Series circuits

In a series circuit all the resistors are placed one after the other so that the electrical current passes in turn through each resistor as it flows around the circuit.

- At all points in the series circuit the current is the same.
- The voltage drop across the two battery terminals is equal to the sum of the voltage drops across each resistor.
- The greater the number of resistors in series the greater is the total resistance.

Additional content—Mathematical extension:

Figure 1.24 shows a typical series circuit for two resistors R_1 and R_2.

- The total resistance (R_T) of this circuit is:

$$R_T = R_1 + R_2$$

As the current (I) is the same at all points in the series circuit, Ohm's law can be used to calculate the voltage drops across each resistor.

Resistor 1: $V_1 = I \cdot R_1$

Resistor 2: $V_2 = I \cdot R_2$

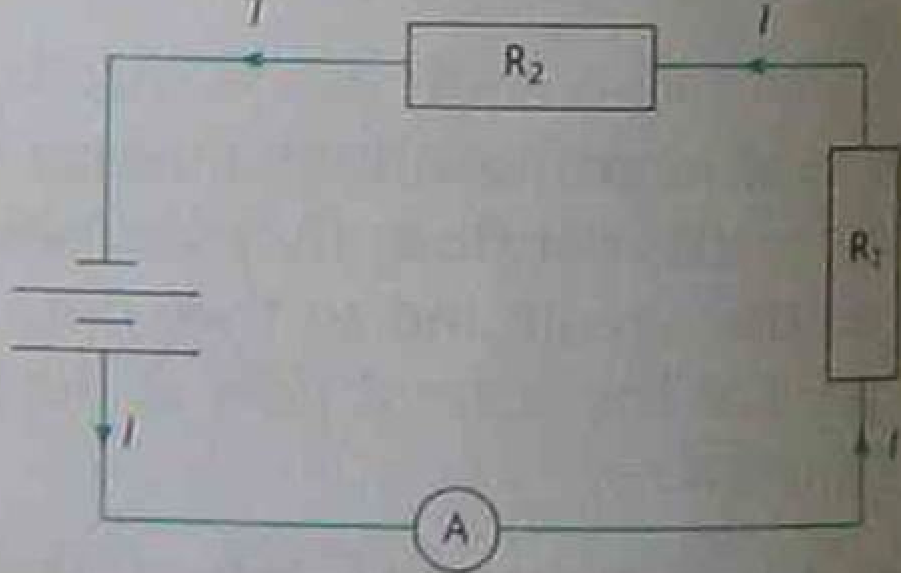


Figure 1.24 Two resistors in series

$I = \frac{V}{R}$

$I = \frac{12}{20}$

Example

$I = 0.6A$

Q An 8 Ω and a 12 Ω resistor are placed in series with a 12 V battery. Calculate:

a the current through each resistor

b the voltage drop across each resistor.

$V = I \times R$

A a Total resistance $= R_T = R_1 + R_2$

$= 8 + 12 = 20\ \Omega$

Total current $= I_T = V/R_T$

$= 12/20 = 0.6\ A$

The current flowing through each resistor is 0.6 A.

b Resistor 1: $V_1 = I \cdot R_1 = (0.6)(8)$

$= 4.8\ V$

Resistor 2: $V_2 = I \cdot R_2 = (0.6)(12)$

$= 7.2\ V$

(*Note:* $V_T = V_1 + V_2 = 4.8 + 7.2$

$= 12.0\ V$)

Parallel circuits

In simple parallel circuits the resistors are arranged so that:

- the battery supplies current to each resistor at the same time;
- the voltage drop across each resistor is the same as the voltage drop across the battery terminals;

Thus for two resistors (R_1 and R_2) in parallel:

$$V_T = V_1 = V_2.$$

- the total current which divides into each parallel resistor is equal to the sum of the currents in each resistor.

For two resistors (R_1 and R_2) in parallel:

$$I_T = I_1 + I_2.$$

Two lamps in parallel are very bright (as bright as a single lamp), but two lamps in series are dimmer. They are, however, as bright as each other. Figure 1.25 shows

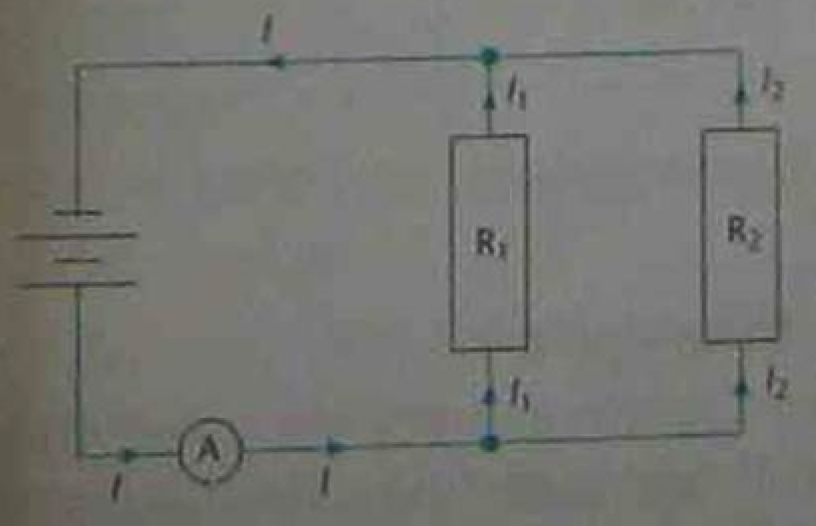


Figure 1.25 Simple parallel circuit with two resistors

a simple parallel circuit containing two resistors.

Additional content—Mathematical extension:

Example

Q A 3 Ω and a 4 Ω resistor are placed in parallel with a 12 V battery. Calculate:

a the voltage drop across each resistor

b the current flowing through each resistor

c the total current in the circuit

d the total resistance of the circuit.

A a The voltage drop across each resistor is the same as the voltage drop across the battery.

Thus: $V_T = V_1 = V_2 = 12$ V

b Resistor 1: $I_1 = V_1/R_1 = 12/3 = 4$ A

Resistor 2: $I_2 = V_2/R_2 = 12/4 = 3$ A

c The total current is the sum of the currents in each branch.

$$I_T = I_1 + I_2 = 4 + 3 = 7 \text{ A}$$

d The total resistance is the total voltage divided by the total current:

$$R_T = V_T/I_T = 12/7 = 1.71\ \Omega$$

This last calculation shows that the total resistance in a parallel circuit is less than the resistance of each individual resistor.

s in
as
s

individual resistor.

Modelling the resistance of series and parallel circuits

From the information and calculations above we can see that the total resistance of a circuit increases when the resistors are placed in series, but decreases when the resistors are placed in parallel. We can use a simple model or analogy to explain why this is so.

a. Modelling a series circuit

Figure 1.26 shows a crowd of people waiting to go into a football match at a poorly designed stadium. Initially, queuing for a ticket hinders the flow of people. Having purchased a ticket they are made to pass through one turnstile before reaching a holding area. The turnstile slows down the flow of people. Once in the holding area the fans have to move through a narrow tunnel under the stands to get to a point where they can go to their seats. The narrow tunnel also reduces the flow of people. Thus the total resistance to people flow is the sum of all the individual points of restricted flow.

$$R(\text{total}) = R(\text{ticket queue}) + R(\text{turnstile}) + R(\text{tunnel})$$

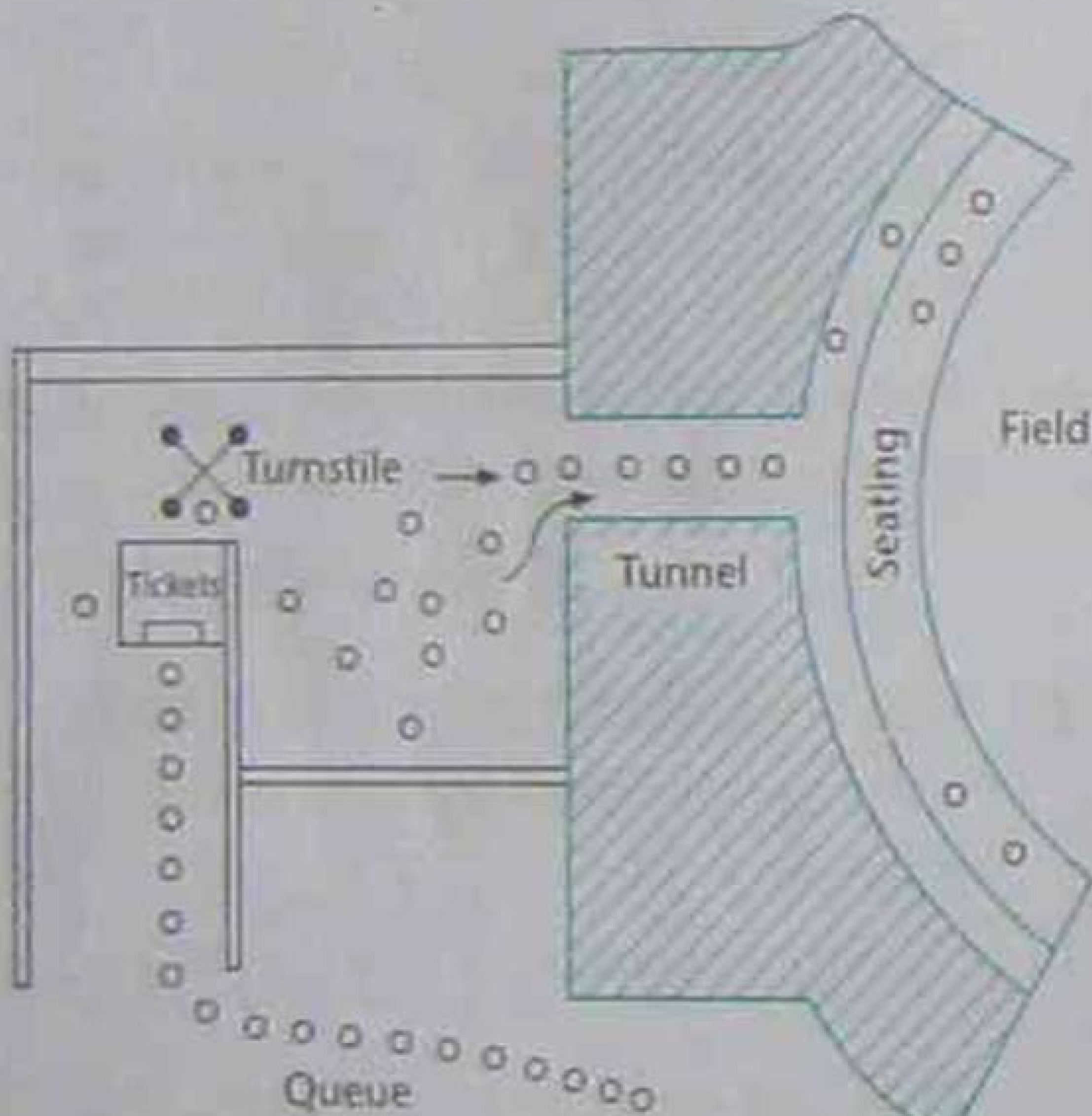


Figure 1.26 Series resistance: Modelling resistance to crowd flow at a football match

b. Modelling a parallel circuit

Figure 1.27 shows a remodelling of the football stadium access to speed up crowd movements. In the new design there are more ticket offices, to reduce waiting time for a ticket. The ticket offices are in parallel. There are also multiple parallel turnstiles so that the fans can move into the holding area faster. There are more parallel access tunnels that are wider than the old narrow tunnel to allow more people to reach their seats faster. The old narrow tunnel is still there and carries some people but the flow through it is not as great as in the wider tunnels. The wider tunnels therefore have lower resistance. The net result of these changes is a larger flow of people to their seats due to decreased resistance.

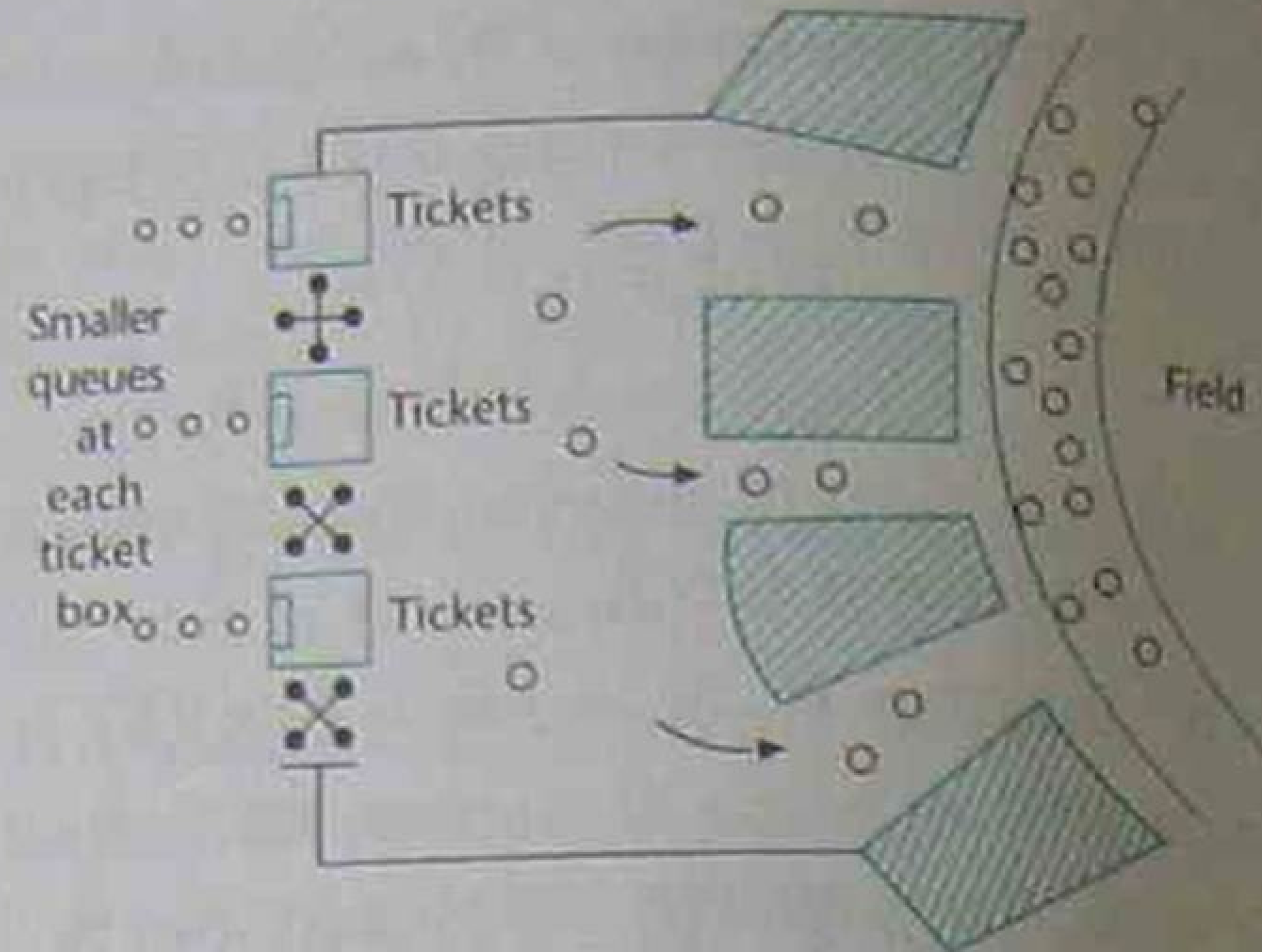


Figure 1.27 Parallel resistance: Modelling resistance to crowd flow in a redesigned stadium

c. Radiators and electric blankets

Radiators and electric blankets use resistors to generate heat. These appliances often use combinations of series and parallel circuits for the resistors to allow variable heat settings (high, medium or low). For a high heat setting the current flow must be high, and thus the resistance must be low. Low resistance is achieved by turning switches so that the resistors are in parallel. For a low heat setting the current flow must be low and thus the resistance must be high. High resistance is achieved by turning switches so that the resistors are in series.

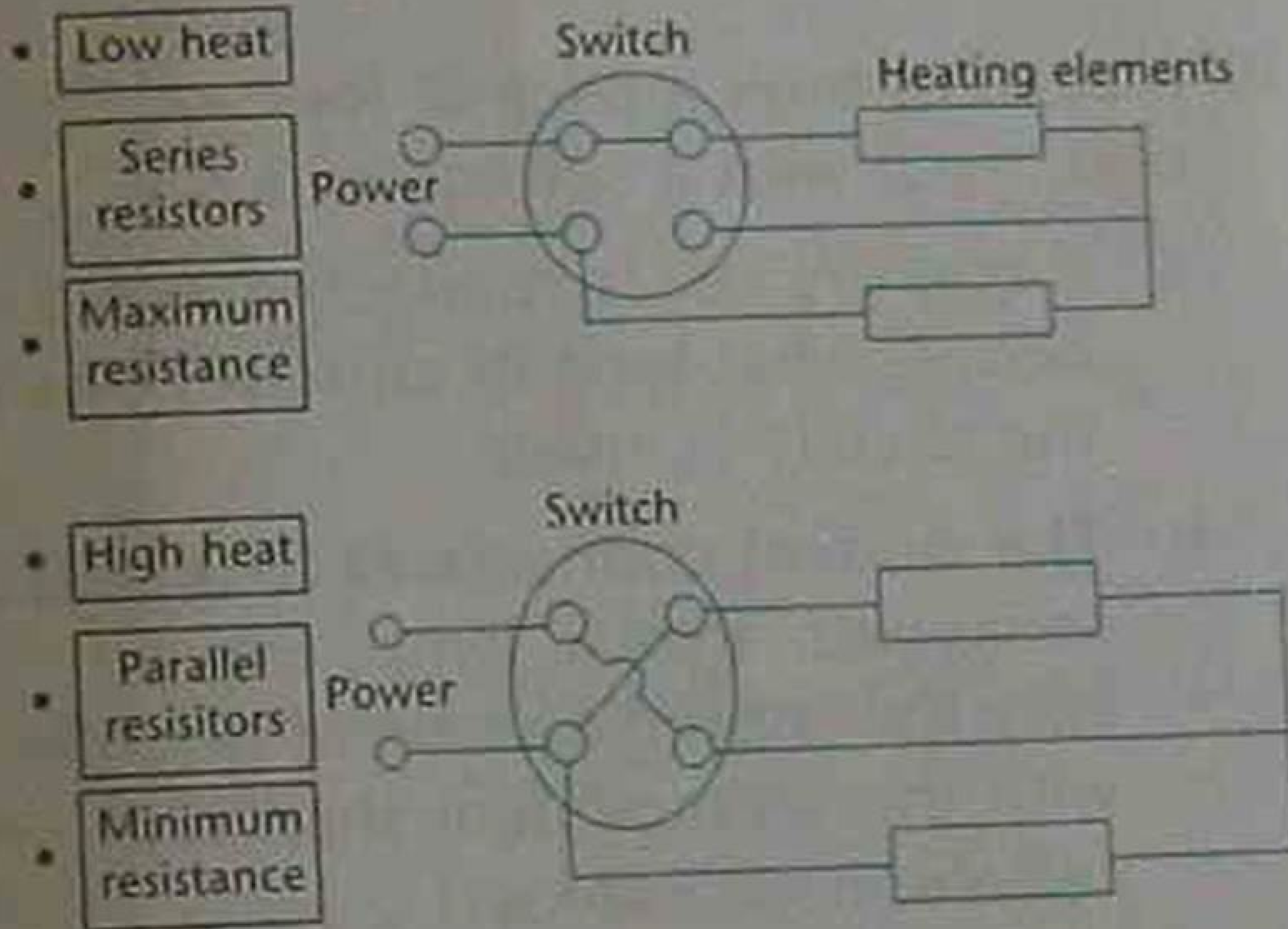


Figure 1.29 Circuits in an electric blanket

Light energy

Light is the general name given to all forms of electromagnetic waves. (See page 4.)

Our eyes are able to detect only the visible band which has wavelengths in the approximate range 400 nm (violet end) to 700 nm (red end). Photographic film or light-meters are also able to detect light.

Light is emitted from a variety of sources such as the Sun, incandescent and fluorescent light bulbs, burning materials and lasers.

Light waves travel at **very high speeds** in **straight lines.** In a vacuum, light travels at a speed of 300 000 km/s. In other materials such as water it is slowed down.

Glossary

Converge—to come together

Diverge—to spread apart

Opaque—describes a material that does not allow light to pass through it

Refraction—the bending of light rays when they pass into different media at an angle

Transmission—passage of light rays into a medium and out the other side

Translucent—describes a material that partially transmits and partially scatters light rays

Transparent—describes a material that allows light to pass through it without scattering

Absorption and reflection

In this section we examine some of the common properties of light rays. When light rays strike an object they may:

- pass straight through the material with some small loss of energy. **Transparent** materials such as window glass or the clear glass in spectacles are like this. The thicker the glass the more light energy is absorbed;

- be **partially transmitted** through the material and **partially reflected or scattered** at the surfaces. **Translucent** materials such as frosted glass in bathroom windows are like this;
- be almost completely **absorbed** so that no light emerges on the other side. **Opaque** objects such as brick walls and wood absorb most of the light rays that fall on them. Some of the light that is not absorbed is **reflected** off the surface of opaque objects. This allows us to see the object. Shiny or lustrous objects such as polished metals or mirrors reflect more light than rough surfaces. **Scattering** of reflected light from an opaque object indicates that the surface is irregular or rough.

scattering of light on reflection.

Reflection of light

A certain amount of light is always reflected from a surface that separates two different media. For example, sunlight reflects off the

- When parallel rays of light reflect off a rough surface the scattering of the rays is called **diffuse reflection**.

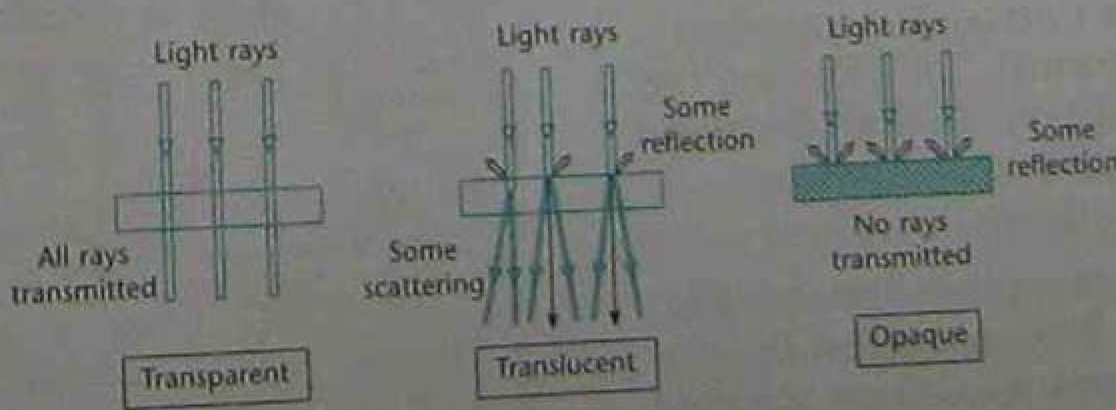


Figure 1.38 Properties of light rays

surface of window glass or off a smooth water surface. If it were not for this reflected light we could not see most objects. Only luminous objects (eg. the Sun and a candle) emit their own light, which allows us to see them. The Moon, however, does not emit its own light. We see it due to the reflection of the Sun's rays into our eyes.

- Smooth surfaces reflect light rays in one particular direction. This is called **regular reflection.**

If light from a torch is shone at an angle of 30° onto the surface of a mirror, the reflected light is brightest when viewed at 30° to the mirror's surface. (See Figure 1.39.)

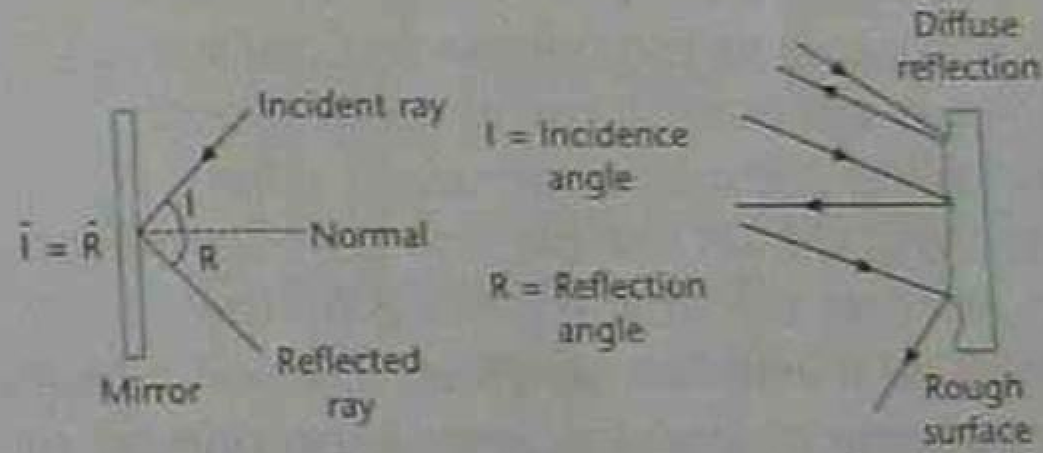


Figure 1.39 Reflection of light at an acute angle to a mirror and a rough surface

Rough surfaces cause the reflected light to be scattered in many directions. Light from a torch which reflects from a rough surface is bright when viewed from many directions. The surface of a white sheet of paper looks uniformly bright when illuminated by overhead lights, due to the scattering of light on reflection.

- When parallel rays of light reflect off a rough surface the scattering of the rays is called **diffuse reflection**.

Curved surfaces reflect light rays in a different way to flat (or plane) surfaces. Figure 1.40 shows examples of plane, concave and convex reflecting surfaces. Parallel light rays are made to **converge** when they reflect off concave mirrors, whereas with convex mirrors the rays **diverge**.

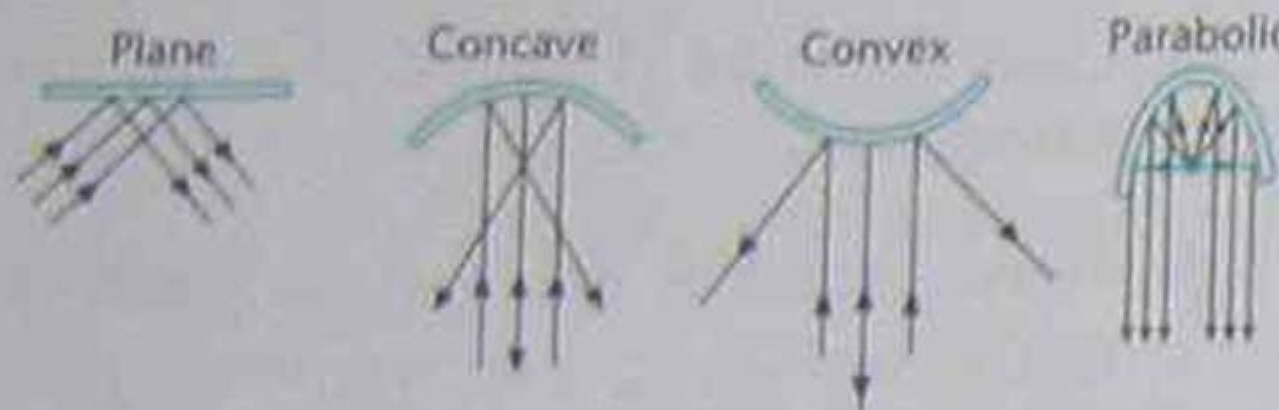


Figure 1.40 Reflection from plane, concave and convex surfaces

Plane mirrors are used in our homes in the bathroom and the bedroom. Concave mirrors are used in many applications, including telescopic mirrors to reflect starlight, dental mirrors and shaving mirrors. In all cases the image formed by the concave mirror is magnified. Convex mirrors are commonly used as rear-vision mirrors on the passenger side of a car. The images are reduced in size and the objects appear closer than they really are but such mirrors give a wide field of view. Parabolic shaped mirrors are useful in car headlights as they cause light rays to reflect off them to form parallel beams. When light rays reflect off a surface, they obey the **law of reflection**. This law states:

The angle of incidence is equal to the angle of reflection.

Figure 1.41 shows that the angle of incidence and the angle of reflection are both measured from an imaginary line at right angles to the surface. This imaginary line is called the **normal**. The incoming ray is called the incident ray. This law is obeyed when light rays reflect off any surface, including rough surfaces.

The image formed in a plane mirror is also **laterally inverted**. This means that the left side of the object now appears on the right

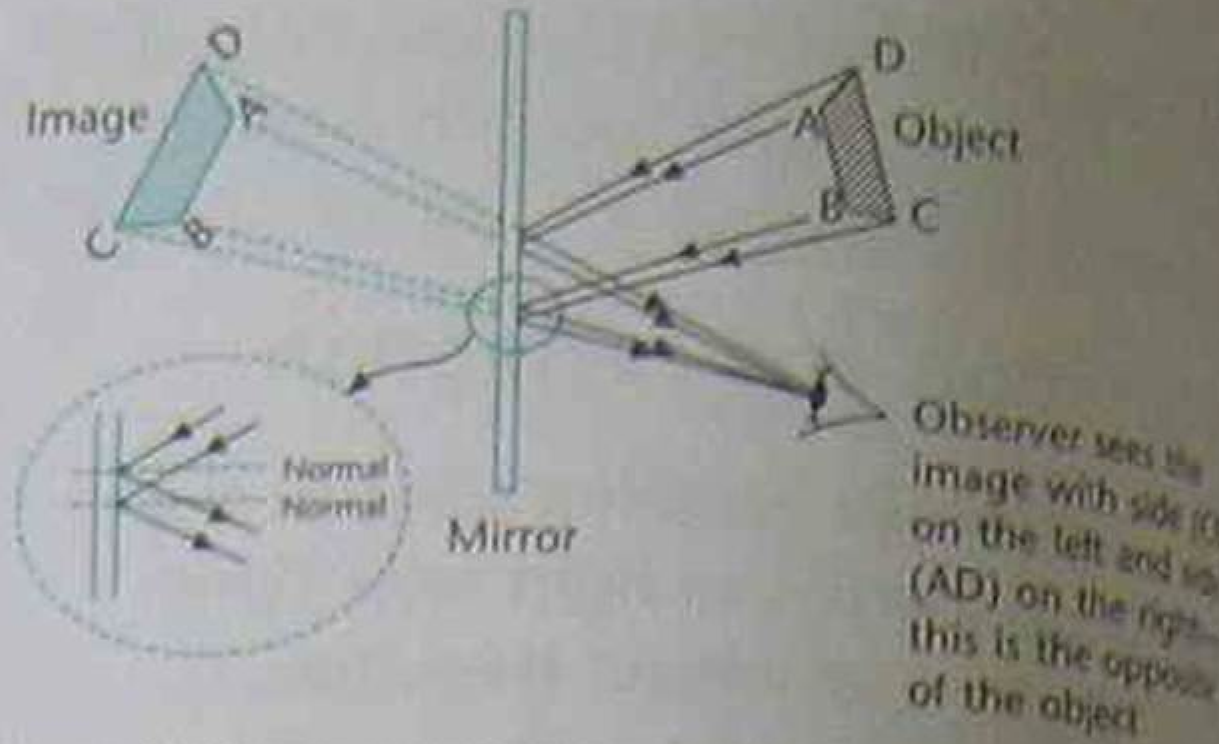


Figure 1.41 Law of reflection and lateral inversion

of the image. Because of this, some emergency vehicles such as ambulances an police cars have words written backward o the front of the vehicle so that a motorist i front can read it correctly when looking in the rear vision mirror.

Refraction

Light rays only travel at 300 000 km/s in a vacuum. In gases the speed is slightly reduced, but in liquids and transparent solids the speed of the light is considerably reduced. For example, in glass the speed drops to around 200 000 km/s.

If a ray of light passes from air into a block of glass it will slow down while in the glass. If the ray is incident at right angles to the surface, it will continue on into the glass and emerge into the air on the other side. The ray does not deviate from its original direction. If the incident ray strikes the glass surface at some other angle, the slowing of the ray while in the glass leads to a deviation or **bending** of the ray. This bending of the ray of light is called **refraction**. Figure 1.42 shows the path of two rays through a glass block.

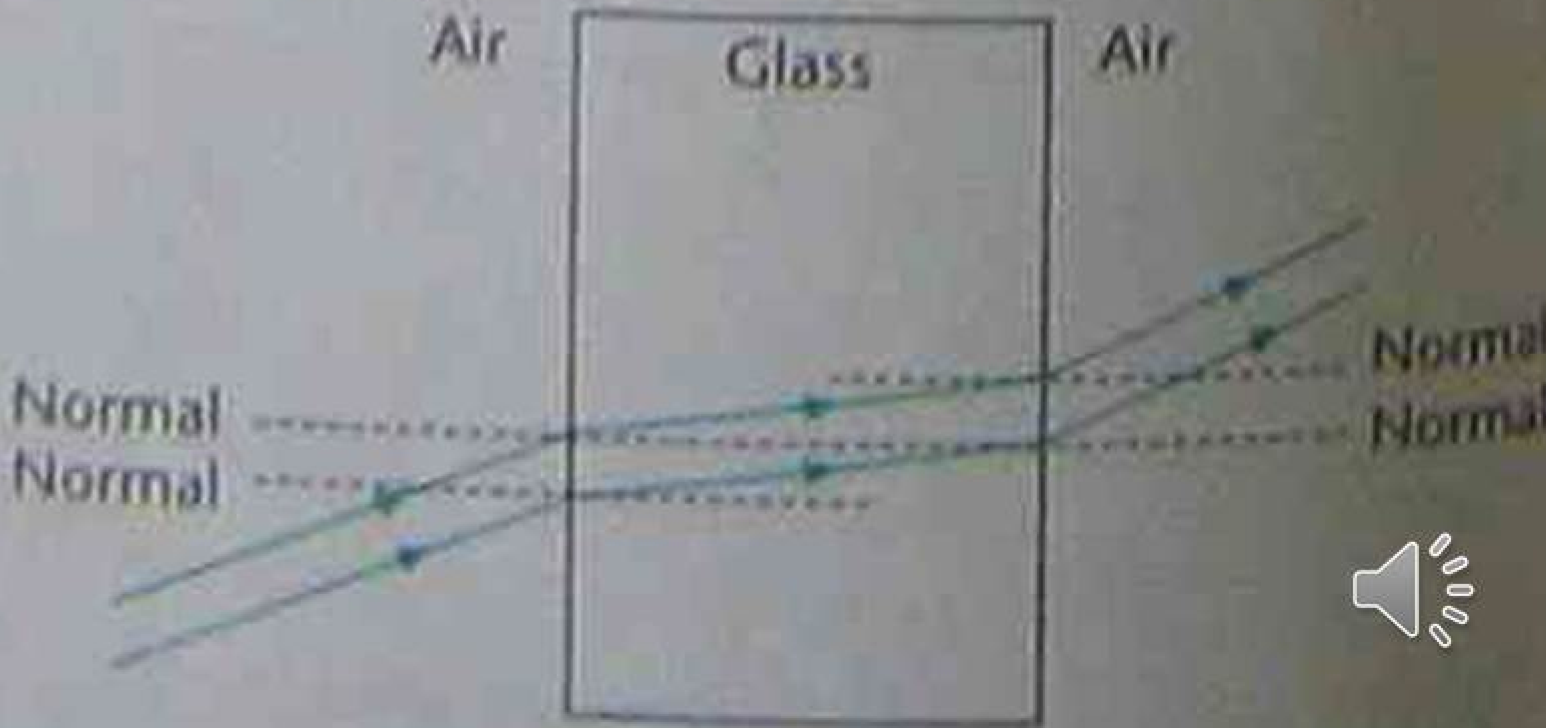


Figure 1.42 Refraction of light through a glass block

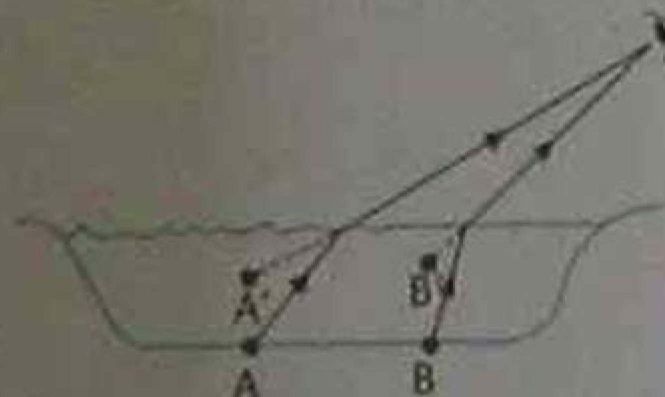
Generally when light rays are incident at an acute angle to a surface they:

- **bend towards the normal** when they pass from a less dense medium into a more dense medium (eg. from air to water, from water to glass);
- **bend away from the normal** when they pass from a more dense medium into a less dense medium (eg. from water to air, from glass to water).

The above generalisations help us to explain some common observations.

Example 1. A pool of water appears shallower than it really is

Figure 1.43 shows that the apparent depth of a pool is less than its real depth due to the bending of light rays away from the normal as they emerge from the water into the air.



Light rays appear to come from A' and B'. Thus, the depth of the pool appears less than it really is

A and B are two points on the bottom of the pond

Figure 1.43 Apparent depth of a pool of water

Example 2. The apparent altitude of the Sun

Figure 1.44 shows the bending of rays of sunlight while they pass through different layers of atmosphere. Near the ground the density of the atmosphere increases and the refraction increases. The Sun appears to be higher in the sky than it really is.

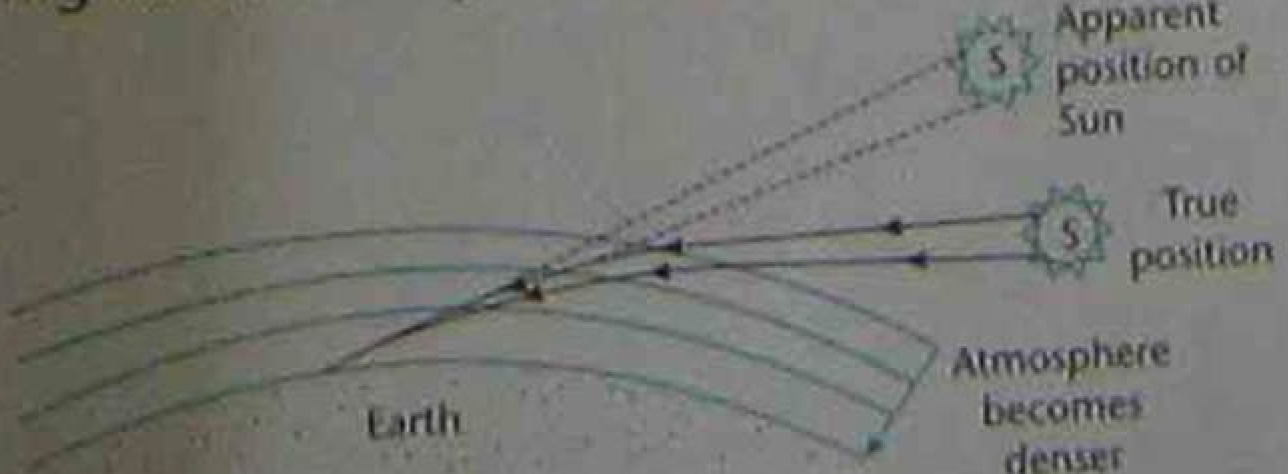


Figure 1.44 Apparent altitude of the Sun