

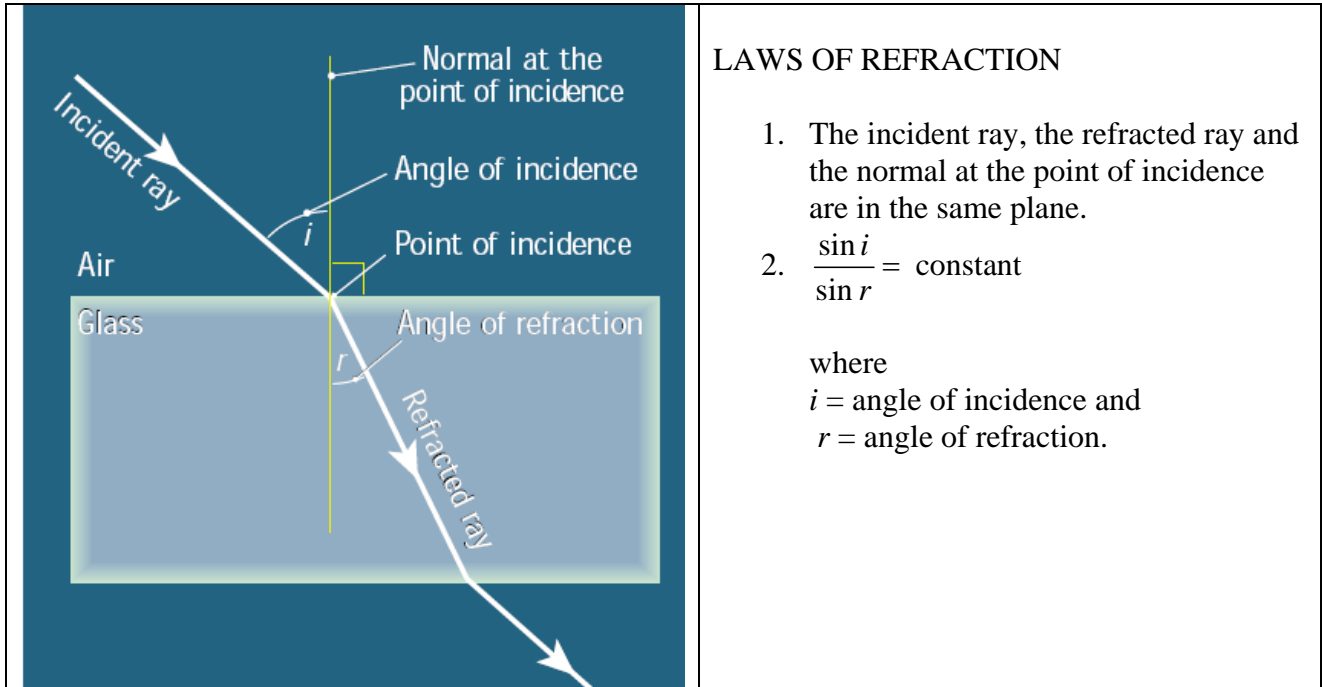
OPTICS: REFRACTION

REFRACTION

Refraction is the bending a ray of light as it passes from one medium to another.

Click here to see an applet on refraction. You can drag the incident ray or type in different angles of incidence.

<http://www.walter-fendt.de/ph14e/refraction.htm>



REFRACTIVE INDEX OF A MEDIUM

$\frac{\sin i}{\sin r} = n$ where i is the angle of incidence measured in a vacuum (air will do) and r is the angle of refraction measured in the medium. The refractive index of the medium is thus given by n .

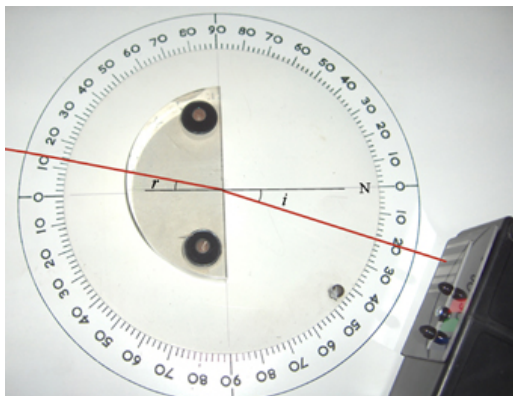
MANDATORY EXPERIMENT

To verify Snell's law and hence to find the refractive index of Perspex.

Apparatus

Raybox, semi-circular Perspex block, protractor.

Method



Set up apparatus as in diagram.

Record i , the angle of incidence, and r , the angle of refraction. Measure these angles from the normal.

Repeat for different values of i and r .

Graph $\sin i$ against $\sin r$.

A straight line graph through the origin verifies Snell's law.

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Sources of Error

Too small an angle of incidence leads to a high percentage error as the protractor is only accurate to the nearest degree.

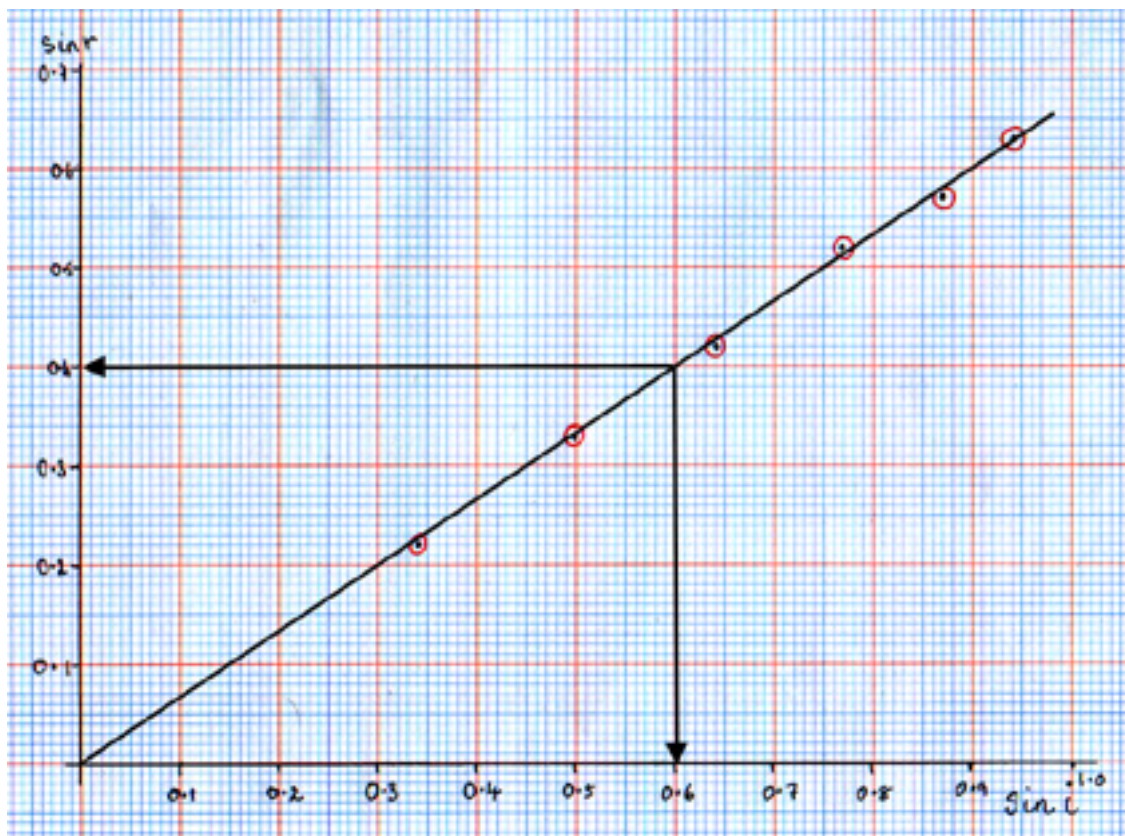
Solution

Ensure that the smallest value of i is 20° .

Results

$i / ^\circ$	20	30	40	50	60	70
$r / ^\circ$	13	19	25	31	35	39

$\sin i$	0.34	0.50	0.64	0.77	0.87	0.94
$\sin r$	0.22	0.33	0.42	0.52	0.57	0.63



(i) A straight line graph through the origin shows that $\sin i$ is proportional to $\sin r$. This verifies Snell's law.

(ii)
$$n = \frac{\sin i}{\sin r} = \frac{0.6}{0.4} = 1.5$$

REAL DEPTH AND APPARENT DEPTH

$n = \frac{RD}{AD}$ if the line of view is perpendicular to the surface of the liquid. (diagram p34.)

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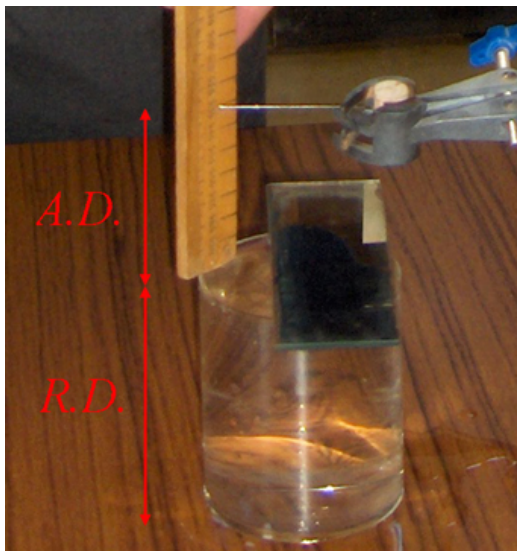
MANDATORY EXPERIMENT

To find the refractive index of water using the method of real depth and apparent depth.

Apparatus

Glass containers (without a lip for pouring), two large pins, metre stick, cork, retort stand and clamp.

Method



Measure the real depth, *R.D.* of the container.

Fill the container completely to the brim.

Place a pin at the bottom of the container.

Place a mirror on the top of the container, so that its back touches the water.

Stick a second pin into a cork which is held by the retort stand and clamp.

Move the second pin. Stop when there is no parallax between the **image of the second pin in the mirror** and the **image of the first pin in the water**.

It is essential to view the images **perpendicularly downwards** when checking for no parallax.

The **apparent depth**, *A.D.* is given by the distance between the second pin and the back of the mirror. It may be easier to measure from the front of the mirror and add on its thickness. (This can be measured with a Vernier callipers.)

Calculate the refractive index of water, *n*, using the formula: $n = \frac{R.D.}{A.D.}$

Repeat using containers of different depths. Calculate an average value for *n*.

Sources of Error

- The error of parallax when reading the metre stick.
- The images of the pins may not have been viewed perpendicularly downwards.
- The container may not be completely filled with water.
- There may be some parallax between the images of the two pins.

Solutions

- Ensure that the metre stick is at right angles to the line of sight.
- View the images of the pins perpendicularly downwards.
- Fill the container completely. If water spills, refill the container.
- Ensure that there is no parallax between the images of the two pins.

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Results

Real Depth / cm	17.3	14.2	12	9.1
Apparent Depth / cm	13.1	10.7	9.0	6.8

$$n = \frac{R.D.}{A.D.} = \frac{17.3}{13.1} = 1.32$$

$$n = \frac{R.D.}{A.D.} = \frac{14.2}{10.7} = 1.33$$

$$n = \frac{R.D.}{A.D.} = \frac{12}{9} = 1.33$$

$$n = \frac{R.D.}{A.D.} = \frac{9.1}{6.8} = 1.34$$

$$\text{Average value: } n = \frac{1.32 + 1.33 + 1.33 + 1.34}{4} = \frac{5.32}{4} = 1.33$$

REFRACTIVE INDEX AND THE SPEED OF LIGHT, c .

Light travels more slowly in e.g. glass than in a vacuum.

Suppose light travels with a speed c_1 in medium 1 and with a speed c_2 in medium 2.

Then the refractive index of medium 1 relative to medium 2 is given by ${}_1n_2 = \frac{c_1}{c_2}$.

CRITICAL ANGLE

When light travels from a denser to a rarer medium, the angle of incidence corresponding to an angle of refraction of 90° is called the critical angle.

TOTAL INTERNAL REFLECTION

Total internal reflection occurs when the angle of incidence in a medium is greater than the critical angle for that medium.

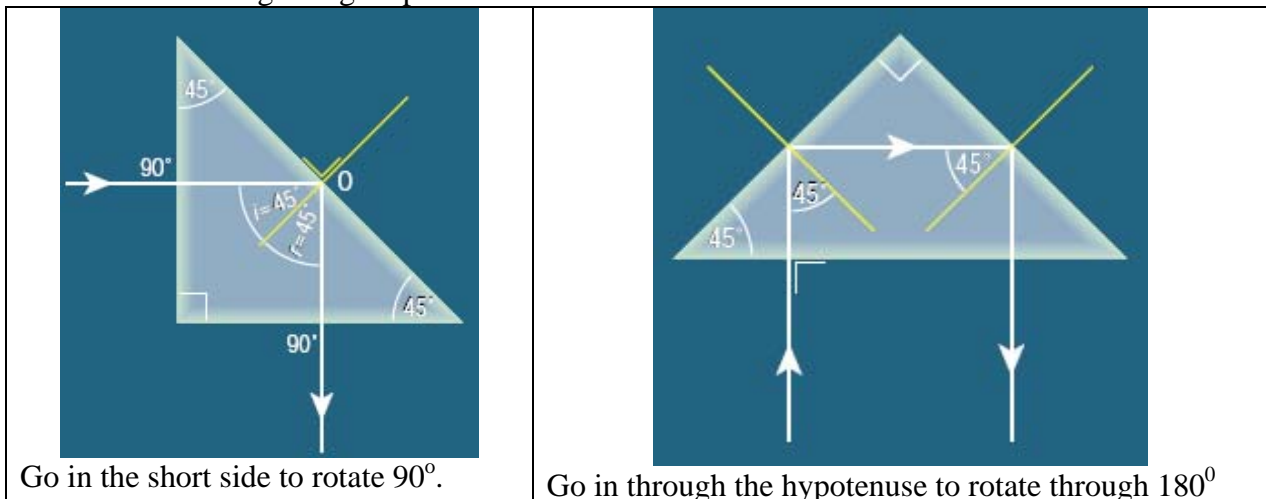
Click here to see an applet which demonstrates TIR.

http://www.physics.uoguelph.ca/applets/Intro_physics/kisalev/java/totintrefl/index.html

$$n = \frac{1}{\sin c} \quad \text{or} \quad \sin c = \frac{1}{n}$$

DIAGRAMS SHOWING HOW A PRISM TURNS A LIGHT RAY THROUGH (i) 90° (ii) 180°

Use an isosceles right-angled prism.



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Prisms are better reflectors than mirrors as mirrors absorb more light energy e.g. a periscope arrangement in a camera so that when you look through the eyepiece you see through the aperture.

OPTICAL FIBRE

An optical fibre is a very thin rod through which light can travel by total internal reflection.

Optical fibres are coated with a material of lower refractive index to prevent light escaping from one fibre to another when in contact.

USES OF OPTICAL FIBRES

telecommunications, medical endoscopy.

ADVANTAGES OF OPTICAL FIBRES OVER COPPER CABLES.

- Cheaper raw materials
- Higher bandwidth
- Less energy loss, thus less boosting required.

ON A HOT SUMMER'S DAY THE ROAD AHEAD MAY APPEAR TO BE WET.

- The air just above the road is very hot. It cools gradually with height.
- This causes refraction until total internal reflection occurs.
- An image of the sky is seen and the road appears wet.

(diagram p.41)

EXAM QUESTIONS

2007 H 5(e)

The refractive index of a liquid is 1.35, what is the critical angle of the liquid? (7)

2005 H 3

In an experiment to verify Snell's law, a student measured the angle of incidence i and the angle of refraction r for a ray of light entering a substance. This was repeated for different values of the angle of incidence. The following data was recorded.

$i/\text{degrees}$	20	30	40	50	60	70
$r/\text{degrees}$	14	19	26	30	36	40

Describe, with the aid of a diagram, how the student obtained the angle of refraction. (9)

Draw a suitable graph on graph paper and explain how your graph verifies Snell's law. (18)

From your graph, calculate the refractive index of the substance. (9)

The smallest angle of incidence chosen was 20° . Why would smaller values lead to a less accurate result? (4)

2004 H 12(b)

Give two reasons why the telecommunications industry uses optical fibres instead of copper conductors to transmit signals. (6)

Explain how a signal is transmitted along an optical fibre. An optical fibre has an outer less dense layer of glass. What is the role of this layer of glass? (13)

An optical fibre is manufactured using glass of refractive index of 1.5. Calculate the speed

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of light travelling through the optical fibre. (9)
(speed of light in air = $3.0 \times 10^8 \text{ m s}^{-1}$)

2003 H 5(f)

Calculate the critical angle for diamond. The refractive index of diamond is 2.4. (7)