

**Learning Objectives:**

At the end of this topic you will be able to:

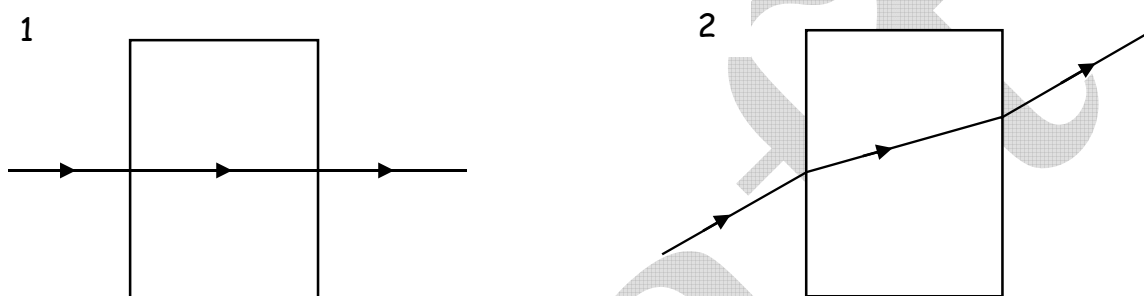
- ☑ remember the terms refraction, incident ray, refracted ray, angle of incidence, angle of refraction, critical angle and total internal reflection;
- ☑ draw diagrams showing refraction and total internal reflection;
- ☑ describe how to investigate the total internal reflection;
- ☑ predict whether total internal reflection will happen in a given situation;
- ☑ explain how light can travel along optical fibres so that we can use it for communication;

Dr. A. K. S.

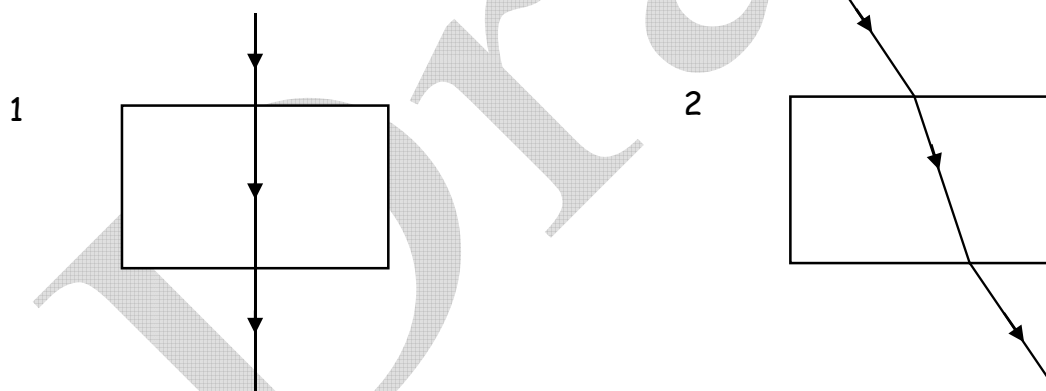
### Refraction in glass - recap from Key Stage 3

You'll remember from your Key Stage 3 course that light rays change direction when they travel between two different materials and that we call this effect **refraction**.

When a light ray goes through a parallel-sided glass block, it behaves as follows:



Of course, the blocks might not be this way round:

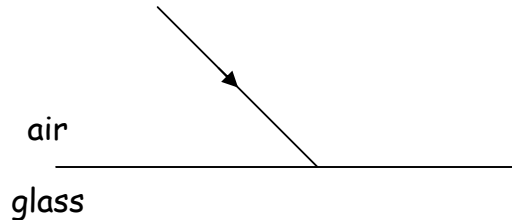


This unit will look at this in more detail and we'll learn that sometimes the light ray reflects instead - and how and when this happens.

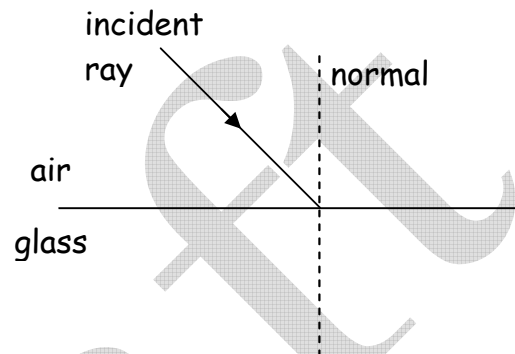
We can see from these diagrams that a light ray goes carries straight on if it hits the block at right angles - it only changes direction if it hits the block at an angle.

Let's look at this in more detail on the next page:

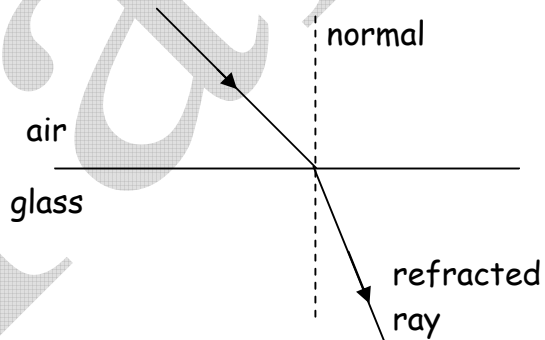
Here is a light ray which is travelling in air. A light ray travelling towards a surface is called the *incident ray*. What happens to it when it hits the surface of the glass block?



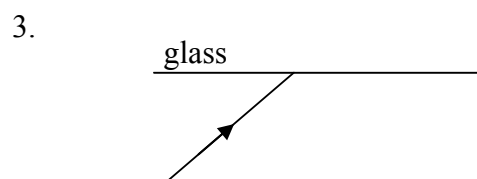
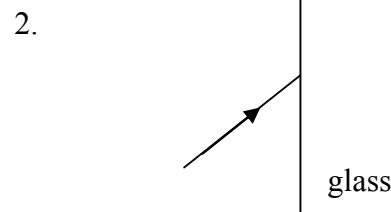
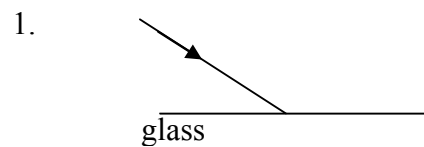
It helps to remember if we drawn another line on the diagram at right angles to the air-glass surface. This is called the *normal*.



The first thing to remember is that the light ray crosses the normal; the second thing is that it is bent **towards the normal**. The light ray is closer to the normal in the glass than it is in the air.



Self-assessment questions: Complete these diagrams. The diagrams all show a light ray, travelling in air, hitting a glass surface. Draw in the *normal* and the *refracted ray* in each case:



What happens if a light ray, in glass, hits an air boundary?

From the diagrams on page 2, we can see than it bends **away from the normal** - it still crosses the normal when it does this.

Can you finish this diagram?

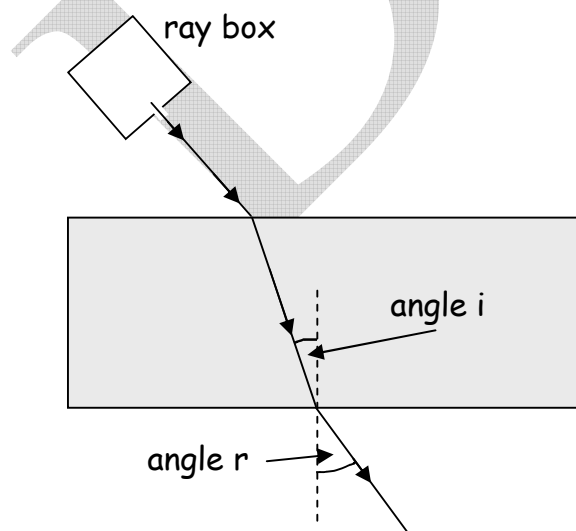


Don't worry about how the light ray got there!

Investigating what happens to a light ray, which is travelling in glass hits the surface at different angles:

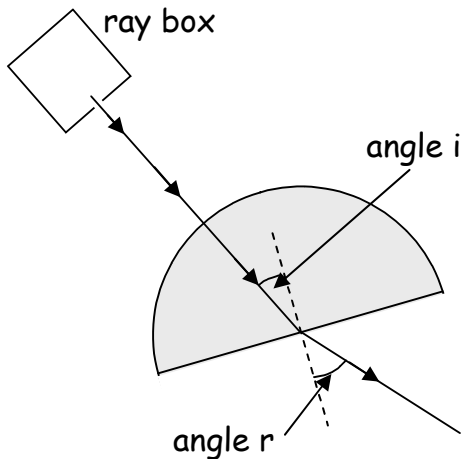
There are 2 easy ways of doing this:

1.



- Set the ray box with a light ray going through the glass.
- Use a pencil to mark the path of the light ray.
- Draw on the normal
- Measure the angles  $i$  and  $r$
- Move the ray box to alter the angles.
- Carry on for lots of different angles

2. Although you won't be asked any exam questions about it, it's easier to investigate this using a semi-circular glass block.



The trick here is to point the ray box at the centre of the flat side of the block. It passes into the block without changing direction (can you see why?).

Again, trace the ray using a pencil, draw the normal and measure  $i$  and  $r$ . Change the angle  $i$  by turning the glass block - so you don't need to move the ray box.

This way, it is easy to get a series of readings with  $i$  from 0 to nearly  $90^\circ$ .

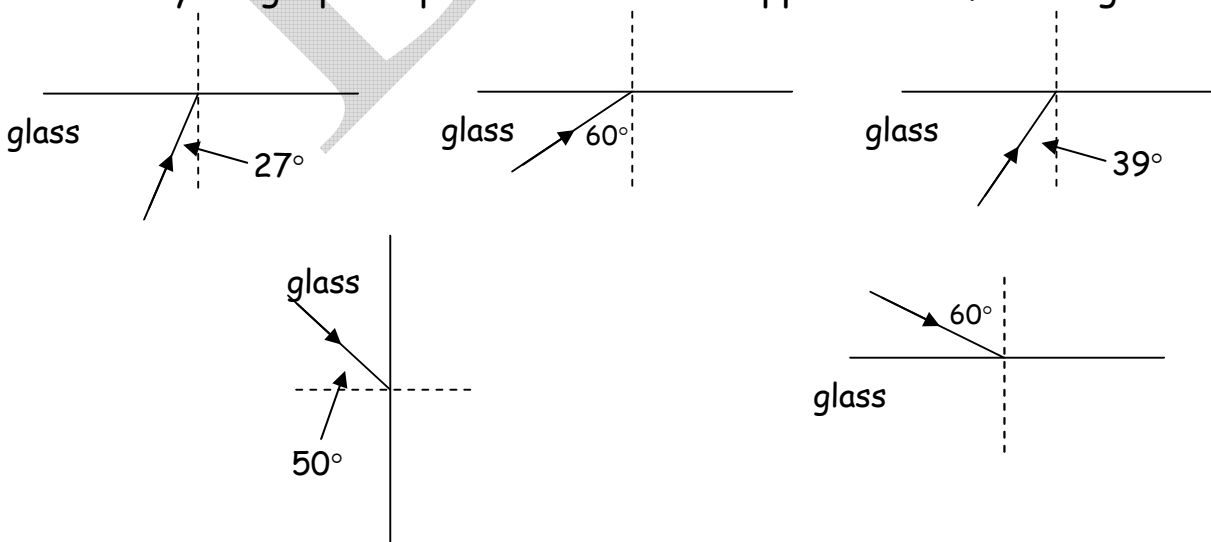
Here is a set of results from this kind of experiment.

Angle $i$	$0^\circ$	$10^\circ$	$20^\circ$	$25^\circ$	$30^\circ$	$35^\circ$	$38^\circ$	$40^\circ$	$45^\circ$	$50^\circ$
Angle $r$	$0^\circ$	$15^\circ$	$32^\circ$	$40^\circ$	$50^\circ$	$61^\circ$	$70^\circ$	$80^\circ$	*	*

\* For angles more than about  $41^\circ$  the light ray reflected - it didn't refract. We call this Total Internal Reflection.

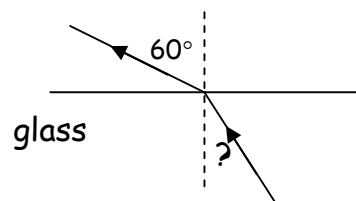
Time for you to do some work.

1. Draw a graph of angle  $r$  [on the vertical axis] against  $i$ .
2. Use your graph to predict what will happen in the following cases:



**Light rays from air into glass.**

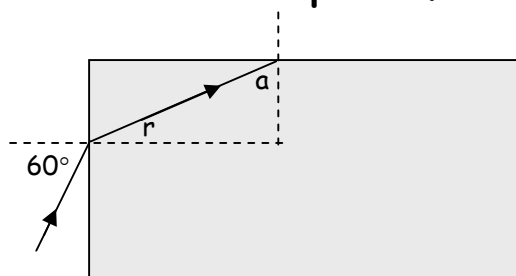
Did you work out how to do the last one on the previous page? The trick is to realise that you can always send a light ray back along its own path - so the question is the same as the one on the right:→



In other words, what angle  $i$  would give an angle  $r$  in the air of  $60^\circ$ ?

We'll use this idea straight away when we come to looking at glass blocks and optical fibres.

**Glass blocks and optical fibres**



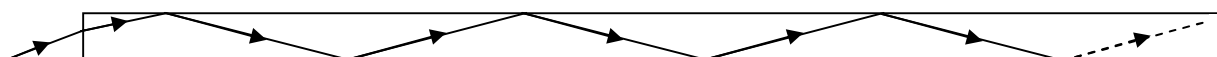
We've already worked this one out. We know what the angle of refraction -  $r$  - is in the glass. We don't need the actual value: we just know that it's less than  $45^\circ$ .

So what about angle 'a' in the diagram? Notice the two dotted normals make a right angles triangle with the light ray as hypotenuse. Angles  $r$  and  $a$  add up to make  $90^\circ$ , so if  $r < 45^\circ$ ,  $a > 45^\circ$ .

So what happens to the light ray when it hits the top surface of the block? .....

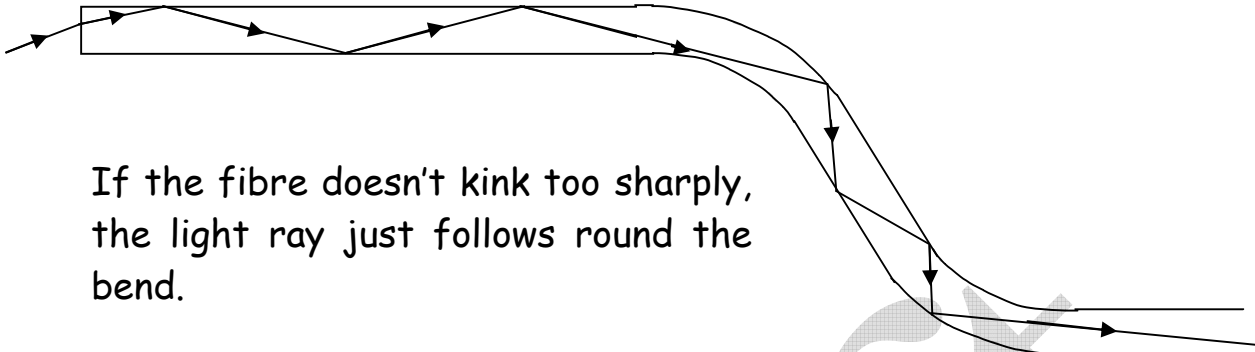
You should be able to see that this will happen for any light ray entering the block, as long as it goes on to hit the top or bottom surface.

So, for a very long block:



This is starting to look like an optical fibre....

But how does it work if the optical fibre isn't straight?



If the fibre doesn't kink too sharply, the light ray just follows round the bend.

A good way of demonstrating this is to heat a glass rod and pull it out into a fibre<sup>1</sup>. About a 1 metre fibre is good.

Next shine a bright light onto one end and hold a piece of paper up to the other end - you should see a greenish circle where the light coming from the end hits the card. It is green because the glass contains iron and copper impurities. If the fibre is very thin, it should be flexible.



<sup>1</sup> This is a demonstration for your teacher. It works well with soda glass. For a light source a 100 W, 12 V planar filament bulb (of the sort for demonstrating Young's fringes) is suitable. After demonstrating the transmission of light, putting greasy fingers on the fibre is instructive.

## Optical Fibres

So what do we need to know about optical fibres? We know already that a short [ $\sim 1\text{m}$ ] length of glass will conduct light along it. Now read on.....

Question: signals in communications systems are electrical signals, so what's the advantage in turning them into light, sending them along optical fibres and then turning them back into electrical signals?

Answer: how many reasons do you want?

1. Optical fibres are made of glass, which is made from sand - about the cheapest raw material you can get, unlike copper which is very expensive.
2. Optical fibres are very light - an individual fibre, with its cladding is less than a mm across. A bundle of optical fibres, enough for thousands of telephone conversations or T.V. channels is less than 1 cm across. The equivalent in copper cables would be several cm across, very heavy and difficult to install.
3. Security - you can't tap a signal in an optical fibre - all the light is totally internally reflected - it stays inside the fibre. The electric signals in copper cable give out radio signals which can be intercepted.
4. Interference - optical fibres are immune from this.
5. Transmission distance - all signals get weaker as we send them along cables and optical fibres, but optical fibres can transmit them for several hundred km before they need boosting again - a copper cable would need a booster every 10 km or so.

Question: how far will the light go?

Answer: it depends upon the kind of glass and the wavelength of the radiation you use. Communications engineers have developed a glass which is so transparent that they can send signals over hundreds of

km without needing to be boosted. They work with Infra-red radiation, which is scattered much less than visible light.

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