1) REFRACTIVE INDEX (n) OF A MATERIAL

When a ray of light is shone from air onto the flat face of a semi-circular block of transparent material which is denser than air, at any angle other than 90°, the ray changes direction on entering the material (due to a change in velocity) - The ray is refracted:

On entering the material, the light ray bends towards the normal line - The angle \( \theta_{\text{material}} \) is always less than the angle \( \theta_{\text{air}} \).

If you change \( \theta_{\text{air}} \) several times, measure \( \theta_{\text{air}} \) and \( \theta_{\text{material}} \) each time, then calculate values for \( \sin \theta_{\text{air}} \) and \( \sin \theta_{\text{material}} \), you can plot a graph of \( \sin \theta_{\text{air}} \) against \( \sin \theta_{\text{material}} \). The graph you obtain is a straight line passing through the origin:

\[
\sin \theta_{\text{air}} \propto \sin \theta_{\text{material}}
\]

or \( \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{material}}} = \text{constant} \)

The graph shows that:

The constant is known as the refractive index of the material. It is given the symbol \( n \).

It does not have a unit:

\[
\text{refractive index (n)} = \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{material}}}
\]

Note
- This equation applies to any material that light can pass through, e.g., glass, plastic, water.
- Each material has its own distinct value of refractive index (which is always equal to or greater than 1).
- The greater the refractive index, the greater the change in direction of the light ray.
- The refractive index of a material is the same whether light moves from air into the material or vice versa.
- The term absolute refractive index is used when air is replaced by a vacuum. (The values obtained using air and a vacuum are almost identical).

Example

Calculate the refractive index of the glass block shown:

\[
n = \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{material}}} = \frac{\sin 40^\circ}{\sin 25^\circ} = \frac{0.643}{0.423} = 1.52
\]
Refractive Index and Frequency of Light

The refractive index of a material depends on the frequency (colour) of the light hitting it.

When white light passes through a glass prism, a visible spectrum is produced because each component colour of white light has a different frequency, so is refracted by a different amount.

Violet is refracted more than red, so the refractive index for violet light must be greater than the refractive index for red light.

Refractive Index, Angles, Velocity and Wavelength of Light

When light passes from air into a denser material such as glass:
Its velocity decreases. Its wavelength decreases. Its frequency remains constant.

This equation shows the relationship between refractive index, angles, velocity of light and wavelength of light in air and a material:

\[
\text{refractive index (n)} = \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{material}}} = \frac{\text{velocity (v)_{air}}}{\text{velocity (v)_{material}}} = \frac{\text{wavelength (\lambda)_{air}}}{\text{wavelength (\lambda)_{material}}}
\]

Calculate the velocity of light in a glass block which has a refractive index of 1.50. (Velocity of light in air = \(3 \times 10^8 \text{ ms}^{-1}\)):

\[
\text{velocity (v)}_{\text{air}} = \frac{\text{wavelength (\lambda)}_{\text{air}}}{\text{wavelength (\lambda)}_{\text{material}}}
\]

Red light (wavelength 700 nm in air) is passed into a plastic material of refractive index 1.47. Calculate the wavelength of the light in the plastic:
2) CRITICAL ANGLE and TOTAL INTERNAL REFLECTION

When a monochromatic light ray is passed from air into a semi-circular **crown glass** block at an angle of incidence close to the normal line, most of the light ray is **refracted** into the air at the flat surface. A small amount of the light is **reflected** back into the glass by the flat surface - the *dim, partially reflected light ray*.

If the angle of incidence between the incoming light ray and the normal line is increased to 42°, most of the light ray is **refracted** along the flat surface into the air (at 90° to the normal line). A much larger amount of the light is **reflected** back into the glass by the flat surface - the partially reflected light ray is **much brighter**.

We call the angle of incidence at which this happens the **CRITICAL ANGLE** for the material.

**Total internal reflection** occurs when the angle of incidence at which a light ray strikes the inside surface of a material is **greater than** the material’s critical angle.

**Relationship Between Critical Angle and Refractive Index**

At the **critical angle** ($\theta_c$), $\theta_{\text{air}} = 90^\circ$.

$$\text{refractive index } (n) = \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{material}}} = \frac{\sin 90^\circ}{\sin \theta_c} = \frac{1}{\sin \theta_c}$$

- $\theta_c$: critical angle
- $\theta_{\text{air}}$: angle of incidence in air
- $\theta_{\text{material}}$: angle of incidence in material
Adam performed an experiment to find the critical angle and refractive index of a plastic material which had been shaped into a semi-circular block. Adam typed up and saved his report on a PC - but when he opened the file next day, he found that the PC had not saved some words, a calculation and the labels and arrows on his diagrams (as shown below):

Help Adam by fully-labelling his diagrams, filling in the missing words and completing his refractive index calculation:

**Experiment to Find the Critical Angle and Refractive Index of a Semi-Circular Plastic Block**

I passed a ray of red light into the plastic block. The angle of incidence between the ray and the normal line was small. Most of the light ray ______________

but a _____ amount of the light was ______________

I increased the angle of ________ between the incoming light ray and the normal line until most of the ray was _________ along the flat surface of the block (at ___ to the normal line). A much larger amount of light was ____________________________

The angle of incidence at which this happened is called the __________ ________ for the material. Its value was ___.

When I increased the angle of ________ between the incoming light ray and the normal a little bit further (above the ________ angle) ______________

- This is known as __________ ________ _________.

Here is how I derived the relationship between the refractive index and critical angle of the plastic:

Here is how I calculated the refractive index of the plastic:
1) Jane used a ray of red light to determine the refractive index of special glass X (in the form of a semi-circular block). Jane adjusted her apparatus until she observed the following:

(a) How does the size of angle \( a \) compare with the size of angle \( b \)? ________________

(b) State the value of angle \( b \): ________

(c) What name is given to angle \( a \) when the light rays are as shown? ________________

(d) Use the diagram to derive an equation which links the refractive index of special glass X to its critical angle:

(e) Calculate the refractive index of special glass X:

(f) Describe what will happen when angle \( a \) is increased above 45°. Include the name of this process: ________________

2) (a) Explain how you know whether a ray of light which strikes the inside surface of a material will be totally internally reflected: ________________

(b) Determine whether this light ray will be totally internally reflected by the optic fibre:

3) Calculate the critical angle for a material with a refractive index of 1.55.

4) Calculate the refractive index of a substance which has a critical angle of 42.5°.