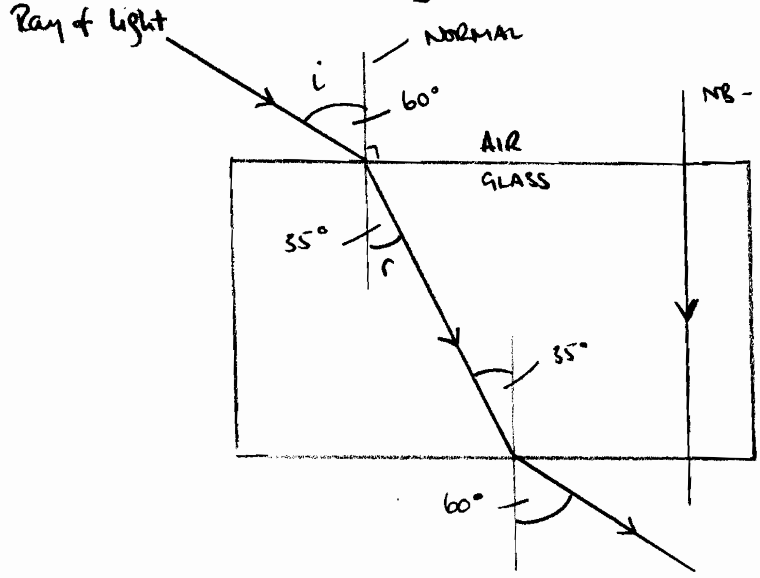
REFRACTION OF LIGHT

- Refraction of light by a glass prism:



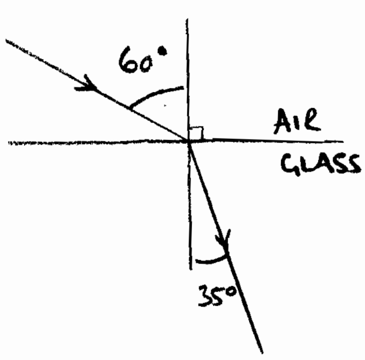
NB - Parallel light goes straight through.

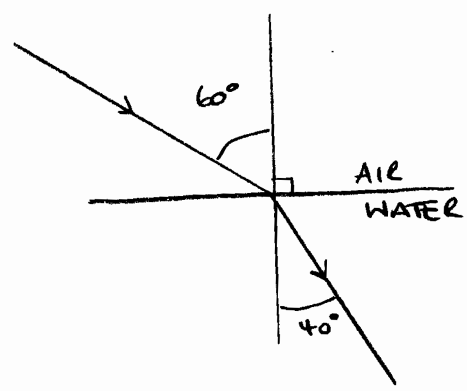
DIAGRAM A.

Above - experiment to show how light rays bend when they go into a glass block.

- Angle i (between the incident ray and the normal) - ANGLE OF INCIDENCE.
- Angle r (between the refracted ray and the normal) - ANGLE OF REFRACTION.
- NORMAL - imaginary line that is perpendicular to the surface

- When a light ray travels from air into a clear material eg. glass or water the ray can be observed to change direction. => REFRACTION.
- Why does this occur - because light travels faster in air than in these other mediums.





- Light travels more slowly in glass than it does in water ∴ the light ray bends more when it goes into glass.

- The amount by which a light ray bends when it goes from air into another material depends on two things
  - the material
  - Angle of Incidence.

SNELL'S LAW

- Snell's Law states that:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = \text{constant.}$$

Where n_1 & n_2 = the ABSOLUTE REFRACTIVE INDEX's OF THE MEDIUM (eg air/glass)

θ_1 = Angle of Incidence

θ_2 = Angle of refraction

This can be re-arranged to give: $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$

- In IGCSE, you are normally given the ratio $\frac{n_2}{n_1}$ ~ refractive index of the interface.

eg. for an air to glass-boundary ⇒ Absolute refractive index air = 1.0003
Absolute refractive index glass = 1.51

$\therefore$ air n glass $= \frac{1.51}{1.0003} = 1.509 \simeq \underline{1.5}$

Where as glass n air $= \frac{1.003}{1.51} = \underline{0.66}$

(glass to air boundary)

Note: the absolute refractive index is based on the speed of light in a vacuum divided by the speed of light in given medium.

ie. $n = {}_{\text{vac}}n_{\text{medium}} = \frac{\text{Speed of light in a vacuum}}{\text{Speed of light in a medium}}$.

As there is only a small difference in the speed of light in a vacuum, compared with the speed of light in air, we get that the Absolute Refractive index of air = 1.0003 $\simeq$ 1.

- Accordingly - in most GCSE Q's, you will need to use.

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

n = the given refractive index ratio

i = angle of incidence

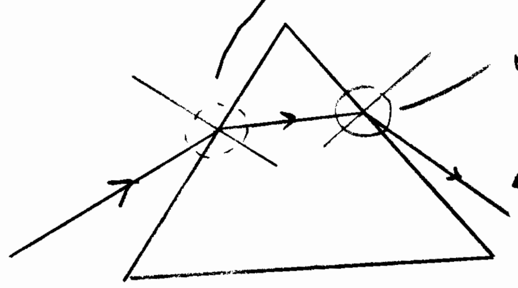
r = angle of refraction.

- based on Snell's Law, simple statements can be determined.
  - When light rays move from a LESS OPTICALLY DENSE to a MORE OPTICALLY DENSE medium, they TURN TOWARDS THE NORMAL.
  - When light rays move from a MORE OPTICALLY DENSE to a LESS OPTICALLY DENSE medium they TURN AWAY FROM THE NORMAL.

Also note from DIAGRAM A:

- If a block has parallel sides, light comes out at the same angle it comes in.
- A ray parallel to the normal goes straight through.

LIGHT IN PRISM



less dense → more dense ⇒ BENDS TOWARDS NORMAL

more dense → less dense → BENDS AWAY FROM NORMAL.

← Outgoing light may DISPERSE into the individual colours of the spectrum

Note DISPERSION occurs ∵ the refractive index for light in glass increases with FREQUENCY.

Blue light = high frequency = higher deviation
Red light = lower frequency = less deviation.

Note: More OPTICALLY DENSE ⇒ Higher absolute refractive index eg. glass
less OPTICALLY DENSE ⇒ lower absolute refractive index eg. air

TOTAL INTERNAL REFLECTION

- What is Total Internal Reflection (TIR)?
  - When rays travel from a more OPTICALLY DENSE MEDIUM to a LESS OPTICALLY DENSE MEDIUM (i.e. from GLASS to AIR), the ANGLE OF REFRACTION is <u>larger</u> than the angle of INCIDENCE.
  - However, the ANGLE OF REFRACTION <u>CANNOT</u> exceed 90°
  - ∴ there is a <u>limiting</u> ANGLE OF INCIDENCE, beyond which <u>no</u> refracted ray can be formed. → the CRITICAL ANGLE (θ_c).
  - For incident angles greater than θ_c the rays reflect back into the first medium ⟹ TOTAL INTERNAL REFLECTION.

<u>NOTE</u>: TIR ONLY OCCURS WHEN LIGHT TRAVELS FROM A MORE OPTICALLY DENSE MEDIUM TO A LESS OPTICALLY DENSE MEDIUM.

So... to define the CRITICAL ANGLE:

"The CRITICAL ANGLE, θ_c, is the angle of Incidence for a ray crossing the boundary from a medium of higher refractive index into one of lower refractive index at which the law of refraction predicts a refracted angle of 90°. No refracted ray can form so then incident ray undergoes Total Internal Reflection."

DETERMINING CRITICAL ANGLE.

Method 1: θ_c is related to the refractive index:

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

But $\theta_1 = \theta_c$ and $\theta_2 = 90°$ at the CRITICAL ANGLE

$$n_1 \sin\theta_c = n_2 \sin 90° = n_2$$

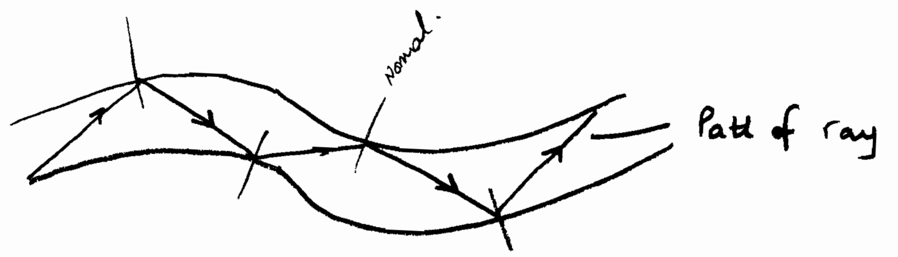
$$\sin\theta_c = \frac{n_2}{n_1}$$

However, and as is normally the case in GCSE, if the ray is travelling out into air, $n_2 = 1$, ∴

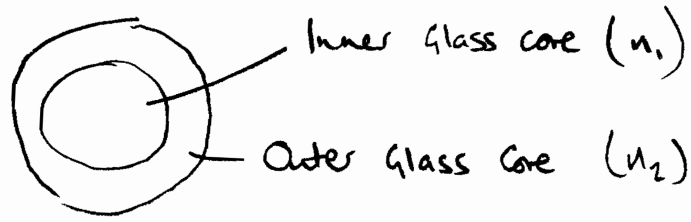
$$\sin \theta_c = \frac{1}{n_1}$$, where n_1 is the refractive index of the material.

Fibre Optic Cables

- work using TIR.



- How does this work:



$n_1 > n_2$ ∴ ray is travelling from more optically dense to less optically dense medium ∴ TIR refraction occurs if critical angle exceeded.

Note: Sometime they will ask a question to show a ray of light entering a fibre optic cable.