3   Refraction

Example 1

Speed of light in **vacuum**   = <u>1.33</u> **times** of speed of light in **water**.
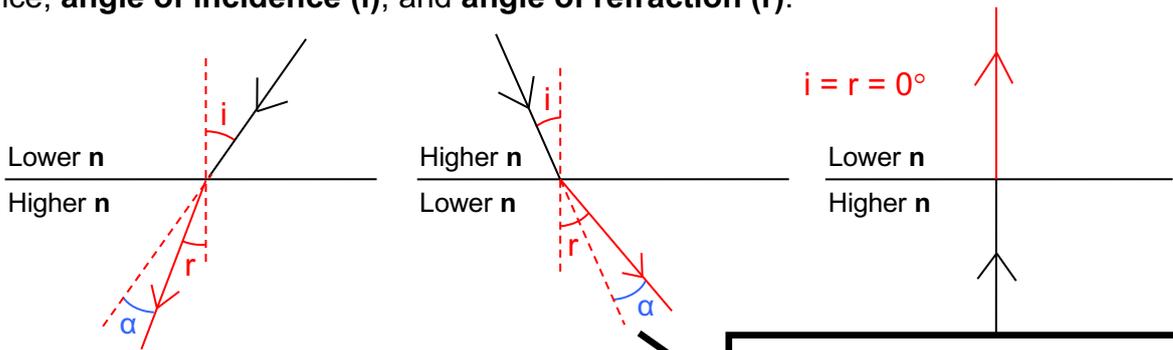
= <u>1.50</u> **times** of speed of light in **glass**.

speed of light in water = 3×10^8 / 1.33 = $2.25 \times 10^8 \approx 2.3 \times 10^8$ m s^{-1}

speed of light in glass = 3×10^8 / 1.50 = 2.0×10^8 m s^{-1}

Example 2

For each diagram below, label the **incident ray**, **refracted ray**, **normal** at the point of incidence, **angle of incidence (i)**, and **angle of refraction (r)**.
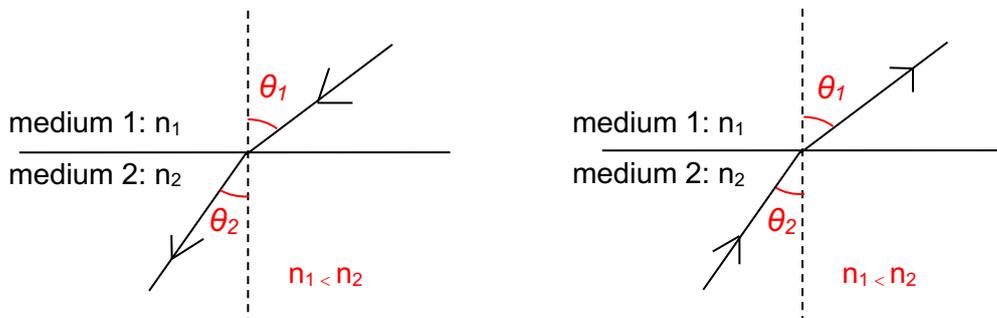

Lower **n** / Higher **n**

Higher **n** / Lower **n**

$i = r = 0°$

Lower **n** / Higher **n**

Note:

- α is the <u>angle of deviation</u>.
- *Draw <u>real</u> light rays with <u>continuous</u> lines.*
- *Draw virtual rays & construction lines with <u>dashed</u> lines.*

Check your knowledge of bending towards or away from normal. Also check which are angles of incidence, angles of refraction, etc.

Example 3

medium 1: n_1

medium 2: n_2

$n_{1 < n_2}$

medium 1: n_1

medium 2: n_2

$n_{1 < n_2}$

θ_1 θ_2

Example 4

Using $\quad n_1 \sin \theta_1 \quad = n_2 \sin \theta_2$

$1.0 \times \sin (90 - 55)^o = n \sin (90 - 70)^o$

$$n = \frac{\sin 35^0}{\sin 20^0}$$

$$= 1.68$$

Example 5

Applying Snell's law, $\qquad n_1 \sin \theta_1 = n_2 \sin \theta_2$

$n_1 = n$, $\theta_1 = c$ and $n_2 = 1.0$, $\theta_2 = 90^o$

Hence, $\qquad\qquad\qquad n \sin c = 1.0 \sin 90° = 1$

$\qquad\qquad\qquad\qquad n = 1 / \sin c$

Example 6

(a) 90°

(b) Using $n = \dfrac{1}{\sin c}$

$$\sin c = \frac{1}{n} = \frac{1}{1.5}$$

$c = 41.8^o$

Example 7

- *Draw the path of the rays in the diagram until it emerges out of the prism.*
- *Mark all relevant angles and show clearly all necessary calculations.*

$n_1 \sin \theta_1 = n_2 \sin \theta_2$
$1.5 \sin c = 1.0 \sin 90°$
$\qquad c = 42° \text{ (2 sf)}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$
$1.5 \sin 30° = 1.0 \sin \theta_2$
$\qquad \theta_2 = 49° \text{ (2 sf)}$

Approach:
- *Whenever a light ray reaches a boundary, draw the normal & determine its angle of incidence.*
- *Compare the refractive indices of the 1st & 2nd medium and check how this ray should refract (bend).*
- *If the 1st medium is optically denser (higher refractive index), compare angle of incidence i with critical angle c. If i > c, total internal reflection occurs.*
- *Else, normal refraction occurs.*
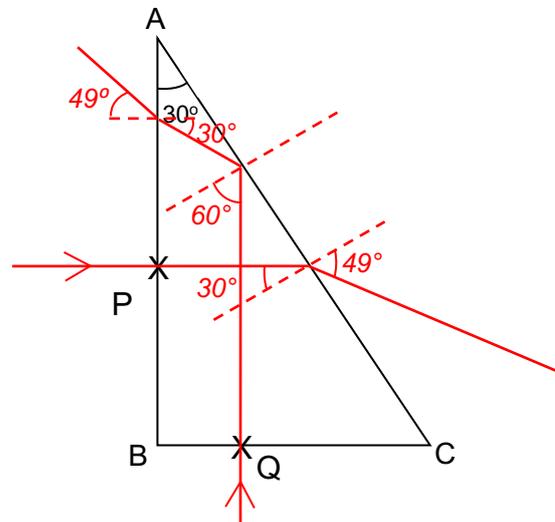
Example 8

Total internal reflection can only happen when <u>the incident ray travels from an optically denser medium to an optically less dense medium</u>. The optically less dense cladding makes sure that this condition <u>is always present</u> each time the light beam hits the <u>boundary</u> between the glass core and the cladding.
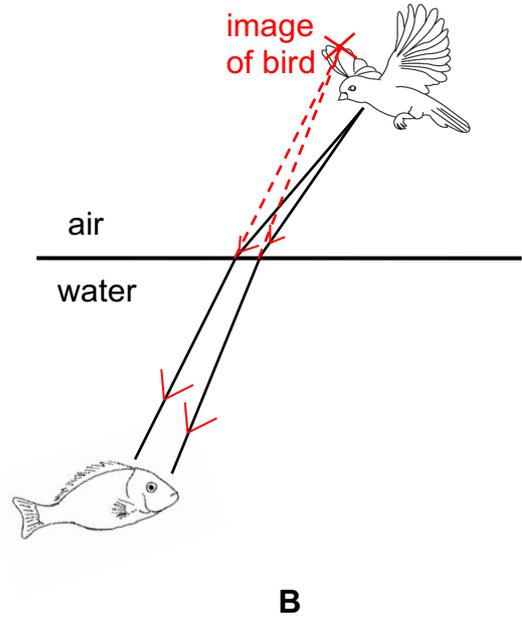
This enables the transmission of signal between two ends of the fibre by total internal reflection.

Example 9

(a)

(b)

image of bird

air
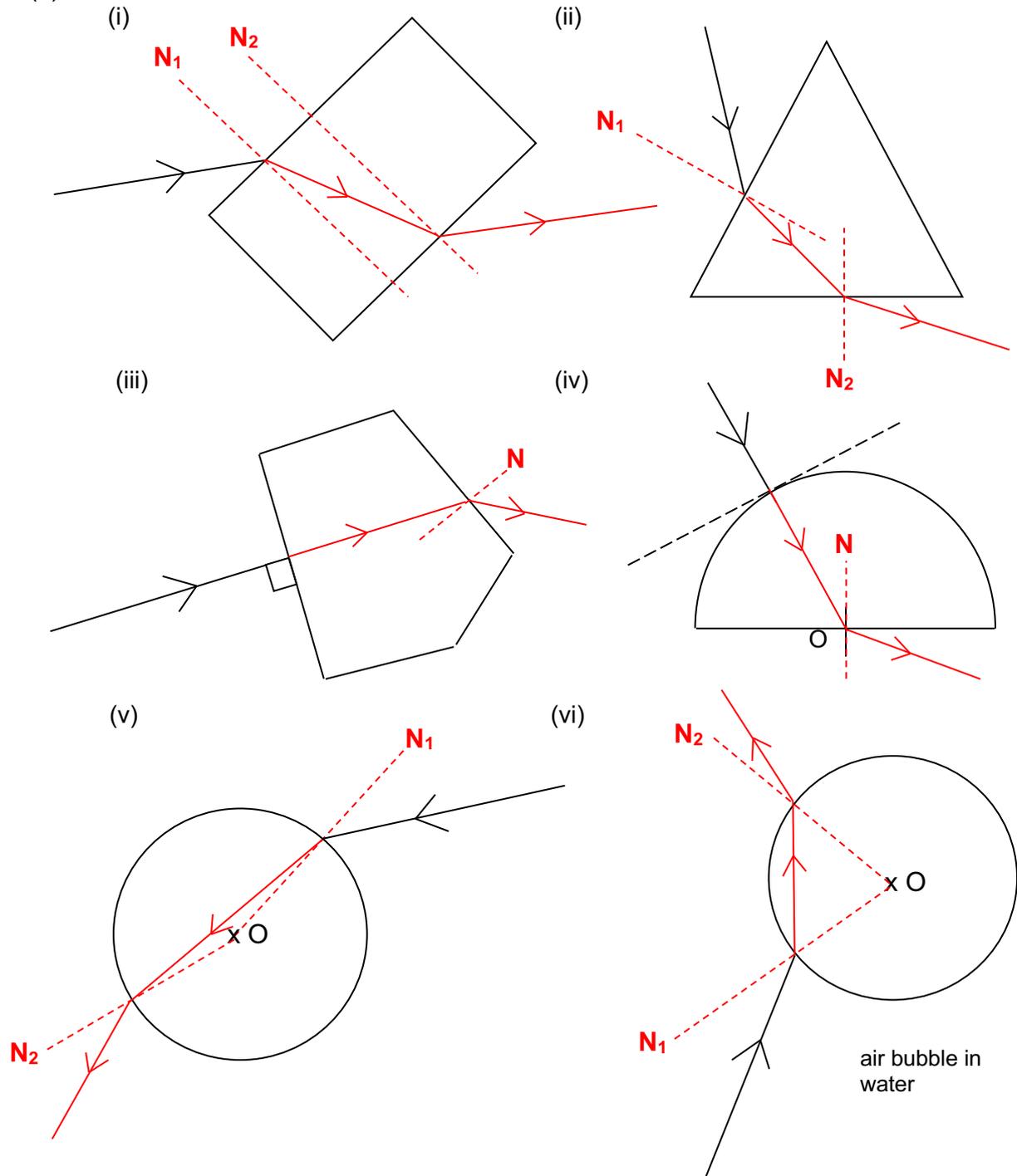
water

air

water

image of fish

A

B
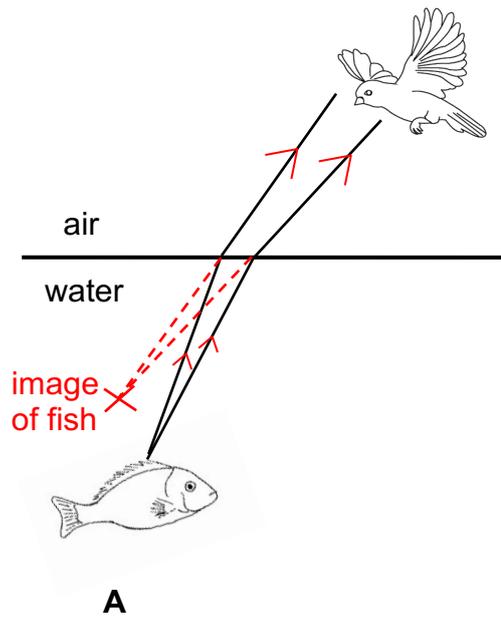
(c) Further

Refraction

1 (a) <u>Monochromatic light refers to light of a single frequency (or wavelength)</u>.

   [mono: single; chroma: colour]

1 (b)
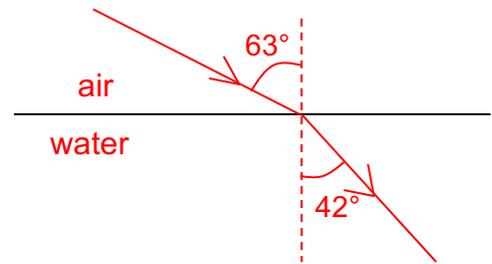
(i)

(ii)

(iii)

(iv)

(v)

(vi)

air bubble in water

2. $n = c / v$

   $2.4 = 3.0 \times 10^8 \text{ m s}^{-1} / v_{diamond}$

   $v_{diamond} = 1.25 \times 10^8 \approx 1.3 \times 10^8 \text{ m s}^{-1}$ (2 s.f.)

3.   Using $n_{air} \sin \theta_{air}$ $= n_{water} \sin \theta_{water}$

         $1.00 \times \sin \theta_{air}$ $= 1.33 \times \sin 42°$

               $\sin \theta_{air} = 0.88994$

                   θ_{air} $= 62.9°(3 \text{ s.f.}) \approx 63° (2 \text{ s.f.})$
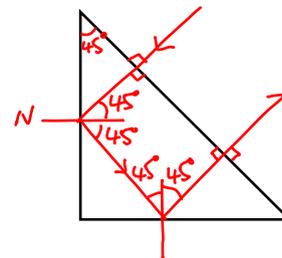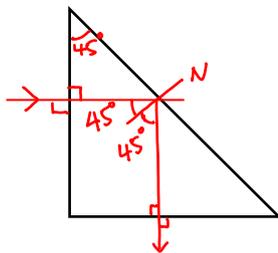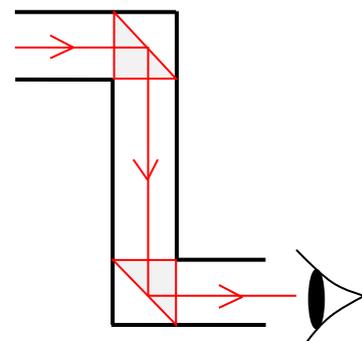

Critical Angle and Total Internal Reflection

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

                $1.33 \sin c$ $=$ $(1.0) \sin 90°$

                    c $=$ **49°**

    OR $n = 1 / \sin c$ ➔ $\sin c = 1 / n$ ➔ Calculate c

5.   (a) deviate the ray of light through 90°   (b) deviate the ray of light through 180°

    (c) Complete the diagram to show how two 45° right-angled glass prisms may be used in a periscope. Draw the path of a ray through the periscope to show how it reaches the eye.
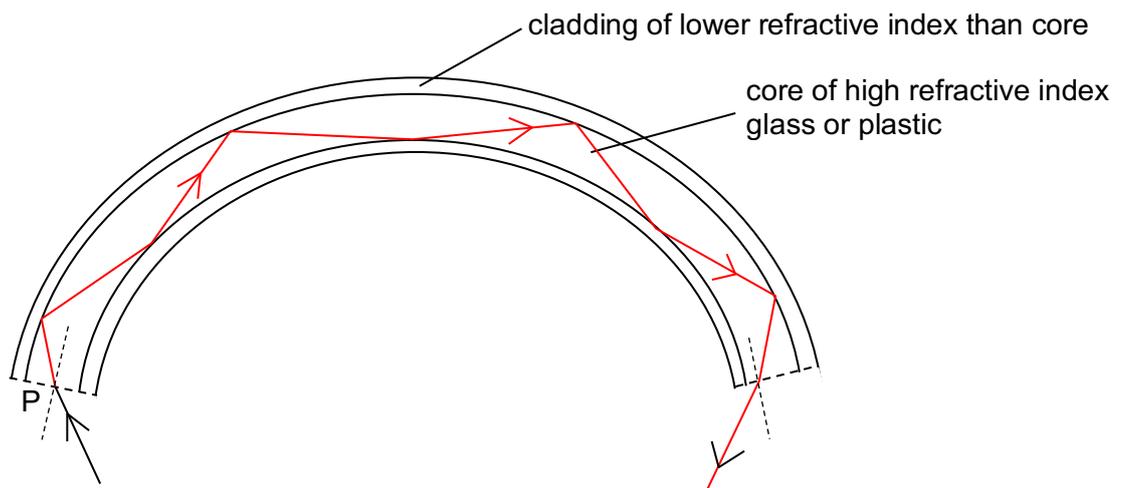
6. Optical fibres are rapidly replacing copper wires in telecommunications and computer networks.

(a) State 3 advantages optical fibres have over copper wires in telecommunications.

- The speed of data transmission (speed of light) is <u>much faster</u>
- There is <u>less signal loss</u> as compared to copper wires
- Optical fibres are <u>lighter and cheaper</u> as compared to copper wires of the same length
- The data transmission is <u>not affected</u> by <u>electric and magnetic fields</u> in the surroundings.
- The <u>bandwidth and capacity</u> for data is much <u>greater</u>.
- Optical fibres are <u>not affected by corrosion</u> (unlike copper wires).

(b) The diagram below shows a simple structure of an optical fibre with a ray of light incident at point P.

cladding of lower refractive index than core

core of high refractive index glass or plastic

Note:
- At the entrance, the angle of refraction should be smaller than the angle of incidence
- At each reflection, check that the angle of incidence and angle of reflection look reasonably equal
- At the exit, the angle of refraction should be larger than the angle of incidence

(i) Explain the advantage of cladding the core.

- Since optical fibre can only transmit light when it travels from an <u>optically denser to less dense medium</u> (by total internal reflection), the cladding ensures that <u>this condition is always present</u>

  i.e. even when the optical fibre is placed in a medium denser than the core.