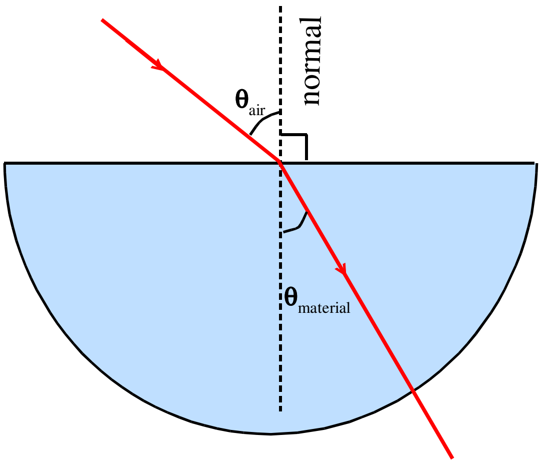
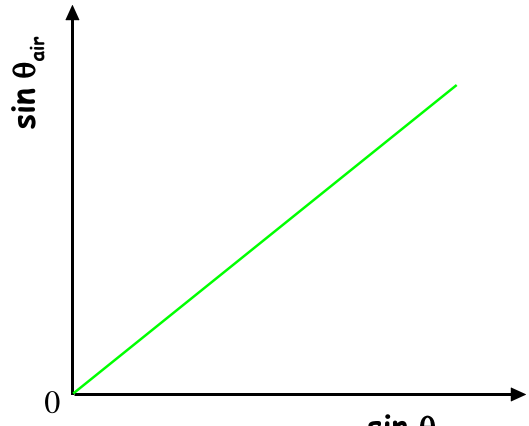
1) REFRACTIVE INDEX (n) OF A MATERIAL

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 $\theta_{material}$ is always less than the angle θ_{air}.

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



The graph shows that:

$$\sin\theta_{air} \propto \sin\theta_{material}$$

or

$$\frac{\sin\theta_{air}}{\sin\theta_{material}} = \text{constant}$$

The constant is known as the **refractive index** of the material. It is given the symbol **n**. It does not have a unit :

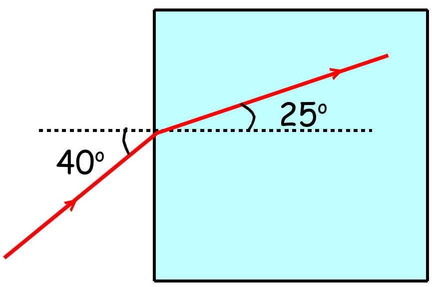
$$\text{refractive index (n)} = \frac{\sin\theta_{air}}{\sin\theta_{material}}$$

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

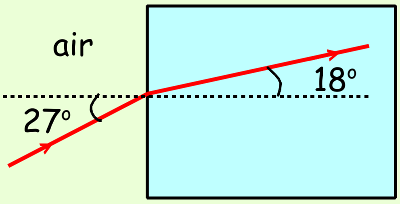
Calculate the refractive index of the glass block shown:



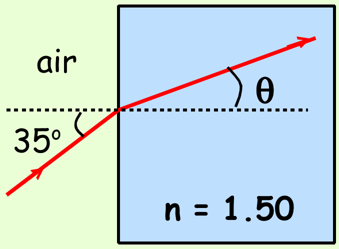
$$n = \frac{\sin\theta_{air}}{\sin\theta_{material}} = \frac{\sin 40°}{\sin 25°} = \frac{0.643}{0.423}$$

$$= \underline{1.52}$$

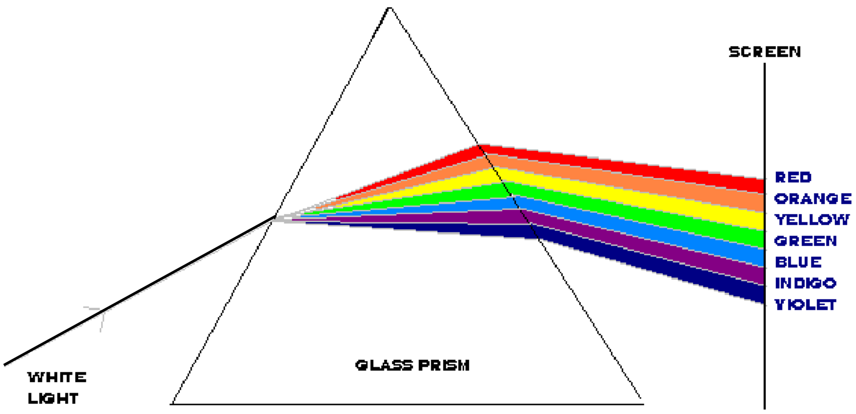
Calculate the refractive index of the material this block is made from:



Calculate the value of the unknown angle θ :



Refractive Index and Frequency of Light



DISPERSION OF WHITE LIGHT BY A PRISM

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**.

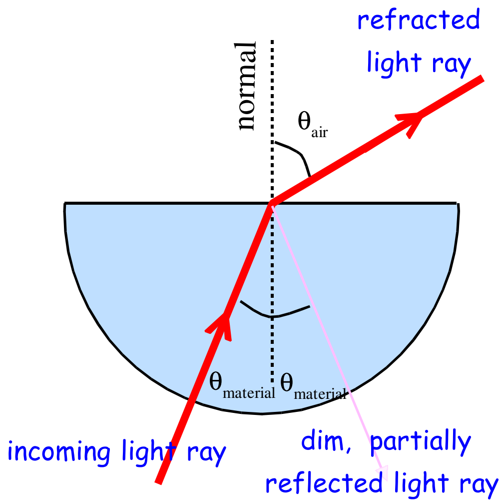
This equation shows the relationship between **refractive index**, **angles**, **velocity of light** and **wavelength of light** in air and a material:

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

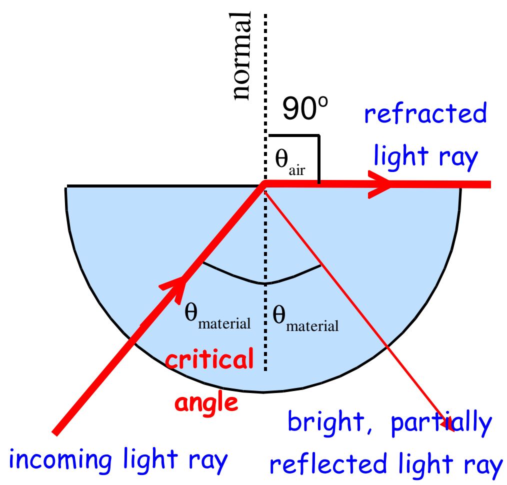
Calculate the velocity of light in a glass block which has a refractive index of 1.50. (Velocity of light in air = 3×10^8 ms^{-1}):

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

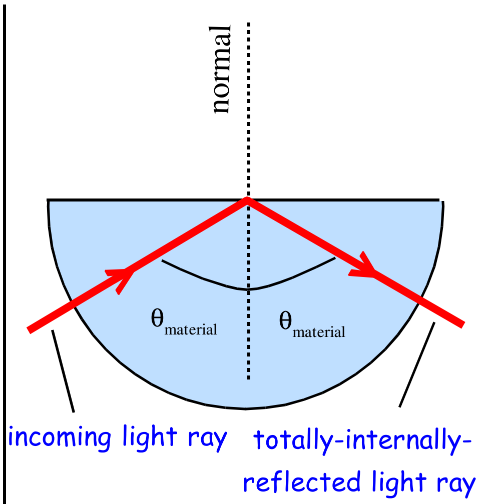


When a monochromatic light ray is passed from air into a semi-circular **crown glass** block at an angle of incidence close to the normal line, most of the light ray is **refracted** into the air at the flat surface. A small amount of the light is **reflected** back into the glass by the flat surface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

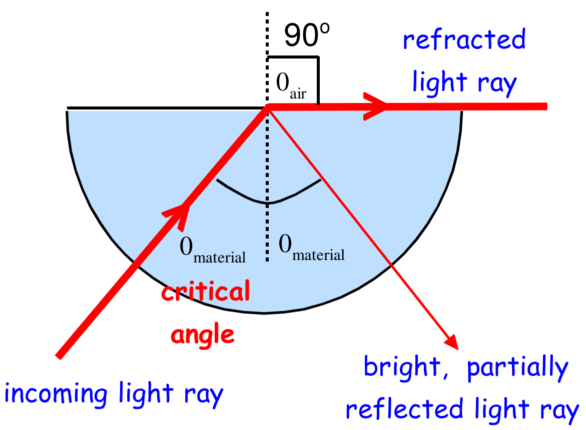


If the angle of incidence between the incoming light ray and the normal line is increased **above** the **critical angle** (**42°**), **all** of the light ray is **reflected** back into the glass by the flat surface.

This is called **TOTAL INTERNAL REFLECTION**.

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** (θ_c), $\theta_{air} = 90°$.

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

$$= \frac{1}{\sin \theta_c}$$

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 ______________

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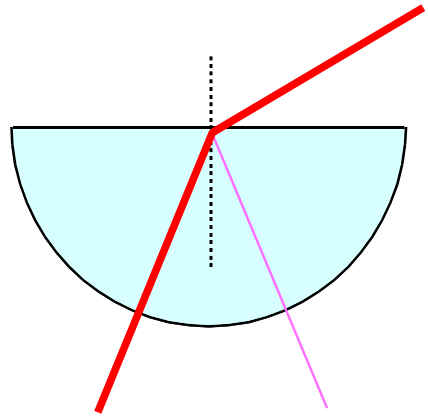
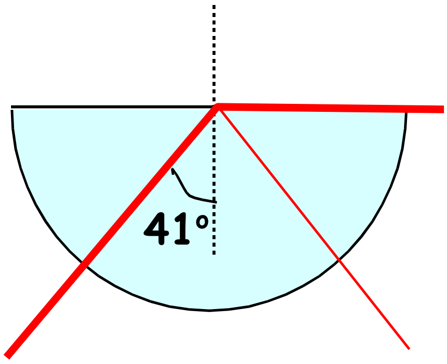


I increased the angle of ___________ between the incoming light ray and the normal line until most of the ray was ___________ along the flat surface of the block (at ___ to the normal line). A much larger amount of light was ________________________

____

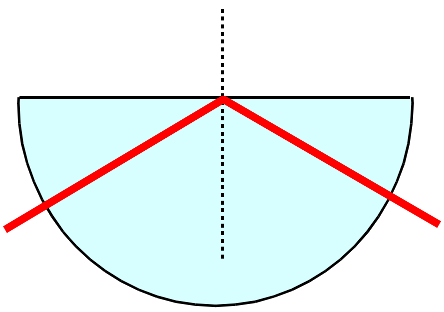
The angle of incidence at which this happened is called the ____________ _______ for the material. Its value was ____.



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

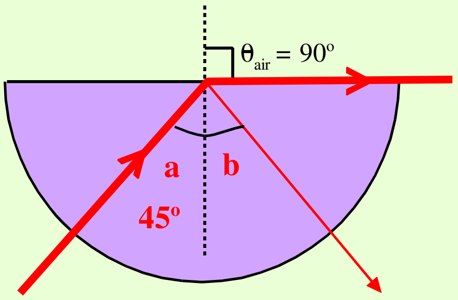
____

- 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 45º. 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: ______________________________

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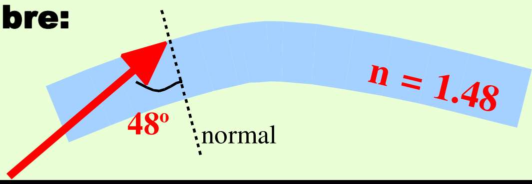
(b) Determine whether this light ray will be totally internally reflected by the optic fibre:



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 42.5º.