Refraction and Snell's law

Specification references

- *4.4.1 f) (i)*
- *4.4.2 d) (i)*
- *M1.1*
- *M4.5*

Introduction

At GCSE you became familiar with the concept of refraction and refractive indices. This worksheet will help you revise the key points of refraction and gain confidence in answering questions on refraction, using Snell's law to calculate angles of incidence/refraction or refractive indices.

Learning outcomes

After completing the worksheet you should be able to:

- state what refraction is
- recall that transparent materials have a refractive index, n
- apply the equation $n_1 \sin \theta_1 = n_2 \sin \theta_2$ (Snell's law) to problems on refraction
- draw or complete ray diagrams showing refraction.

Background

- Refraction is the change in direction of light when it passes, at an angle, across a boundary between two transparent substances, such as air and glass.
- Refraction does not occur if the light passes across the boundary at 90° to the surface.
- Refraction occurs because light travels at different speeds in different materials. Light travels more slowly in an optically dense material (i.e., a material with a higher refractive index).
- The refractive index, n, is a measure of the optical density of a material relative to air. It is given by the equation $n_1 = \frac{c}{c_1}$, where c is the speed of light in air and c_1 is the speed of light in the material of interest. The refractive index has no units.
- The greater the difference in refractive index between two substances, the more the light is refracted at the boundary.
- The normal is an imaginary line, used on ray diagrams, and is drawn at 90° to the surface.
- The angle of incidence is the angle between the light ray *arriving* at the boundary and the normal.
- The angle of refraction is the angle between the light ray *leaving* the boundary and the normal.

- A light ray bends *towards* the normal when the ray passes from a material with a lower refractive index to a material with a higher refractive index ($n_1 < n_2$). The angle of refraction is less than the angle of incidence.

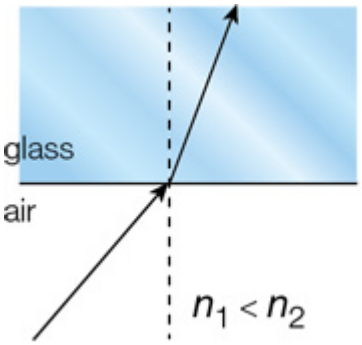

Figure 1

- A light ray bends *away from* the normal when the ray passes from a material with a higher refractive index to a material with a lower refractive index ($n_1 > n_2$). The angle of refraction is greater than the angle of incidence.

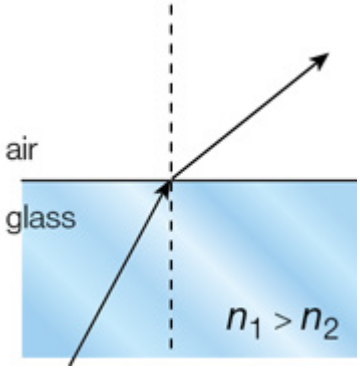

Figure 2

- Some common refractive index values are provided in Table 1.

  $n_{water} > n_{air}$ $n_{glass} > n_{air}$ $n_{glass} > n_{water}$

Material	Refractive index
air	1.00
water	1.33
glass	1.50

Make sure you remember this value.

Table 1 *Some common refractive index values*

- Snell's law relates the angle of incidence, the angle of refraction, and the refractive index of each material:

  $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Worked example

Question

A ray of light, passing from glass into water, strikes the boundary at an angle of 35° to the normal. The refractive index of glass is 1.5 and the refractive index of water is 1.33. Calculate the angle of refraction.

Answer

Step 1

Draw a diagram.

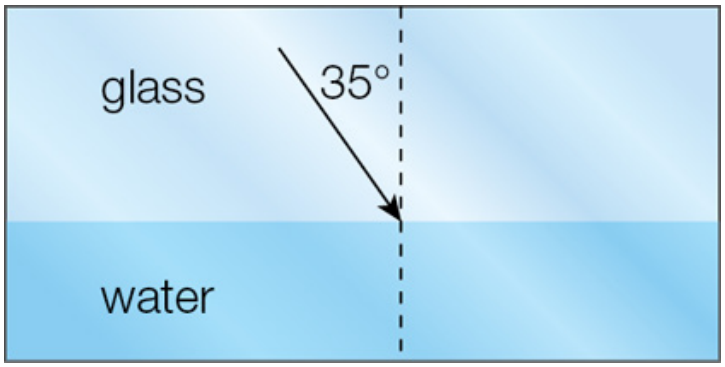

Figure 3

Make sure you read the question carefully and are clear where the light is coming from and where it is going to.

Step 2

Write down Snell's law and identify the values.

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

The light passes from glass (n_1) into water (n_2). The angle of incidence, θ_1, is given in the question. You have been asked to calculate the angle of refraction, θ_2.

$n_1 = 1.5$

$n_2 = 1.33$

$\theta_1 = 35°$

$\theta_2 = ?$ (*This is the angle you need to find.*)

Step 3

Substitute the values into the equation n and rearrange to find θ_2.

$1.5 \sin 35 = 1.33 \sin \theta_2$

$1.5 \times 0.5736 = 1.33 \sin \theta_2$

During the calculation, write down values to a higher number of significant figures.

$$\sin\theta_2 = \frac{1.5 \times 0.5736}{1.33}$$

$$= 0.6469$$

$\theta_2 = \sin^{-1}(0.6469)$ *On your calculator: [shift][sin] 0.6469*

$= 40.3°$

$= 40°$

Give the answer to two significant figures, since this is the smallest number of significant figures quoted for values given in the question.

Questions

1 A ray of light, travelling in air, passes into a glass block at an angle of 65° to the normal in air. The refractive index of glass is 1.5.
Calculate the angle of refraction. (*2 marks*)

2 A ray of light, travelling in glass, passes through the glass–air boundary at an angle of 25° to the normal in the glass. The refractive index of glass is 1.5.
Calculate the angle of refraction. (*2 marks*)

3 A ray of light, travelling in air, passes into water. The angle of refraction is 23°. The refractive index of water is 1.33.
Calculate the angle of incidence. (*2 marks*)

4 The refractive index of acrylic glass is 1.49. The speed of light in air is approximately $3 \times 10^8\ \text{ms}^{-1}$.
Calculate the speed of light in acrylic glass. (*2 marks*)

5 A ray of light, travelling in liquid water, passes into an ice cube at an angle of 25.5° to the normal in water. The ray of light is refracted to an angle of 25.9° to the normal in the ice. The refractive index of liquid water is 1.33.
Calculate the refractive index of ice. (*3 marks*)