LIGHT

Theories of Light

In the 17th century Descartes, a French scientist, formulated two opposing theories to explain the nature of light. These two theories are the particle theory and the wave theory.

Particle Theory

Descartes' particle theory describes light as being made up of small particles moving linearly. He uses this theory to explain reflection and refraction. Descartes' particle theory was supported and further developed by Sir Isaac Newton in 1704. Newton believed that light was made up of tiny streams of particles, traveling at very high speeds, in straight line.

Descartes' particle theory, however, could not be used to explain diffraction of light.

In the 18th century Newton and Huygens proposed theories. The central issue was that the particle and wave theories predicted opposite effects on the speed of light going from air to water. Newton proposed that the speed of light in greater in more dense medium than less dense medium while Huygens predicted it would be less.

Foucault experiments supported Huygens' theory. He was able to actually measure the speed of light in air and water and found that it was less in water. The result was that Huygens' theory was accepted and Newton's theory was discarded.

Wave Theory

Descartes proposed that light could be due to pressure or action transmitted from the object seen to the eye through the matter or a surrounding space.

Huygens also supported the wave theory. He thought that light was a luminous energy due to a vibrating source which produces longitudinally waves in all directions in the space around the source.

As the wave touches points in its paths it causes them to vibrate longitudinally sending out secondary waves. The sum of the wavefronts of these secondary wavelets forms an envelope that is the new wavefront of a wave.

Young's Interference Experiment and the Wave Theory

Young's double slit experiment demonstrates that two coherent beams of light crossing each other's path will produce observable interference patterns.

The diagram below shows the apparatus used to observed light interference. Each slit is needed to cause diffraction and the diffracted beams to produce the interference.

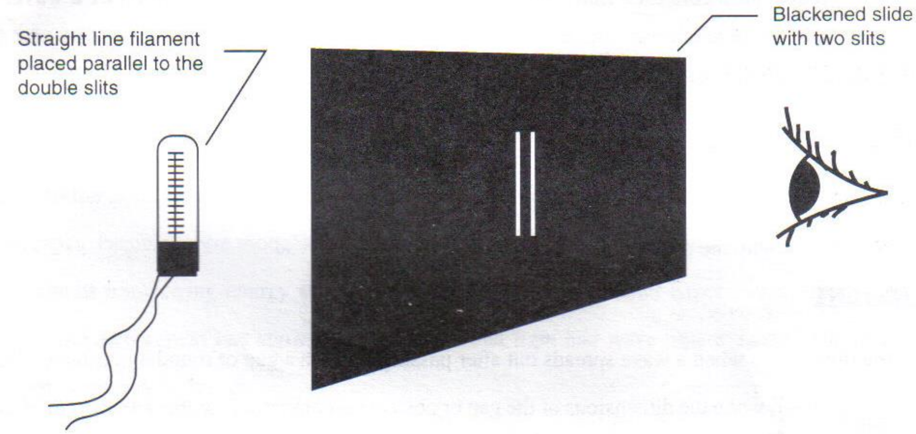


Fig. 9.1(b) *Set-up for Observing Interference.*

Where the waves overlap, superposition enables constructive and destructive interference which results in an unchanging pattern.

The diagram shown the pattern formed by the interference in a darken room.

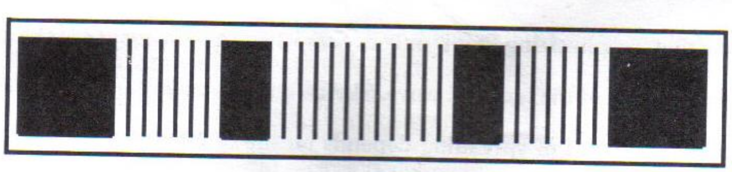


Fig. 9.1 (c) *Pattern Seen With Young's Slits*

When the crests (or troughs) overlap a bright spot is obtained because there is constructive interference. When the crest and trough overlap, darkness or destructive interference occurs.

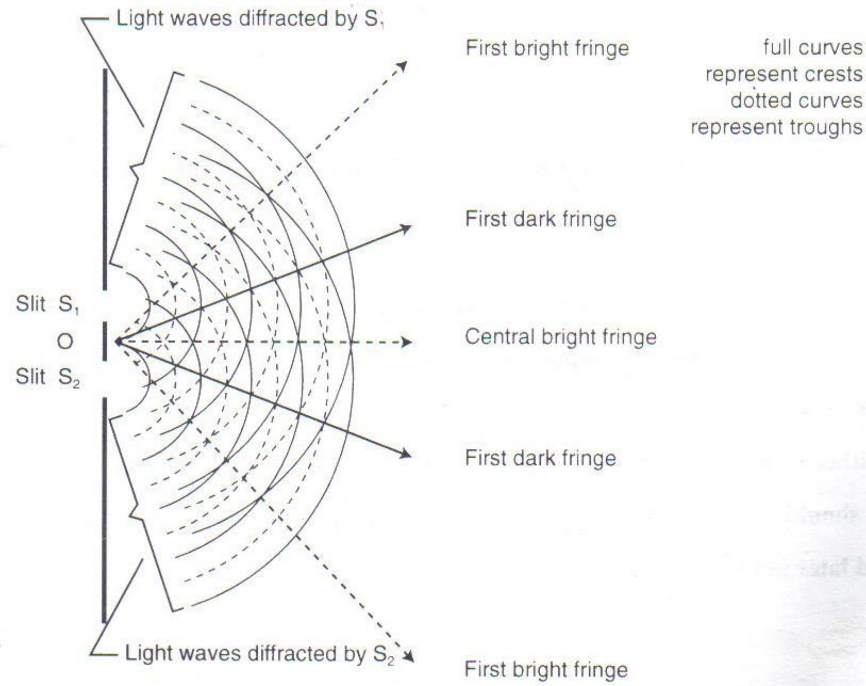


Fig. 9.1(a) ***The Resulting Interference Pattern***

Diffraction of Light

Diffract of light waves occur when the wave spreads out after passing through a gap or around an obstacle. This is observed when the dimension of the gap is comparable to the wavelength of the light. (approximately 10^{-6} m)

Wave - Particle Duality of Light

Before the 20th century, scientists regarded particles and waves as two separate entities with separate properties. Particles were thought to have mass and occupy define volumes while waves were means of transferring energy and spread out into space.

At the beginning of the 20th century, however, the idea of light having BOTH wave and particle properties were considered. With further conclusive evidence that light has particle and wave properties, the dual nature of light is now accepted.

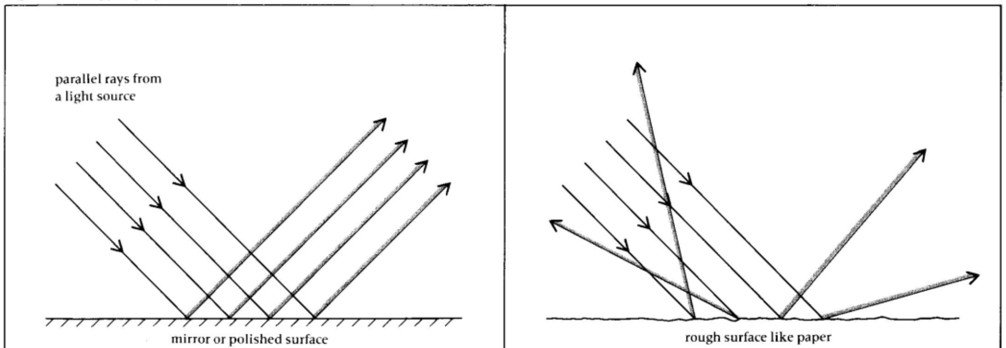
Reflection of Light

Light Rays

A ray of light is a narrow beam of parallel light which can be represented by a line diagram with an arrow to represent the direction it is traveling.

Types of Reflection

Figure 1.5 *Types of reflection*



regular reflection or specular reflection	irregular reflection or diffuse reflection
all parallel rays are reflected in the same direction	all parallel rays are randomly reflected in different directions
mirror-like surfaces form images	matt or rough surfaces scatter or diffuse light

Mirrors

A plane mirror is a flat smooth reflecting surface by which regular reflection is used to form images.

The images formed by in a mirror are virtual images, i.e., the rays appear to come from behind the mirror. The image is also laterally inverted, left and right are reversed.

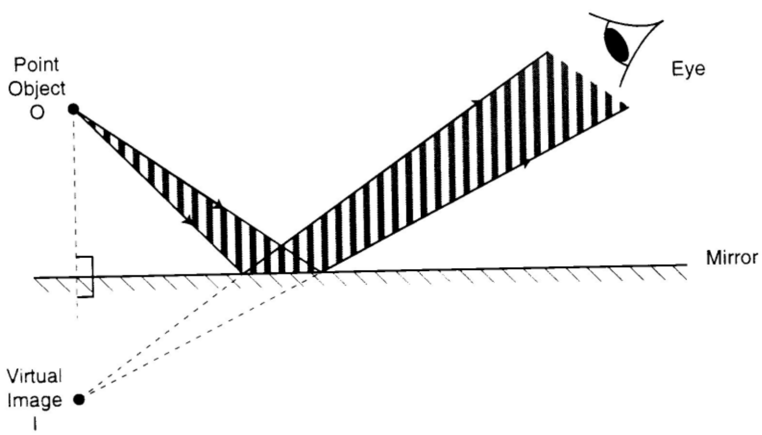


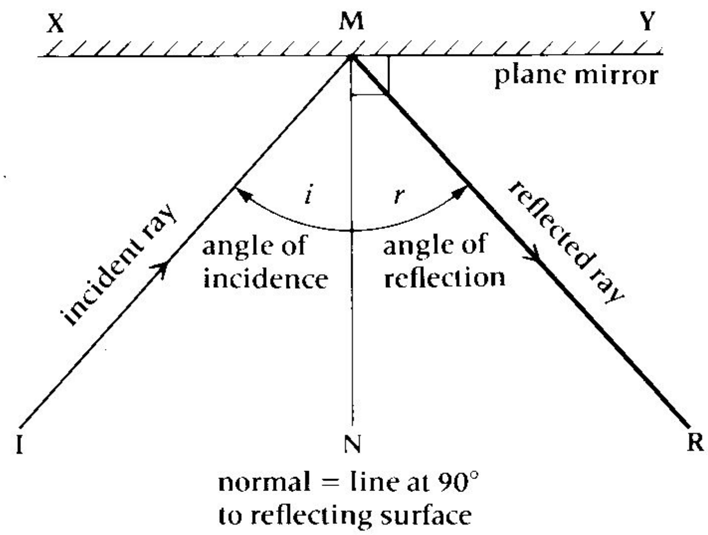
Fig. 9.5 (b) ***Seeing a Virtual Image of an Object (Rays are reflected from the mirror and diverge to the eye. They appear to be diverging from the image.***

Laws of Reflection

1. The angle of incidence, ***i***, is equal to the angle of reflection, ***r***.

$$\boldsymbol{i} = \boldsymbol{r}$$

2. The incidence ray, the normal and the reflected ray all lie in the same plane.



Read and make notes (also include diagrams) on:

PFC Page 7 - 14

- images
- periscope, kaleidoscope
- instrument scales, laser, spot galvanometer
- curved mirrors

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- shadows
- eclipses

Refraction

Refraction is the bending of light which occurs when it travels form one medium into another.

Examples of Refraction

(A)

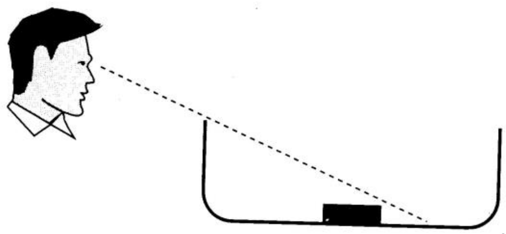


Fig. 9.7 (a) No water: Coin not visible

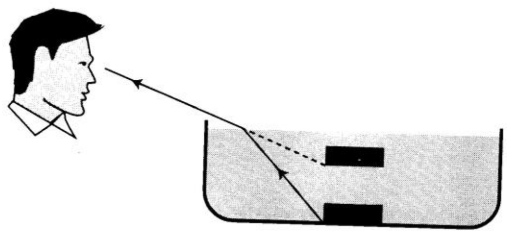


Fig. 9.7 (b) Refraction Trick: Water: Coin becomes visible

(B)

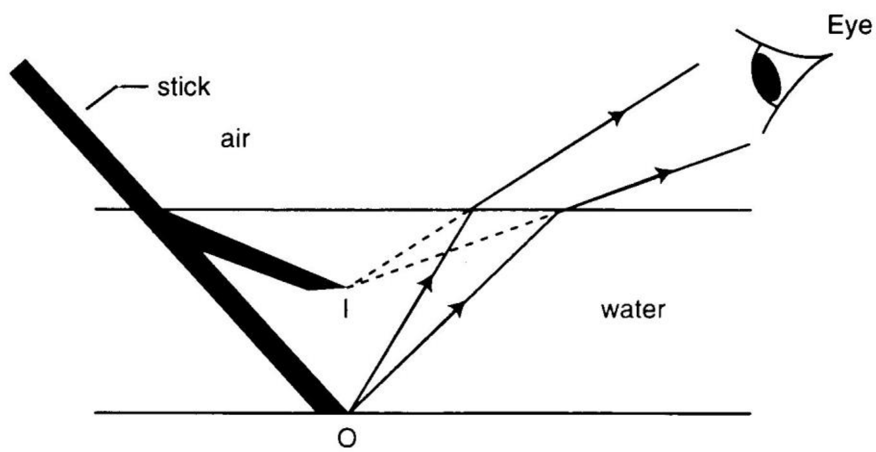
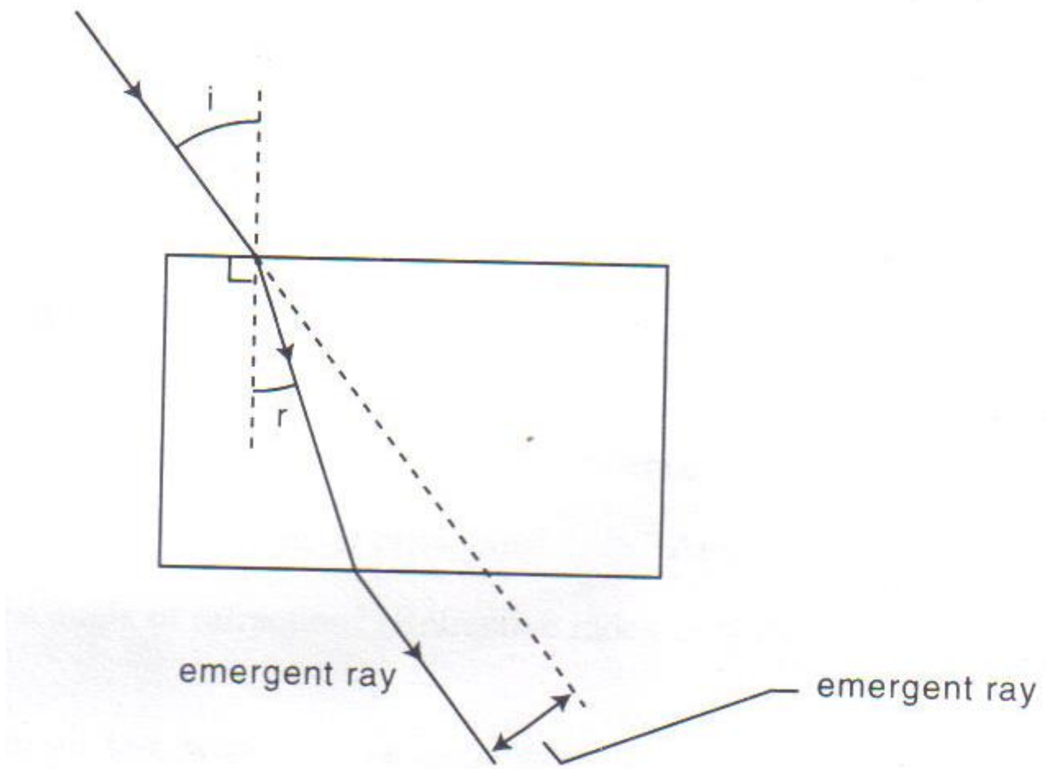


Fig. 9.8 Another Refraction Effect

The angle of incidence, ***i***, is the angle between the normal and the incident ray. The angle of refraction, ***r***, is the angle between the normal and the refracted ray.

When a light ray enters an optically dense medium, it bends towards the normal (the angle of refraction is less than the angle of incidence, ***i*** > ***r***).

Hence when in light ray enters a less optically dense medium it bends away from the normal (the angle of refraction is greater than the angle of incidence, ***i*** < ***r***).



Laws of Refraction

1. The incidence ray, the normal and the reflected ray all lie in the same plane.

2. ***Snell's Law***
   The ratio of the sine of the angle of the incidence to the sine of the angle of refraction is called the refractive index, ***n***.

$$\textit{refractive index (n)} = \frac{\sin i}{\sin r}$$

Examples of Refractive Indices of Some Transparent Materials

MEDIUM	REFRACTIVE INDEX
Glass	1.50
Perspex	1.50
Water	1.33
Ice	1.30
Diamond	2.40

The Reversibility of Light

The principle of the reversibility of light states that the paths of light are reversible. This that means if a light ray is sent in the exact opposite direction, it will follow the exact same path.

When a ray of light passes from medium 1 to medium 2, we can use the symbol, ${}_1n_2$ to represent this. We can calculate the refractive index by using:

$${}_1n_2 = \frac{\sin i}{\sin r}$$

If this ray of light travels in the opposite direction, from medium 2 to medium 1, we can calculate the refractive index by using:

$${}_2n_1 = \frac{\sin r}{\sin i}$$

From these equations, we can see that:

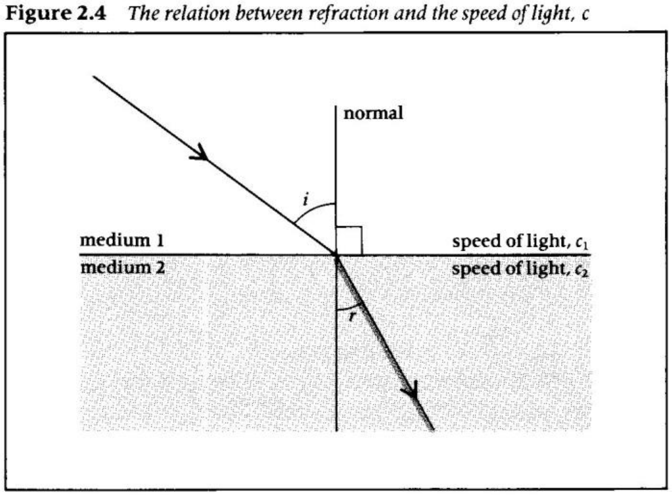
$${}_2n_1 = \frac{1}{{}_1n_2}$$

The direction of the bending of light can be determined from the refractive index and is summarized in the table below

Refractive Index	Ray Direction	What happens to the ray
n greater than 1 *(n > 1)*	The ray is entering a more optically dense medium	The ray bends towards the normal
n equal to 1 *(n = 1)*	The ray is travelling in the same medium (no change in optical density)	No bending of the ray occurs. (The ray travels in a straight line)
n less than 1 *(n < 1)*	The ray is entering a less optically dense medium	The ray bends away from the normal

Refractive Index and the Speed of Light

Figure 2.4 *The relation between refraction and the speed of light, c*



The speed of light in a vacuum is approximately 3 * 10^8 m/s. Light travels more slowly in transparent material and it is thought that the bending or refraction of light is due to this change of speed.

We can therefore calculate the refractive index passing from medium 1 to medium 2 by using the speed of light in each medium:

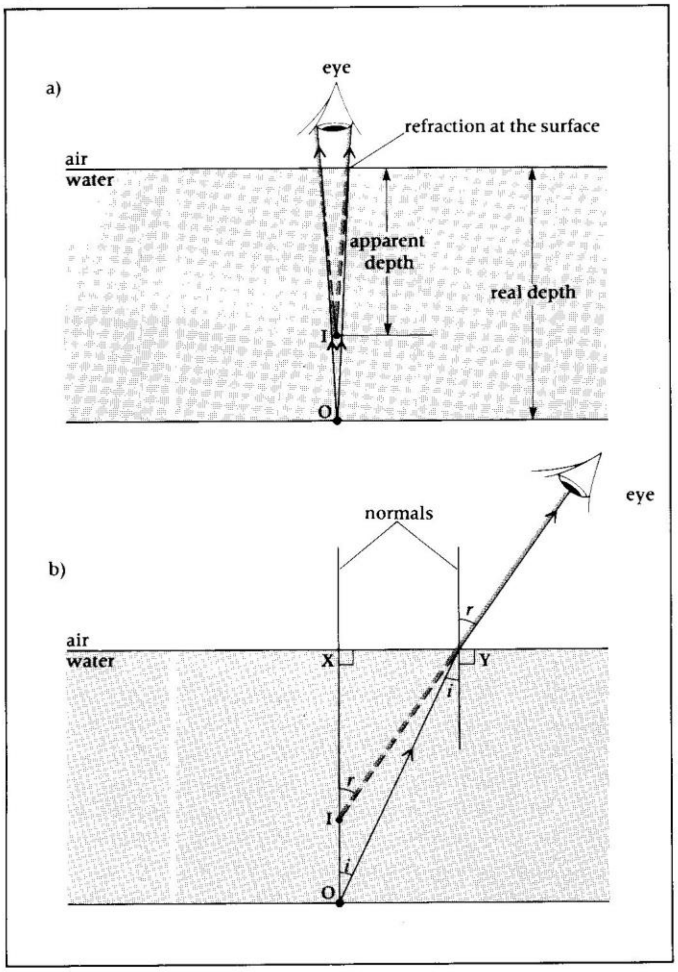
$$ {}_1n_2 = \frac{\textit{speed of light in medium 1}}{\textit{speed of light in medium 2}} = \frac{c_1}{c_2} $$

Real and Apparent Depth

If we look at a swimming pool it appears to be shallower than it really is and if we look at an object in the pool it seems to be closer than it really is. This effect is caused by refraction at the surface of the water.

Rays of light coming from the object in the pool are bent away from the normal as they leave the water, so they appear to come from a virtual image which is above the actual object.

Figure 2.5 *Real and apparent depth*



We can determine the refractive index of the air to water in this situation by using the formula:

$$_a n_w = \frac{\text{real depth}}{\text{apparent depth}}$$

Critical Angle and Total Internal Reflection

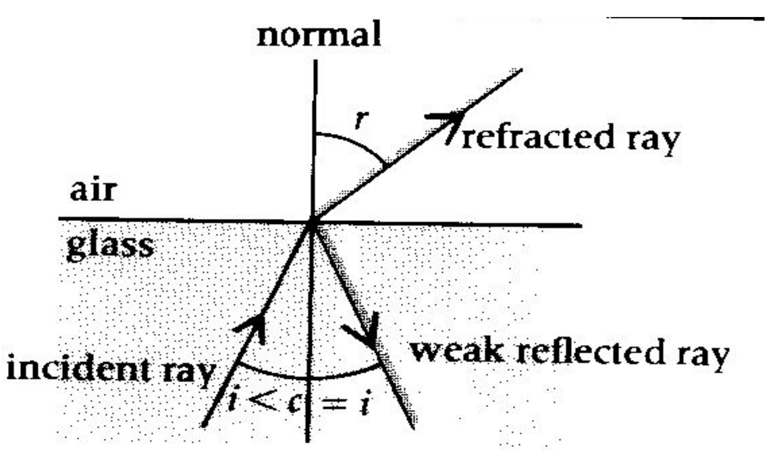
Critical Angle

The critical angle, ***c***, is the angle of incidence, ***i***, in the optically denser medium for which the angle of refraction, ***r***, is 90°. We can use the critical angle to calculate the refractive index by using the formula:

$$\sin c = \frac{1}{\text{refractive index}}$$

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

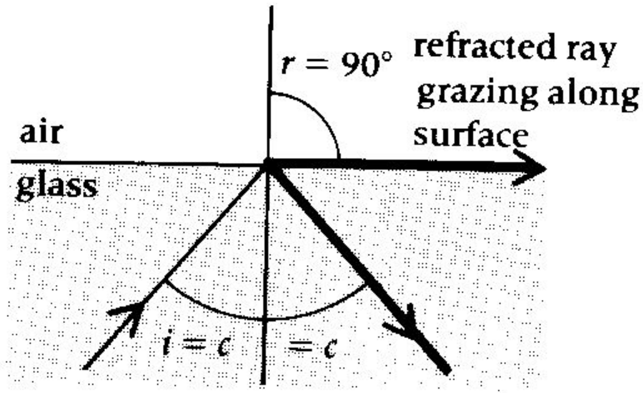
<u>CASE A</u>: Angle of incidence is less than the critical angle (i < c)



a) Angle of incidence *i* less than the critical angle *c*

The light ray meets the surface at a small angle, i, a weak internal ray is produced along with the refracted ray, r.

<u>CASE B</u>: Angle of incidence is equal to the critical angle (i = c)

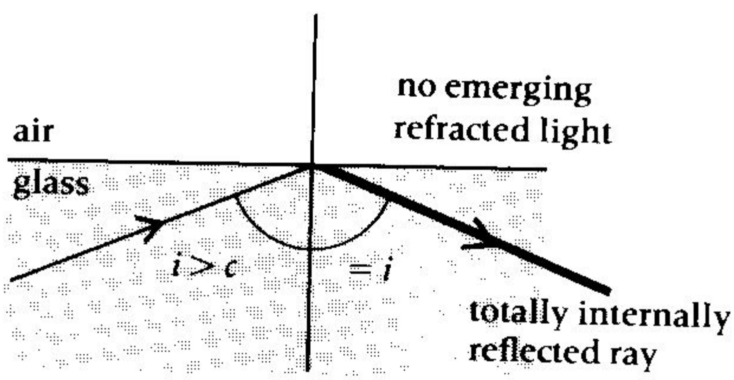


**b) When the angle of refraction *r* = 90°,
the angle of incidence *i* = the critical angle *c***

If the angle of incidence, ***i*** , is increased it will reach the critical angle, ***c***. This is the value where the angle of reaction is 90^o.

Hence when the angle of incidence equals to the critical angle, then the angle of refraction is 90^o.

<u>CASE C</u>: Angle of incidence is greater than critical angle (i > c)



c) When the angle of incidence *i* is greater than the critical angle *c*, total internal reflection occurs

If the angle of incidence, ***i***, is greater than the critical angle, ***c***, then no light will emerge from the glass block. The glass block behaves like a mirror and ***TOTAL INTERNAL REFLRCTION*** occurs.

Read and make notes (also include diagrams) on:

PFC Page 20 - 23

- how thick mirrors form multiple images
- how water appears to bend a ruler
- the mirage
- prisms at work
- optical fibre or light pipe
- prism binoculars

PFC Page 24 - 25 COLOUR

- Newton's experiment
- deviation and dispersion
- producing a pure spectrum
- recombining the spectrum
- rainbow