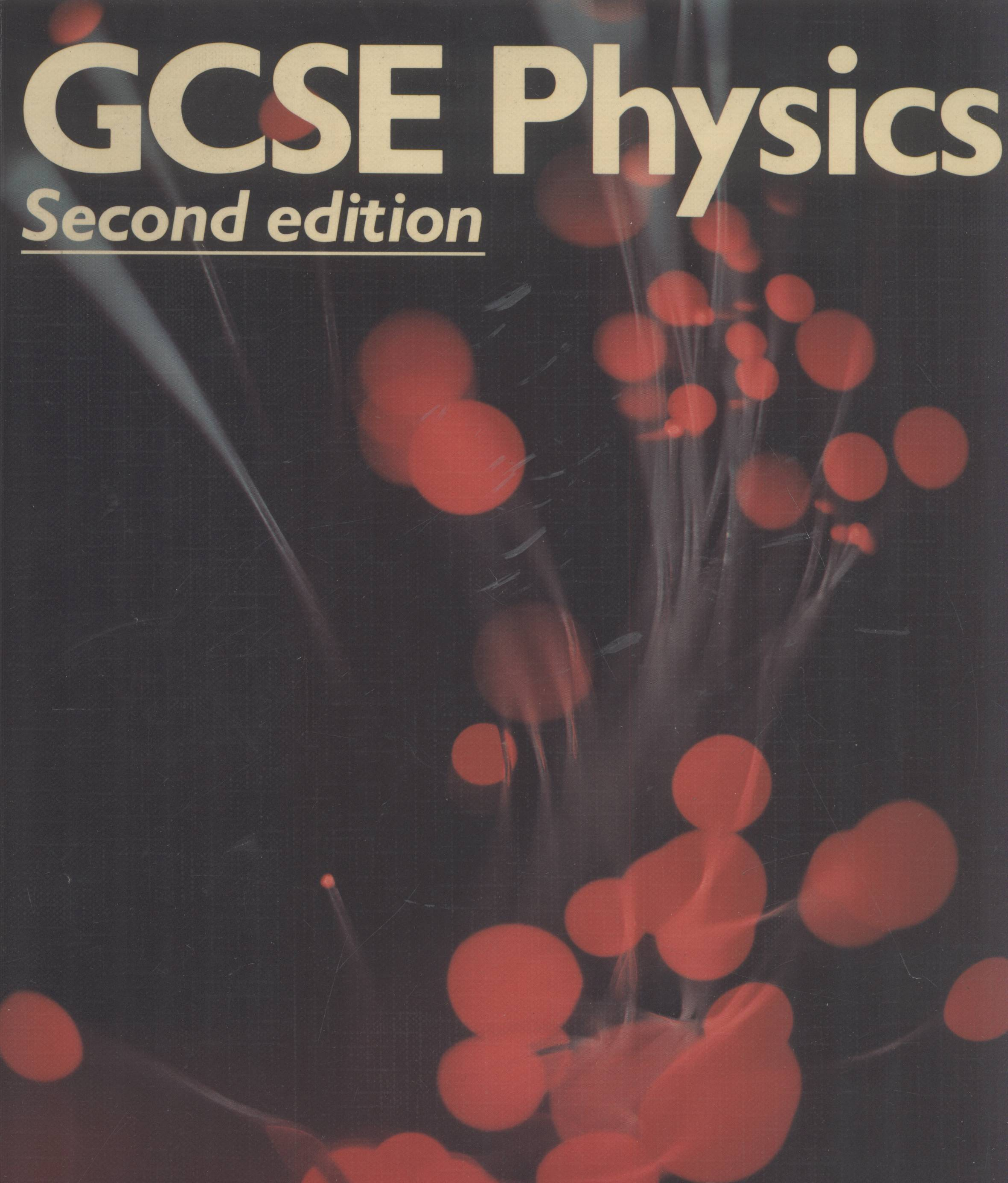
GCSE Physics

Second edition



Tom Duncan

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Cover photo

Abstract representation of an optical fibre communications system in which messages are carried over long distances by pulses of infrared 'light' travelling in glass fibres as fine as a human hair.
This area of modern technology is one of the most rapidly developing.

(Photo: Paul Brierley)

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To F.D.B.

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Preface

This book is developed from *Physics for Today and Tomorrow* (2nd edition), modified to bring it into line with the requirements of those taking the first GCSE examinations. There is full coverage of the S.E.C. approved syllabuses of all six GCSE Examining Groups. *Check lists* of specific objectives have been added to help students monitor their progress and to aid revision.

There are over 800 questions, for which a two-level grading system has been adopted. This is designed to meet the needs of a wide range of students and enable questions of an appropriate level to be found readily. The *Questions* at the end of every topic are intended for class use and, along with the *Additional questions* after each group of related topics, for setting as homework. Each group of *Additional questions* is organized into the two-level system: '*Core*' *level* (for all students for whom the material is relevant), while the rest are at the higher '*Further*' *level* (for those seeking higher grades).

For quick but comprehensive revision of basic material before examinations, a set of over 100 mostly objective-type *Core level revision questions*, of a straightforward nature, have been added. The *Further level revision questions* are suitable mainly for students hoping to obtain higher grades.

Second edition. In this second edition, *which is completely compatible with the first*, the opportunity has been taken to make some useful amendments in a number of chapters. Also, material required by only one or two syllabuses has been grouped into three additional *Other topics*.

The author is grateful to Peter Knight for his painstaking analysis of GCSE syllabus requirements.

Acknowledgement is made to the following boards (answers given being the sole responsibility of the author):

Cambridge Local Examination Syndicate (*C.*)
Joint Matriculation Board (*J.M.B.*)
University of London (*L.*)
Northern Ireland G.C.E. Examination Board (*N.I.*)
Oxford Local Examinations (*O.L.E.*)
Oxford and Cambridge Examination Board (*O. and C.*)
Southern Universities Joint Board (*S.*)
Welsh Joint Education Committee (*W.*)
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East Midland Regional Examination Board (*E.M.*)
North West Regional Examinations Board (*N.W.*)
Southern Regional Examinations Board (*S.R.*)
South-East Regional Examinations Board (*S.E.*)
West Midlands Examinations Board (*W.M.*)

To the student

During your course one way of using this book is to:

1 study the *topic* concerned (e.g. *Light rays*),
2 use the *check list for that topic* to test that you can satisfy the objectives stated (page no. of check list is given at end of topic),
3 try the *questions* at the end of the topic,
4 try the *additional questions at core level* for the topic, and
5 try the *additional questions at further level* if you are hoping for higher grades.

When revising before an examination you might find it better to:

1 use the *check lists for each group of related topics* (e.g. *Light and sight*) to test yourself and refer back to the text when necessary,
2 try the *revision questions at core level* for the group of topics, and
3 try some of the *revision questions at further level* if you are aiming for higher grades.

Contents

Electricity and magnetism

Electrons and atoms

Other topics

Physics and technology

Physicists explore the Universe. Their investigations range from stars that are millions and millions of kilometres away to particles that are smaller than atoms, Fig. 1*a*, *b*.

As well as having to find the *facts* by observation and experiment, they also must try to discover the *laws* that summarize (often as mathematical equations) these facts. Sense has then to be made of the laws by thinking up and testing *theories* (thought-models) to explain the laws. The reward, apart from a satisfied curiosity, is a better understanding of the physical world. Engineers and technologists use physics to solve *practical problems* for the benefit of mankind, though in solving them social, environmental and other problems may arise.

In this book we will study the behaviour of *matter* (the stuff things are made of) and the different kinds of *energy* (such as light, sound, heat, electricity). We will also consider the applications of physics in the home, transport, medicine, industry, communications and electronics, Fig. 2*a*, *b*, *c*, *d*.

Mathematics is an essential tool of physics and a 'reference section' of some of the basic mathematics is given at the end of the book along with a suggested procedure for solving physics problems.

Fig. 1*a*. Astronomers have found that the many millions of stars in the Universe, of which the Sun is just one, are in widely separated groups called galaxies. The spiral galaxy M81 near the Plough is shown at the left. The Sun and its planets belong to the galaxy called the Milky Way.

The number of galaxies is huge. Most appear as tiny blurred specks. It is estimated that the farthest are 5000 million light-years from the Sun. One light-year is the distance travelled by light in 1 year—about 10 000 000 000 000 km.

Fig. 1*b*. The photograph below shows the atoms in the tip of a tungsten needle (the metal used for lamp filaments) magnified about 2 million times. It was taken by an instrument called a field ion microscope.

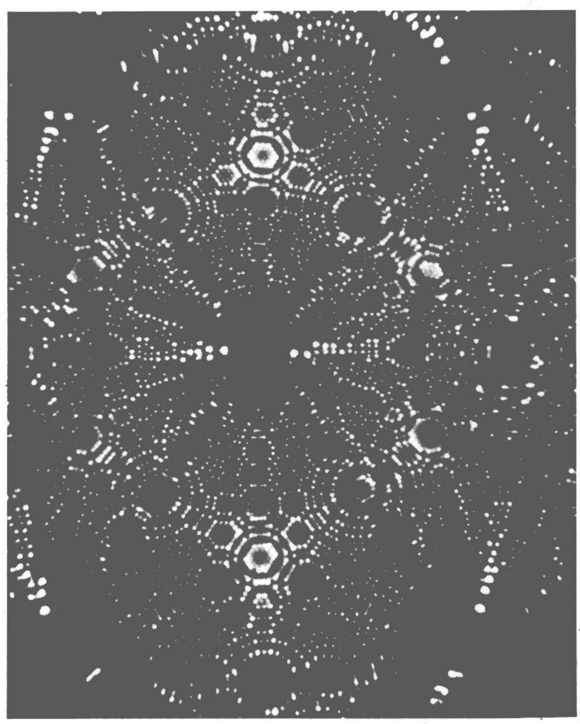


Fig. 2*a*. The space shuttle *right* is the world's first, and as yet only, re-usable 'Space Transport System' (STS). After being launched like a rocket it glides back to earth like an aeroplane to be used again. Satellites and other materials can be carried in its cargo bay to be placed into orbit when the shuttle is in space. The black tiles on the underside of the vehicle protect it against the fierce heat caused by friction as it re-enters the earth's atmosphere.

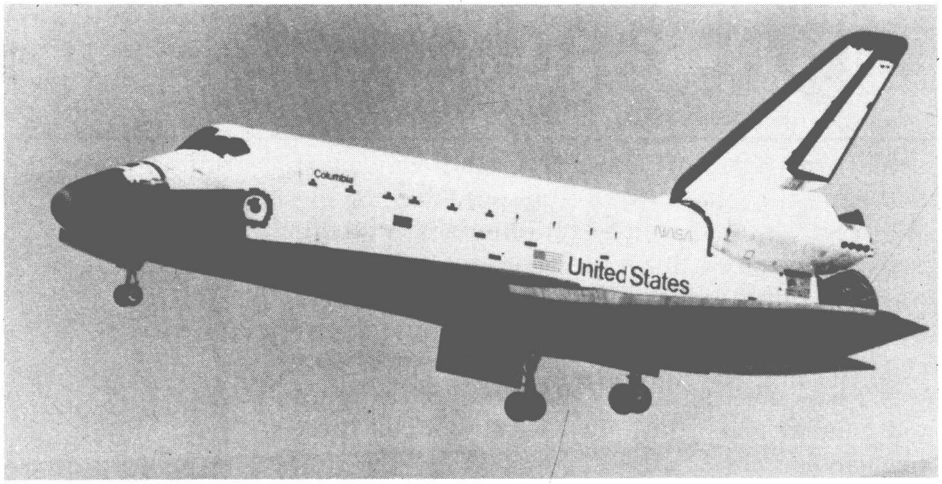


Fig. 2*b*. In the search for alternative energy sources, giant windmills like that *below* are being developed to drive electrical generators where wind power is sufficiently reliable.

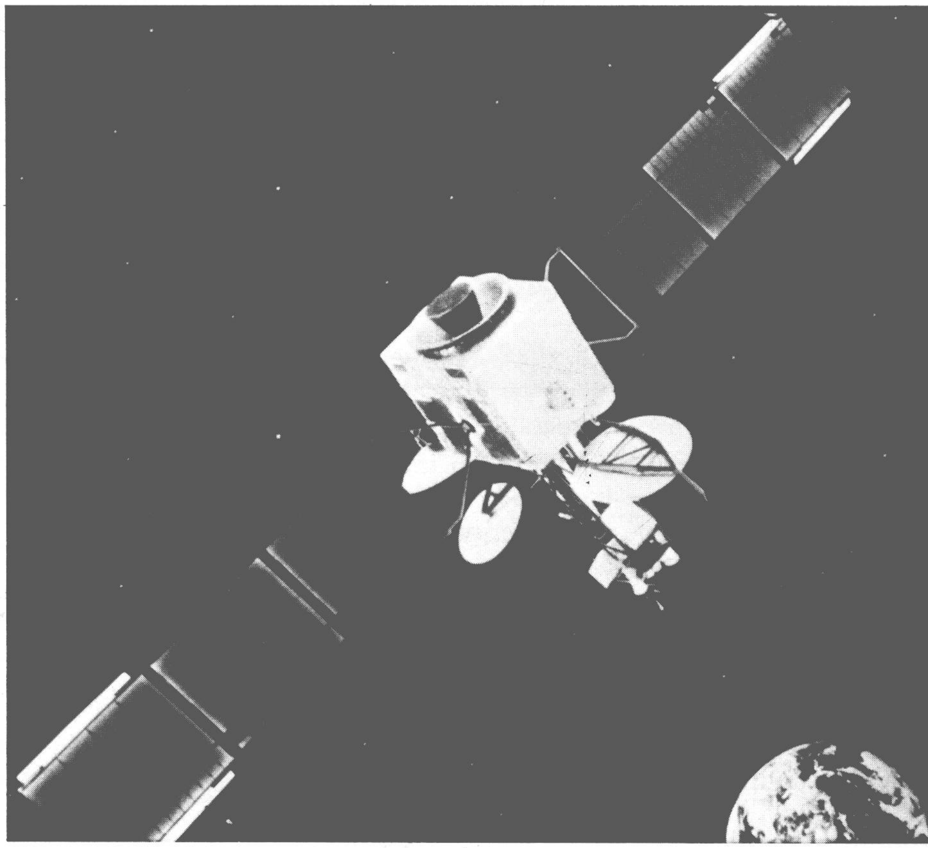


Fig. 2*c*. Communications satellites, like the one shown *above* with its power-generating solar panels, can handle two television channels plus 12 000 telephone circuits. They are launched either by the American *Space Shuttle* (Fig. 2*a*) or by the European rocket *Ariane* into a geostationary orbit 36 000 km (22 500 miles) above the equator where they circle the earth in 24 hours and appear to be at rest. Microwave signals are sent to it and received from it by earth stations with large dish aerials like those in Fig. 77.2.

Fig. 2*d*. The production worker *left* is showing a silicon wafer containing computer memory 'chips' that can store over one million bits of information. The process, which can require up to three months, must be done in a controlled, absolutely clean environment.

Light and sight

1 Light rays

You can see an object only if light from it enters your eyes. Some objects such as the sun, electric lamps and candles make their own light. We call these *luminous* sources.

Most things you see do not make their own light but reflect it from a luminous source. They are *non-luminous* objects. This page, you and the moon are examples. Fig. 1.1 shows some others.

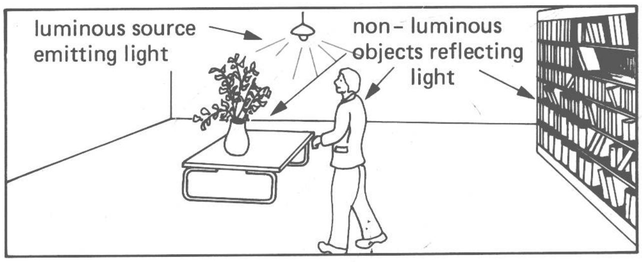


Fig. 1.1

Luminous sources radiate light when their atoms become 'excited' as a result of receiving energy. In a light bulb, for example, the energy comes from electricity. The 'excited' atoms give off their light haphazardly in most luminous sources.

A light source that works differently is the *laser*, invented in 1960. In it the 'excited' atoms act together and emit a narrow, very bright beam of light which can cut a hole through a key 2 mm thick in a thousandth of a second, Fig. 1.2. Other uses are being found for the laser in industry, telecommunications and medicine.

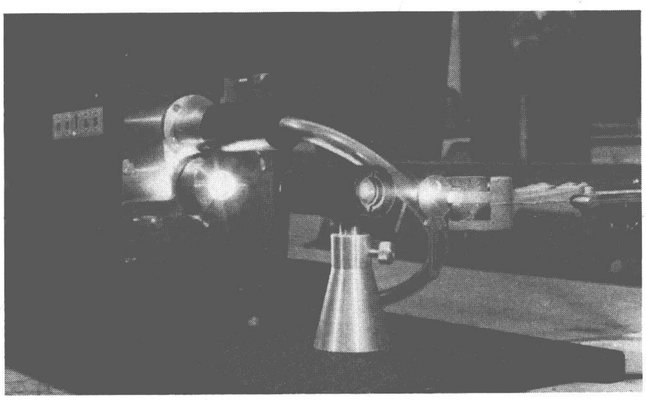


Fig. 1.2

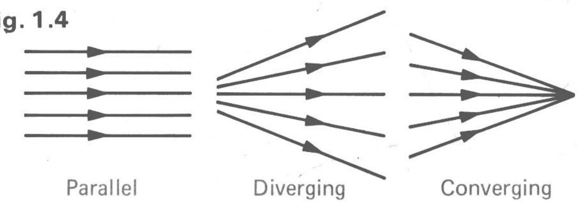
Fig. 1.3

Rays and beams

Sunbeams streaming through trees, Fig. 1.3, and light from a cinema projector on its way to the screen both suggest that *light travels in straight lines.* The beams are visible because dust particles in the air reflect light into our eyes.

The direction of the path in which light is travelling is called a *ray* and is represented in diagrams by a straight line with an arrow on it. A *beam* is a stream of light and is shown by a number of rays; it may be parallel, diverging (spreading out) or converging (getting narrower), Fig. 1.4.

Fig. 1.4



Experiment: the pinhole camera

One is shown in Fig. 1.5*a*. Make a small pinhole in the centre of the black paper. Half-darken the room. Hold the box at arm's length so that the pinhole end is nearest to and about 1 metre from a luminous

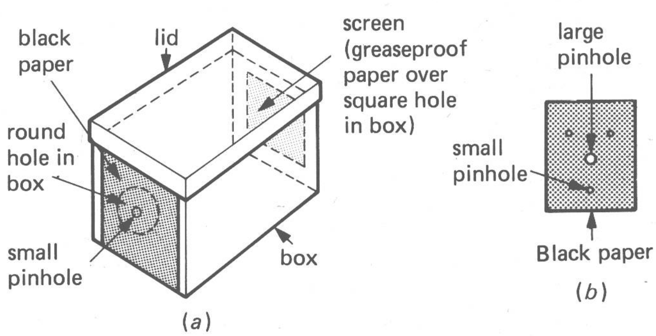


Fig. 1.5

object, e.g. a carbon filament lamp or a candle. Look at the *image* on the screen (an image is a likeness of an object and need not be an exact copy).

Can you see *three* ways in which the image differs from the object? What is the effect of moving the camera closer to the object?

Make the pinhole larger. What happens to the (i) brightness, (ii) sharpness, (iii) size of the image?

Make several small pinholes round the large hole, Fig. 1.5*b*, and view the image again.

The forming of an image is shown in Fig. 1.6.

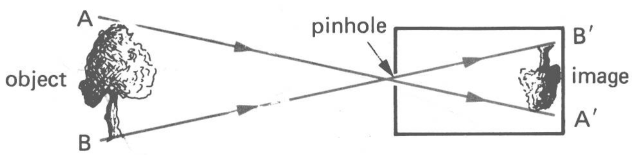


Fig. 1.6

Shadows

Shadows are formed because light travels in straight lines. A very small source of light, called a *point* source, gives a sharp shadow which is equally dark all over. This may be shown as in Fig. 1.7*a* where the small hole in the card acts as a point source.

If the card is removed the lamp acts as a large or *extended* source, Fig. 1.7*b*. The shadow is then larger and has a central dark region, the *umbra*, surrounded by a ring of partial shadow, the *penumbra*. You can see by the rays that some light reaches the penumbra but none reaches the umbra.

Eclipses

There is an eclipse of the sun by the moon when the sun, moon and earth are in a straight line. The sun is an extended source (like the bulb in Fig. 1.7*b*). People

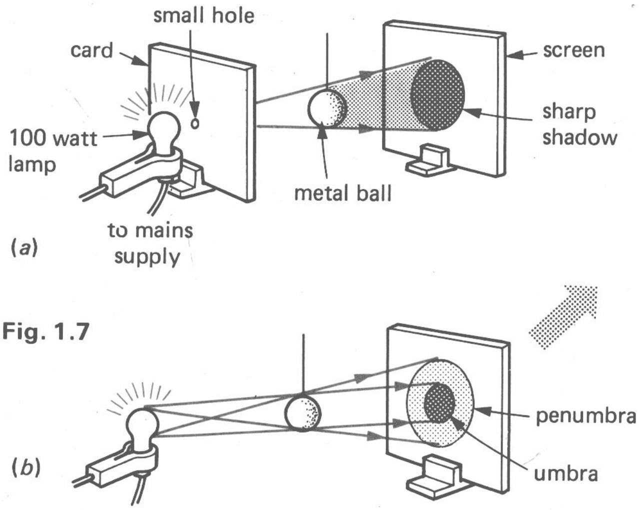


Fig. 1.7

in the umbra of the moon's shadow, at B in Fig. 1.8, see a *total* eclipse of the sun (that is, they can't see the sun at all). Those in the penumbra, at A, see a *partial* eclipse (part of the sun is still visible).

Sometimes the moon is farther from the earth (it does not go round the earth in a perfect circle), and then the tip of the umbra does not reach the earth, Fig. 1.9. In that case people at A still see a partial eclipse, but those at B see an *annular* eclipse (only the central region of the sun is hidden).

A total eclipse seen from one place may last for up to 7 minutes. During this time, although it is day, the sky is dark, stars are visible, the temperature falls and birds stop singing.

A lunar eclipse occurs when the moon passes into the earth's shadow and the light it reflects from the sun is cut off.

Q Questions

1. How would the size and brightness of the image formed by a pinhole camera change if the camera was made longer?

2. What changes would occur in the image if the single pinhole in a camera was replaced by **(a)** four pinholes close together, **(b)** a hole 1 cm wide?

3. A long narrow bench has two small identical lamps mounted one at each end as in Fig. 1.10. A vertical rod is

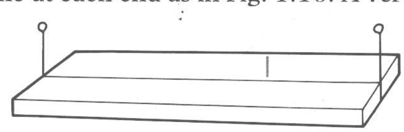


Fig. 1.10

placed on the bench. Copy the diagram and draw the shadows formed, showing the correct size and position. State, giving a reason, which shadow is the darker.

(*E.A.*)

4. Draw a diagram to show a possible position of the moon for a lunar eclipse to be seen on earth.

Fig. 1.8

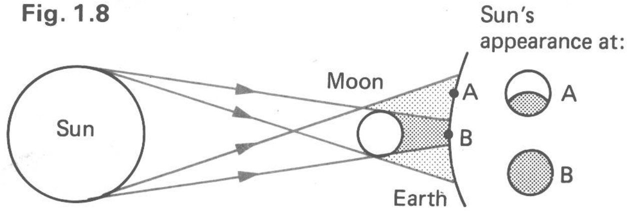
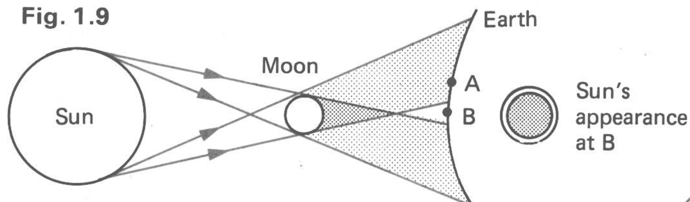


Fig. 1.9



check list p.279

2 Reflection of light

If we know how light behaves when it is reflected we can use a mirror to change the direction in which it is travelling. This happens when a mirror is placed at the entrance of a concealed drive to give warning of approaching traffic.

An ordinary mirror is made by depositing a thin layer of silver on one side of a piece of glass and protecting it with paint. The silver—at the *back* of the glass—acts as the reflecting surface.

Experiment: reflection by a plane mirror

Draw a line AOB on a sheet of paper and using a protractor mark angles on it. Measure them from the perpendicular ON, which is at right angles to AOB. Set up a plane (flat) mirror with its reflecting surface on AOB.

(a) Ray method. Shine a narrow ray of light along say the 30° line, onto the mirror, Fig. 2.1.

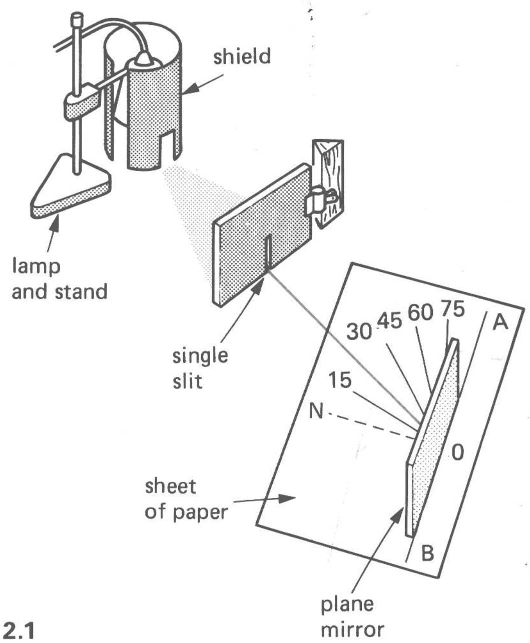


Fig. 2.1

Mark the position of the reflected ray, remove the mirror and measure the angle between the reflected ray and ON. Repeat for rays at other angles. What can you conclude?

(b) Pin method. Insert two pins P_1 and P_2 on the 30° line, Fig. 2.2, to indicate a 'ray' of light falling at this angle on the mirror. Look into the mirror and insert two sighting pins P_3 and P_4 so that they are in line

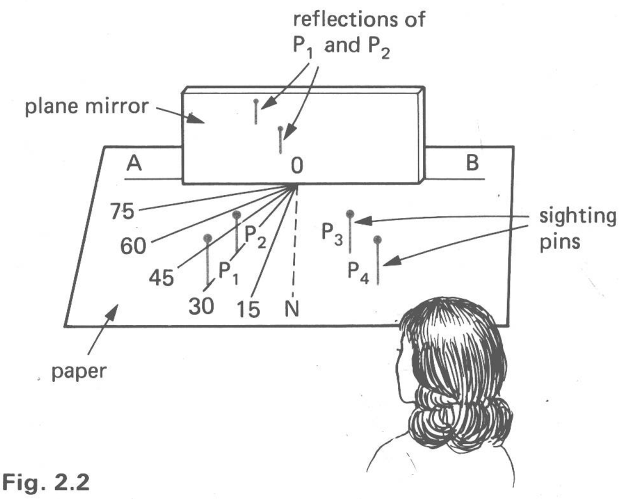


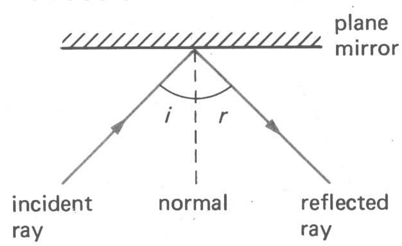
Fig. 2.2

with the reflections (images) of P_1 and P_2. P_3P_4 gives the path of 'ray' P_1P_2 after it is reflected.

Remove P_3 and P_4 and mark their positions with crosses (lettered P_3 and P_4). Remove the mirror and draw a straight line through P_3 and P_4 to meet the mirror; this should be at O. Measure angle P_4ON. Repeat for other angles. What do you conclude?

Laws of reflection

Fig. 2.3



Terms used in connection with reflection are shown in Fig. 2.3. The perpendicular to the mirror at the point where the incident ray strikes it is called the *normal*. Note that the angle of incidence *i* is the angle between the incident ray and the *normal*; similarly for the angle of reflection *r*. There are two laws of reflection.

1. *The angle of incidence equals the angle of reflection.*

2. *The incident ray, the reflected ray and the normal all lie in the same plane.* (This means that they can all be drawn on a flat sheet of paper.)

Periscope

A simple periscope consists of a tube containing two plane mirrors, fixed parallel to and facing one another. Each makes an angle of 45° with the line

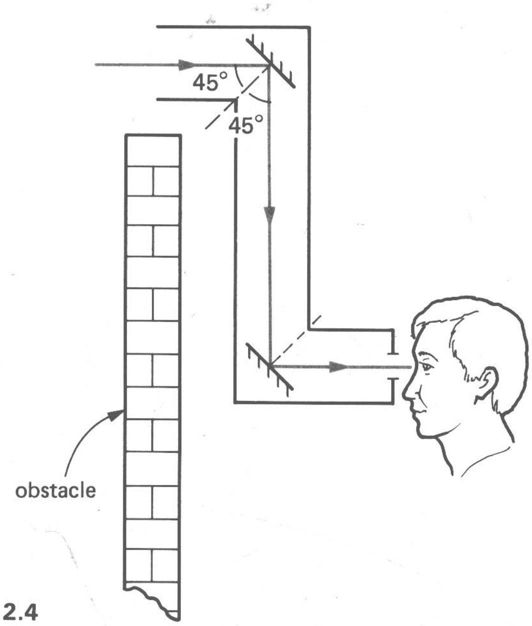


Fig. 2.4

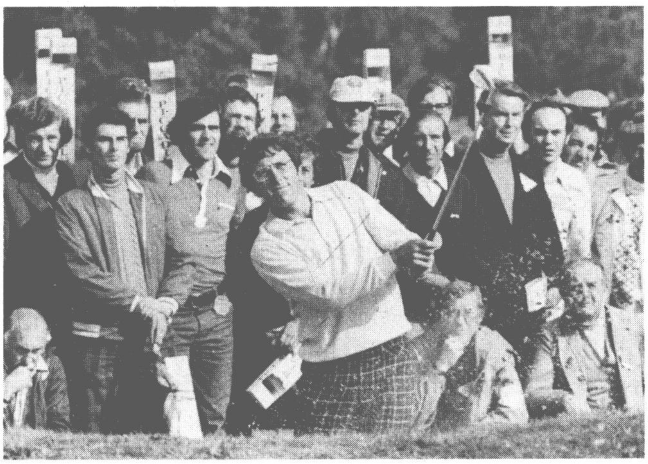


Fig. 2.5

joining them, Fig. 2.4. Light from the object is turned through 90° at each reflection and an observer is able to see over a crowd, for example, Fig. 2.5, or over the top of an obstacle.
In more elaborate periscopes like those used in submarines, prisms replace mirrors (see p. 21).

Regular and diffuse reflection

If a parallel beam of light falls on a plane mirror it is reflected as a parallel beam, Fig. 2.6*a*, and *regular* reflection is said to occur. Most surfaces however reflect light irregularly and the rays in an incident parallel beam are reflected in many directions, Fig. 2.6*b*.

Irregular or *diffuse* reflection is due to the surface of the object not being perfectly smooth like a mirror. At each point on the surface the laws of reflection are obeyed but the angle of incidence and so the angle of

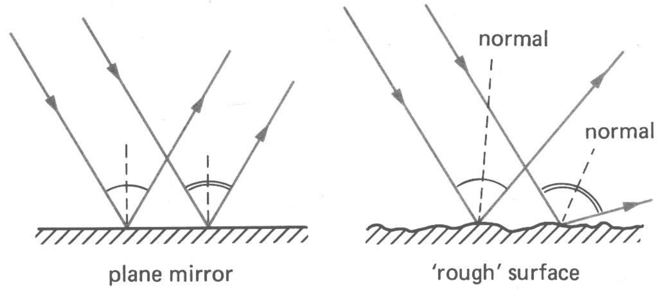


Fig. 2.6 (*a*) (*b*)

reflection varies from point to point. The reflected rays are scattered haphazardly. Most objects, being rough, are seen by diffuse reflection.

Q Questions

1. Fig. 2.7 shows a ray of light PQ striking a mirror AB. The mirror AB and the mirror CD are at right angles to each other. QN is a normal to the mirror AB.

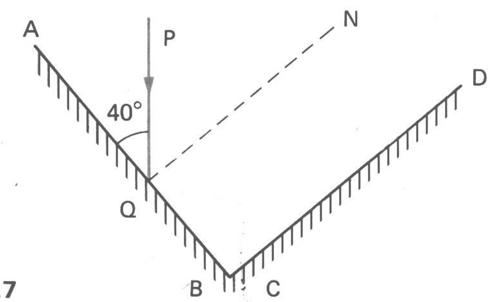


Fig. 2.7

(a) What is the value of the angle of incidence of the ray PQ on the mirror AB?
(b) Copy the diagram and continue the ray PQ to show the path it takes after reflection at both mirrors.
(c) Mark on your diagram the value of the angle of reflection on AB, the angle of incidence on CD and the angle of reflection on CD.
(d) What do you notice about the path of the ray PQ and the final reflected ray? (*E.M.*)

2. When a ray of light incident on a plane mirror at an angle of incidence of 70° is reflected from the mirror it subsequently strikes a second plane mirror placed so that the angle between the mirrors is 45°. The angle of reflection at the second mirror, in degrees, is

A 20 **B** 25 **C** 45 **D** 65 **E** 70 (*N.I.*)

3. A person is looking into a tall mirror in front, Fig. 2.8. What part of the mirror is actually needed to see from eye to toes? (*S.R.*)

Fig. 2.8

check list p.279

3 Plane mirrors

When you look into a plane mirror on the wall of a room you see an image of the room behind the mirror; it is as if there was another room. Restaurants sometimes have a large mirror on one wall just to make them look larger. You may be able to say how much larger after the next experiment.

The position of the image formed by a mirror depends on the position of the object.

Experiment: position of image

Support a piece of thin glass on the bench, as in Fig. 3.1. It must be *vertical* (at 90° to the bench). Place a small paper arrow O about 10 cm from the glass. The glass acts as a poor mirror and an image of O will be seen in it; the darker the bench top the brighter is the image. How do the sizes of O and its image compare?

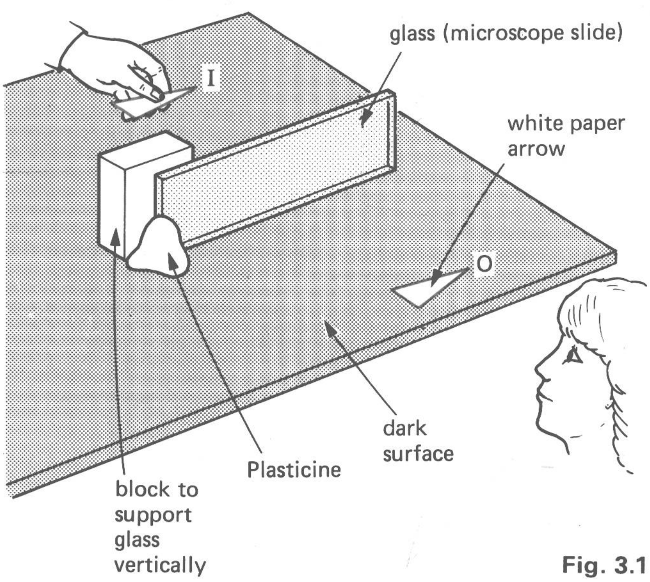


Fig. 3.1

Imagine a line joining them. What can you say about it?

Lay another identical arrow I on the bench behind the glass; move it until it coincides with the image of O. Measure the distances of the points of O and I from the glass along the line joining them. How do they compare? Try O at other distances.

Real and virtual images

A *real* image is one which can be produced on a screen (as in a pinhole camera) and is formed by rays that actually pass through it.

A *virtual* image cannot be formed on a screen and is produced by rays which seem to come from it but do not pass through it. The image in a plane mirror is virtual. Rays from a point on an object are reflected at the mirror and appear to come from the point behind the mirror where the eye imagines the rays intersect when produced backwards, Fig. 3.2. IA and IB are construction lines and are shown by broken lines.

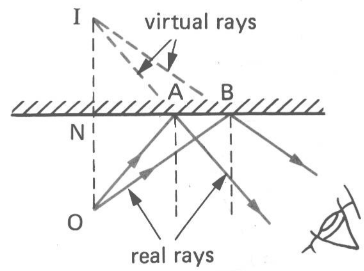


Fig. 3.2

Lateral inversion

If you close your left eye your image in a plane mirror seems to close the right eye. In a mirror image, left and right are interchanged and the image is said to be *laterally inverted.* The effect occurs whenever an image is formed by one reflection and is very evident if print is viewed in a mirror, Fig. 3.3. What happens if two reflections occur as in a periscope?

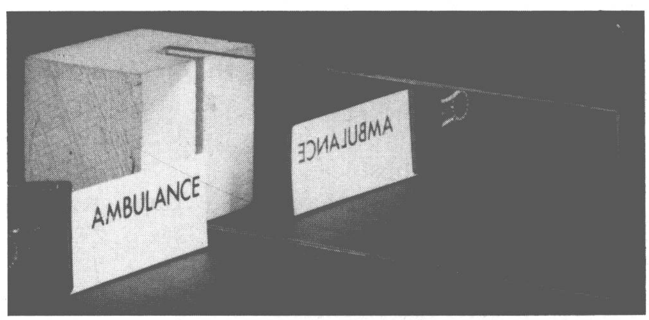


Fig. 3.3

Properties of the image

The image in a plane mirror is

(i) as far behind the mirror as the object is in front and the line joining the object and image is perpendicular to the mirror
(ii) the same size as the object
(iii) virtual
(iv) laterally inverted.

Uses of plane mirrors

Apart from their everyday use, plane mirrors can improve the accuracy of measurements in science.

A reading made on a meter which has a pointer moving over a scale is correct only if your eye is directly over the pointer. In any other position there is an error, called the 'parallax' error. (There is parallax between two objects—here the pointer and the scale—if they appear to move in opposite directions when you move your head sideways. It arises when objects do not coincide; if they do coincide they move together.)

If a plane mirror is fitted in the scale the correct position is found by moving your head until the image of the pointer in the mirror is hidden behind the pointer, Fig. 3.4. (A similar error occurs when reading a ruler, due to its thickness, if you do not look at right angles to it.)

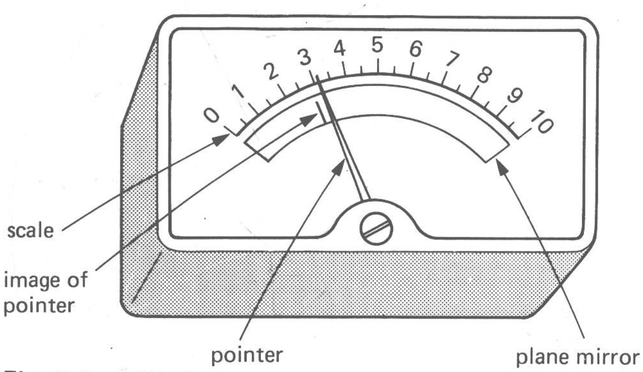


Fig. 3.4

Rotation of a plane mirror

When a mirror is rotated through a certain angle, the reflected ray turns through *twice* that angle. In Fig. 3.5*a*, when the mirror is in position MM, the ray IO is reflected along OR. Suppose the mirror is rotated through angle θ into position M′M′, the direction of IO still being the same; the angle between the reflected ray OR′ and OR can be shown to be 2θ.

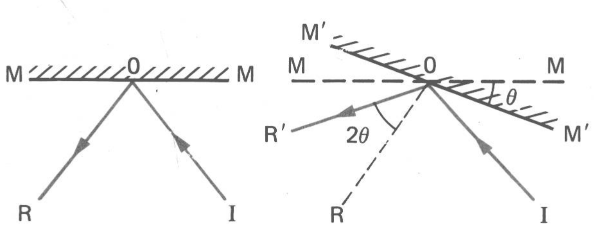


Fig. 3.5*a*

The idea is used in light-beam galvanometers, Fig. 3.5*b*, to enable them to measure very small electric currents, i.e. to make them more sensitive.

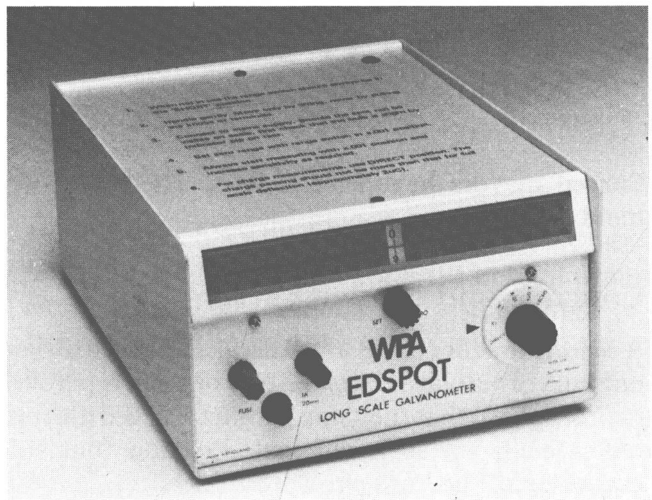


Fig. 3.5*b*

Questions

1. Fig. 3.6 shows a plan view of a jar of water and a vertical sheet of glass in a box, the inside of which is painted black.

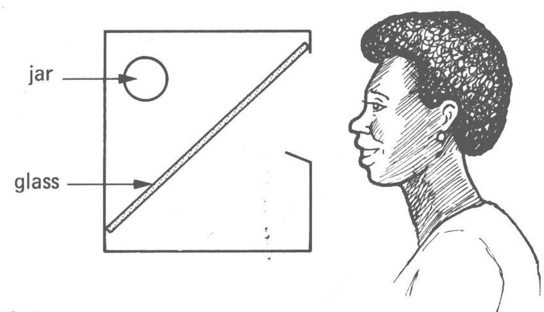


Fig. 3.6

(a) Copy the diagram and show where a candle might be placed so that it appears to the viewer to burn in the jar of water.
(b) Trace the path of two rays of light from the candle to the eye and show with dotted lines how they appear to come from inside the jar.
(c) What does the glass do to the light to get this effect? (*S.E.*)

2. The image in a plane mirror of a modern clock (with dots instead of numbers) looks as in Fig. 3.7.
The correct time is

A 2.25 B 2.35 C 8.35 D 9.25 (*W.M.*)

Fig. 3.7

3. A girl stands 5 m away from a large plane mirror. How far must she walk to be 2 m away from her image?

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4 Curved mirrors

Curved mirrors have several uses. There are two main types.

Concave and convex mirrors

A *concave* mirror curves inwards, like a cave; a *convex* one curves outwards. A plane mirror reflects parallel rays of light so that they stay parallel. Curved mirrors reflect each ray in a different direction (but still according to the laws of reflection).

A concave mirror brings parallel rays together to a point, called a real *focus* F, in front of the mirror, as in Fig. 4.1*a*.

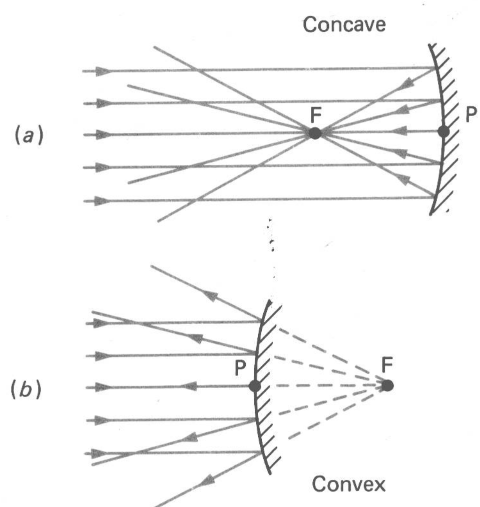

Fig. 4.1

A convex mirror spreads out parallel rays so that they appear to come from a point, called a virtual *focus* F, behind the mirror, as in Fig. 4.1*b*.

Uses of curved mirrors

(a) Reflectors. Concave mirrors are used as reflectors in, for example, car headlamps and flashlamps, because a small lamp at their focus gives a *parallel* reflected beam. This is only strictly true if the mirror has a parabolic shape (rather than spherical) like that in Fig. 4.2.

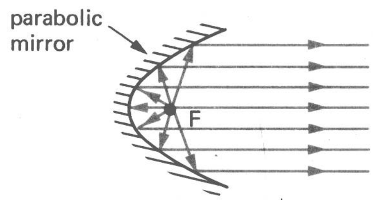

Fig. 4.2

(b) Make-up and shaving mirrors. A concave mirror forms a *magnified*, upright image of an object *inside* its focus. This accounts for these two cosmetic uses. The image appears to be behind the mirror and is virtual.

(c) Driving mirrors. A convex mirror gives a wider field of view than a plane mirror of the same size, Fig. 4.3*a*,*b*. For this reason and because it always gives an erect (but smaller) image, it is used as a car driving mirror. However it does give the driver a false idea of distance.

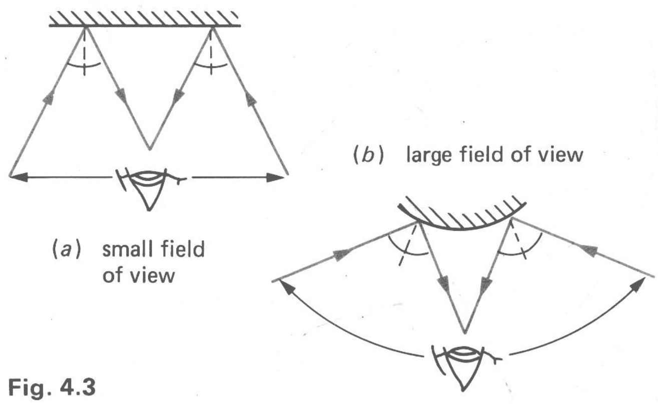

Fig. 4.3

Q Questions

1. A communications satellite in orbit sends a parallel beam of signals down to earth. If they obey the same laws of reflection as light and are to be focused on to a small receiving aerial, what is the best shape for the metal 'dish' used to collect them?

2. Account for the use of a convex mirror on the stairs of a double-decker bus.

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