11.3 Reflection and refraction Follow up sheet

Refraction

Specification references

- *4.4.2 d) (i) (ii) e)*

Learning outcomes

After completing the worksheet you should be able to:

- apply your understanding of refraction
- apply your knowledge of total internal reflection to understand communications via optical fibres and endoscopy.

Information

When a wave passes from one medium to another it refracts due to a change in speed.

When a ray of light passes a boundary between a material of low refractive index and a material of higher refractive index it slows. It will also refract towards the normal if it does not enter perpendicular to the surface.

On moving from a material of lower refractive index to higher refractive index, the ray will speed up and refract away from the normal. If the angle of incidence at the boundary is greater than a critical angle, the ray will totally internally reflect.

There are a range of equations you will need to apply to successfully answer questions involving refraction of light (and other waves). It can be difficult to decide which equation is necessary and angles can become confused. Take great care and sketch diagrams where needed to help you understand what the question is asking.

The equations needed to answer refraction questions are shown below.

$n = \frac{c}{v}$	$n \sin\theta = k$ For a boundary between media (medium 1 and medium 2) this can be expressed as $n_1 \sin\theta_1 = n_2 \sin\theta_2$	$\sin C = \frac{1}{n}$
n = refractive index c = speed of light in vacuum v = speed of light in medium	θ = angle in the material n = refractive index of material	C = critical angle n = refractive index

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Questions

These questions check your ability to apply your understanding of refraction and total internal reflection.

1

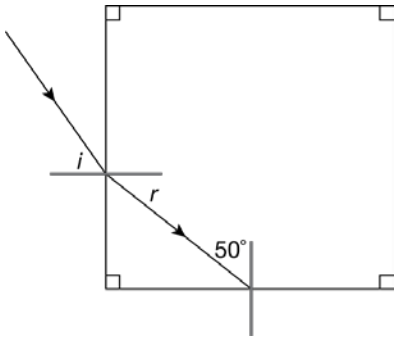

Figure 1

A ray of violet light enters a glass cubic block as shown in Figure 1. The ray hits the internal side of the cube such that it is just totally internally reflected as shown.

a Calculate the refractive index for the air–glass boundary. (*2 marks*)

b State the value of the angle *r* marked on Figure 1. (*1 mark*)

c Calculate the angle of incidence *i*. (*1 mark*)

d Complete the figure showing the ray leaving the glass block. (*2 marks*)

e A ray of red light is shone into the block along an identical path. Describe and explain the path of this ray after it enters the block. (*3 marks*)

2

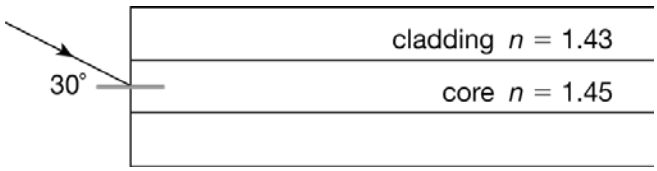

Figure 2

An optical fibre consists of two transparent layers of glass – a core with a refractive index of 1.45, and a cladding layer with refractive index 1.43 – as shown in Figure 2. A ray of infrared light passes from air into the fibre as shown, and goes on to be totally internally reflected along the full length.
Speed of light in air 3.00×10^8 m s^{-1}. Refractive index for air = 1.00.

a Calculate the angle of refraction for the air–core boundary. (*2 marks*)

b Copy and complete Figure 2 by drawing in the ray of light until it has undergone one total internal reflection. (*2 marks*)

c Calculate the speed of the infrared light in the fibre core. (*1 mark*)

d Calculate the critical angle for the core–cladding boundary. (*3 marks*)

3 During an experiment to measure the refractive index of a glass block the angles of incidence are measured with a protractor, as shown in Table 1. The protractor used in the experiment has a precision of ± 0.5°.

Table 1

Angle of incidence *i* / °	Angle of refraction *r* / °	sin *i*	sin *r*
15.0	10.0		
20.0	14.0		
25.0	17.0		
30.0	20.0		
35.0	23.0		

a Complete the table to find sin *i* and sin *r*. (*2 marks*)

b Plot a graph of sin *i* against sin *r*. (*4 marks*)

c Use the graph to determine the refractive index of the boundary between the air and the glass. (*2 marks*)

d For which of the angles of incidence will the percentage error due to the protractor be largest? (*1 mark*)

e State the range of possible values for the angle of incidence in part **d**. (*1 mark*)

f Use the values in part **e** to find the percentage uncertainty in the value of sin *i* for this reading. (*2 marks*)

Research questions

These questions allow you to research two of the applications of total internal reflection – communications via optical fibres and endoscopes.

1 The internet relies on communication via optical fibres. These are very thin glass fibres through which digital pulses of light are transmitted. Produce a piece of written work to describe how signals are transmitted through these fibres. In your description you should:

- explain the role of total internal reflection in the transmissions
- explain which frequencies of light are used and why
- describe signal spreading
- state some examples of transmission times and bandwidth.

2 Keyhole surgery is performed through small incisions in the body. To see inside the cavity, endoscopes are used. Produce a piece of written work to describe the operation of a medical endoscope. In your description you should include:

- the function of coherent and non-coherent fibre bundles
- the frequencies of light used
- the tools which can be used
- the use of laser light in endoscopic surgery and the safety precautions taken.