

# CHAPTER 18

## Refraction

### 18.1

### INTRODUCTION

Refraction is a property of waves that has been with us since time began. The refraction of light waves and radio waves through the universe has gone on since the beginning of the universe. Early hunters and spearfishermen used the refractive properties of water to accurately spear fish. However, the use of refraction, particularly in the fields of communication and medicine, has increased beyond belief over the past two decades. The development of optical fibres has revolutionised the way we receive telephone calls and TV programs (pay TV), and has reduced the time we spend in hospital with exploratory surgery.

- But what is refraction?
- How do optical fibres rely on refraction?
- Why are optical fibres in so much demand today?
- There are many uses made of optical fibres — can you name a few?

Questions related to everyday phenomena and which can be explained by refraction include these:

- Why do swimming pools or clear mountain streams seem shallower than they are?
- What causes mirages?
- Did you know a rainbow can only be observed when the rain is in front of you and the Sun is behind you?
- Did you know that the 'glass frogs' of Central America, whose bodies are so transparent you can see their insides, use refraction to vanish from sight when they slip into the water?

These questions and many more odd characteristics of the way light travels can be answered by a study of the refraction of light. By the end of this chapter many interesting phenomena will be able to be discussed with a knowledge of refraction.

### 18.2

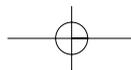
### REFRACTION

Recall the definition of refraction — it is the changing in direction of waves as they go from one medium to another. For water waves this meant that the direction of propagation of waves changed when they travelled from one depth of water to another. For light, refraction occurs when light passes from one medium to another, such as when light rays pass from air to water, from air to glass or from glass to water. This direction change can be easily observed in the case of light — the light rays themselves bend at the boundary between the media. A definition of refraction for light thus becomes:

*Refraction is the bending of light rays at the boundary or interface, as they go from one medium to another.*

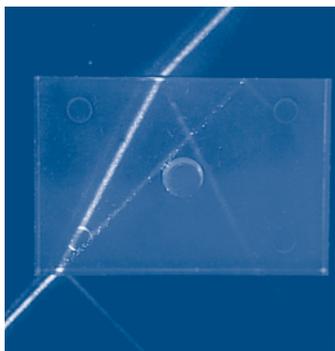
### Activity 18.1 REFRACTION

- 1 Use a light box with a narrow aperture to produce a single light ray.
- 2 Shine this ray at an angle other than  $90^\circ$  onto a block of glass.
- 3 What happens to the ray as it goes from air to glass?



**Photo 18.1**

The refraction of light as it passes through a block of glass.

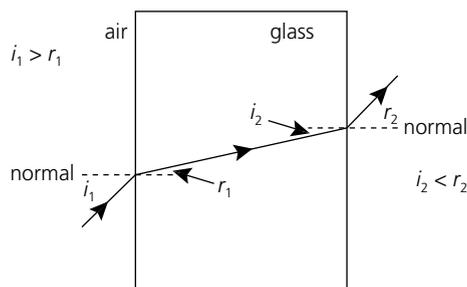


**Figure 18.1**

Light is refracted as it passes through glass, bending towards the normal in the more dense medium, and away in the less dense medium.

You should have noticed that the ray bent as it entered the glass and bent again on exiting from the other side. (See Photo 18.1.) It has been refracted twice. If the normal had been drawn to the surface of the glass at the point the ray entered the glass, it would have also been noticed that the ray bent closer to the normal in the glass on entering and further from the normal on exiting.

We call the ray that strikes the glass **the incident ray**, and the ray that bends in the glass **the refracted ray**. The angle between the incident ray and the normal is **the angle of incidence (i)** and the angle between the refracted ray and the normal is **the angle of refraction (r)** (Figure 18.1).



At the second surface, the surface where the ray passes from glass to air, the ray in the air is the refracted ray and the ray in the glass is the incident ray.

If Perspex is used instead of glass, similar refraction occurs except that for the same angle of incidence the angle of refraction will be different.

Similar effects are observed using any transparent material. The refracted ray bends towards the normal when the light travels from air to the material. The amount the rays bend depends on the **optical density** of the material. Optical density has nothing to do with physical density — mass, volume, etc. — but with the ability of light to pass through it.

A general rule is that **light rays bend toward the normal when they go from a less optically dense medium to a more optically dense medium**. The reverse is also true — **light rays bend away from the normal as they pass from a more optically dense medium to a less optically dense medium**. This illustrates the reversibility properties of light rays through a refractive system.

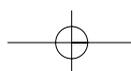
The amount of refraction that occurs results from the changing speed of light as it goes from air to the medium. (This was shown, using water waves, in Chapter 14.) Light travels faster in a vacuum or in air than in glass, water, etc. This is shown in Table 18.1.

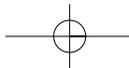
**Table 18.1 THE VELOCITY OF LIGHT IN VARIOUS MEDIA OF DIFFERENT REFRACTIVE INDICES**

MEDIUM	VELOCITY OF LIGHT IN THE MEDIUM, $v$ ( $10^8 \text{ m s}^{-1}$ )	ABSOLUTE REFRACTIVE INDEX OF THE MATERIAL, $n$
Air	3.00	1.00
Ice	2.31	1.30
Water	2.26	1.33
Ethyl alcohol	2.21	1.36
Fused quartz	2.05	1.46
Perspex	2.00	1.49
Benzene	2.00	1.50
Crown glass	1.97	1.52
Light flint glass	1.90	1.58
Heavy flint glass	1.82	1.65
Zircon	1.58	1.90
Diamond	1.24	2.42

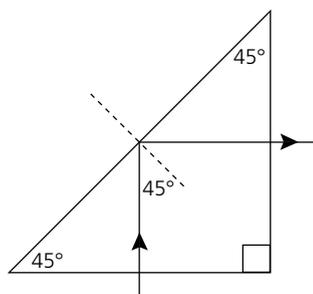
**PHYSICS FACT**

Diamonds have one of the highest refractive indices of all substances. The pioneer in making fake diamonds was teenager Carroll Chatham, who in 1926 dissolved some graphite in molten iron and dropped the fiery solution into a vat of liquid nitrogen ( $-196^\circ\text{C}$ ). Instead of getting diamonds, the explosion blew out the windows in his San Francisco home. Later he had success and his son Tom now produces synthetic diamonds that have similar RI to the real ones.

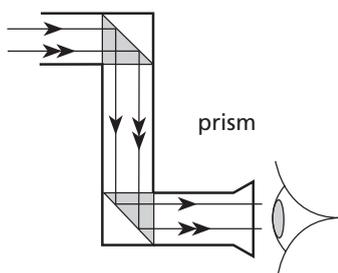




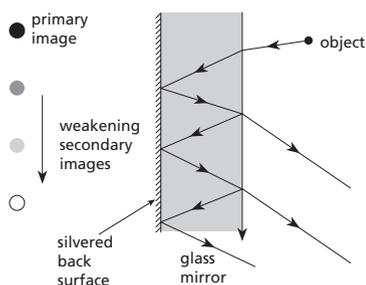
**Figure 18.17**  
Because of total internal reflection prisms are capable of bending light rays through 90°.



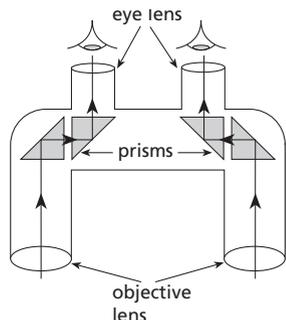
**Figure 18.18**  
Periscopes use total internal reflection in prisms.



**Figure 18.19**  
Quality periscopes use prisms rather than mirrors because mirrors produce multiple images if thick glass is used.



**Figure 18.20**  
A schematic diagram of binoculars using glass prisms.



## Activity 18.2 UNDERWATER BUBBLES

- 1 Hold an empty plastic soft drink bottle upside-down in a bucket of water, an aquarium, or a swimming pool.
- 2 Squeeze the bottle and watch the air bubbles rise. They look shiny.
- 3 Why is this?

## USES OF TOTAL INTERNAL REFLECTION

18.6

### Prisms

A glass 45°/45° prism as shown in Figure 18.17 can be used for total internal reflection and has many uses.

Light striking one surface of the prism at right angles makes an angle of 45° with the second surface. The angle of incidence is greater than the critical angle of 42° and the light is therefore reflected from this surface. It then strikes the third surface at right angles. The rays have thus made right-angled turns.

This makes them useful in quality periscopes (Figure 18.18). They have an advantage over mirrors because mirrors produce multiple images as light is reflected from the back and front surfaces a number of times (Figure 18.19). The coating on mirrors can also flake, reducing the reflected light intensity.

Prisms are also used in prism binoculars, making these pieces of equipment much more compact than older telescopes (Figure 18.20). In single lens reflex cameras a pentaprism is used to reflect the incoming light back to the viewfinder as well as invert it so that the photographer is actually seeing the light which is entering the camera lens used to form the image on the film.

If light is incident at right angles onto the hypotenuse of the prism it is reflected back the way it came (Figure 18.21). This property of prisms makes them useful for reflectors on bicycles and 'cats'-eyes' on roads. Notice, however, that the rays of light are inverted.

Diamonds are cut in similar ways to reflect light incident on them to produce many internal reflections and thus to sparkle.

### Optical fibres

One of the major developing uses of total internal reflection is in optical fibres. Fibre optics is a branch of optics dealing with the transmission of light through fibres or thin rods of glass or some other transparent material of high refractive index. If light is admitted at one end of a fibre, it can travel through the fibre with very low loss, even if the fibre is curved.

Optical fibres have been around for decades. You might remember, or have seen, those stringy plastic lights (Fantasy lights) that were the rage back in the 1970s. These consisted of basic optical fibres. (See Photo 18.4.)

However, the number of medical and communication uses of optical fibres has exploded over the past decade.

An optical fibre consists of a very pure glass fibre as thin as a hair 0.125 mm with a layer of cladding around the outside (Figure 18.22), to protect it from damage and moisture.

The outside layer has a lower refractive index than the inside material, thus creating a situation where light propagating in the central layer is travelling in a more dense material than in the outside layer. This means the light is totally internally reflected if it strikes the boundary between the two media at an angle greater than the critical angle. Thus light is reflected and reflected and reflected along the length of the fibre, which can be bent into any shape as long as it is not kinked. Once kinked, surface cracks allow light to refract out. In underwater cables the glow at the kink attracts fish, which can eat and sever the cable.

