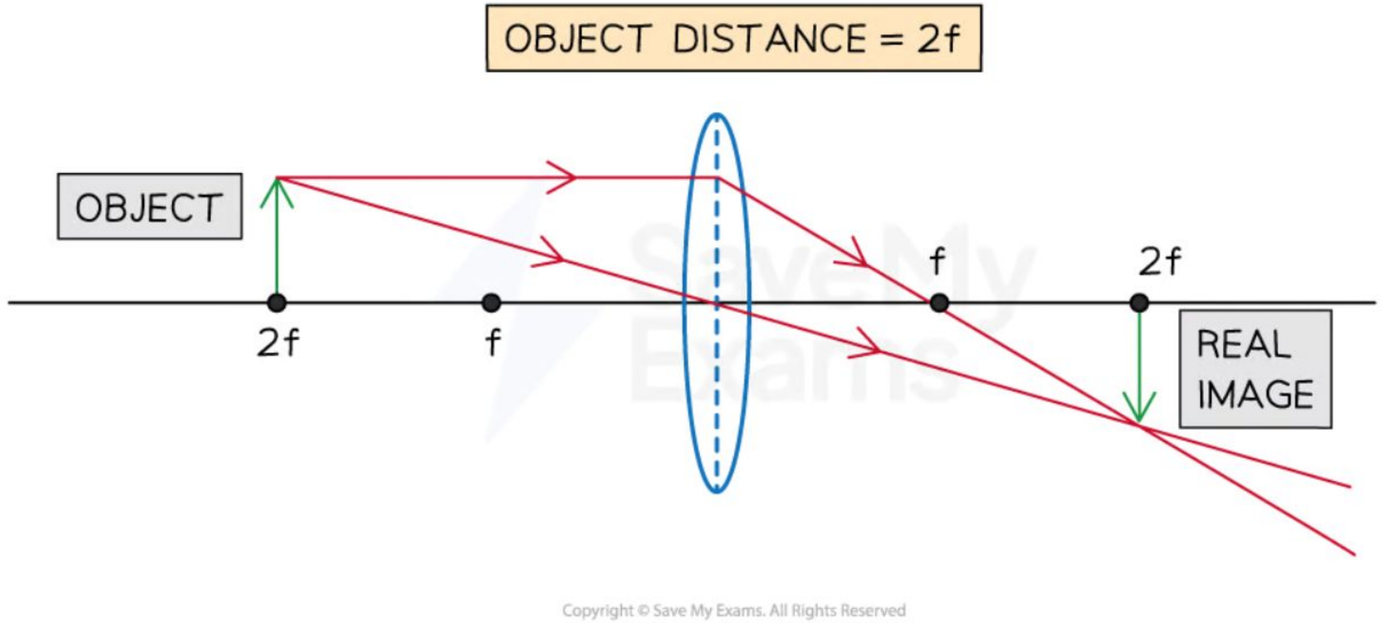
A converging lens ray diagram for an object placed further than 2f



- The image that forms will have the following properties:

The image forms...	between *f* and 2*f*
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	diminished

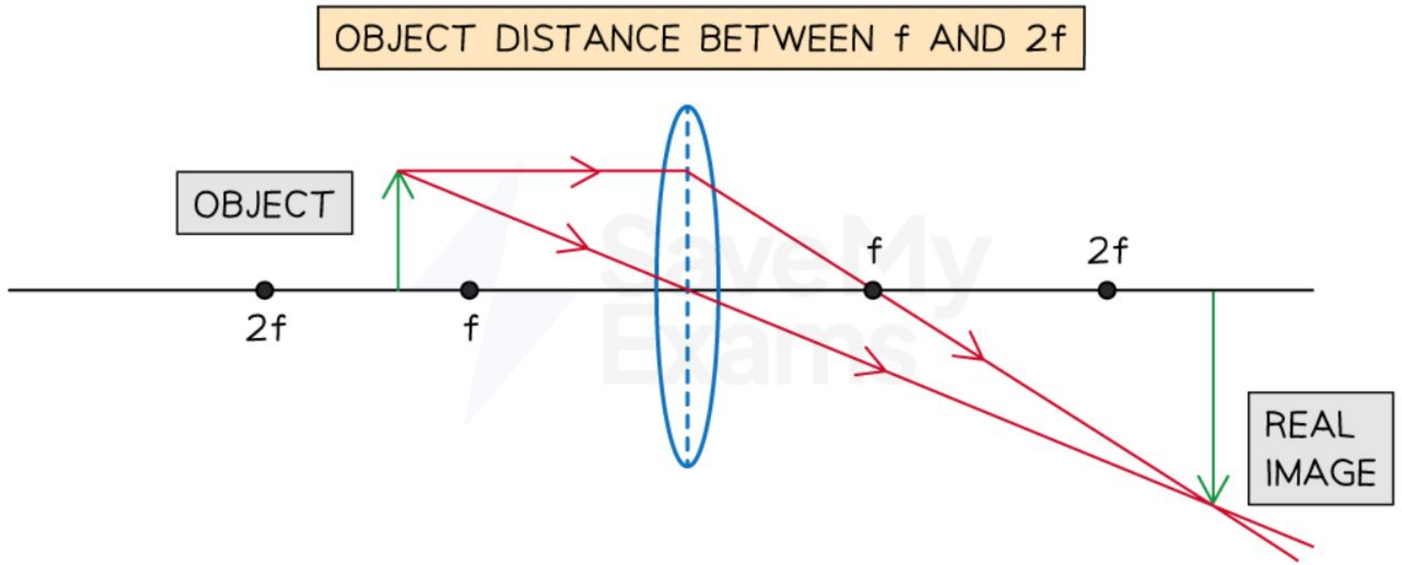
A converging lens ray diagram for an object placed at 2f



- The image that forms will have the following properties:

The image forms...	at 2*f*
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	the same

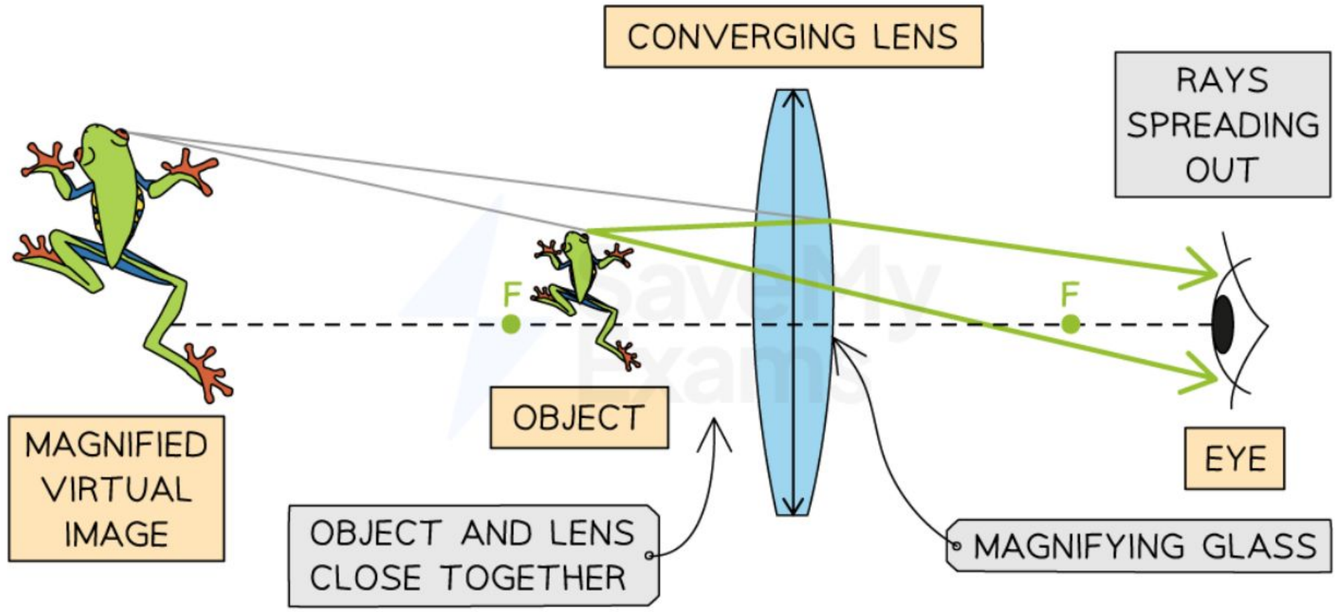
A converging lens ray diagram for an object placed between f and 2f



- The image that forms will have the following properties:

The image forms...	beyond 2*f*
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	magnified

A converging lens ray diagram for an object placed less than f



Ray diagram showing light converging through a magnifying glass to form a magnified virtual image

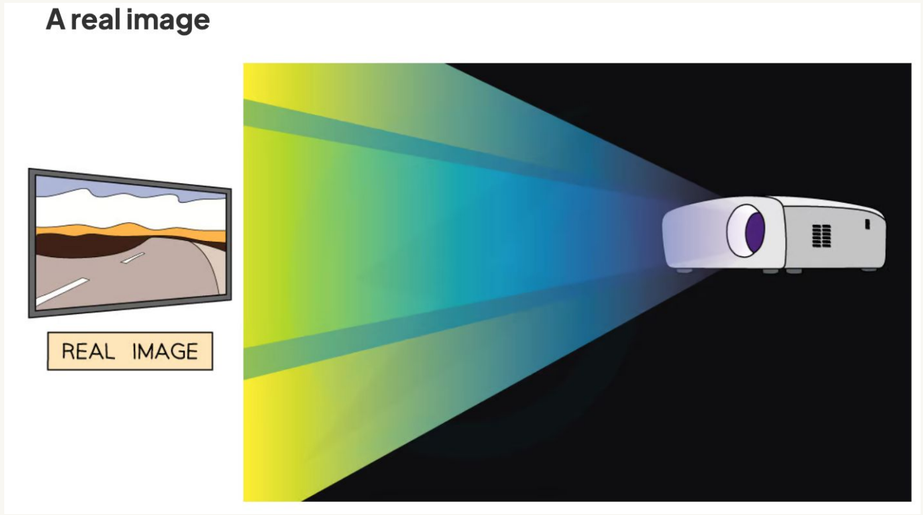
- The image that forms will have the following properties:

The image forms...	at 2*f* (on the same side as the object)
The nature of the image is...	virtual
The orientation of the image is...	upright
The size of the image is...	magnified

Real and virtual image

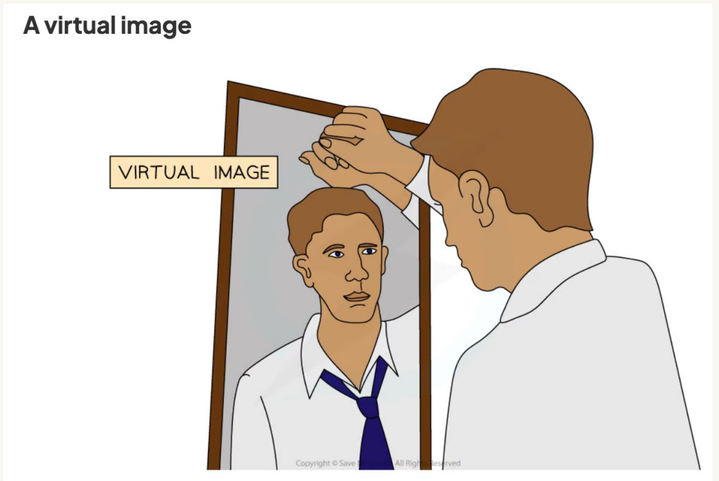
real image

an image that is formed when the light rays from an object converge and meet each other and can be projected onto a screen



virtual image

an image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen



Real images

- A real image is defined as:

An image that is formed when the light rays from an object converge and meet each other and can be projected onto a screen

- A real image is one produced by the **convergence** of light towards a focus
- Real images are always **inverted**
- Real images can be projected onto pieces of paper or screens
    - An example of a real image is the image formed on a cinema screen

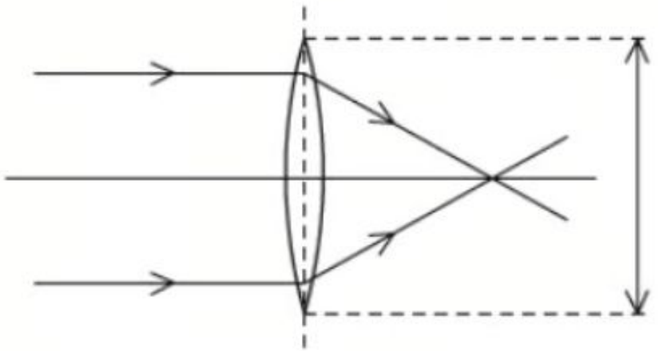
Virtual images

- A virtual image is defined as:

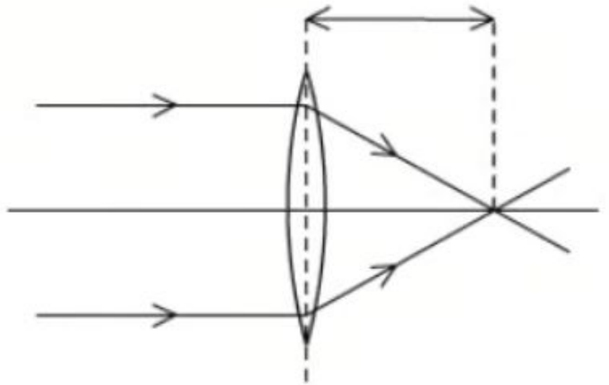
An image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen

- A virtual image is formed by the **divergence** of light away from a point
- Virtual images are always **upright**
- Virtual images **cannot** be projected onto a piece of paper or a screen
    - An example of a virtual image is a person's reflection in a mirror

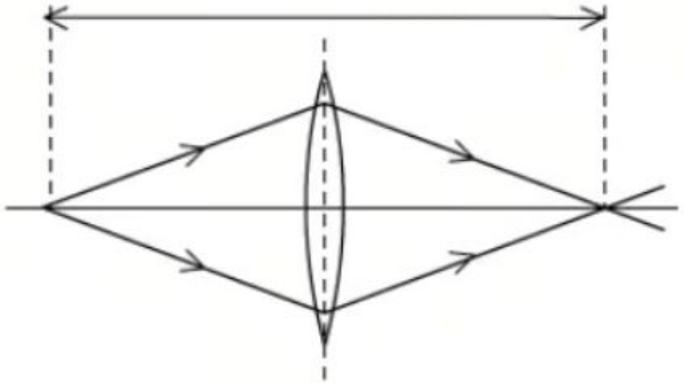
A



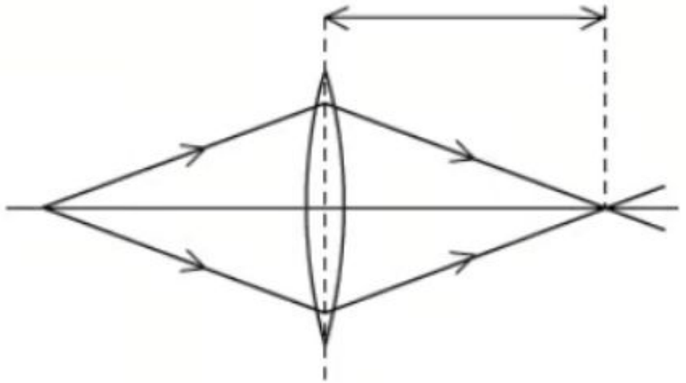
B



C



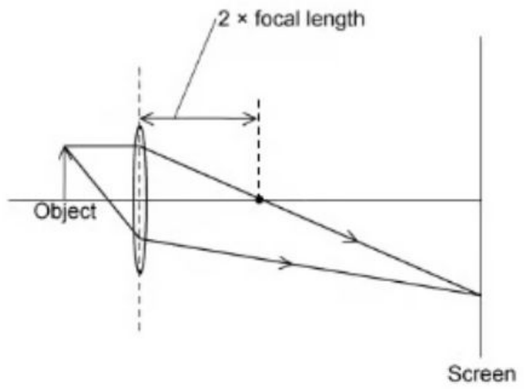
D



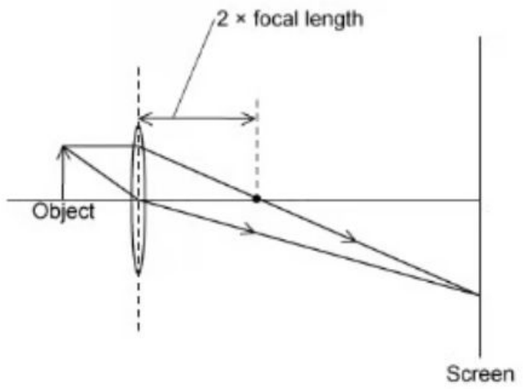
Which of the images correctly shows the focal length of the thin converging lens?

Which diagram correctly shows the formation of a real image on a screen?

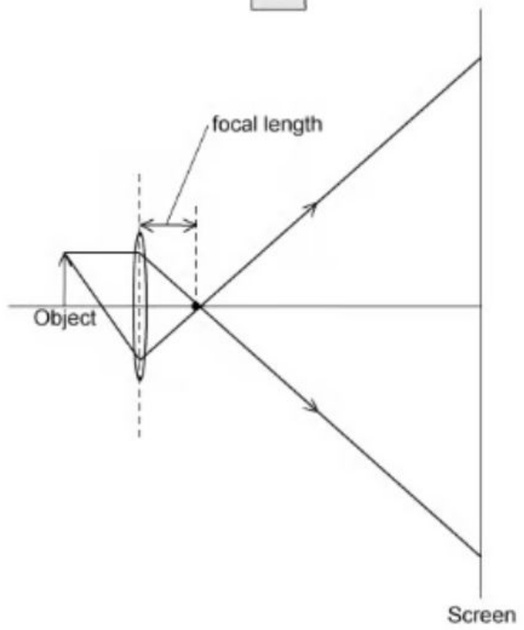
A



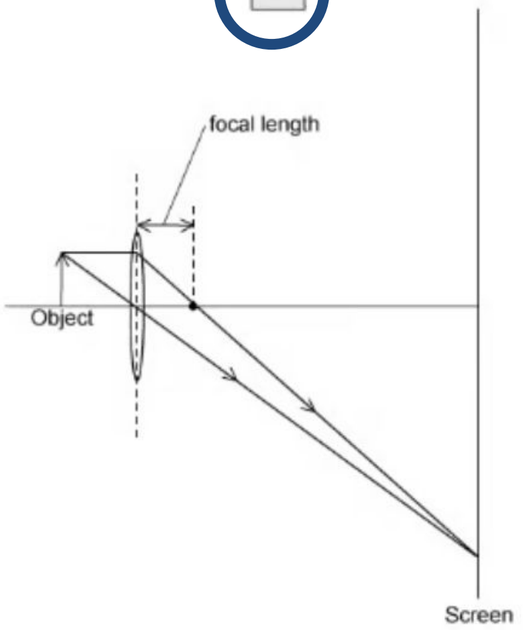
B



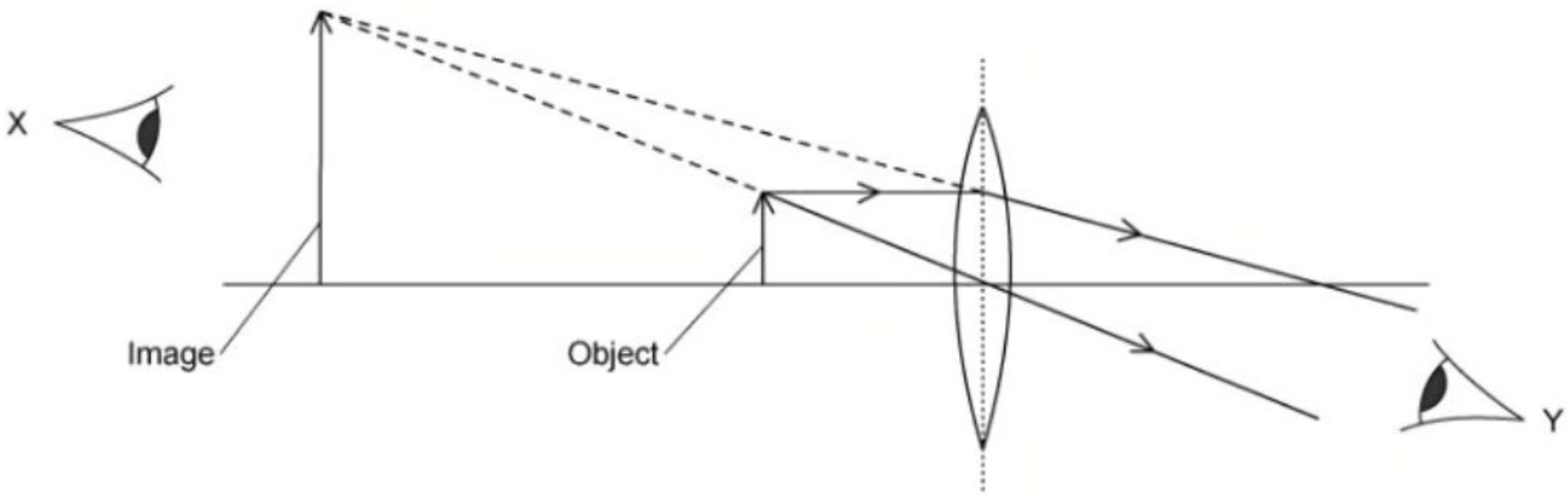
C



D



Below is a ray diagram showing the image formed by a thin, converging lens.



Which of the following statements about the image is c

A. The image is virtual and can be seen by eye Y.

B. The image is inverted and can be seen by eye Y.

C. The image is real and can be seen by the eye at X.

D. The image is virtual and can be seen by eye X.

The correct answer is A because:

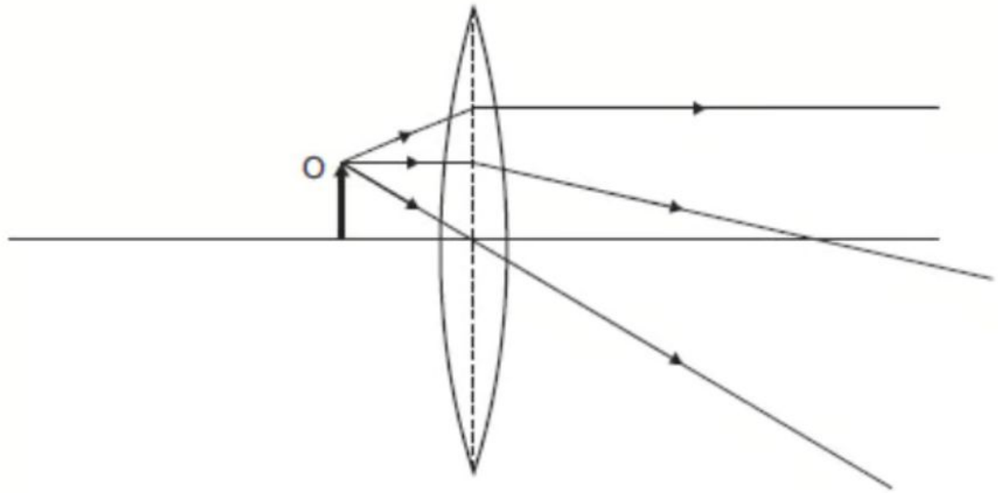
- We know the image is virtual because the light rays do not converge anywhere.
- For an image to be real, light rays must converge, these diverge (get further apart).
- The image is seen at a position which is a backward projection of the diverging light rays that pass through the lens.
- No light gets to X, so the image cannot be seen there. An image can only be seen at a position that light actually reaches.
- The dashed lines represent *projections* of the real light rays that pass through the lens, not actual light.

B is incorrect as the image is not inverted. Inverted means upside-down.

C is incorrect as the image is not real, since no light rays converge on its position.

D is incorrect as the image cannot be seen at X.

The diagram shows an object positioned close to a thin converging lens (inside the focal distance). Three light rays are shown leaving the object and passing through the lens.



Which row in the table correctly describes the properties of the image?

	location	**size**	**real / virtual**
A	to the left of O	reduced	real
B	to the right of O	enlarged	virtual
C	to the left of O	enlarged	virtual
D	at O	the same as O	real

The correct answer is C.

The diagram shows how the ray diagram should be constructed:

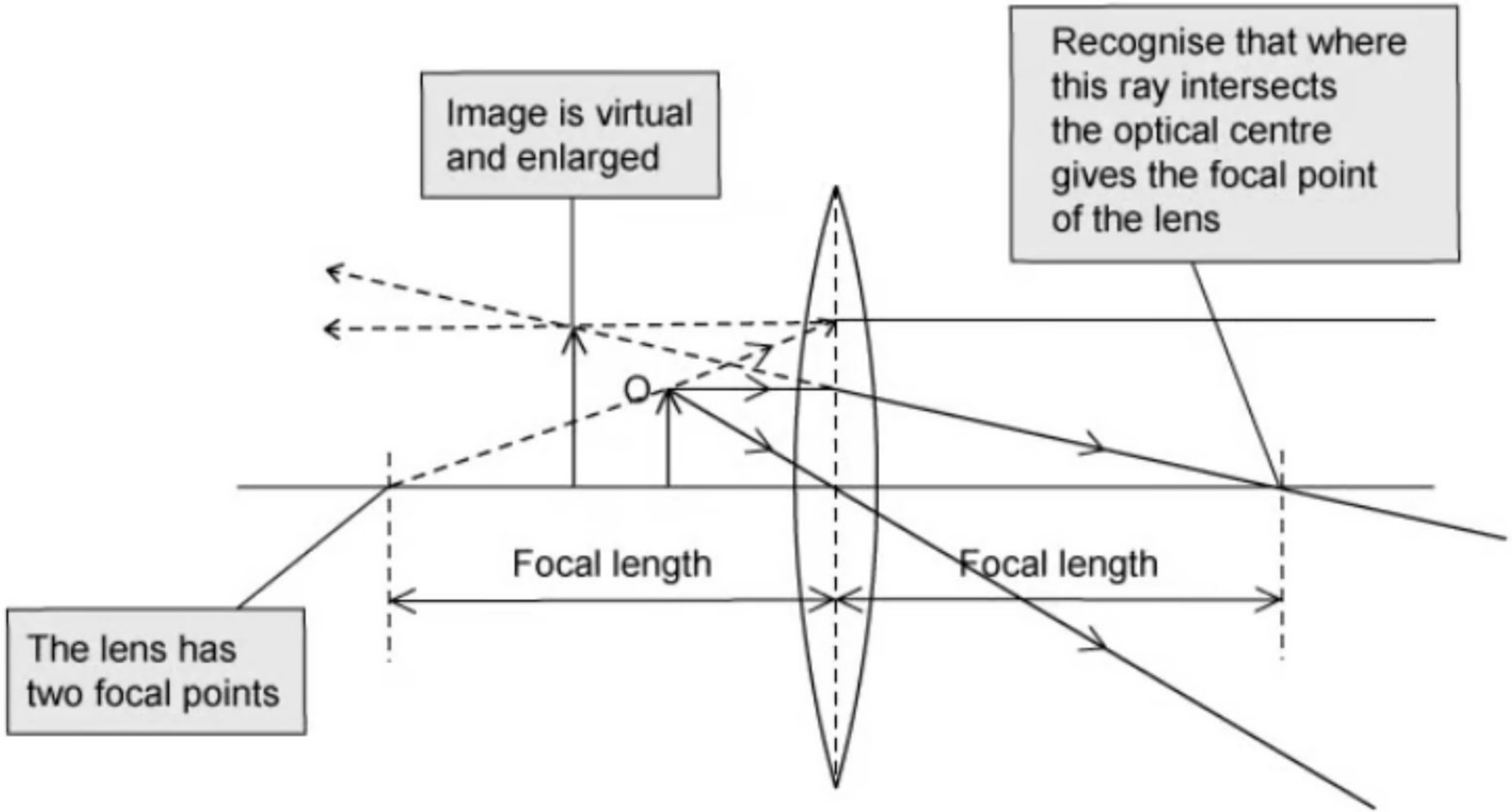


Fig. 5.1 represents an object positioned on the principal axis of a thin lens.

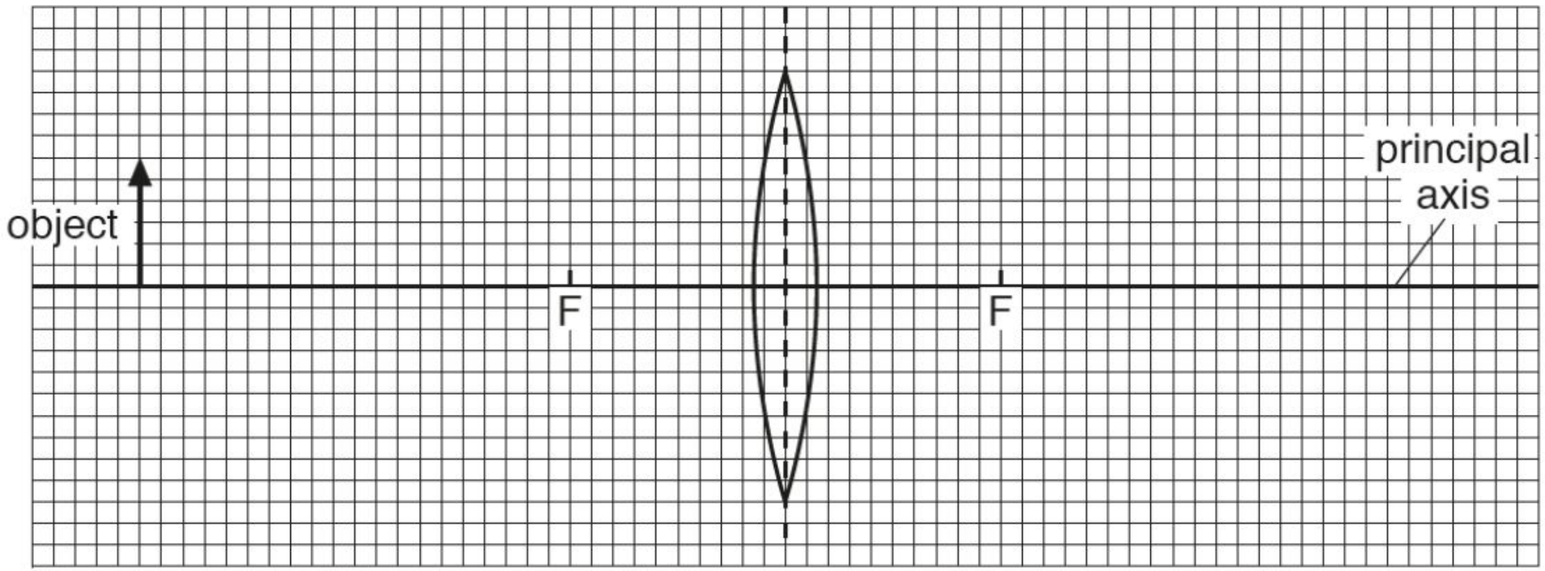


Fig. 5.1

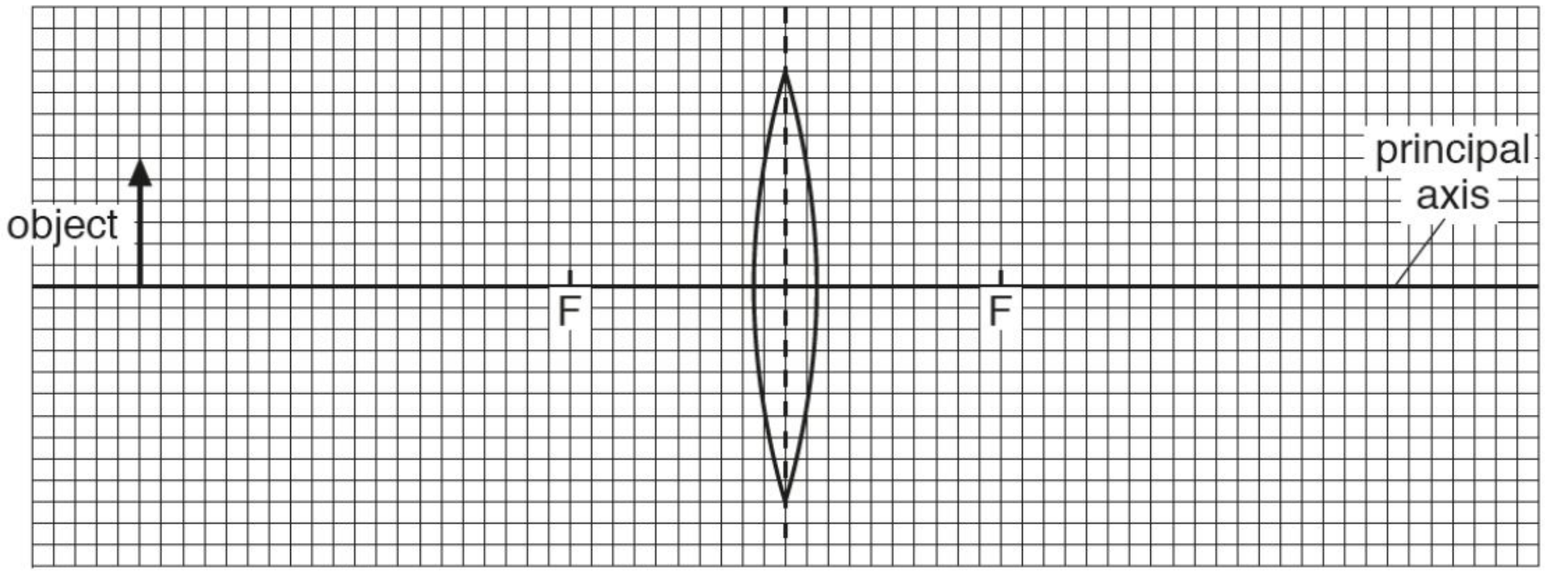
Each small square of the grid represents 0.5 cm. Each principal focus of the lens is labelled F.

Use the grid to determine the focal length of the lens.

focal length = ... cm

5

Fig. 5.1 represents an object positioned on the principal axis of a thin lens.



(i) On Fig. 5.1, draw a ray from the top of the object that passes through a principal focus, then through the lens and beyond it.

[1]

(ii) On Fig. 5.1, draw a second ray from the top of the object that passes through the centre of the lens. Continue the path of this ray to the edge of the grid.

[1]

(iii) On Fig. 5.1, draw an arrow to show the position and nature of the image produced by the lens.

(i) A diagram showing a ray from the top of the object that passes through a principal focus, then through the lens and beyond it would look like:

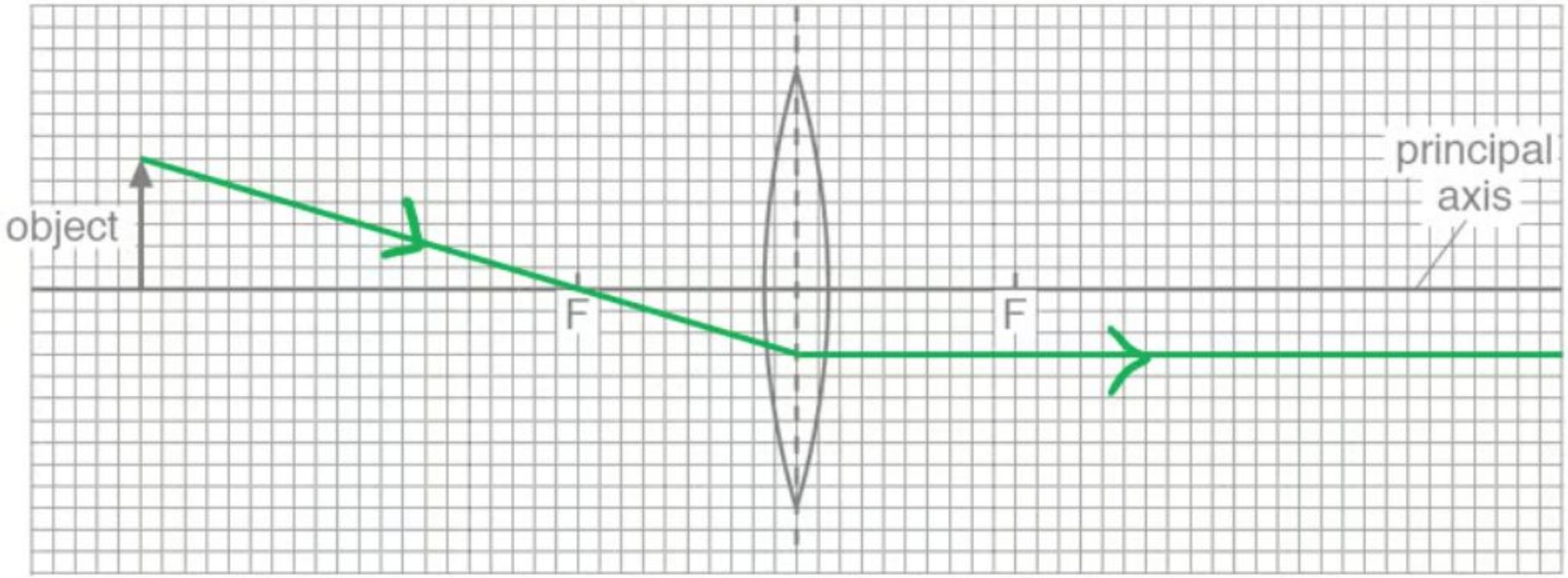


Fig. 5.1

- A straight line drawn through F and then parallel to the principal axis from the centre of the lens; [1 mark]

(ii) A diagram showing a ray from the top of the object that passes through the centre of the lens would look like:

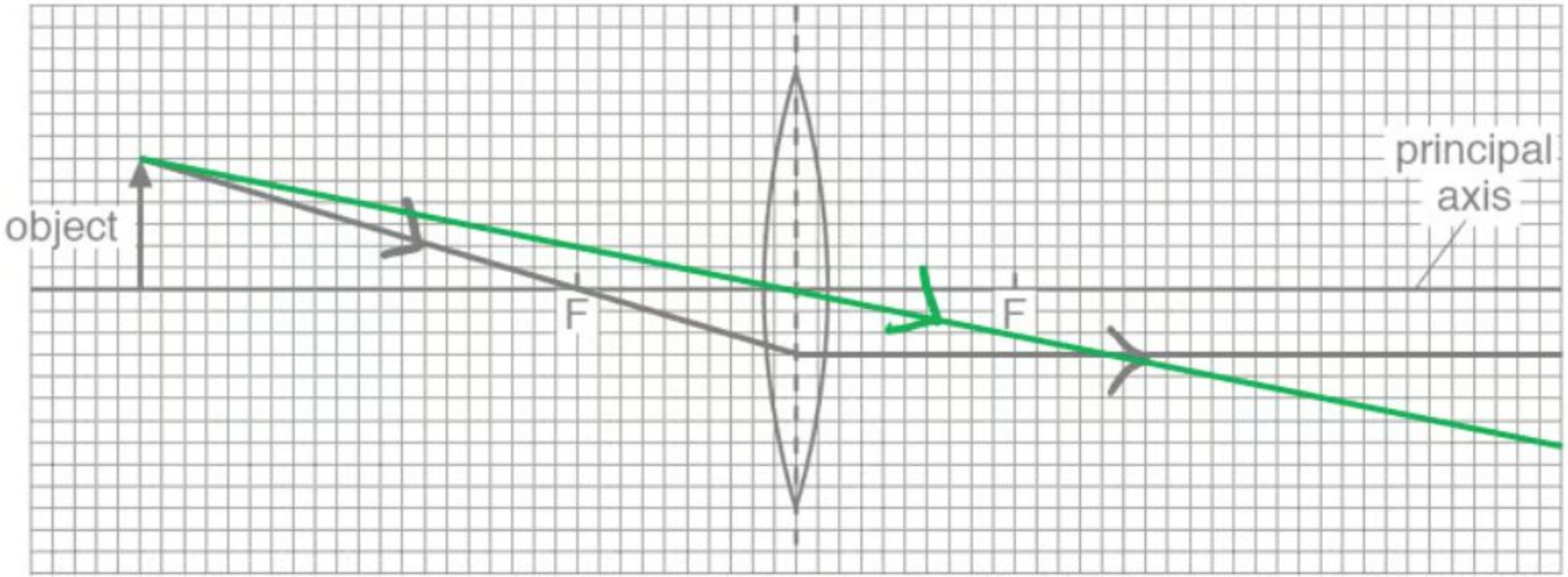


Fig. 5.1

- A straight line drawn from the top of object through the centre of lens; [1 mark]

(iii) A diagram showing the position and nature of the image produced by the lens would look like:

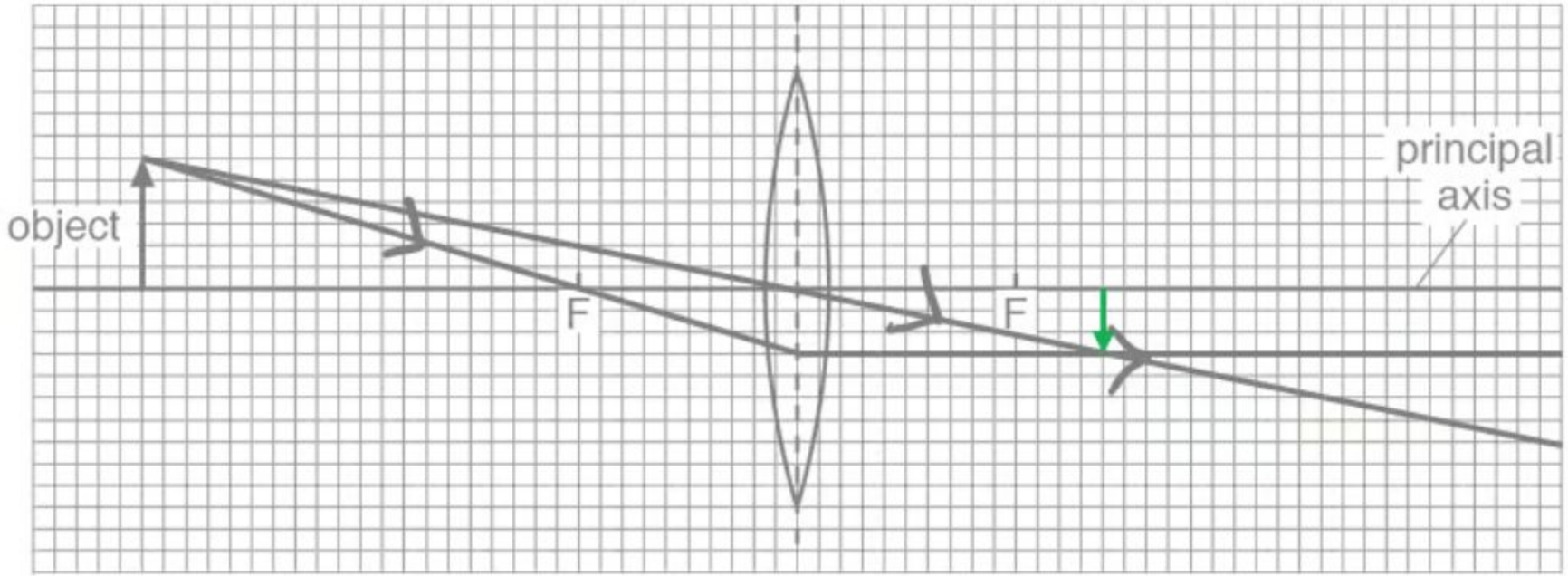


Fig. 5.1

- An arrow should be drawn at the point where rays cross; [1 mark]
- The arrow should be on the right hand side of the lens, and pointing downwards (inverted); [1 mark]

An object, OX, is placed in front of a converging lens.

Fig. 7.1 shows a ray of light from the object passing through the lens.

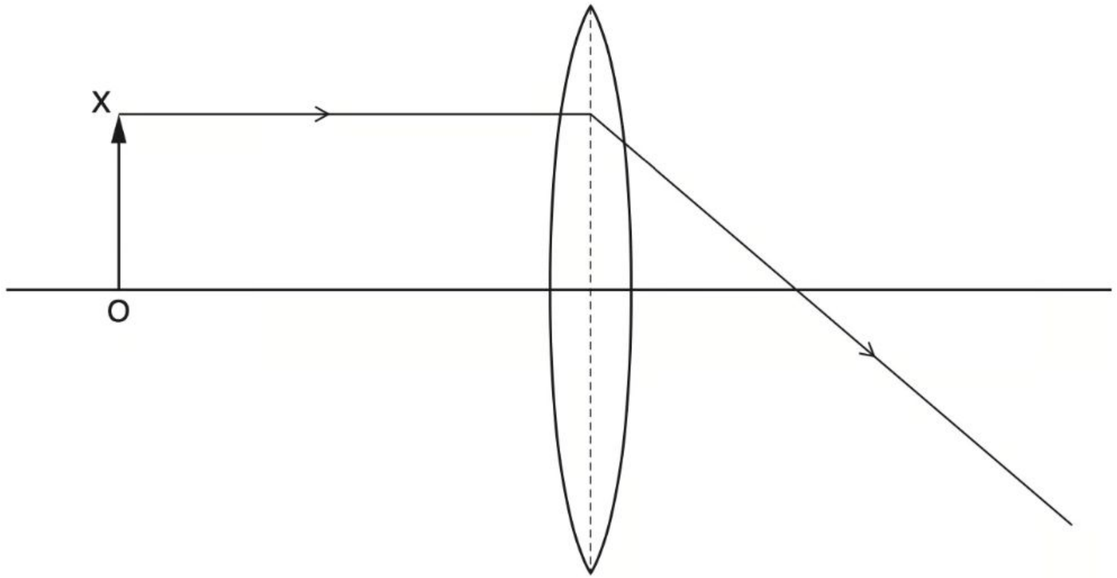


Fig. 7.1

(i) The lens forms an image of object OX.

On Fig. 7.1, draw another ray from X to locate the position of the image.

[1]

(ii) On Fig. 7.1, draw an arrow to represent the image of OX and label it I.

[1]

(iii) On Fig. 7.1, mark a principal focus for the lens and label it F.

(i) Draw another ray from X to locate the position of the image:

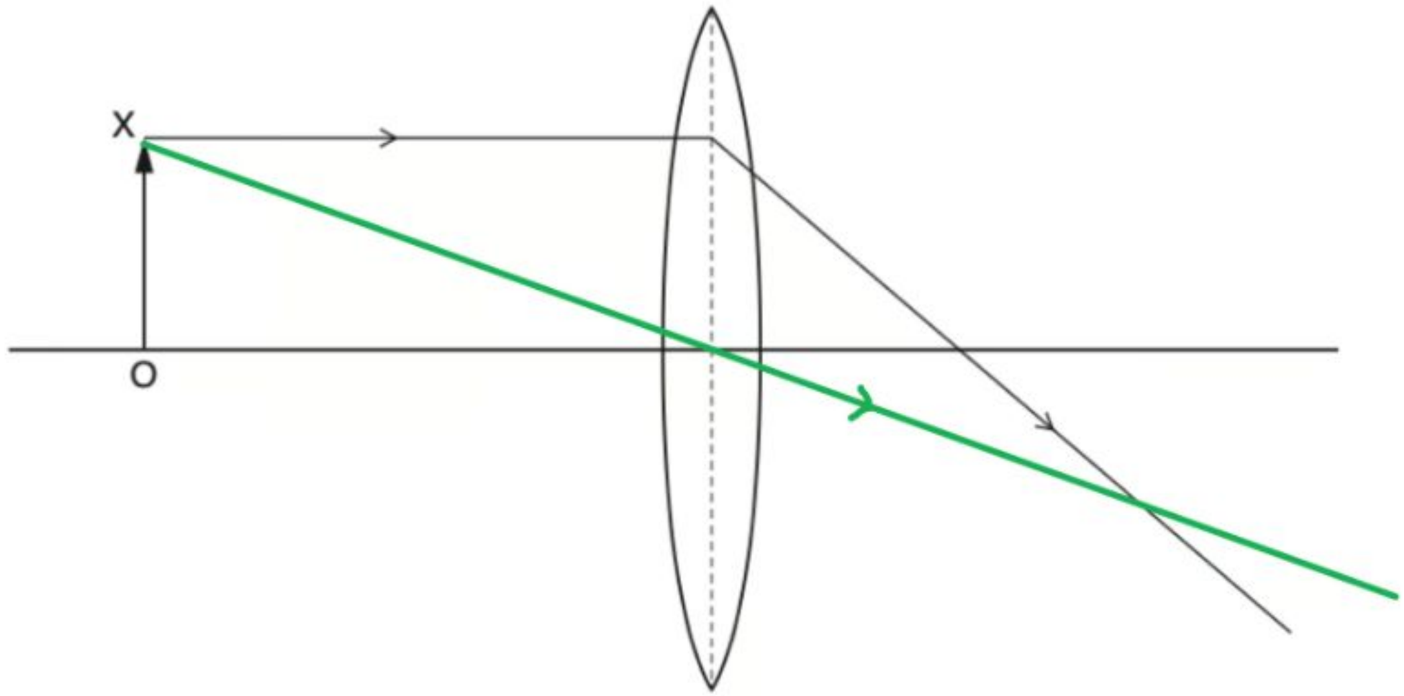


Fig. 7.1

- Ray is a straight line from X through the centre of the lens; [1 mark]

(ii) Draw an arrow to represent the image of OX and label it I:

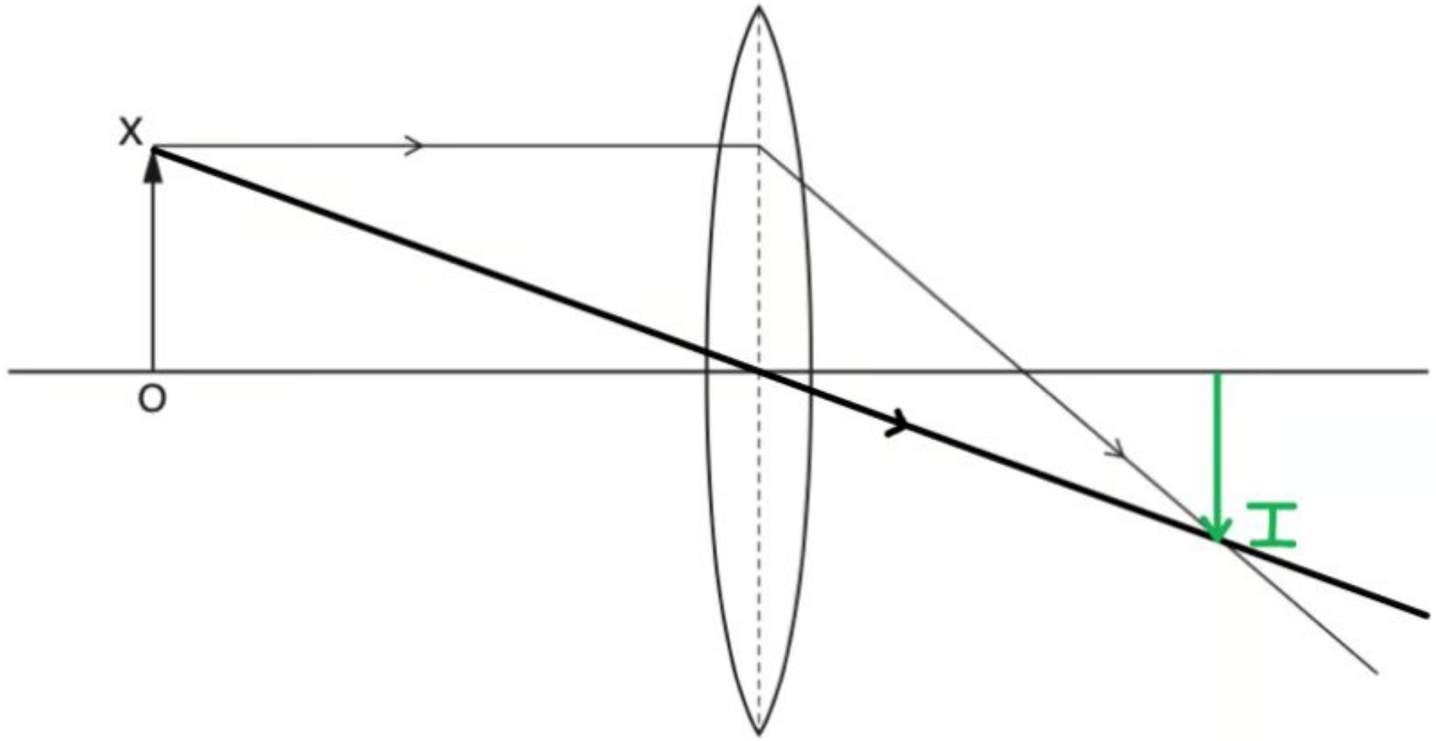


Fig. 7.1

- Arrow drawn from axis to the point where the rays cross **AND** pointing downwards **AND** labelled "I"; [1 mark]

(iii) Mark a principal focus for the lens and label it F:

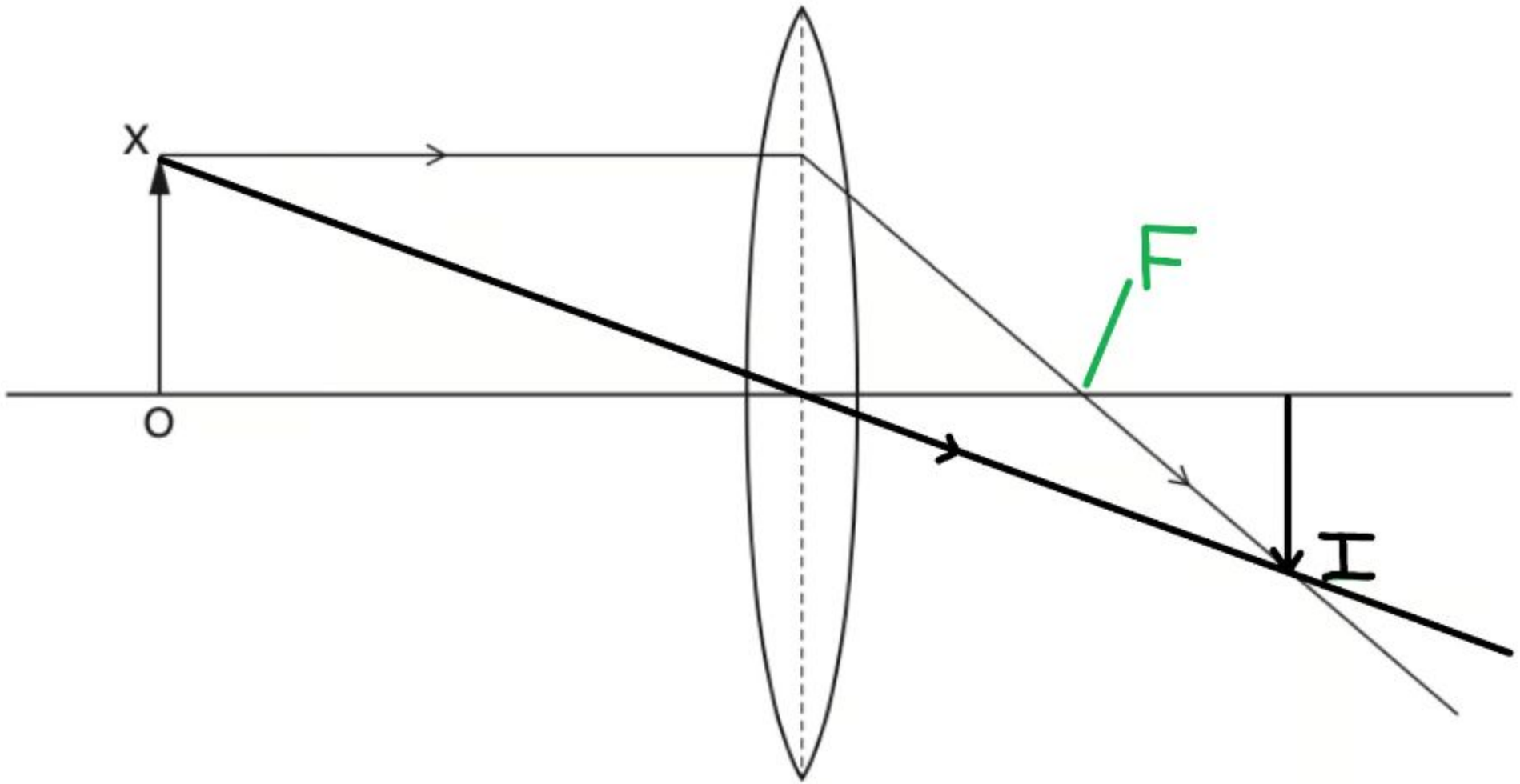
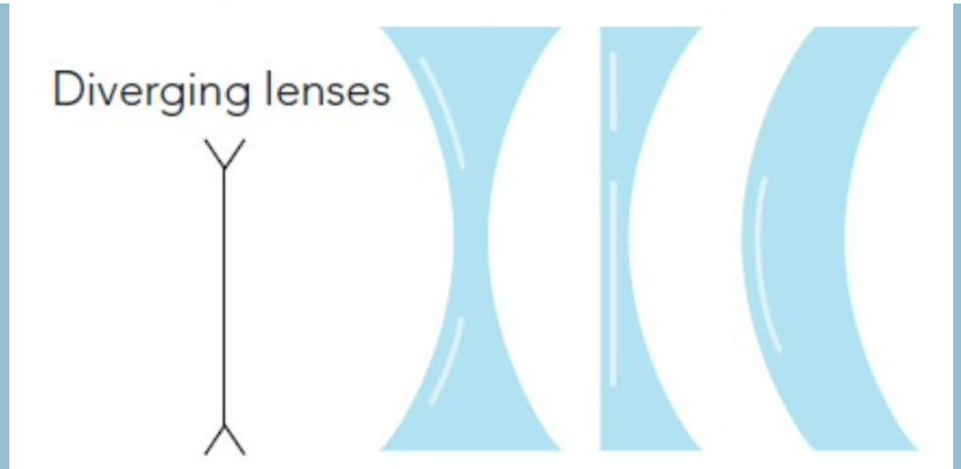


Fig. 7.1

Diverging lenses

A diverging (or concave) lens is thinnest in the centre and spreads light out

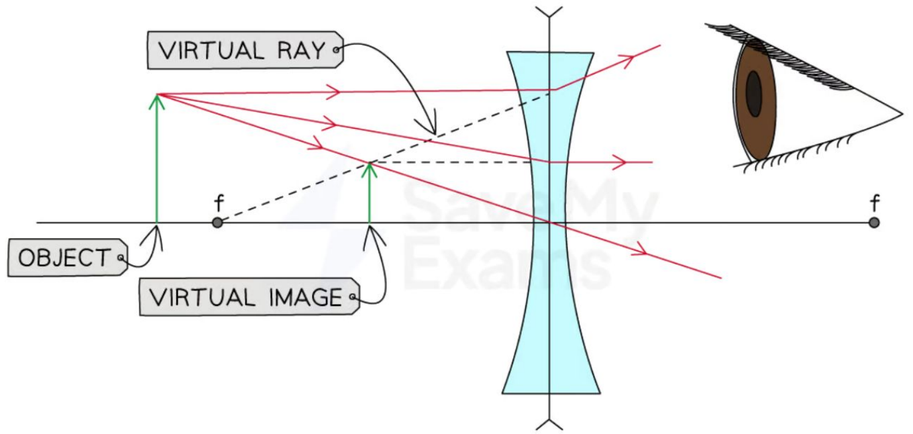
- No matter the position of the object all images formed by diverging lenses are:
  - **Virtual** (and not real)
  - **Upright** (the same as the object)
  - **Diminished** (smaller than the object)
  - On the **same side** of the lens as the object



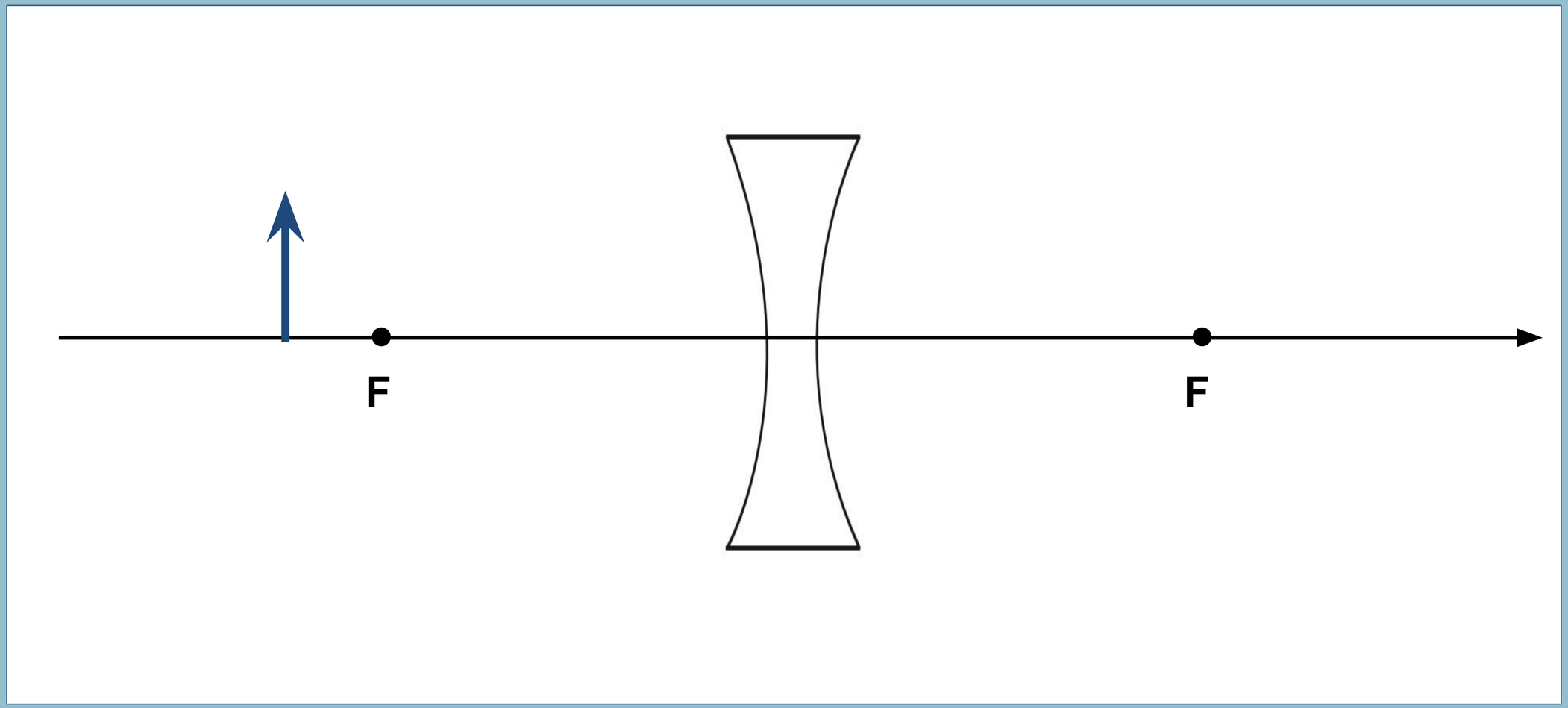
Diverging lenses

- For an object placed at any distance away from the lens (further than the focal point or closer than):
  - The ray of light incident on the centre of the lens does not change direction
  - The rays of light parallel to the principal axis are refracted
  - These rays can be extrapolated backwards
    - It appears that they come from a **virtual focus**
  - A visible projection cannot be formed on a screen

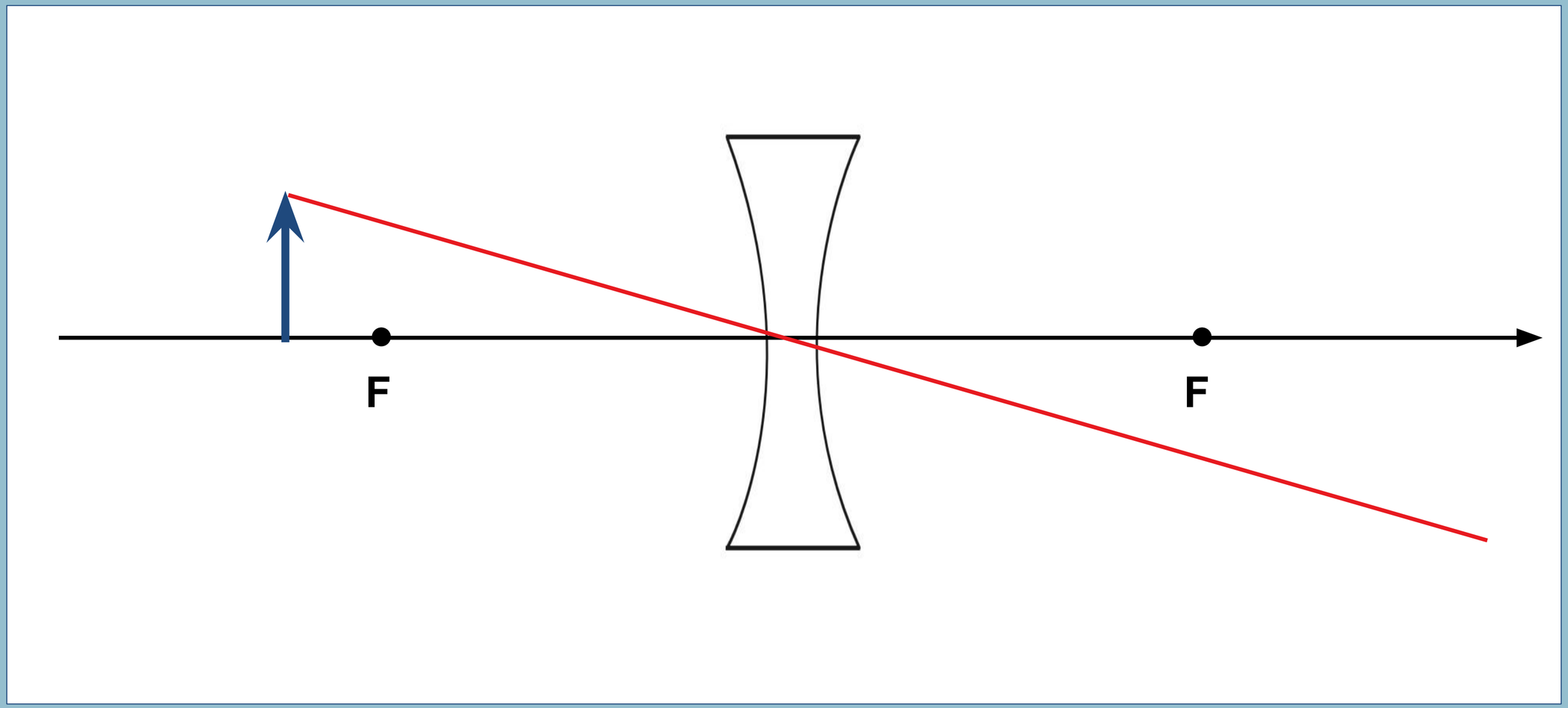
Virtual image produced by a diverging lens with object beyond f



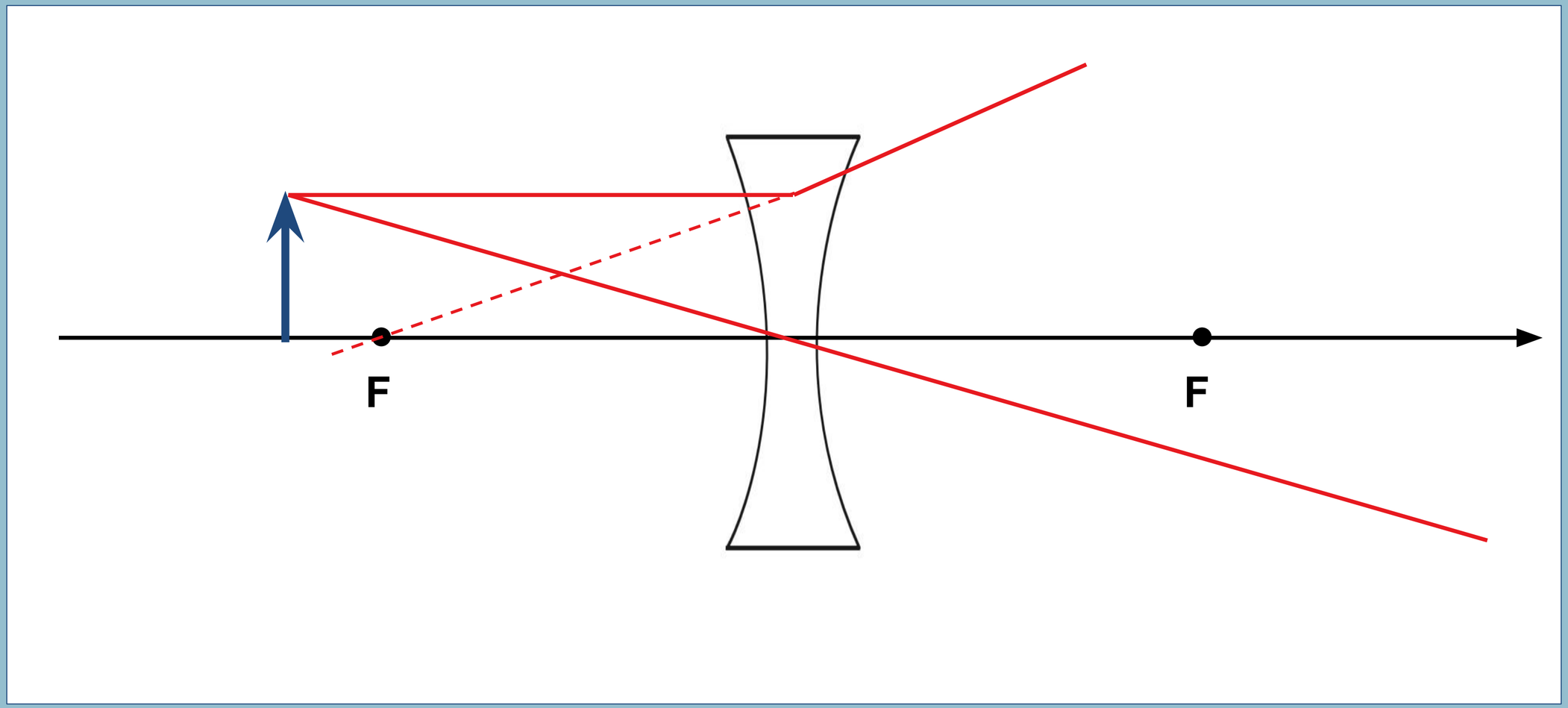
Step 01: draw the important parts



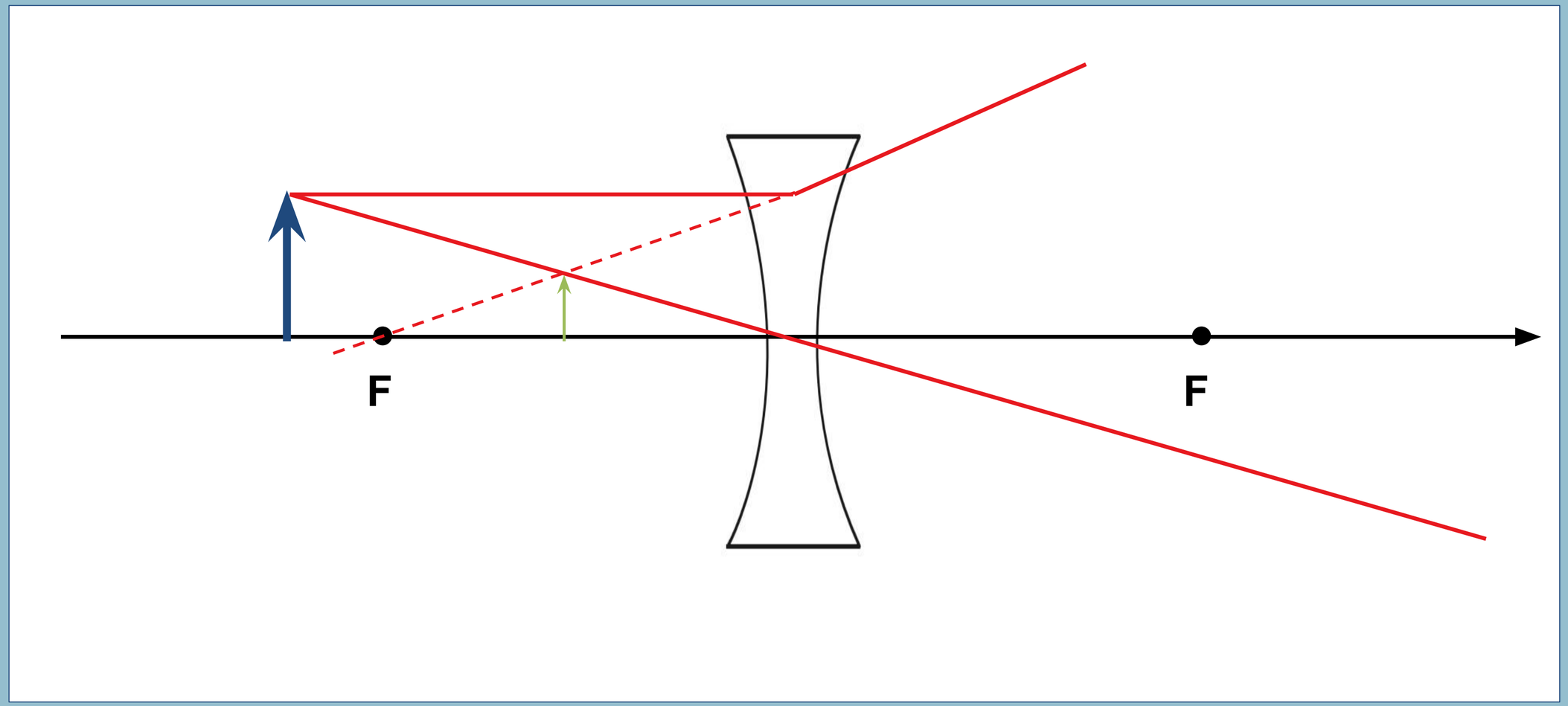
Step 02: draw ray into the center



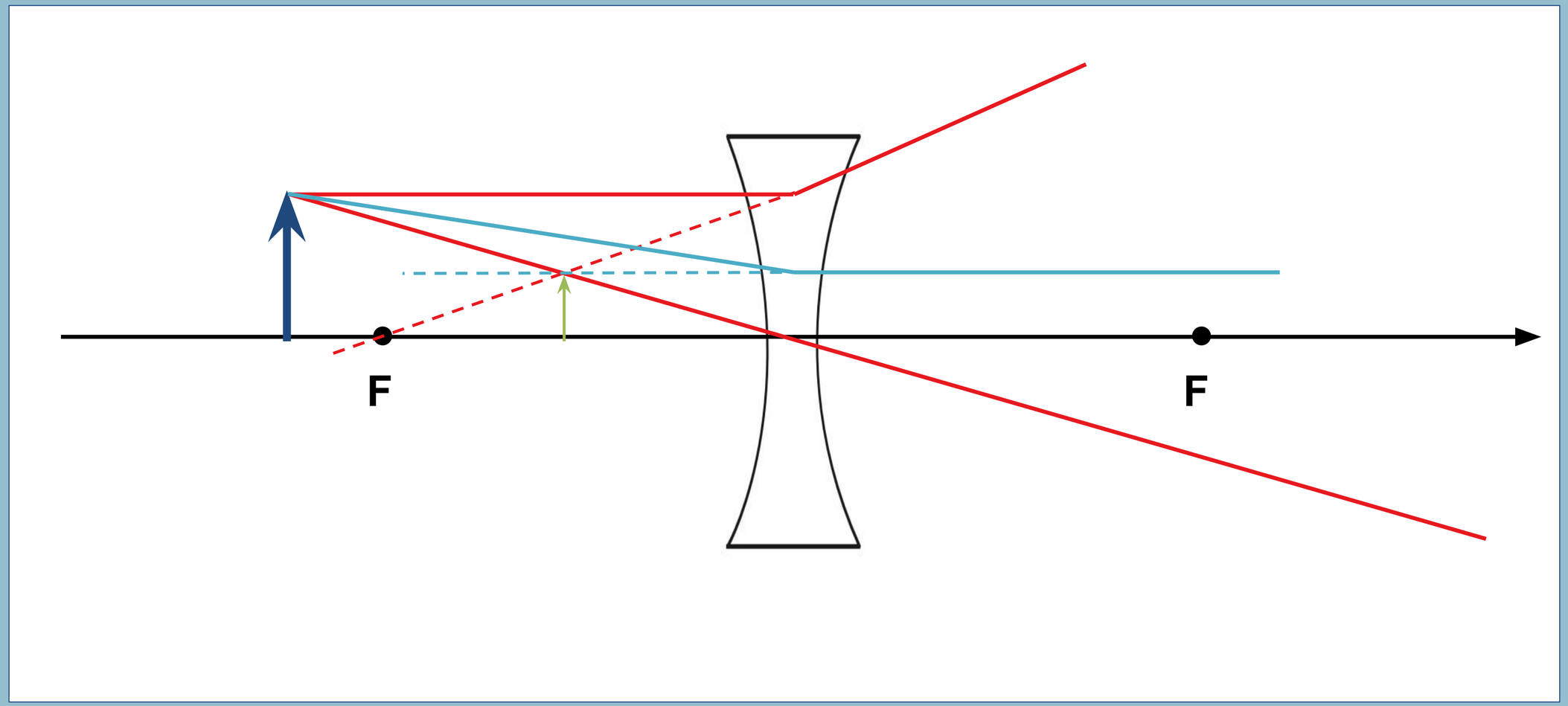
Step 02: draw parallel ray

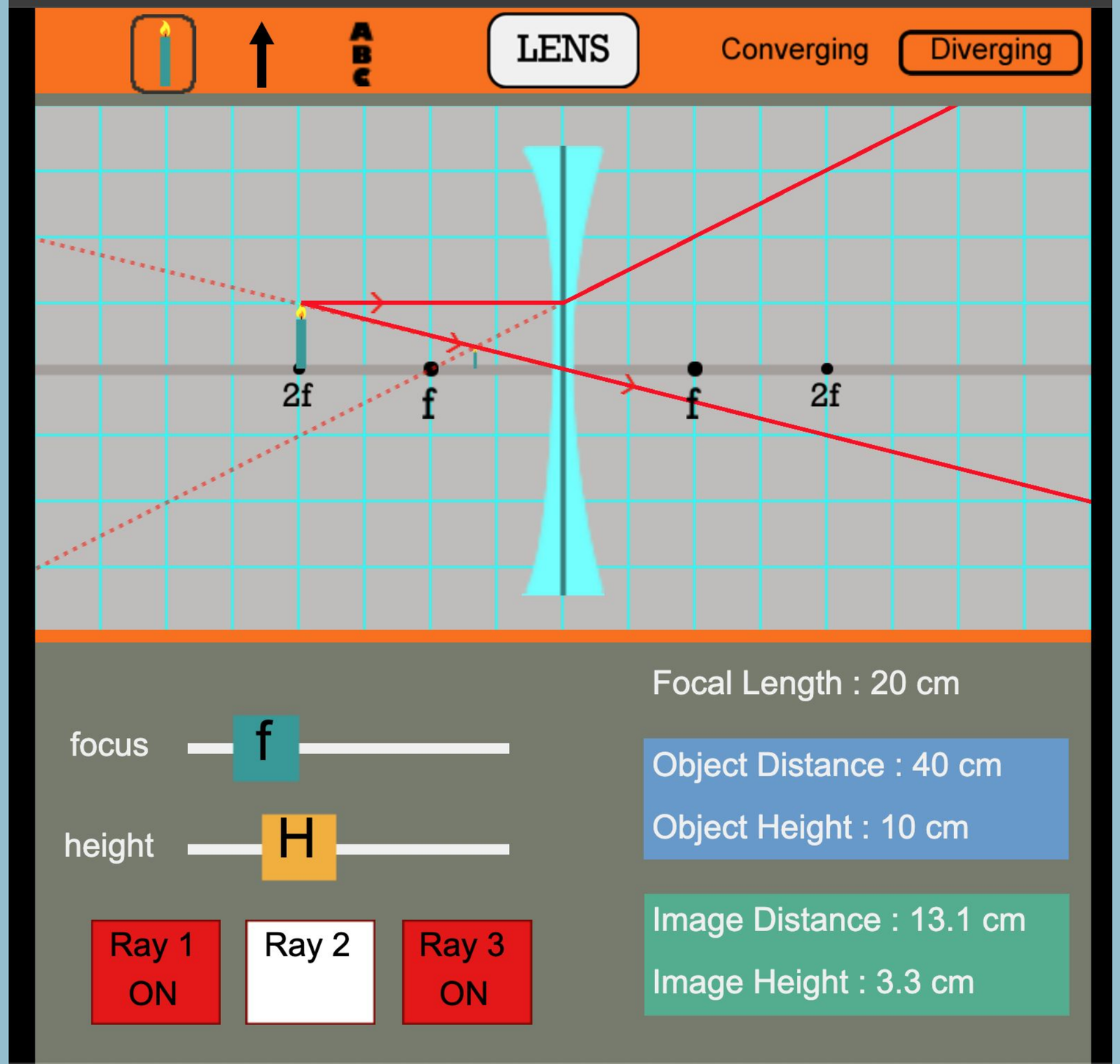


Step 02: the meeting point is the virtual image



Step 02: the meeting point is the virtual image



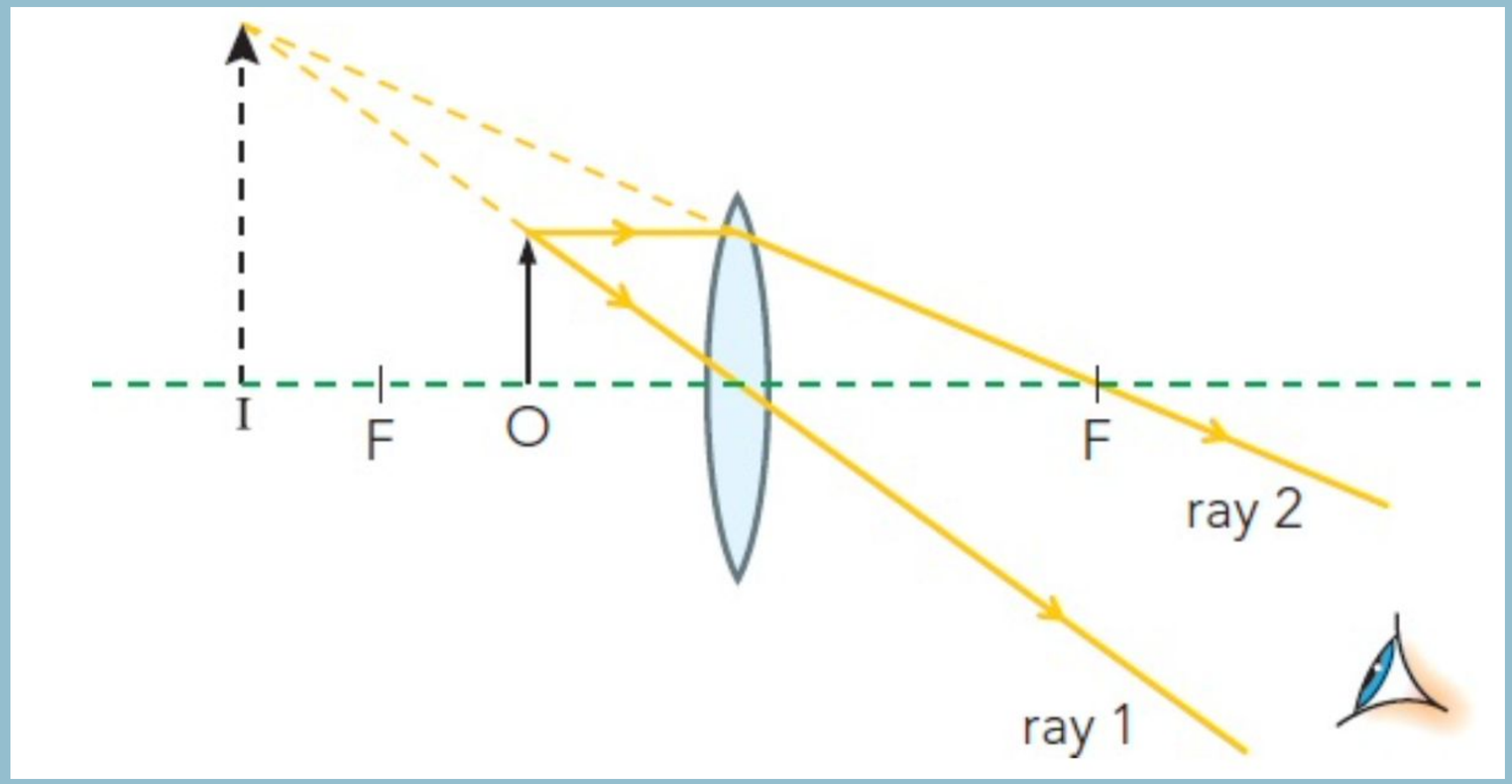

LENS
Converging
Diverging
2f
f
f
2f
focus
f
height
H
Ray 1 ON
Ray 2
Ray 3 ON
Focal Length : 20 cm
Object Distance : 40 cm
Object Height : 10 cm
Image Distance : 13.1 cm
Image Height : 3.3 cm

Magnifying glasses

In magnifying takes advantage of the virtual image produced when an object is placed between the lens and the focal point. Your eyes sees a enlarged (magnified) version of the object. The glass used is a converging lens. You hold it close to a small object and look through the lens.

Magnifying glasses

A converging lens gives an enlarged, upright, virtual image of an object placed between the lens and its principal focus F

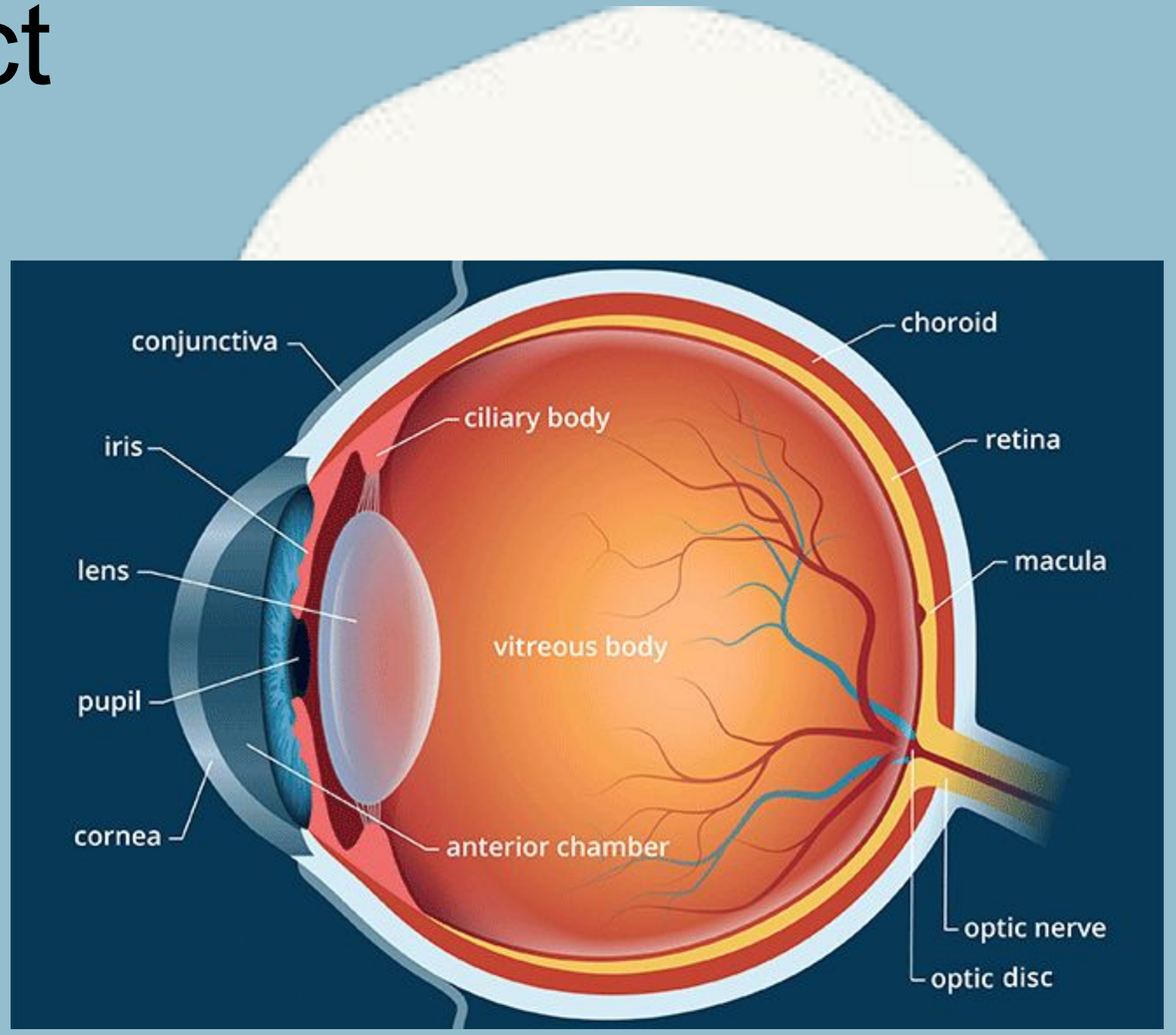


we can see that the image produced by a magnifying glass is:

- upright
- enlarged
- further from the lens than the object
- virtual

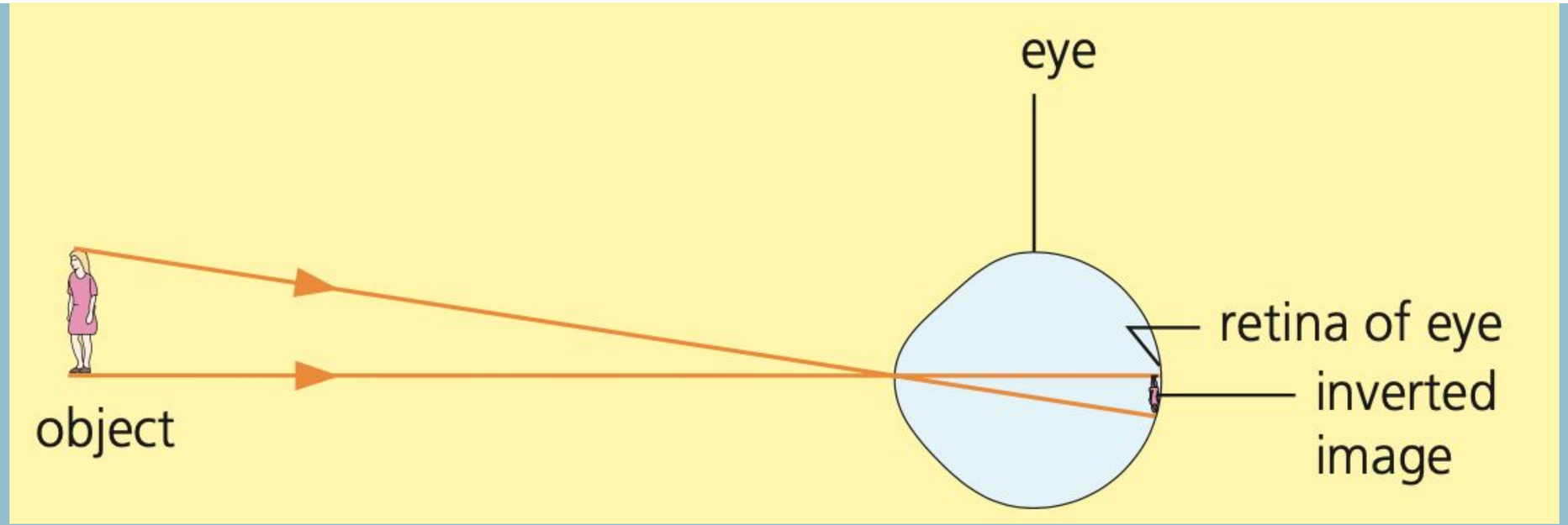
Using lenses to correct eyesight problems

Our eyes contain converging lenses which form an image on the retina at the back of the eye. The lenses in our eyes are flexible and muscles can change the shape and strength of the lens. This allows us to focus on objects at different distances.



Using lenses to correct eyesight problems

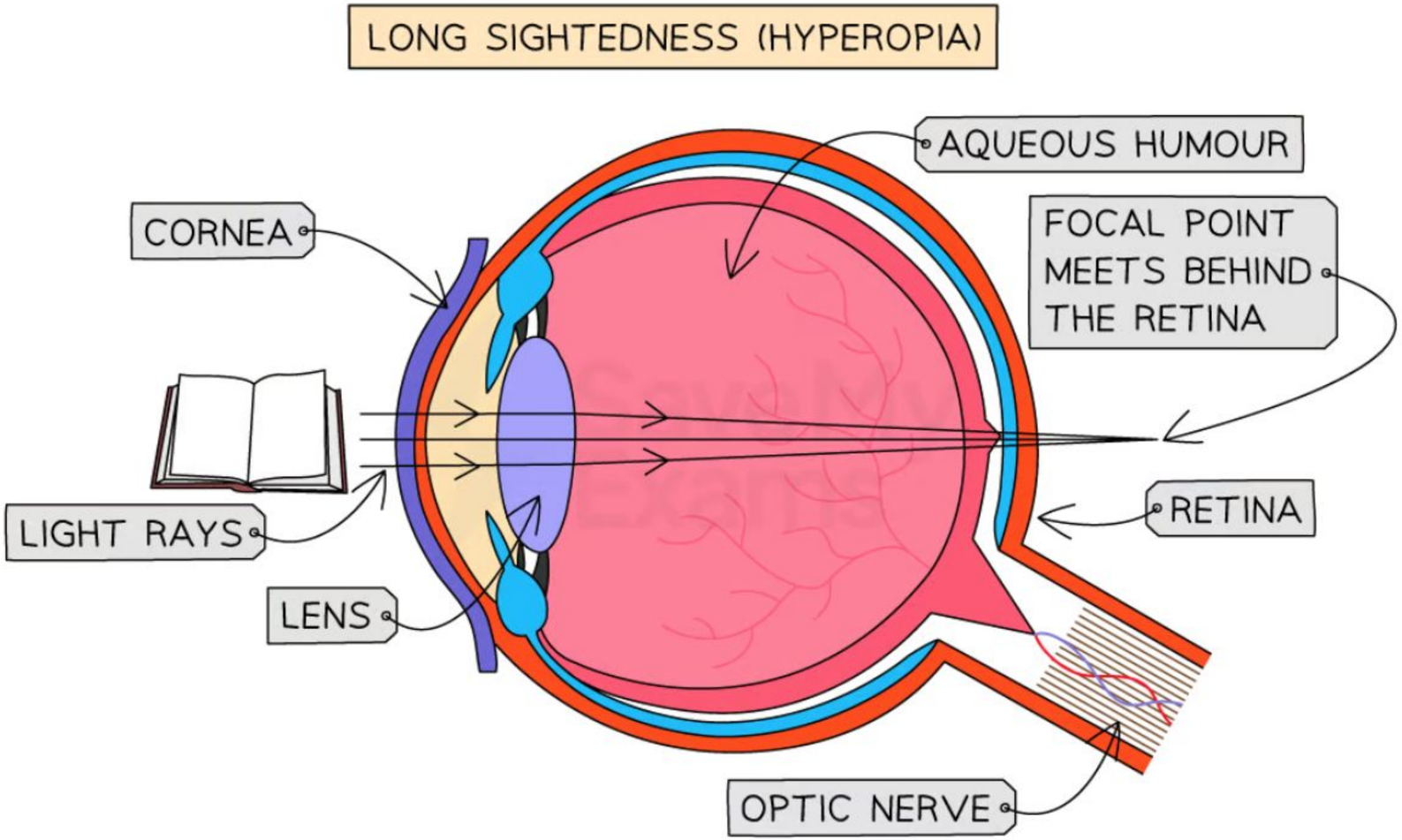
- Converging and diverging lenses are commonly used in glasses and contact lenses to correct defects of sight
  - Converging lenses can be used to correct long-sighted vision
  - Diverging lenses can be used to correct short-sighted vision



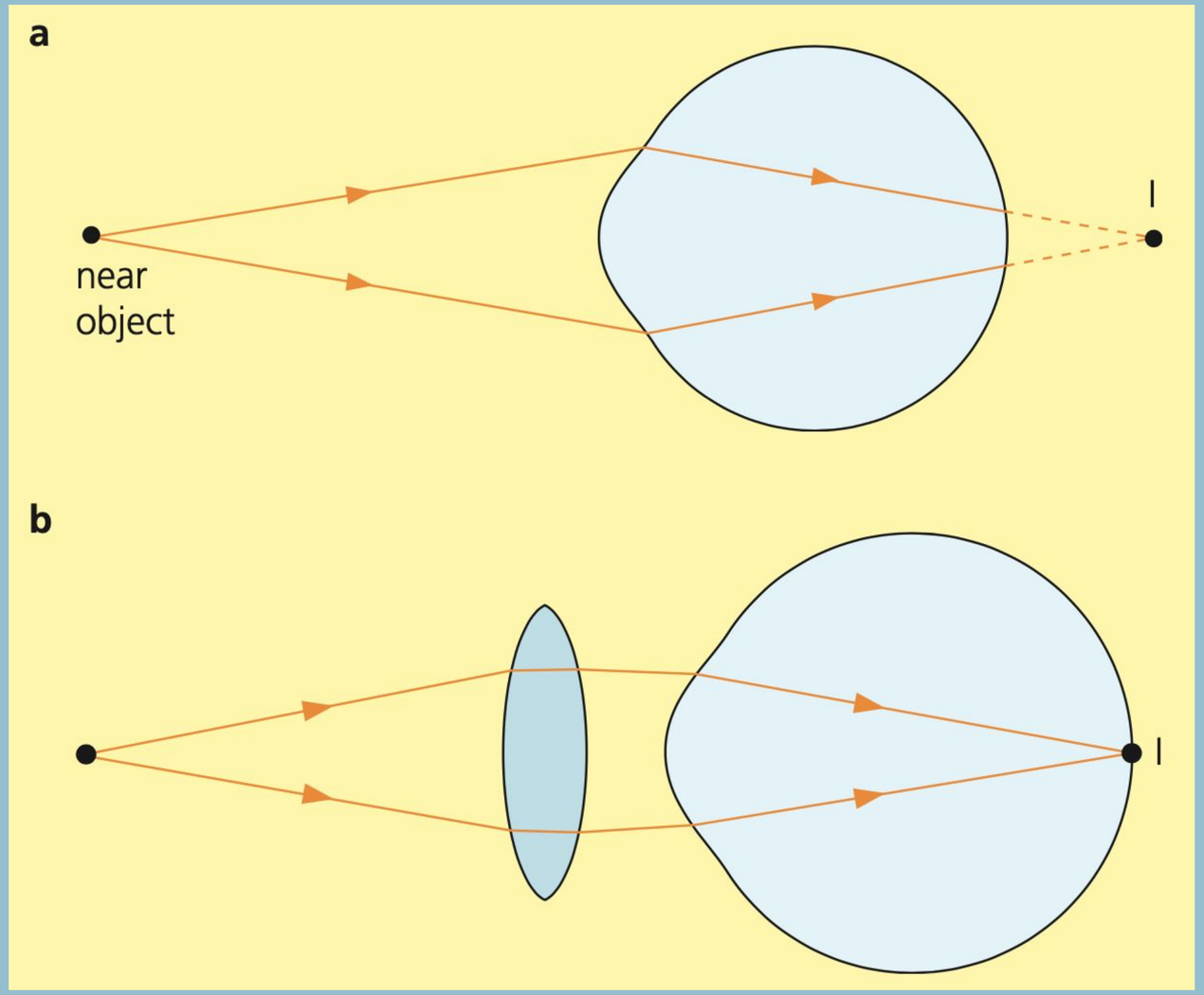
Use of lenses to correct long-sightedness

- Long-sighted people have eyes that are **less curved** than normal or the eyeball is **too short**
  - This means they cannot see things that are close and can only clearly see things that are far away

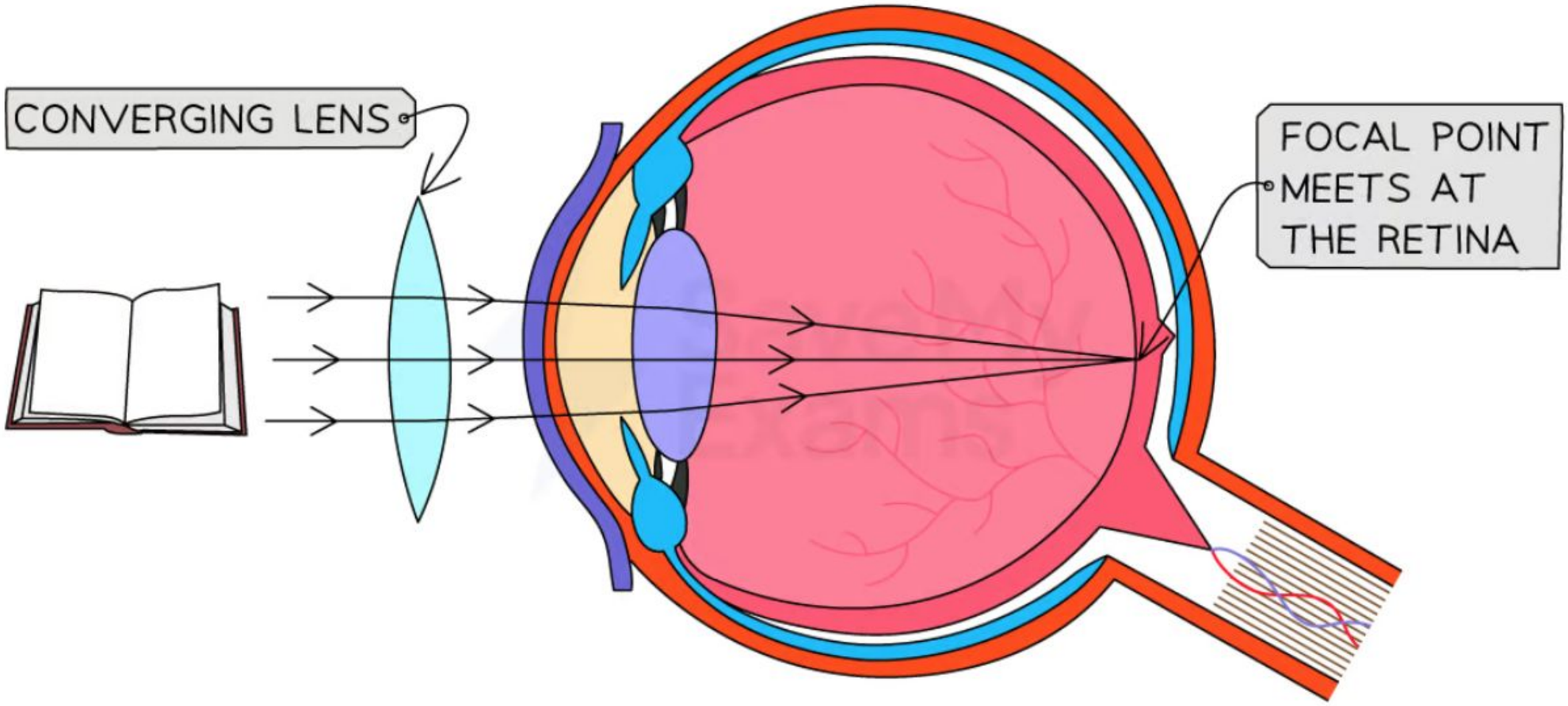
Ray diagram to show long-sightedness



A long-sighted person sees distant objects clearly but close objects appear blurred. The image of a near object is focused behind the retina because the eyeball is too short or because the eye lens cannot be made thick enough. A converging spectacle lens (or contact lens) corrects the problem



The effect of a ~~diverging~~ converging lens on a long-sighted eye

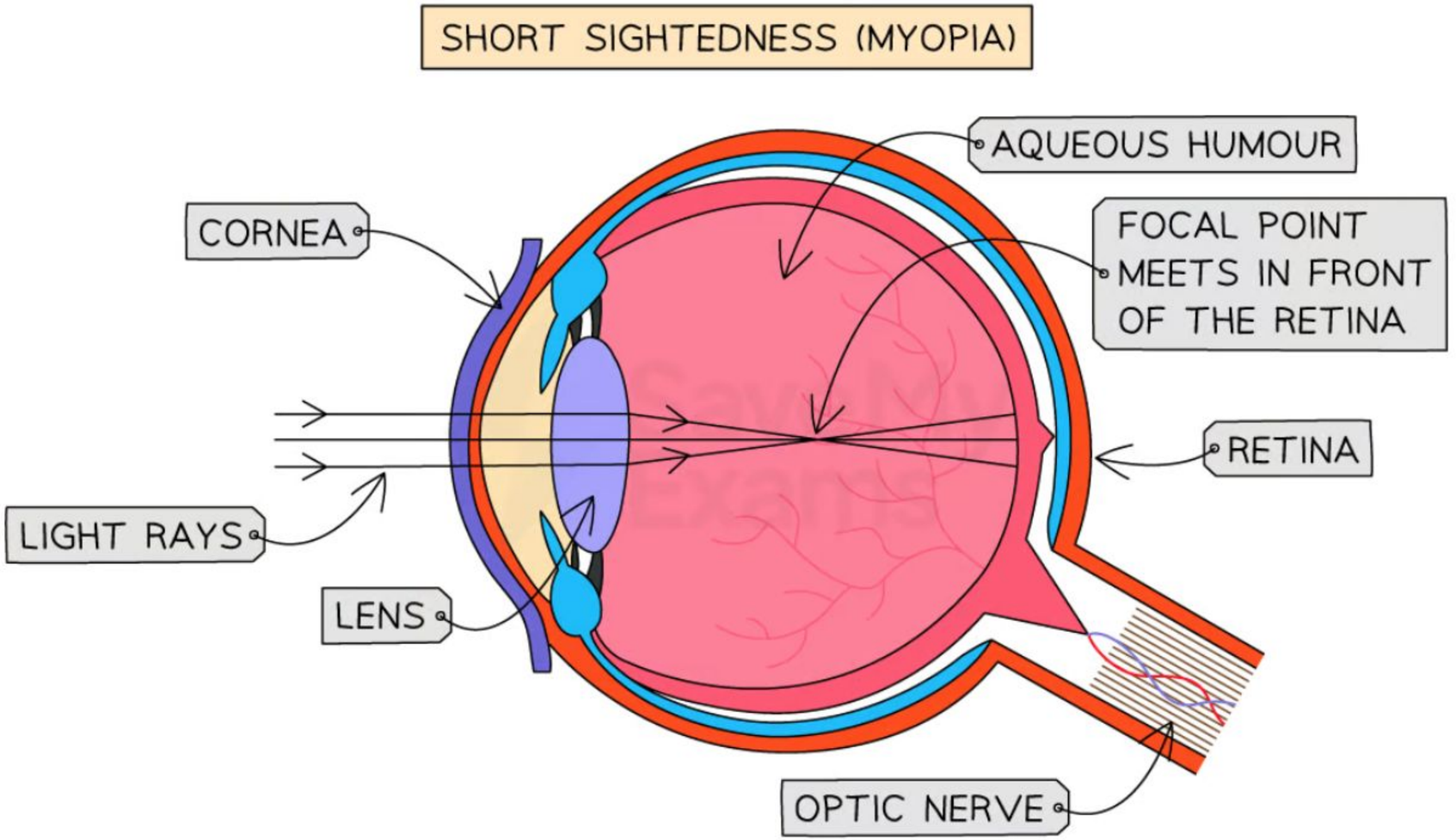


The converging lens causes the rays to converge before they reach the eye, so the image is formed on the retina and not behind it

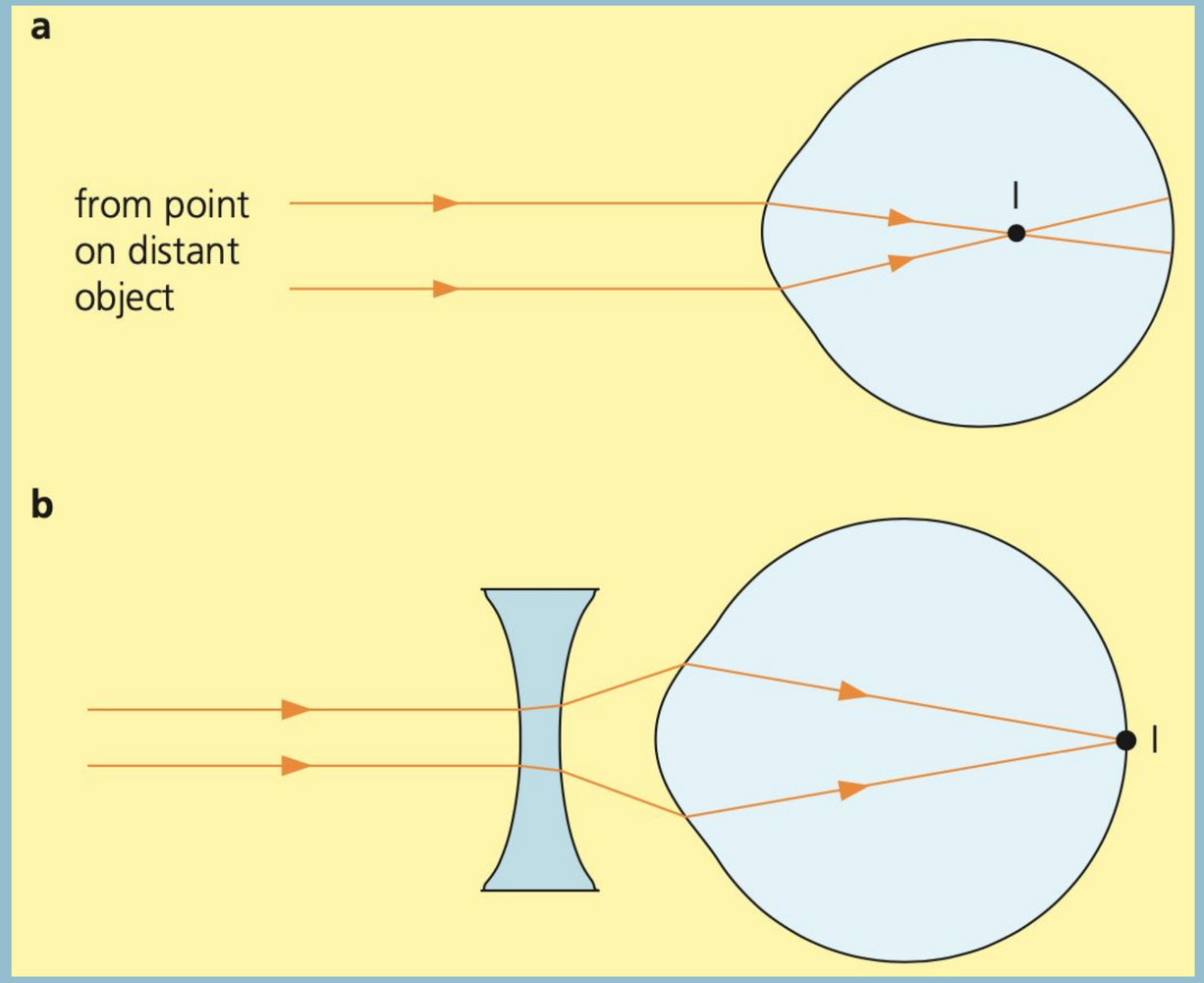
Use of lenses to correct short-sightedness

- People who are **short-sighted** have eyes that are **more curved** than normal or have an eyeball that is **too long**
  - This means they cannot see things that are far away, and only see things that are close to them

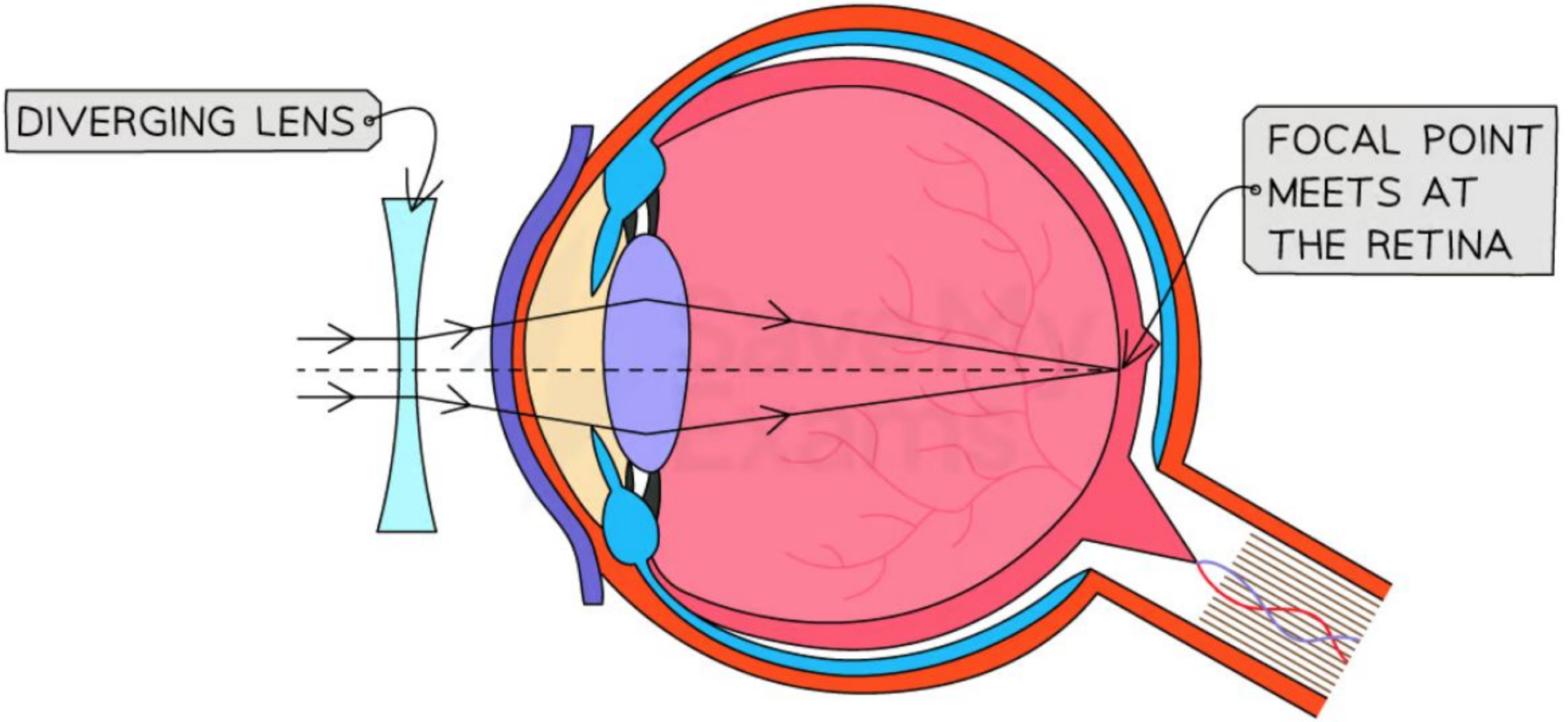
Ray diagram of short-sightedness



A short-sighted person sees near objects clearly but distant objects appear blurred. The image of a distant object is formed in front of the retina because the eyeball is too long or because the eye lens cannot be made thin enough. The problem is corrected by a diverging spectacle lens (or contact lens) which diverges the light before it enters the eye, to give an image on the retina



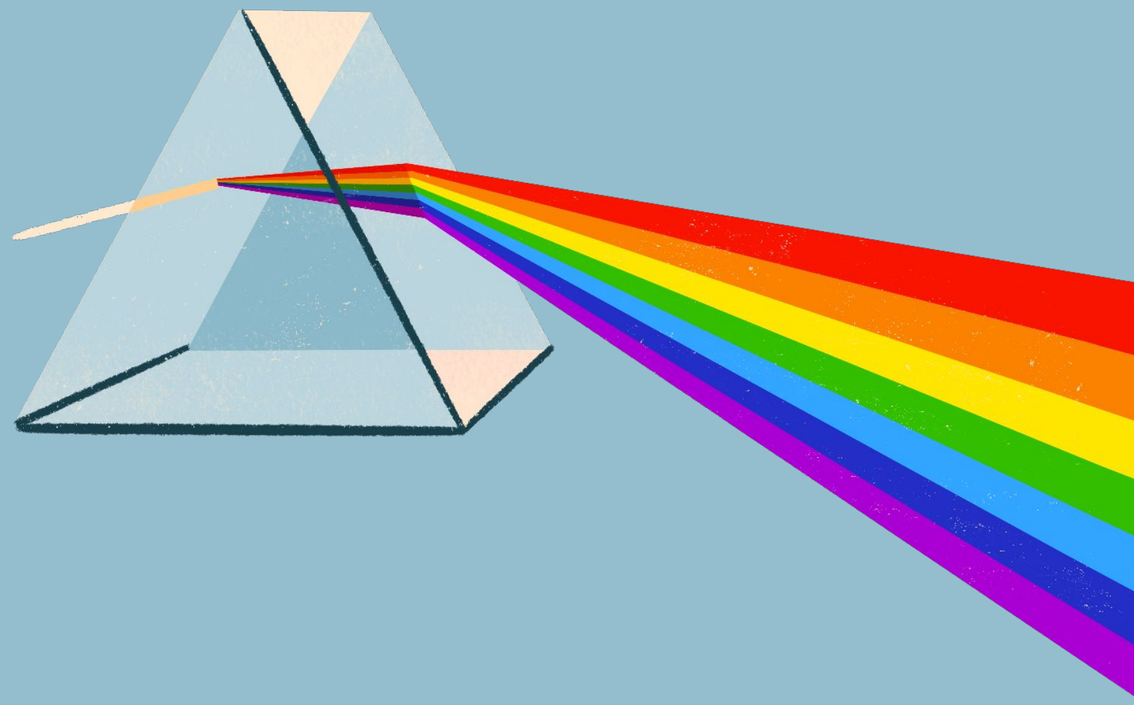
The effect of a diverging lens on a short-sighted eye



The diverging lens causes the rays to diverge before they reach the eye, so the image is formed on the retina and not in front of it

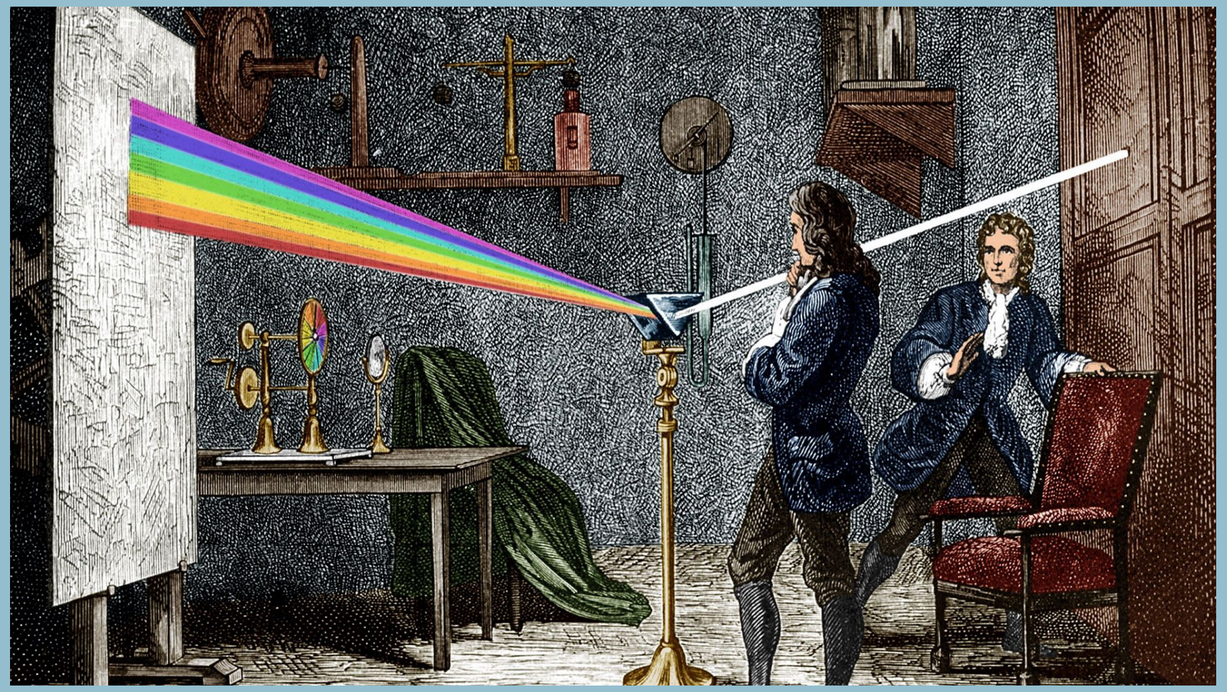
13.5 Dispersion of light

When white light passes through glass, it refracts as it enters and leaves the glass, and can be split into a spectrum of colours. You can see that the colours merge into one another, and they are not all of equal widths in the spectrum. This splitting up of white light into a spectrum is known as dispersion.



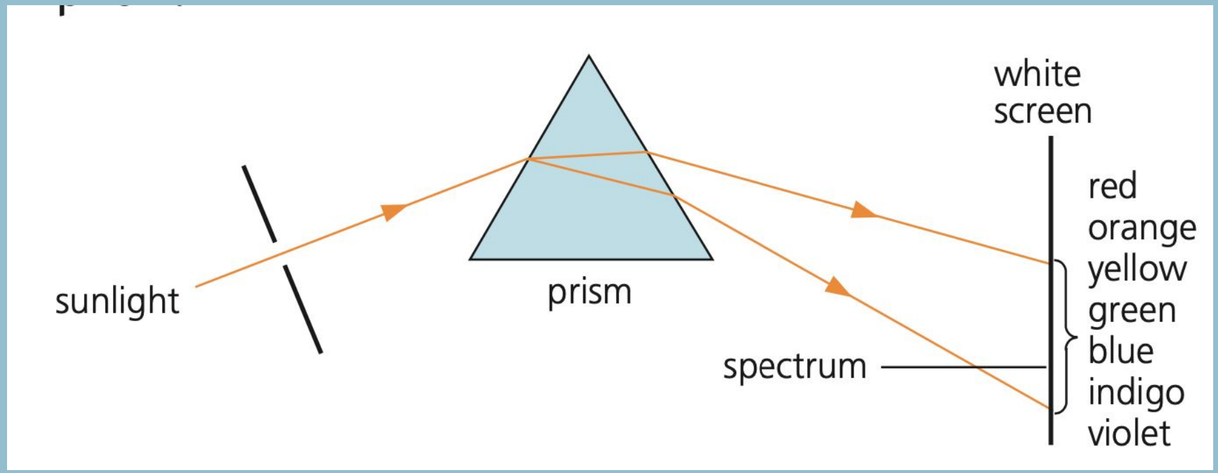
13.5 Dispersion of light

Isaac Newton set out to explain how it happens. He concluded that white light is a mixture of all the different colours of the spectrum. Newton described the visible light spectrum as being made up of seven colours – red, orange, yellow, green, blue, indigo and violet.



13.5 Dispersion of light

The traditional colours of the visible spectrum **in order of increasing wavelength are**: violet, indigo, blue, green, yellow, orange and red. I**n order of increasing frequency, the sequence is reversed.**

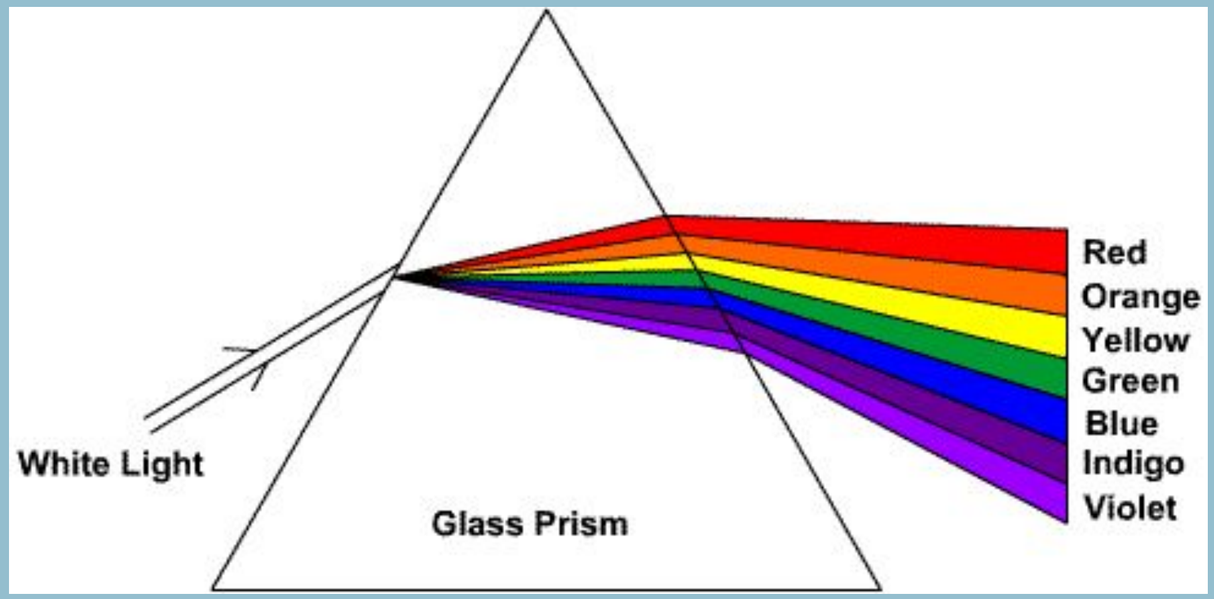


Monochromatic light

Light of one colour and so of one frequency is termed **monochromatic.**

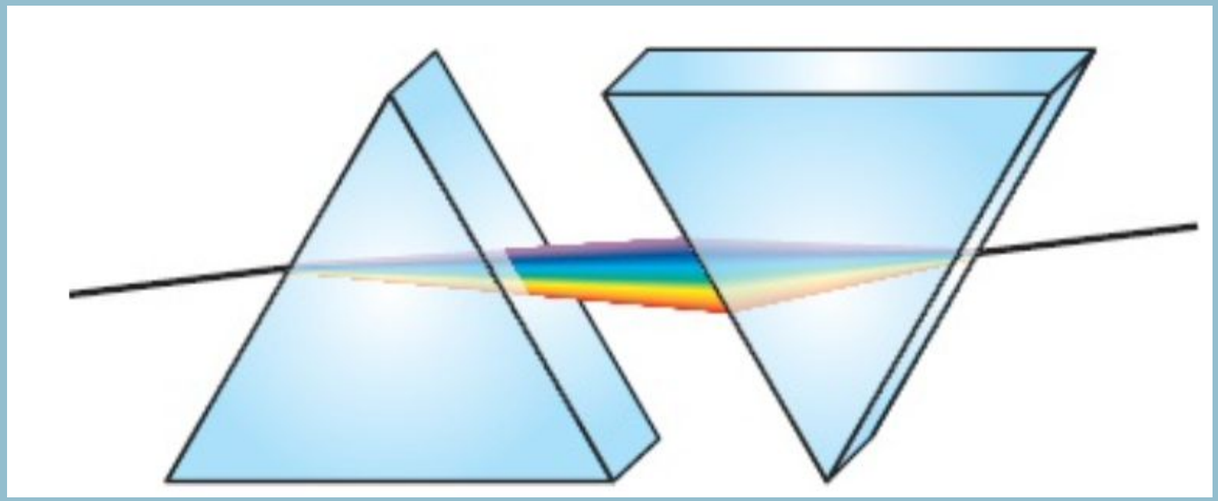
Red vs. Violet

<u>Red light has the longest wavelength</u> in the optical spectrum and hence the lowest frequency and is refracted least by the prism. **<u>Violet light has the shortest wavelength and the highest frequency</u>** in the optical spectrum and is refracted most by the prism.



13.5 Dispersion of light

It had been suggested that light is coloured by passing it through a prism. Newton showed that this was the wrong idea by arranging for the spectrum to be passed back through another prism. The colours recombined to form white light again.

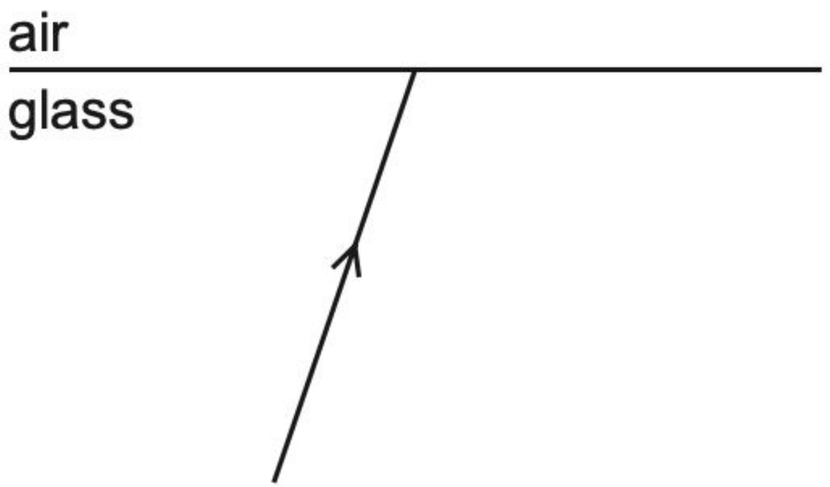


SUMMARY

The law of reflection: angle of incidence = angle of reflection.
The image in a plane mirror is upright, as far behind the mirror as the object is in front and swapped round left to right.
The image in a plane mirror is virtual.
Refraction is the bending of light as it goes from one substance to another.
Refraction is caused by light travelling at different speeds in different materials.
When light passes from air to glass it bends towards the normal. When it passes from glass to air it bends away from the normal.
When light travelling through glass hits a boundary with air, some light passes from glass to air, some light is internally reflected back into the glass.
When the angle of incidence in glass is equal to, or greater than, the critical angle, all the light is reflected back into the glass. This is total internal reflection.
The refractive index is a measure of how much light is slowed, or bent, by a material.
Refractive index can be calculated using the equation $n = \frac{\sin i}{\sin r}$
$\text{Refractive index} = \frac{1}{\text{critical angle}}$.
Optical fibres can transmit information rapidly and efficiently using total internal reflection. This is useful in telecommunications and medicine.
Converging lenses bend parallel rays together so they meet at a point called the principal focus.
Drawing a ray parallel to the axis, and a ray which strikes the centre of a lens allows us to draw a ray diagram and find the type of image formed.
A magnifying glass produces a virtual image.
Our eyes use a flexible convex lens to form images.
A short-sighted eye has a lens which is too powerful. This can be corrected using a diverging lens.
A long-sighted eye has a lens which is too weak. This can be corrected using a converging lens.
White light can be dispersed by passing it through a glass prism. This creates the visible spectrum.

2024 Questions

19 The diagram shows a ray of light in glass incident on the surface between the glass and air.



What happens if the angle of incidence is made larger than the critical angle for the glass?

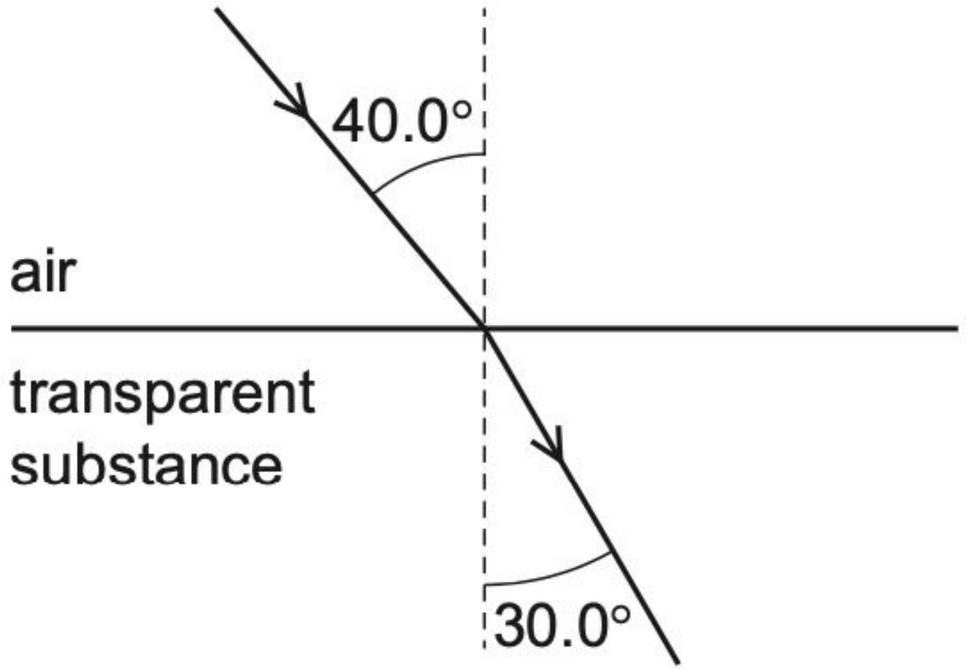
A The angle of refraction becomes equal to 90°.

B There is a refracted ray and a ray reflected inside the glass.

C There is a refracted ray only.

D There is only a ray reflected inside the glass.

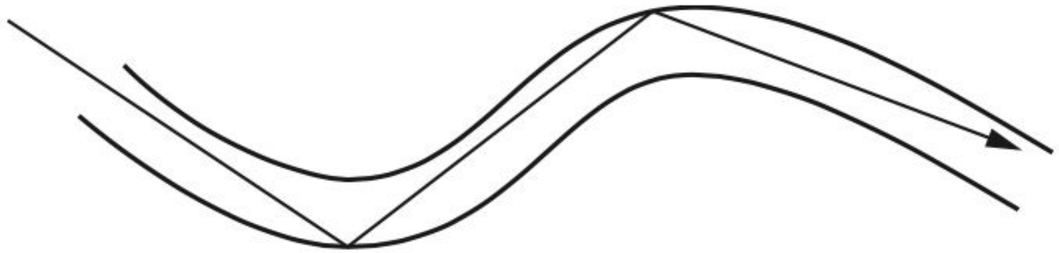
19 The diagram shows a ray of light passing from air into a transparent substance.



What is the refractive index of the transparent substance?

A 1.33 **B** 1.29 **C** 0.778 **D** 0.750

20 The diagram shows a ray of light in an optical fibre.



Which statement correctly explains the condition for the maximum transmission of light by the optical fibre?

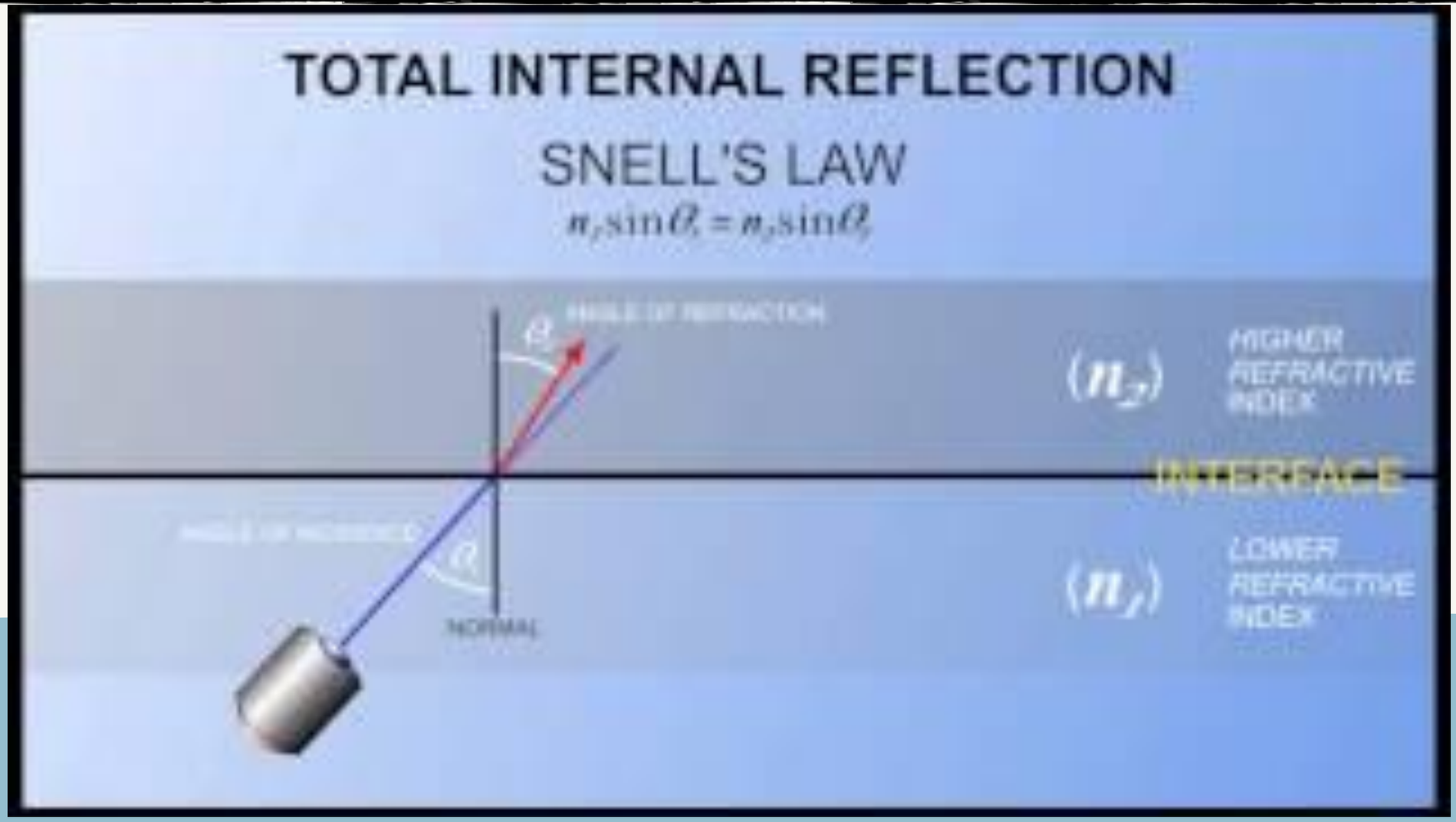
A The glass must slow the light as little as possible to make the critical angle for the fibre as large as possible.

B The glass must slow the light as little as possible to make the critical angle for the fibre as small as possible.

C The glass must slow the light as much as possible to make the critical angle for the fibre as large as possible.

D The glass must slow the light as much as possible to make the critical angle for the fibre as small as possible.

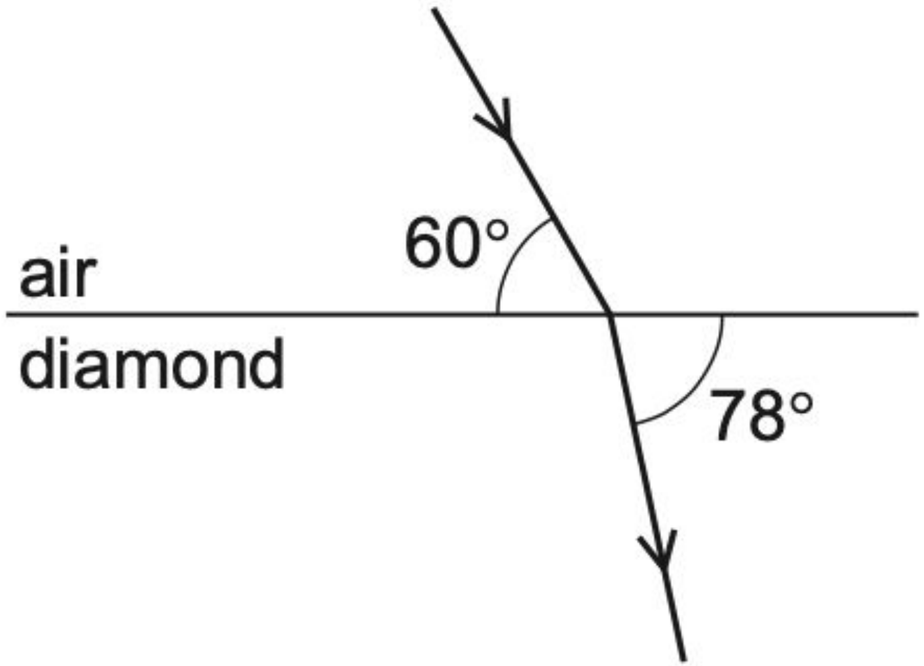
Answer


TOTAL INTERNAL REFLECTION
SNELL'S LAW
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
θ_2
(n_2)
HIGHER REFRACTIVE INDEX
INTERFACE
θ_1
NORMAL
(n_1)
LOWER REFRACTIVE INDEX

18 Which conditions are necessary for light to be totally internally reflected?

	incident light	angle of incidence
A	is in the less dense medium	less than the critical angle
B	is in the less dense medium	greater than the critical angle
C	is in the more dense medium	less than the critical angle
D	is in the more dense medium	greater than the critical angle

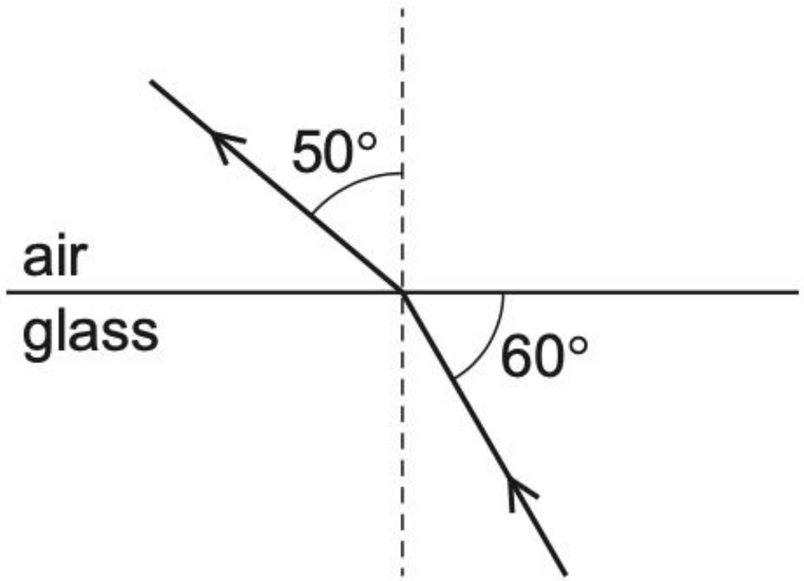
20 The diagram shows a ray of light passing from air into diamond.



What is the refractive index of the diamond?

A 0.89 **B** 1.1 **C** 2.4 **D** 2.5

20 A ray of light is refracted as it enters air from glass, as shown.



What is the speed of light in the glass?

A 2.0×10^8 m/s

B 2.2×10^8 m/s

C 2.3×10^8 m/s

D 2.7×10^8 m/s

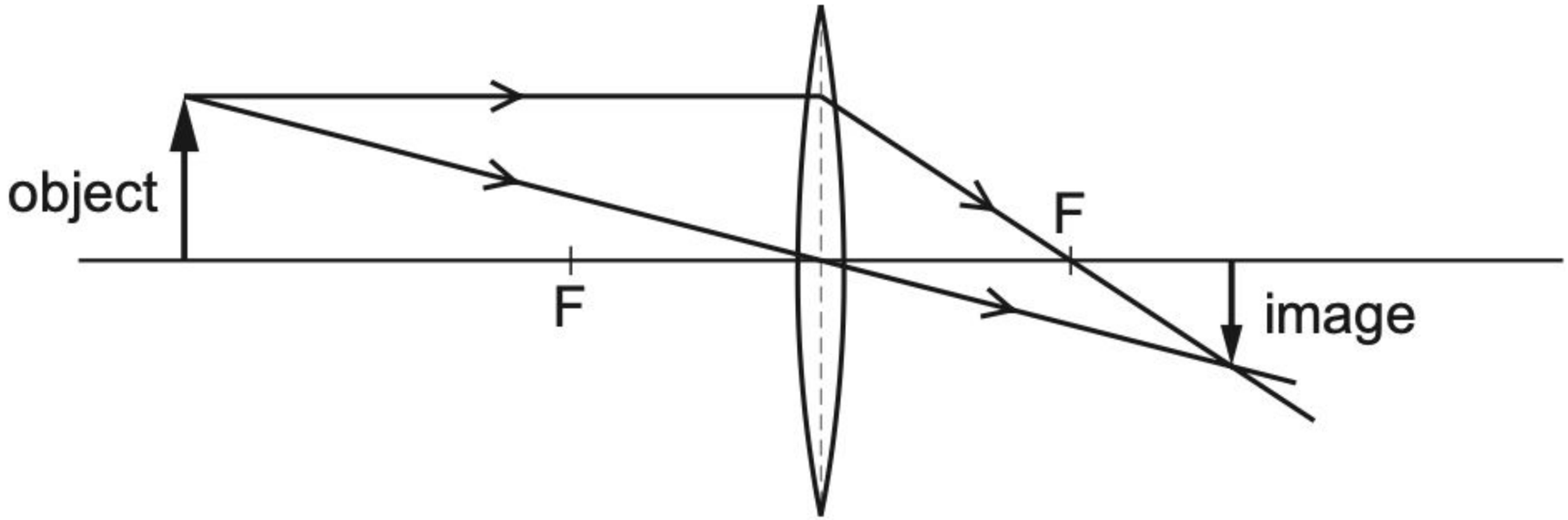
(b) The critical angle for the glass is 42°.

(i) Calculate the refractive index of the glass.

Show your working.

refractive index = ... [2]

19 A converging lens forms an image of an object placed in front of it.



What are the characteristics of the image?

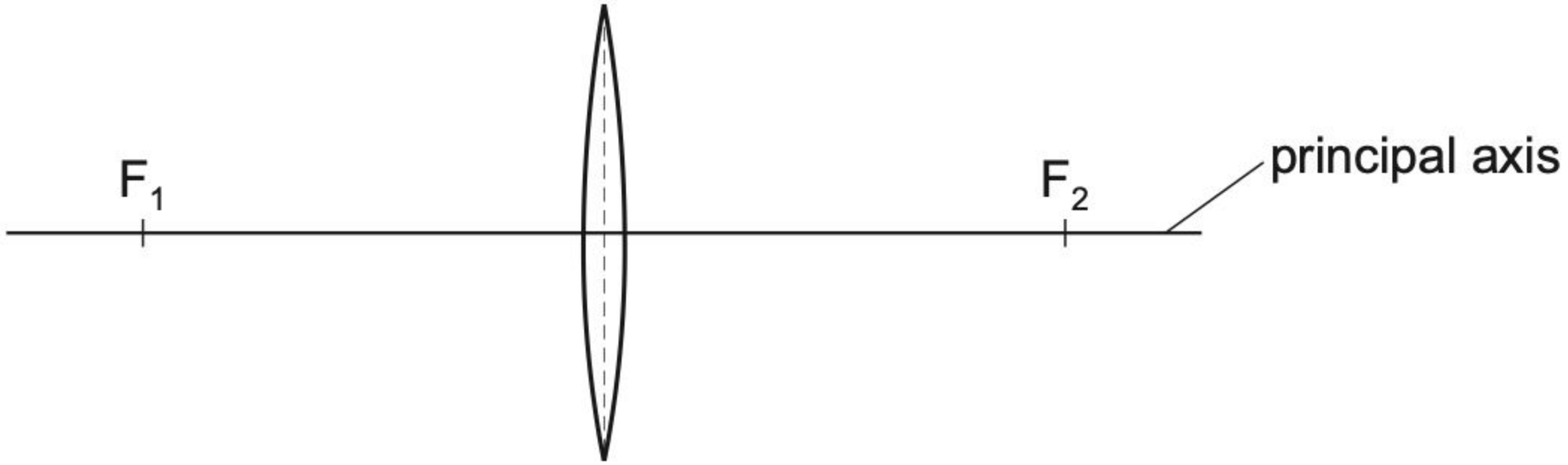
A real, inverted, diminished

B real, upright, enlarged

C virtual, inverted, diminished

D virtual, upright, enlarged

18 The diagram shows a thin converging lens with principal focuses at F_1 and F_2.



A small light source is placed at F_1. A beam of light from the source passes through the lens.

Which statement correctly describes the beam of light emerging from the lens?

A The beam converges to F_2.

B The beam converges to a point to the right of F_2.

C The beam diverges from a point to the left of F_1.

D The beam travels parallel to the principal axis.

21 The ray diagrams show the formation of an image by two different converging lenses.

diagram 1

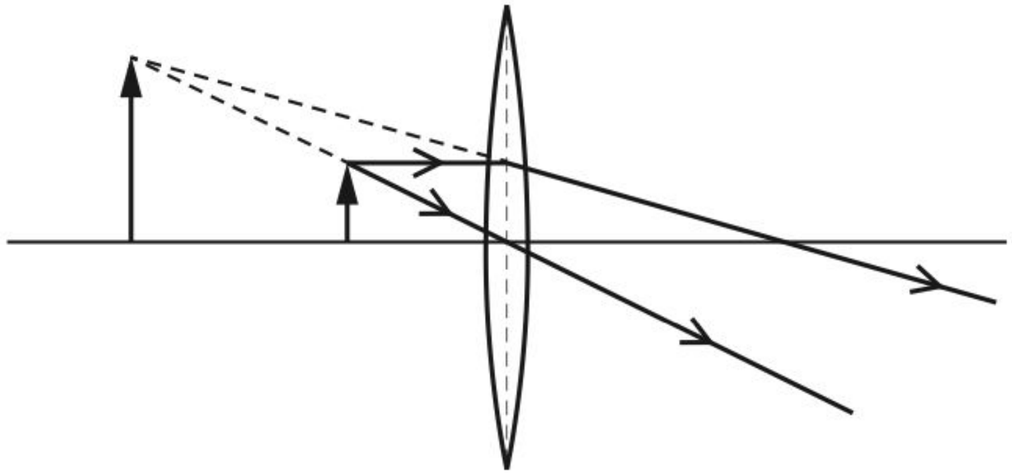
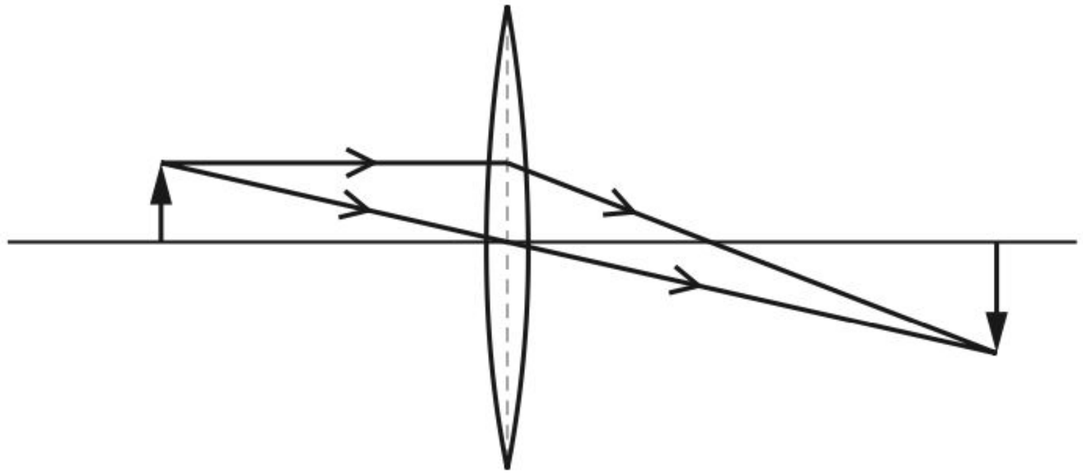


diagram 2



Which row describes the images produced?

	diagram 1	diagram 2
A	real	real
B	real	virtual
C	virtual	real
D	virtual	virtual

(b) An object O is placed to the left of a thin converging lens. F_1 is the principal focus on one side of the lens and F_2 is the principal focus on the other side of the lens.

Two rays from the top of the object are incident on the lens, as shown in Fig. 7.2.

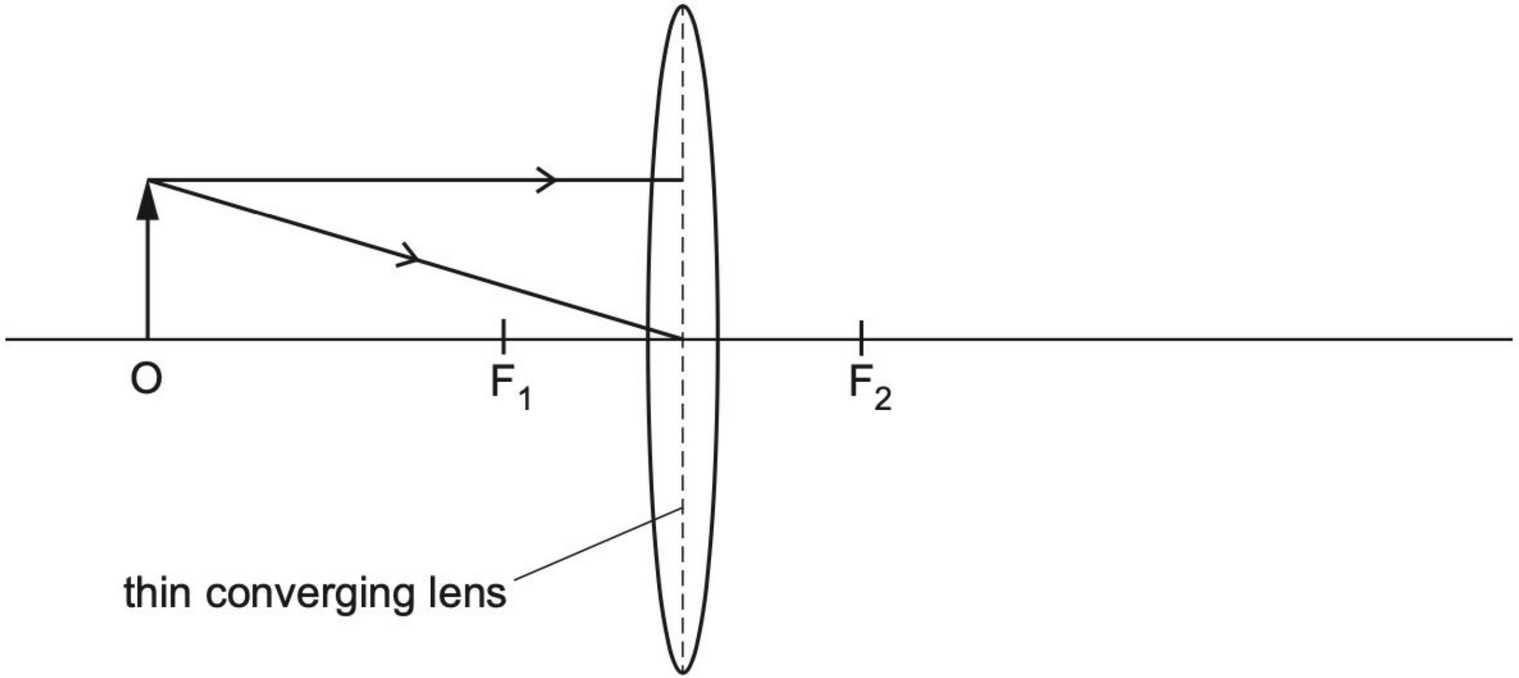


Fig. 7.2

(i) On Fig. 7.2, locate the image of O by continuing the path of each ray. [2]

(ii) Draw an arrow to represent the image of O. [1]

(b) An object O is placed to the left of a thin converging lens. F_1 is the principal focus on one side of the lens and F_2 is the principal focus on the other side of the lens.

Two rays from the top of the object are incident on the lens, as shown in Fig. 7.2.

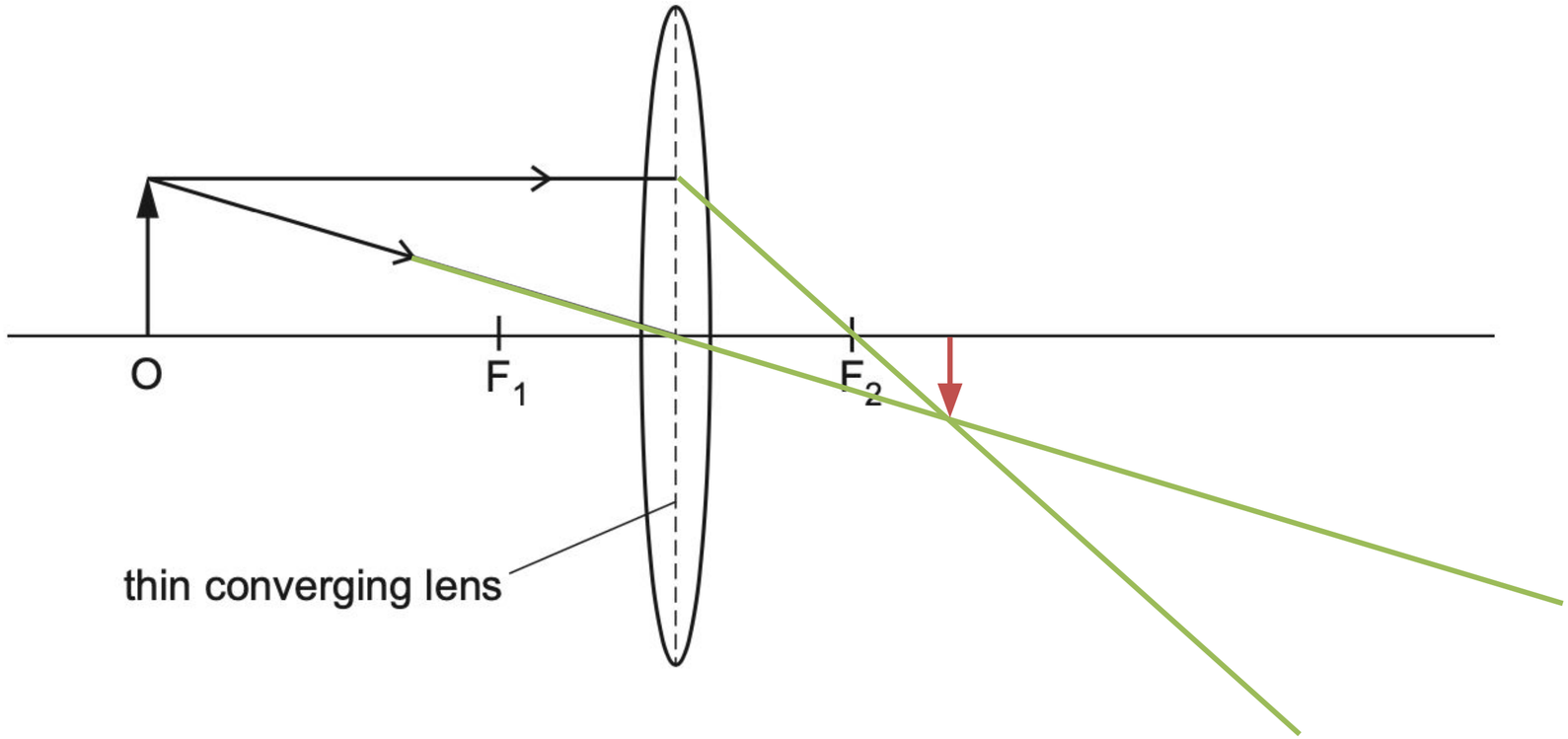


Fig. 7.2

(i) On Fig. 7.2, locate the image of O by continuing the path of each ray. [2]

(ii) Draw an arrow to represent the image of O. [1]

4 The lens in a magnifying glass is a converging lens.

(a) Fig. 4.1 shows the lens of the magnifying glass, its two focal points, F_1 and F_2, and its principal axis.

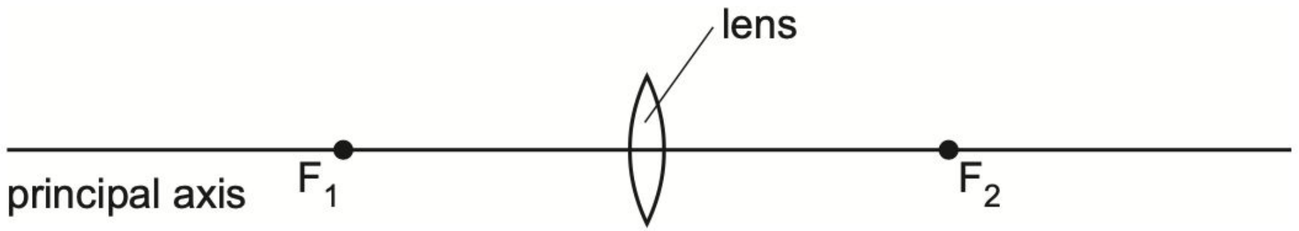


Fig. 4.1

(i) State what is meant by 'focal point'.

It is a point on the principal axis where rays of light from the source converge after passing through lens. The focal point is important because we can understand how the image will look (virtual, real, enlarged, diminished) [2]

6 Fig. 6.1 shows a thin converging lens used to produce a magnified image of an object AB.

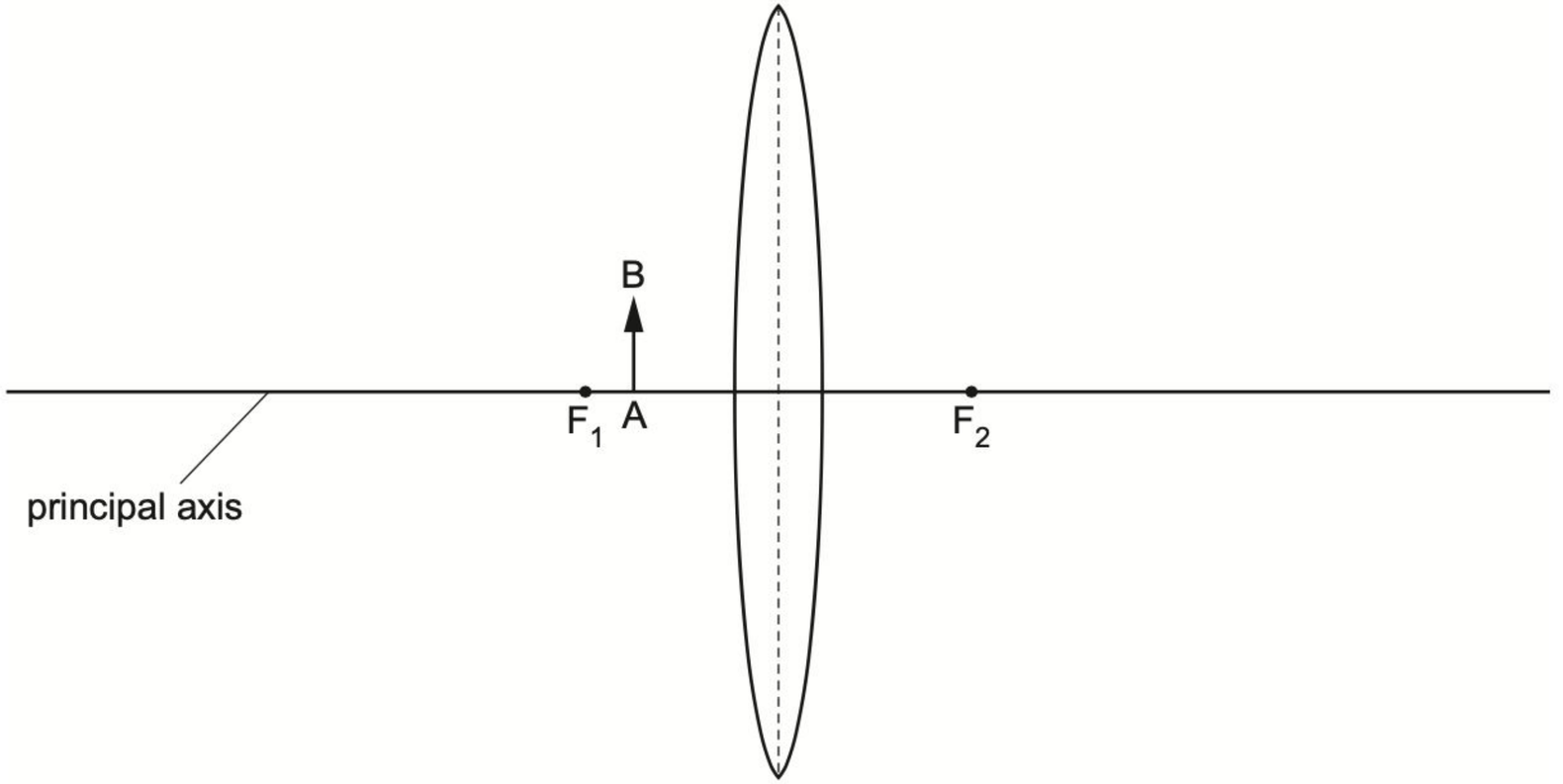


Fig. 6.1

(a) Explain the meaning of the terms principal focus and focal length.

Question	Answer	Marks
6(a)	where rays of light parallel (to the principal axis) converge after passing through lens	**B1**
	(focal length is) the distance between (centre of) the lens and principal focus	**B1**

.....

(b) Fig. 6.2 and Fig. 6.3 each show two parallel rays of light travelling through air towards a lens.

For each lens, draw the path of the two rays as they pass through the lens and back into the air.

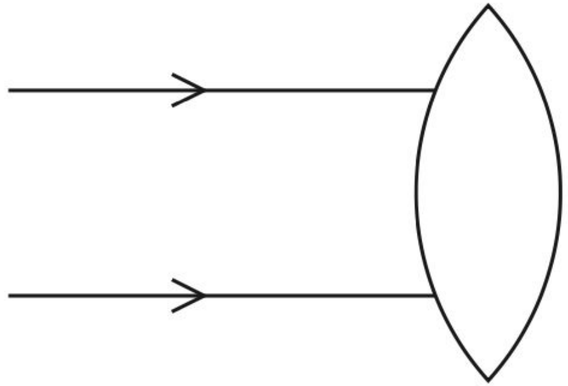


Fig. 6.2

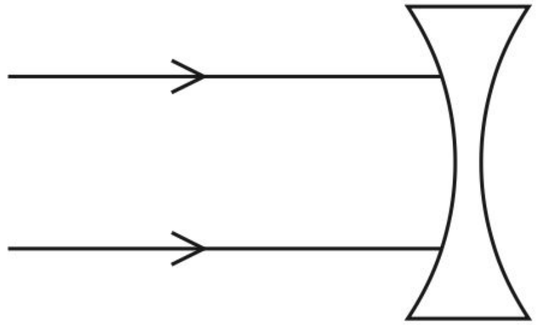


Fig. 6.3

[2]

22 White light enters a glass prism. The light leaving the other side of the prism is separated into colours.

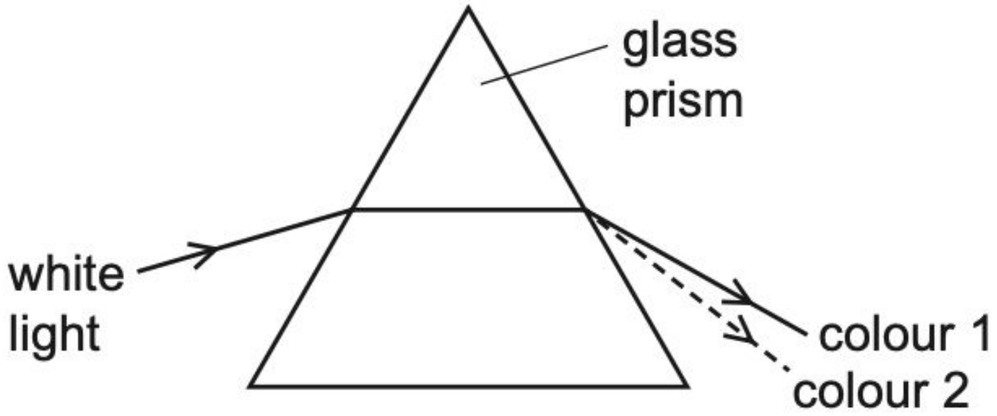


diagram 1

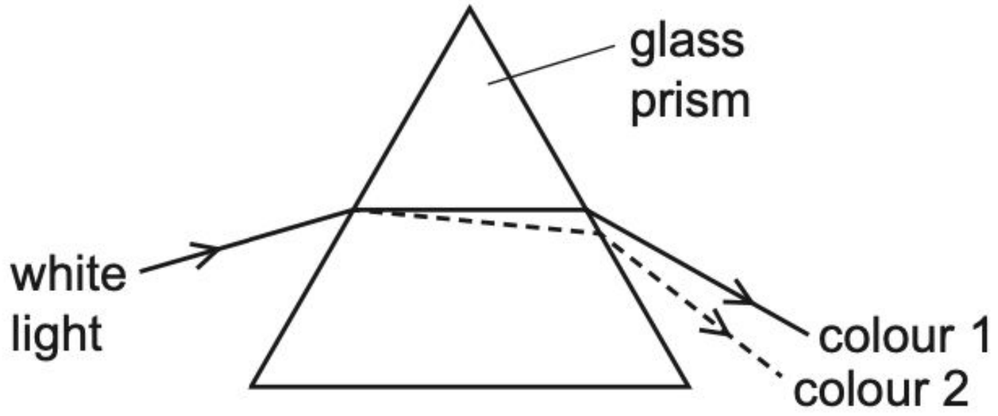
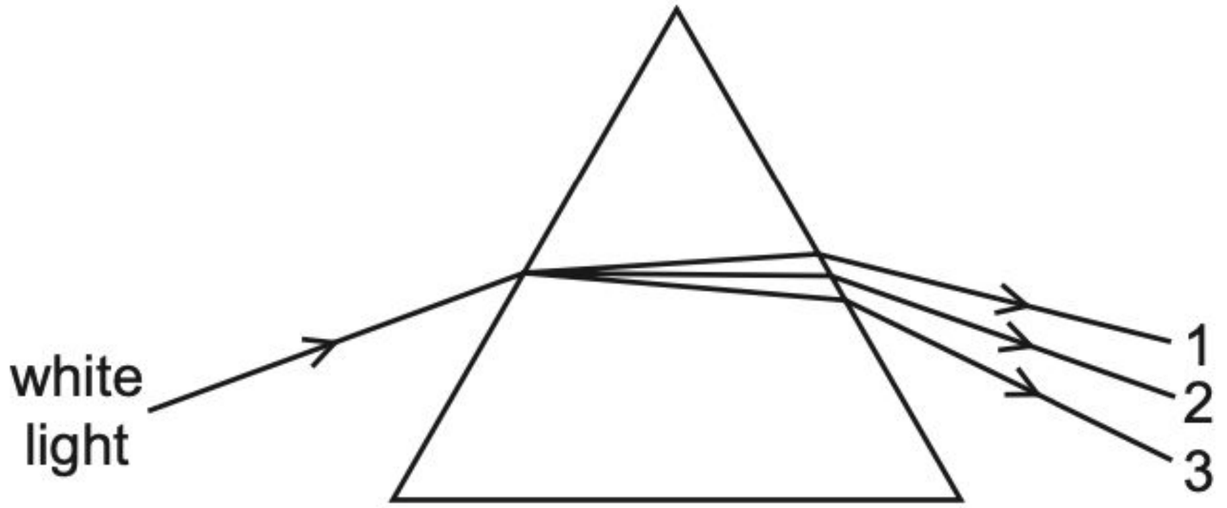


diagram 2

Which row correctly describes what happens?

	path taken by the light	colour 1	colour 2
A	diagram 1	red	violet
B	diagram 1	violet	red
C	diagram 2	red	violet
D	diagram 2	violet	red

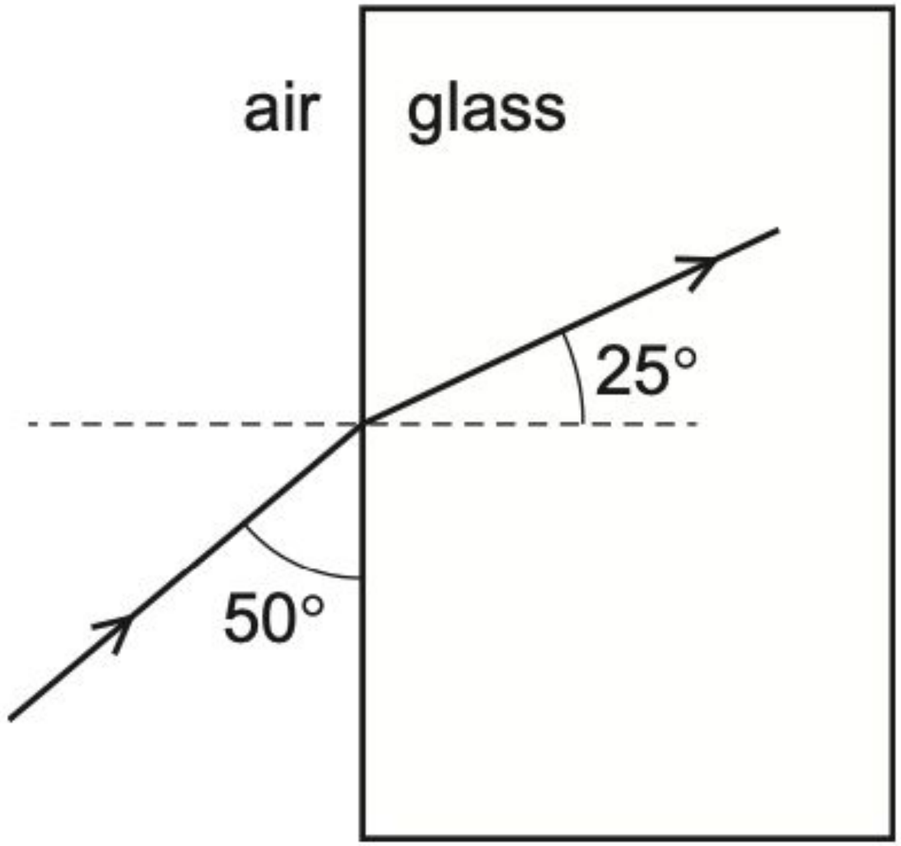
20 A narrow beam of white light passes through a prism and is dispersed into a spectrum.



Which row is correct?

	colour 1	colour 2	colour 3
A	blue	yellow	red
B	red	blue	yellow
C	red	yellow	blue
D	yellow	blue	red

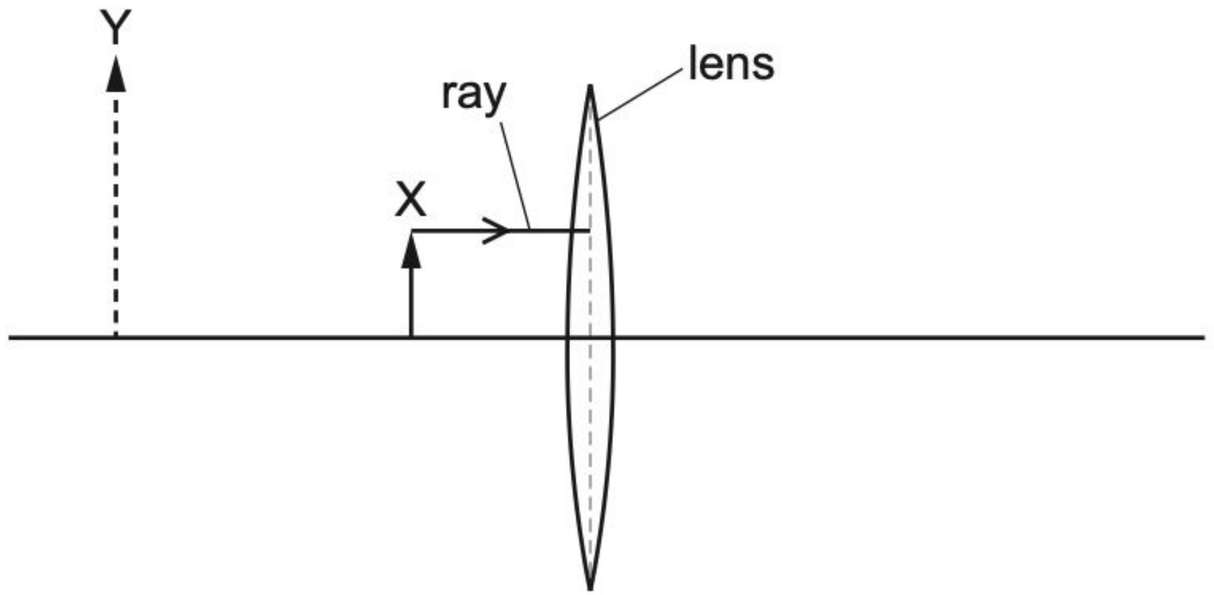
18 The diagram shows a ray of light entering a glass block.



Which calculation gives the refractive index of the glass?

A $\frac{\sin 40°}{\sin 25°}$ **B** $\frac{\sin 40°}{\sin 65°}$ **C** $\frac{\sin 50°}{\sin 25°}$ **D** $\frac{\sin 50°}{\sin 65°}$

19 The diagram shows part of a ray diagram that demonstrates the formation of a virtual image Y of object X by a converging lens.



One ray of light from X is shown approaching the lens.

Which arrow shows the direction of this ray as it leaves the lens?

A

B

C

D

19 A ray of light travels from air into a glass block.

	in air	in glass
speed of ray	v_a	v_g
wavelength of ray	λ_a	λ_g
frequency of ray	f_a	f_g

Three suggestions as to how the refractive index of glass n may be calculated are listed.

1 $n = \frac{v_a}{v_g}$

2 $n = \frac{\lambda_a}{\lambda_g}$

3 $n = \frac{f_a}{f_g}$

Which suggestions are correct?

A 1, 2 and 3 **B** 1 and 2 only **C** 1 and 3 only **D** 2 and 3 only

SUMMARY

The law of reflection: angle of incidence = angle of reflection.
The image in a plane mirror is upright, as far behind the mirror as the object is in front and swapped round left to right.
The image in a plane mirror is virtual.
Refraction is the bending of light as it goes from one substance to another.
Refraction is caused by light travelling at different speeds in different materials.
When light passes from air to glass it bends towards the normal. When it passes from glass to air it bends away from the normal.
When light travelling through glass hits a boundary with air, some light passes from glass to air, some light is internally reflected back into the glass.
When the angle of incidence in glass is equal to, or greater than, the critical angle, all the light is reflected back into the glass. This is total internal reflection.
The refractive index is a measure of how much light is slowed, or bent, by a material.
Refractive index can be calculated using the equation $n = \frac{\sin i}{\sin r}$
$\text{Refractive index} = \frac{1}{\text{critical angle}}$.
Optical fibres can transmit information rapidly and efficiently using total internal reflection. This is useful in telecommunications and medicine.
Converging lenses bend parallel rays together so they meet at a point called the principal focus.
Drawing a ray parallel to the axis, and a ray which strikes the centre of a lens allows us to draw a ray diagram and find the type of image formed.
A magnifying glass produces a virtual image.
Our eyes use a flexible convex lens to form images.
A short-sighted eye has a lens which is too powerful. This can be corrected using a diverging lens.
A long-sighted eye has a lens which is too weak. This can be corrected using a converging lens.
White light can be dispersed by passing it through a glass prism. This creates the visible spectrum.

Thank You