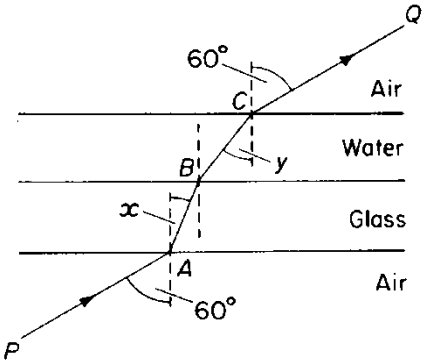
Name: _____ Class: _____ Date: _____

Sec 3 Physics

Worksheet 2: Refraction & Total Internal Reflection

1 The figure shows a slab of glass of uniform thickness, lying horizontally. Above it is a layer of water. A ray of light **PQ** is incident upwards on the lower surface of the glass and is refracted successively at **A**, **B** and **C**, the points where it crosses the interfaces. Calculate



(a) angle ***x***; [1]

$$1.50 = \frac{\sin 60^\circ}{\sin x}$$

$$x = \sin^{-1}\left(\frac{\sin 60^\circ}{1.50}\right) = 35^\circ$$

(b) angle **y**; [2]

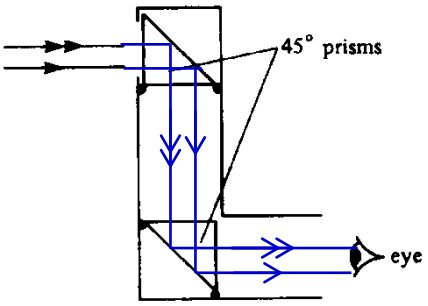
$$1.33 = \frac{\sin 60^\circ}{\sin y} \quad \text{or} \quad \frac{1.50}{1.33} = \frac{\sin y}{\sin 35.3^\circ}$$

$$y = \sin^{-1}\left(\frac{\sin 60^\circ}{1.33}\right) = 41^\circ \qquad y = \sin^{-1}\left(\frac{1.50 \sin 35.3^\circ}{1.33}\right) = 41^\circ$$

(c) the relative refractive index for light passing from the water to glass. (n_{glass} = 1.50, n_{water} = 1.33.) [1]

$$n_{rel} = \frac{1.50}{1.33} = 1.13$$

2 The diagram shows the structure of a simple periscope used at sporting events to see over the heads of the crowd.



(a) When the periscope is in use, total internal reflection occurs at one surface of each prism. Indicate this surface for one of the prisms by a letter "**S**" on the diagram. [1]

(b) Complete the path of the two rays through the periscope to the eye. [1]

(c) Explain why these paths are not affected by the colour of the light.

The incident light ray is not refracted in the prism so that different frequencies of light are not bend to different angles. [OATTE] [1]

(d) Is the image the upright or inverted? Justify your answer.

Upright. From part (a), the light ray from the top of the object emitted from the object is still at the top upon reaching the eye. [OATTE] [2]

(e) In choosing a material for the prism, the critical angle of the material must be less than 45°. What is the smallest possible refractive index for the material of the prism?

$$n = \frac{1}{\sin 45^\circ} = 1.4$$

[J88/2/3]

3 A ray of light is incident at an angle of 60° at the mid-point O of the plane face AB of a semi-circular glass block as shown in figure 3.1.

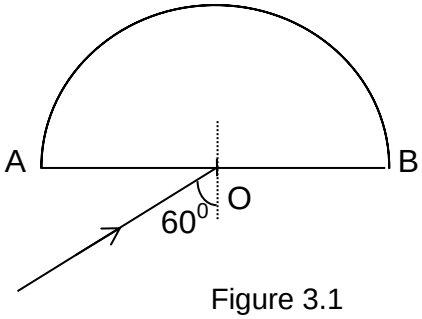


Figure 3.1

(a) Calculate the angle of refraction of this ray at O, given that the refractive index of the glass is 1.5. Draw the path of this ray from O on Figure 3.1 and continue its path until it has emerged into the air. [3]

$$1.5 = \frac{\sin 60^\circ}{\sin r}$$

$$r = 35^\circ$$

The light ray should exit the glass in a straight line since a radial line is always 90° to the tangent of a circle.

(b) Calculate the critical angle for the glass-air boundary. [2]

$$c = \sin^{-1}\frac{1}{1.5} = 42^\circ$$

(c) (i) On Figure 3.2 below, draw the path of a ray which travels through the glass to O in such a way that it strikes the surface AB at an angle of incidence equal to the critical angle. Label the critical angle and continue the path of this ray it has struck the surface AB at O. [1]

(ii) On Figure 3.3 below, draw the complete path of a ray directed towards O which undergoes total internal reflection at the surface AB. [1]

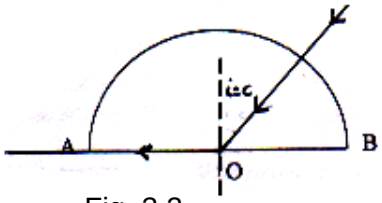


Fig. 3.2

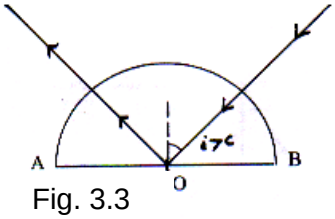
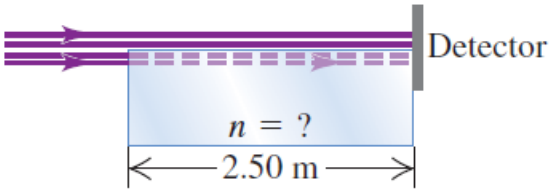


Fig. 3.3

4 *College Phy.*, 9th ed, ch23, p40

A laser beam shines along the surface of a block of transparent material. Half of the beam goes straight to a detector, while the other half travels through the block and then hits the detector. The time delay between the arrivals of the two light beams at the detector is 6.25 ns. What is the index of refraction of this material? [3]

$c = 3.00\times10^{8}\ \text{ms}^{-1}$



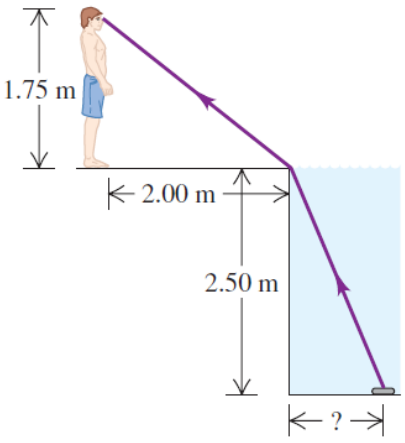
Time taken for unimpeded beam to travel 2.50 m $= \dfrac{2.50}{3.00\times10^{8}} = 8.33$ ns

Speed of light in medium $= \dfrac{2.50}{(8.33+6.25)\times10^{-9}} = 1.71\times10^{8}\ \text{ms}^{-1}$

$n = \dfrac{c}{v} = \dfrac{3.00\times10^{8}}{1.71\times10^{8}} = 1.75$

5 You (height of your eyes above the water, 1.75 m) are standing 2.00 m from the edge of a 2.50-m-deep swimming pool. You notice that you can barely see your cell phone, which went missing a few minutes before, on the bottom of the pool. How far from the side of the pool is your cell phone?

College Phy., 9th ed, ch23, p42



i: incident angle from water ,
r: refracted angle in air

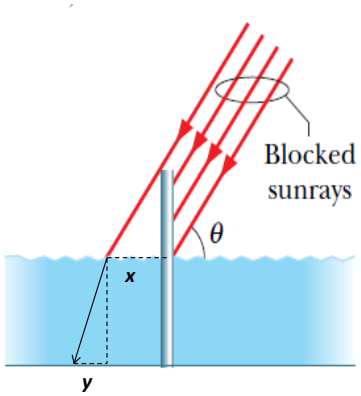
$\dfrac{1}{n} = \dfrac{\sin i}{\sin r}$

$\dfrac{1}{1.33} = \dfrac{\sin\left(\tan^{-1}\left(\dfrac{x}{2.50}\right)\right)}{\sin\left(\tan^{-1}\left(\frac{2.00}{1.75}\right)\right)} \quad \Rightarrow \quad x = 1.72$ m

[3]

Halliday, 9th ed, ch34, p55

6 A 2.00-m-long vertical pole extends from the bottom of a swimming pool to a point 50.0 cm above the water.
Sunlight is incident at angle $\theta = 55.0°$. What is the length of the shadow of the pole on the level bottom of the pool? [3]

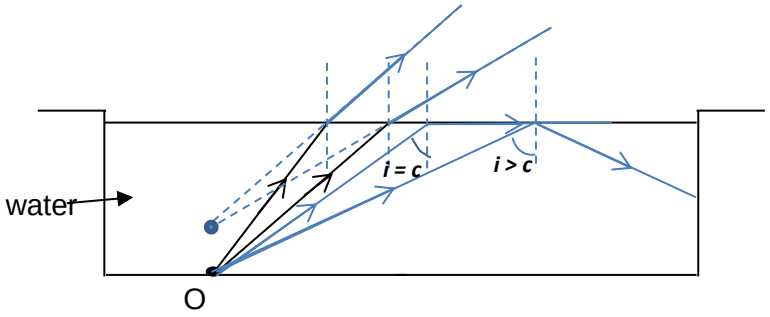


This is a simple trigonometical problem. You just need to find the distance *x* + *y* shown in the diagram.

Ans: 1.07 m

7 **(a)** Explain what is meant by total internal reflection. [3]

Reflection of light at an interface of two media of different refractive indices; the incident ray must be in the medium of higher refractive index; angle of incidence is greater than the critical angle for the two media. [OATTE]



(b) The diagram shows the paths of two rays of light from a bright object O on the bottom of a swimming pool to the surface.

(i) Sketch the paths of the rays as they emerge from the water and travel towards the eye of an observer standing on the right-hand side of the pool. [1]

(ii) Indicate on the diagram, using any necessary construction lines, where the observer sees the image of the object. [1]

(iii) Draw on the diagram the paths of two other rays of light from the object, one of which strikes the water surface at an angle of incidence equal to the critical angle and the other at an angle of incidence greater than the critical angle. [2]

(iv) Given that the refractive index of water is 1.33, calculate a value for the critical angle of water. [2]

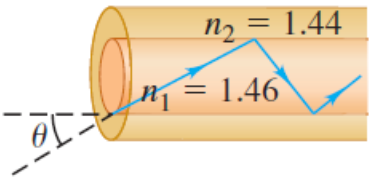
Ans: 48.8°

(c) Draw a diagram to illustrate how a light pipe (optic fibre) makes use of total internal reflection. [2]

Refer to the picture in Problem 8.

College Phy., 9th ed, ch23, p51

8 An optical fibre consists of an outer "cladding" layer and an inner core with a slightly higher index of refraction. Light rays entering the core are trapped inside by total internal reflection and forced to travel along the fibre (see Figure). Suppose the cladding has an index of refraction of 1.44 and the core has an index of refraction of 1.46. Calculate the largest angle between a light ray and the longitudinal axis of the fibre (see the figure) for which the ray will be totally internally reflected at the core cladding boundary. [3]



There is a slight problem with the picture. The angle of incidence should be equal to the angle of reflection. Of course, one can argue that the picture is drawn in the 3D sense and we are simply not viewing in the 'correct' plane.

$$\frac{n_1}{n_2} = \frac{1}{\sin c}$$

$$\frac{1.46}{1.44} = \frac{1}{\sin\left(90^\circ - \theta\right)}$$

$$\theta = 9.5^\circ$$

At the air-glass boundary,

$$n_1 = \frac{\sin i}{\sin\theta} \quad \Rightarrow \quad 1.46 = \frac{\sin i}{\sin 9.5^\circ}$$

$$i = 13.9^\circ$$

i is the angle at which light enters the fibre from air which can result in total internal reflection.

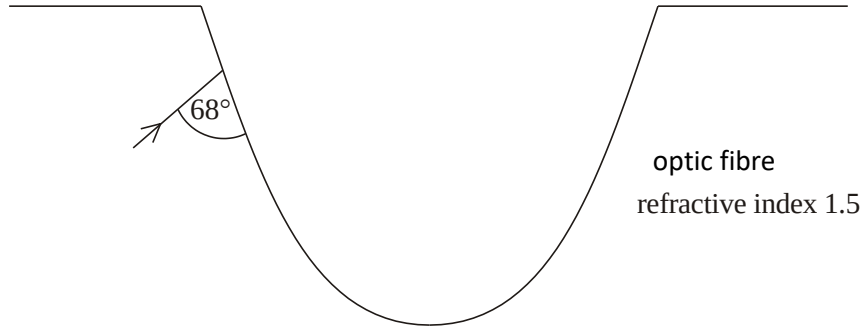
The second part is not necessary but I wrote it down for the benefit of those who thought that θ is the angle which the light enters the fibre. It is not. The question stated that θ is the angle between the light ray and the longitudinal axis of the fibre, which is not at the air-glass boundary.

9 **(a)** Light travels from one optical medium to another. State the conditions necessary for total internal reflection to occur at the boundary between the two media.

light must be incident on boundary from the more (optically) dense medium;

angle of incidence must be greater than the critical angle; [2]

(b) Light is incident on a small scratch in the surface of an optical fibre of refractive index 1.5. The angle between a ray of incident light and the surface of the scratch is 68° as shown below.



(i) Calculate the angle of refraction of the ray at the surface of the scratch.

$i = 22°$;

$\sin r = 1.5 \times \sin 22$
$r = 34°$;

[2]

(ii) On the diagram, draw a sketch of the path of the ray as it emerges from the surface of the scratch. [1]

ray at correct angle (by eye not by measurement)

(c) By reference to **(b) (ii)**, suggest and explain **one** reason why, in practice, optical fibres have an outer covering.

eg refractive index between core and covering constant;
so that refraction in fibre independent of medium in which fibre is placed;

eg core of fibre would not become scratched;
(so that) light would not be scattered out of fibre;

*Award **[1]** for a sensible reason and **[1]** for the explanation.* [2]

d State and explain **two** reasons why lasers are used as light sources for optical fibres. [4]

1. *eg* monochromatic;
so that all light has same speed in fibre;

2. *eg* can be switched very rapidly;
so that more information can be carried;

eg light can be directed;

so that less light losses / less need for amplification;

*Award **[1]** each for two sensible reasons and **[1]** for each explanation.*

Do not allow coherence without explanation.