P1 1.1

Learning outcomes

- Know that all objects emit and absorb infra red radiation.
- Know that the hotter an object is, the more infra red radiation it radiates each second.

Energy transfer by infra red radiation

Energy is transferred from the Sun to the Earth by electromagnetic waves. These waves include visible light waves and infra red waves. They can travel through a vacuum.

Infra red waves are invisible. You cannot see them, but you can feel them. When infra red waves are absorbed, they cause a heating effect. This is why you feel warm in sunlight or standing near a bonfire.

All objects transfer energy by infra red radiation. The hotter an object, the more energy it transfers each second by infra red radiation.

Figure 1.1 A passive infra red (PIR) sensor detects the infra red radiated from a warm object that passes close to the sensor. PIRs are sensitive to the infra red radiated by humans, so they are used to switch on security lights when someone walks by or to activate a burgular alarm. They can also be set off by other mammals.

Beyond the red of the spectrum

HOW SCIENCE WORKS
PRACTICAL SKILLS

Use a glass prism to split the light from a ray-box lamp into a spectrum (Figure 1.2). You will see the colours of the visible light spectrum but not the invisible infra red. Now move a thermometer slowly across the spectrum. The temperature should increase slightly as you go from blue to red. Now move the thermometer just beyond the red end of the spectrum. The thermometer is now in the infra red part of the spectrum.

1. What happens to the temperature reading when the thermometer goes from the red into the infra red part of the spectrum?
2. This experiment works even better when the thermometer has a blackened bulb. Why?

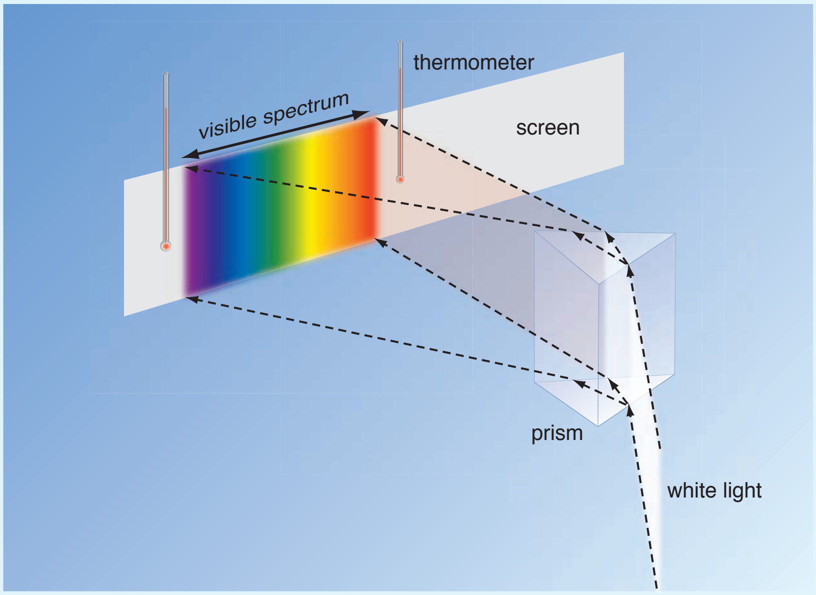

Figure 1.2 Using a prism to form a spectrum.

Test yourself

1. What type of waves transfer energy from the Sun to the Earth?
2. Which transfers infra red radiation the fastest, a mug of coffee at 80°C or an identical mug of coffee at 50°C? Give the reason for your answer.

P1 1.2

Learning outcomes

- Know that dark, matt surfaces are good absorbers and good emitters of infra red radiation.
- Know that light, shiny surfaces are poor absorbers and emitters of infra red radiation.
- Know that light, shiny surfaces are good reflectors of infra red radiation.

The effect of surface on infra red radiation

All objects **emit** (give out) and **absorb** (take in) infra red radiation. But which surfaces are better emitters and which are better absorbers?

Emitting infra red radiation

Dark-coloured matt surfaces emit infra red radiation faster than light-coloured shiny surfaces. (A matt surface is dull and non-shiny.)

Each side of the metal cube (Figure 1.3) has a different colour or texture. The cube is filled with hot water so that each side is at the same temperature. The infra red detector is used to compare the radiation emitted from the four vertical sides.

The detector gives the highest reading when opposite the matt black side of the cube, and the lowest reading when opposite the shiny white side of the cube.

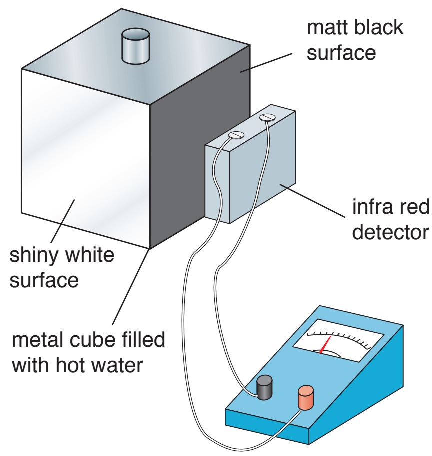

Figure 1.3 Investigating the emission of infra red radiation from different surfaces.

Absorbing infra red radiation

Objects heat up when they absorb infra red radiation more quickly than they emit it. The example given in Figure 1.4 shows that:

- dark-coloured surfaces absorb infra red radiation more quickly than light-coloured surfaces
- shiny surfaces reflect more infra red radiation than dull, matt surfaces

Objects that emit and absorb infra red radiation at the same rate have a constant temperature.

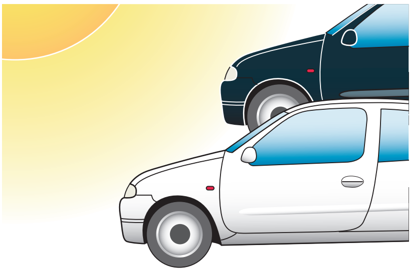

Figure 1.4 The outside metal of a dark-coloured car warms up more quickly in sunlight than the outside metal of a light-coloured car. A polished shiny car will not get as hot as an unpolished dull car.

Variables

A variable is a quantity or characteristic that can change. In any investigation there is always an independent variable and a dependent variable.

- The **independent variable** is what you choose to change.
- The **dependent variable** is what you measure to find out the effect of changing the independent variable.

These two variables can be either continuous or categoric.

- **Continuous variables** have numerical values given by either measuring or by counting. So the temperature of an object (found by measuring) and the number of sweets in a jar (found by counting) are both continuous variables.

Test yourself

3 It is important that the detector in Figure 1.3 is held the same distance from each vertical side of the cube when taking a reading. Why?

4 What happens to the temperature of an object that emits more infra red radiation than it absorbs?

5 Why are the suits worn by these firefighters bright and shiny?

Boost your grade

Lots of specialist words are used in investigations. Make sure you learn them and remember what they mean.

- **Categoric variables** have values that are given a name or label. So the colour of a surface (black or white) and surface texture (matt or shiny) are both categoric variables.

There is one other type of variable: a control variable. This is a variable that must be kept the same; it must be controlled. If it changes, it could cause the value of the dependent variable to change and alter the outcome of the investigation.

Does the intensity of infra red radiation increase as you move towards the source of radiation?

HOW SCIENCE WORKS
PRACTICAL SKILLS

To answer this question, Lee designed a simple experiment. He used a thermometer to detect infra red radiation. When the intensity of the radiation absorbed by the thermometer went up, the reading on the thermometer also went up.

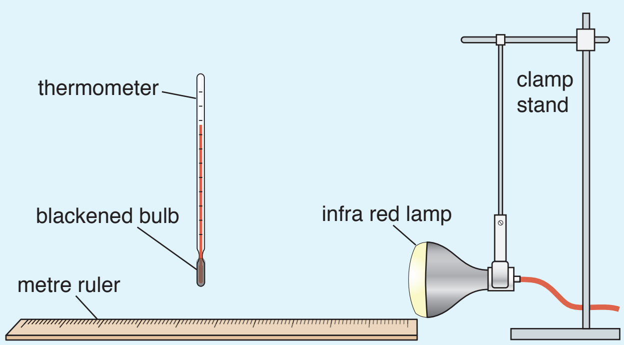

Figure 1.5 Apparatus used by Lee to investigate infra red radiation.

Lee wrote this plan for his experiment.

- Place a thermometer with a blackened bulb 60 cm in front of the infra red lamp and record the reading.
- Switch on the lamp.
- Wait for 2 minutes, then take the thermometer reading again.
- Move the thermometer 10 cm at a time towards the lamp.
- Each time the thermometer is moved, wait 2 minutes and then take the new reading.
- Repeat the experiment.

The temperature recorded before the lamp was switched on was 22°C.

The thermometer readings after the lamp was switched on are recorded in Table 1.1. These measurements are Lee's **data**.

Table 1.1 The data from Lee's experiment.

Distance from lamp	Thermometer reading First	Second	Mean
60	37	38	37.5
50	41	40	40.5
40	44	44	44.0
30	51	50	50.5
20	73	73	73.0

1. Why did Lee take the temperature before the lamp was switched on?
2. Why did Lee use a thermometer with a blackened bulb, rather than a clear bulb?
3. Why did Lee wait 2 minutes before taking each temperature?
4. Give two reasons why the second set of temperatures was not exactly the same as the first set.
5. Lee moved the thermometer 10 cm between temperature readings. What advantage would Lee gain by moving the thermometer 5 cm between temperature readings?
6. A results table should always include both the quantity measured and the unit in which the quantity is measured. What is missing from Lee's results table?
7. In an experiment, the **independent variable** is the quantity that you change. The **dependent variable** is the quantity you measure when you change the independent variable.
   a What is the independent variable in this experiment?
   b What is the dependent variable in this experiment?
   c Is the temperature a **categoric variable** or a **continuous variable**?
   d Name one **control variable** in this experiment.
8. Lee repeated the experiment in order to improve the **reliability** of the results. You can trust reliable results because they can be reproduced. Are Lee's results reliable? Give a reason for your answer.

9 The **resolution** of a measuring instrument refers to the smallest change that the instrument can detect. A thermometer that can be read to the nearest 0.1°C has a greater resolution than one that can be read to the nearest 1°C. Did the thermometer Lee used have a great enough resolution for this experiment? Give a reason for your answer.

10 Drawing a graph or putting results in a table often helps us to identify **anomalous results**. An anomalous result is one that does not fit the expected pattern. Are any of Lee's results anomalous?

11 The way in which we present results depends on the type of variable they represent. If either the independent variable or the dependent variable is categoric, the results are best presented as a bar chart. If the independent variable and dependent variable are continuous, the results are best presented as a line graph. How should the results of Lee's experiment be presented?

12 A set of results has a certain **range**. The range of results is from the smallest to the largest value.
a What is the range of Lee's temperature readings?
b How could Lee have increased the range of these results?

13 To give results that answer the question being asked, the procedure used in an investigation must be **valid**. Lee wanted to find out if the intensity of infra red radiation increases as you move towards the source of radiation. Explain why the procedure used by Lee in his experiment was valid.

P1 1.3

Learning outcome

Kinetic theory can be used to explain the differences between the three states of matter.

Every substance exists as a solid, a liquid or a gas. These are the **three states of matter**.

Figure 1.6 Ice, water and steam (water vapour) are all the same material but different states of matter. The steam is actually invisible.

Kinetic theory

Kinetic theory is a model used by scientists to explain how solids, liquids and gases behave. This theory states that all matter is made up of small particles that are constantly moving. The higher the temperature the faster the particles move. When close together the particles attract each other strongly.

In **solids** the particles are packed closely together in a three-dimensional pattern (Figure 1.7). Although the particles are constantly vibrating, they cannot move out of their fixed position. If a solid is heated, the particles vibrate faster and take up more space, which means the solid has expanded a little.

In **liquids** the particles are close together (Figure 1.8) but not in a fixed pattern. They are free to move and slide about. This means that a liquid can flow and will change its shape to fit the container it is poured into. Some particles at the surface of the liquid may have enough energy to leave the liquid and become a gas (or vapour).

In **gases** the particles are a long way apart with virtually no forces between them (Figure 1.9). This is why a gas is easy to compress. The particles are

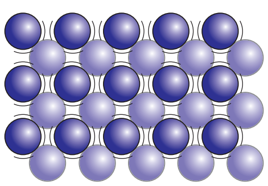

Figure 1.7 The particles in a solid are held in position by strong attracting forces.

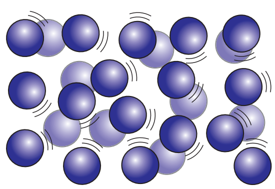

Figure 1.8 The particles in a liquid attract each other but the forces are not strong enough to hold them in a fixed pattern.

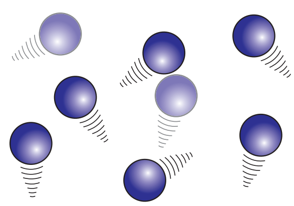

Figure 1.9 The particles in a gas have a rapid random motion. The pressure inside a gas container is caused by the particles hitting the walls of the container.

constantly moving at high speed all over the place and will quickly fill any space available to them. The particles have more energy than the particles in a liquid.

Boost your grade

The particles referred to in kinetic theory are sometimes atoms and sometimes molecules. So keep it simple and use the term particle in your answer to an exam question.

Test yourself

6 Use kinetic theory to explain why a solid is difficult to compress.

7 Compare the forces between particles in a solid with the forces between particles in a gas.

8 Copy the following sentences. Write after each sentence the state of matter that is being described.
a The particles are close together but can move to change position.
b The particles have a rapid random motion.
c The particles vibrate about a fixed position.

P1 1.4 Energy transfer by conduction

Learning outcomes

- Know that the transfer of energy by conduction involves particles.
- Know that conduction occurs mainly in solids.
- Know that metals contain free electrons and understand that this makes metals better conductors than non-metals.

If you walk around barefoot, you will notice that ceramic floor tiles feel much colder to your feet than carpet. Your feet feel cold because they are transferring energy to the tiles. This transfer of energy from your feet to the tiles is an example of **conduction**.

All metals are good conductors (Figure 1.10) but plastic, wood and glass are poor conductors. Gases are very poor conductors. Materials that are poor conductors are called **insulators**.

When one end of a metal bar is placed in a Bunsen flame, energy is quickly transferred along the bar from the hot end to the cold end. This happens because metals contain atoms and free electrons.

Figure 1.10 The four metal bars are the same size but made of different materials. The Bunsen burner heats the bars equally. The water on the best conductor boils first.

At the heated end of the metal bar (Figure 1.11), the energy from the flame:

- increases the kinetic energy of the **ions**, making them vibrate faster and with a bigger amplitude. These ions collide with their neighbours, passing on energy, so they also vibrate faster. This process transfers energy slowly through the bar.
- increases the kinetic energy of the free electrons. The rapid movement of the free electrons in the hotter parts of the metal is transferred via collisions to adjacent electrons and

Atoms that have lost an electron are called **ions**.

Test yourself

9 Why is it important that the metal bars in Figure 1.10 are all the same size?

ions. These, in turn, transfer energy to other electrons and ions and so energy is rapidly conducted through the metal.

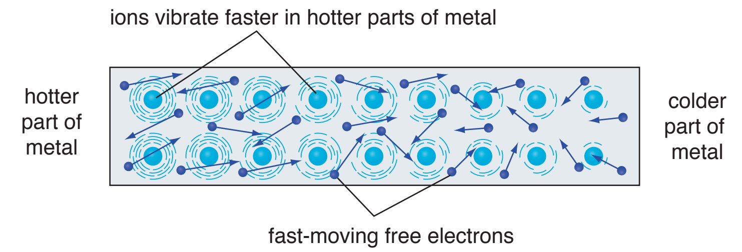

Figure 1.11 Conduction through a metal involves ions and free electrons.

Energy is transferred along a metal bar by a series of collisions between neighbouring ions and by the movement of free electrons.

In an insulator there are no free electrons. In these materials, the transfer of energy relies on the collisions between neighbouring atoms (Figure 1.12). This is usually a very slow process.

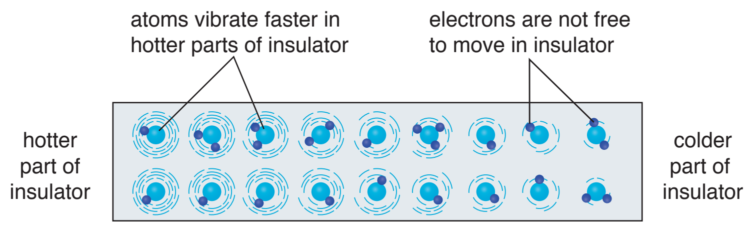

Figure 1.12 Conduction through an insulator relies on atoms only.

Test yourself

10 Daisy rides her bicycle to school. One day during the winter she notices that the rubber handlebar grips feel warm but the metal frame feels cold. Explain why.

11 Why are non-metals better insulators than metals?

Testing different insulators

HOW SCIENCE WORKS
PRACTICAL SKILLS

To compare different insulating materials, you can measure how fast the temperature of a beaker of hot water decreases. Wrap a beaker with an insulating material. Pour hot water into the beaker and take its temperature. Wait 10 minutes and then take the temperature of the water again. You can then repeat the experiment with a different type of insulating material. Each time you test a different material you must make sure that the volume and temperature of the water poured into the beaker is the same.

1. What type of variable is the volume of water?
2. What is the independent variable?
3. Is the independent variable continuous or categoric?
4. How should you use the data to tell which material is the best insulator?
5. Give an advantage of using a temperature sensor and data logger rather than a thermometer.

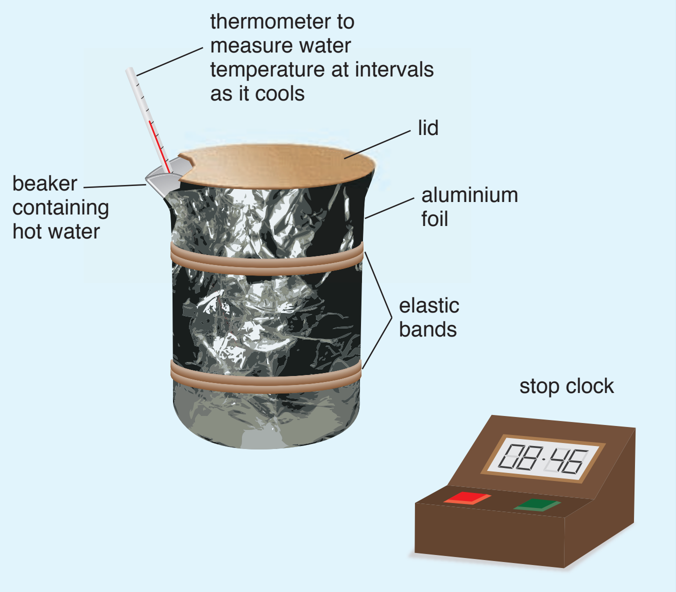

Figure 1.13 One way to compare different insulating materials.

P1 1.5

Learning outcomes

- Know that the transfer of energy by convection involves particles.
- Know that convection occurs in liquids and gases.

Figure 1.14 Some birds use the rising hot air of a convection current to soar into the sky.

Boost your grade

To explain how convection happens in air, just change the word 'water' to 'air' and 'flask' to 'room'. Don't learn a whole new explanation.

Test yourself

12 Energy cannot be transferred through a solid by convection. Why not?

13 Explain why smoke detectors are fitted to the ceiling of a room and not to the floor.

14 Why are hot taps connected to the top of the hot water tank?

15 Explain how a convector heater warms a room.

Energy transfer by convection

Convection occurs when a **fluid** is heated. A fluid is a liquid or a gas.

During convection, the warmer fluid moves, transferring energy from the warmer to the cooler part of the fluid.

Figure 1.15 shows what happens when water is heated.

As the water at the bottom of the flask is heated, the water particles (in this case molecules) gain energy. This extra energy causes:

- the particles to move around each other faster
- the particles to move apart and take up more space
- the water in the warmer region to expand
- the warm water, as it expands, to become less dense than the cooler water around it
- the less dense warm water to rise

As the warm water rises, cooler water flows in to replace it. This water then gets heated and also rises. These movements of hot and cold water, due to changes in density, are called **convection currents**. Convection currents stop when all parts of the water are at the same temperature.

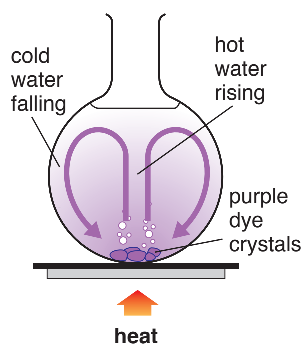

Figure 1.15 Convection currents transfer energy through a heated liquid.

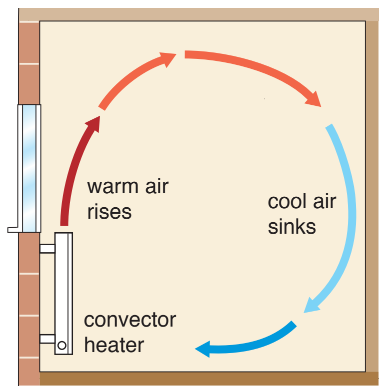

Figure 1.16 A convector heater creates an airflow in a room. Energy is transferred by convection through the air in the same way as through water.

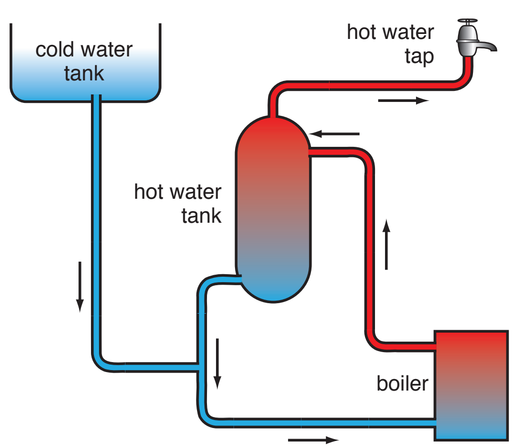

Figure 1.17 Hot water systems in most homes use convection currents. Water heated in the boiler rises and is stored in the hot water tank. Cooler water falls to replace the hot water that has gone from the boiler. When you turn on a hot water tap or a power shower at home, the hot water comes from the top of the tank.

P1 1.6 Energy transfer by evaporation and condensation

Learning outcomes

- Know that a liquid can change state by evaporation.
- Know that evaporation has a cooling effect.
- Know that a gas can condense back into a liquid.

Evaporation happens when a liquid changes into a gas without boiling.

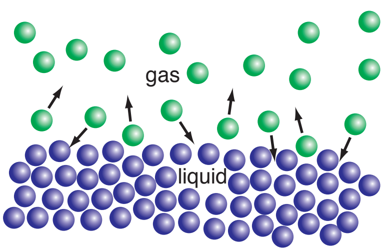

Figure 1.19 The fastest particles can escape from the surface of the liquid but some of these particles will fall back in.

Figure 1.20 Having wet skin can soon make you feel cold. Why?

Figure 1.21 Sweating keeps you cool. Sweat is mainly water. When your sweat evaporates, it takes energy from your body. If the weather is very humid, your sweat cannot evaporate as fast, so you feel hot and 'sticky'.

Water does not have to be boiling to change into an invisible gas (water vapour). Even on a cold day wet roads will dry after the rain stops, and water will disappear from a birdbath. The water is not boiling away — it is **evaporating**.

We can explain evaporation using **kinetic theory**. Some of the particles in a liquid have more kinetic energy than others. Particles with more kinetic energy move faster. If one of the faster particles is close to the liquid surface, it may have enough energy to break away and escape from the liquid (Figures 1.18 and 1.19).

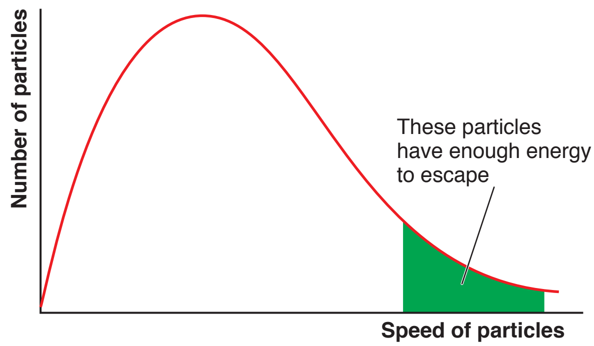

Figure 1.18 The particles in a liquid have a range of speeds. The particles with the highest speeds have enough energy to evaporate.

Liquids can be made to evaporate faster by:

- **increasing the temperature**. This increases the energy and speed of the particles. So more particles have enough energy to escape from the liquid.
- **increasing the surface area**. There will be more of the fastest particles next to the surface. So more particles will be able to escape from the liquid.
- **having a draught or wind**. Some particles that escape from the liquid immediately fall back in again (Figure 1.19). A draught or wind will take many of the escaping particles away from the liquid surface before they fall back in.
- **reducing the humidity**. Damp air has a high humidity. This means that the air contains a lot of water vapour. So particles in the water vapour fall back into the liquid at almost the same rate as particles escape from the liquid.

Evaporation causes cooling

When a liquid evaporates it loses its fastest particles, the ones with the most energy. The average energy of the particles left behind is less than before. The lower the average energy, the lower the temperature.

Condensation

Condensation occurs when a gas changes back into a liquid.

If you leave a saucepan of water boiling, you may soon see water running down the kitchen walls or the windows. This is condensation. When the damp air hits a cold surface, it cools and some of the water vapour in the air changes back into a liquid.

Water vapour in the atmosphere condenses to form clouds, fog or mist.

Investigating the effects of a draught on the rate of cooling

HOW SCIENCE WORKS
PRACTICAL SKILLS

Figure 1.22 shows one way that the cooling effect caused by evaporation can be investigated. The greater the cooling effect, the faster the temperature of the sensor falls.

1. Which of the temperature sensors cooled the fastest and why?
2. Why was an uncovered sensor not in a draught included in the investigation?

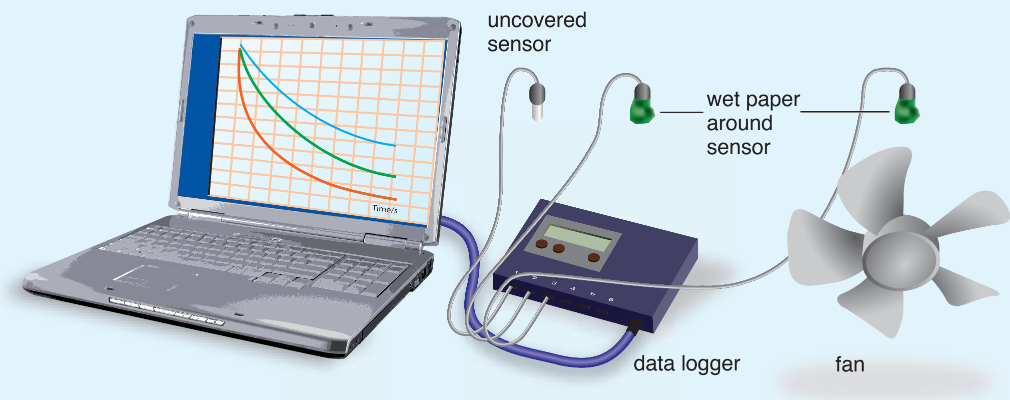

Figure 1.22

Test yourself

16 A take-away mug of coffee stays hot for longer if the mug has a lid. Explain why.

17 Give two ways to reduce the rate of evaporation from a liquid.

18 Fog often forms close to a river. Why?

A **risk assessment** is used to identify possible hazards, the risks they pose to you and to others and what can be done to reduce the risks. For example, hot metal can cause burns. To reduce the risk, the metal can be handled with tongs.

Choosing a coolant

HOW SCIENCE WORKS
PRACTICAL SKILLS

Plan an investigation to show that water is a much better coolant than air for car engines? Think about how you can model a hot engine (perhaps using a metal block) and include a **risk assessment**.

P1 1.7

Learning outcomes

- Know that under similar conditions different materials transfer energy by heating at different rates.
- Understand that the temperature of an object and the temperature of the surroundings affect the rate of energy transfer by heating to or from the object.

Figure 1.23 Cooling fins help to lower the temperature of the motorbike engine. They do this by greatly increasing the surface area of the engine, allowing more cooling air to come into contact with more hot metal. This increases the energy loss through convection in the air and through radiation.

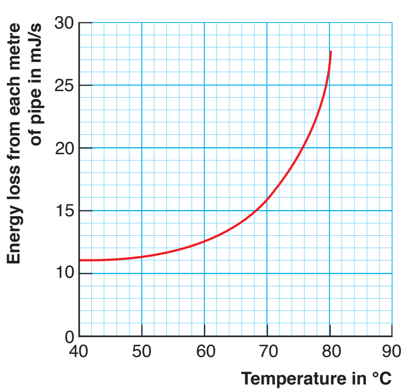

Figure 1.24 The energy lost each second from a hot water pipe increases as the temperature difference between the pipe and the surrounding air increases.

The rate of energy transfer by heating

The rate at which an object transfers energy by heating depends on:

- the type of material the object is made from
- the shape of the object
- the dimensions (size) of the object
- what the object is touching
- the difference in temperature between the object and its surroundings

Type of material

Two hot objects of the same size and shape but made from different materials may start at the same temperature but after a few minutes their temperatures will be different. The two objects will transfer energy and cool down at different rates.

Surface area and volume

The rate of energy transfer from an object depends on its surface area. Increasing the surface area by changing the shape of the object will increase the rate of energy transfer (Figure 1.23).

The rate at which the temperature of a hot object falls (or a cold object rises) depends on its surface area-to-volume ratio.

In general, for objects of the same shape, the rate of temperature change increases as the volume decreases. This means that smaller objects cool down faster than larger ones.

What the object is touching

When an object is touching a conductor it will lose energy faster than when it is touching an insulator. In a building, energy loss is reduced by using insulating materials (see Section 1.9).

Temperature of the surroundings

The bigger the temperature difference between an object and its surroundings, the faster the rate at which energy is transferred (Figure 1.24).

Test yourself

19 Figure 1.25 shows three ball bearings in a beaker of hot water.
The ball bearings are left to reach the same temperature as the water. They are then taken out and placed on a table.

a Which ball bearing cools down most slowly? Give the reason for your choice.

b How would the rate of cooling of the ball bearings change if instead of being placed on a table they had been put in a refrigerator?

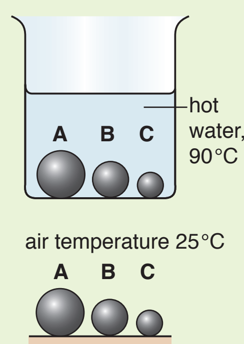

Figure 1.25

P1 1.8

Learning outcomes

- Understand that the design of an appliance can reduce or increase energy transfer by conduction, convection and radiation.
- Explain how animals are adapted to cope with their environment.

Changing the rate of energy transfer by design

How does a vacuum flask keep hot drinks hot or cold drinks cold?

A vacuum flask keeps drinks hot (or cold) by slowing the energy transfer by conduction, convection and radiation.

A vacuum flask (Figure 1.26) slows down energy transfer by having:

- a vacuum between the double walls of the container — this reduces energy transfer by conduction and convection
- walls with shiny surfaces — this reduces energy transfer by infra red radiation
- a stopper made of a good insulator such as cork or plastic — this reduces energy transfer by conduction. The stopper also reduces energy transfer by convection.

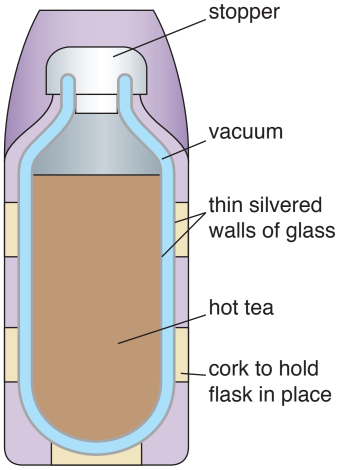

Figure 1.26 A vacuum flask is designed to reduce energy transfer.

Heat sinks

The heat sink inside a computer is a metal sheet with a lot of vertical fins (Figure 1.27). This gives a large surface area from which to lose energy. The cooling unit also has a small electric fan. This increases the flow of air over the components and the heat sink.

The radiator in a car is another example of a type of heat sink.

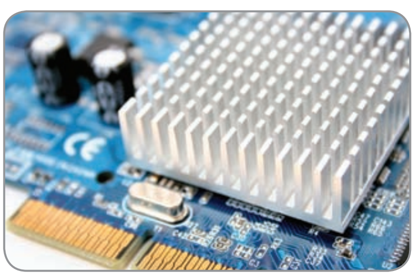

Figure 1.27 The cooling unit inside a computer is designed to stop the electronic components from overheating.

Coping with the cold

Animals and humans cope with the cold in various ways. Seals have a thick layer of fat all around their bodies. Fat is a good insulator, so it reduces the rate of energy transfer from the seal.

Air is a good insulator. Animal fur traps pockets of air. On a cold day an animal will fluff up its fur to trap more air. In this way, it can stay warm even in very cold weather.

Humans wear clothes to keep warm. When it is very cold, it is a good idea to put on several layers of clothes. Air is then trapped between the layers as well as in the fabric of the clothes. The trapped air reduces energy loss by conduction and convection.

In winter you might put extra blankets on your bed, or use a duvet with a higher tog rating. The tog rating of a duvet or sleeping bag is a measure of how good it will be at keeping you warm. The higher tog rating the warmer it will keep you.

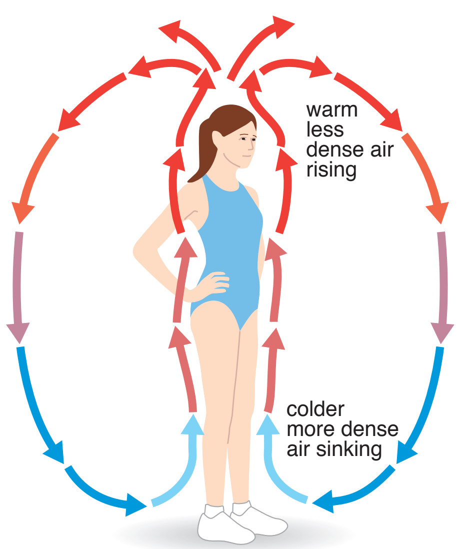

Figure 1.28 Without clothes we would lose a lot of thermal energy by convection.

Figure 1.29 A bird fluffs out its feathers to trap small pockets of air. Since air is a poor conductor, the bird stays warm.

Figure 1.30 Arctic foxes live in cold snowy places where it is important not to lose thermal energy.

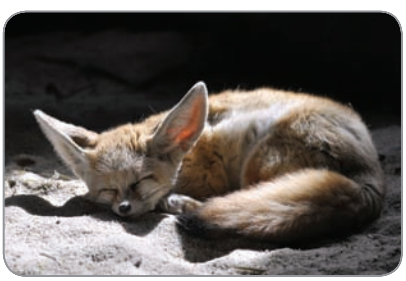

Figure 1.31 Desert foxes live in a hot environment where overheating could be a problem.

Table 1.2 Choosing the right tog rating will keep you warm all year round.

Type of duvet	Tog rating
Summer lightweight	4.5
Spring and autumn mid-weight	9.0–11.0
Winter heavyweight	12.0–14.0

If you were guessing what tog ratings are measured with, you might guess a togmeter — and you would be right! This device measures the tog rating of different duvets and sleeping bags from different manufacturers in the same way and to the same standard.

Animal adaptations

Unlike humans, animals cannot take clothes on and off depending on the weather. So different types of animal have features that enable them to survive in the environment that they live. The animals have adapted to their environment.

Arctic foxes (Figure 1.30) can survive in cold conditions because they have:

- a thick layer of body fat, which is a good thermal insulator
- a rounded, compact body with small furry ears, so a low surface area-to-volume ratio
- thick, furry foot pads to insulate against the cold ground

Now compare an Artic fox with a desert fox (Figure 1.31), an animal than can survive in a hot environment.

- The desert fox has a smaller body with large ears, up to 15 cm long. This gives the desert fox a large surface area from which to lose energy.
- The sandy coloured fur helps to reflect infra red radiation.
- Like the Arctic fox, the desert fox has thick furry foot pads, this time to insulate against the hot desert sand.
- The desert fox also has thick fur, which may seem odd but it can get very cold in the desert at night.

Test yourself

20 What feature of a vacuum flask is designed to reduce energy transfer by radiation?

21 A manufacturer produces two different duvet weights. One has a tog rating of 4.5, the other a tog rating of 9.5. Explain why these two duvets are suitable for using all year round.

22 Why is it important that all tog ratings are measured in the same way and to the same standard?

23 Why do Arctic foxes have small ears and desert foxes have large ears?

P1 1.9

Learning outcomes

- Understand that insulation reduces the transfer of energy from a building.
- Know that the U-value measures how effective a material is as an insulator.
- Know that infra red radiation from the Sun can be used to heat buildings or to provide hot water.

Energy transfer and buildings

Keeping your home warm

Keeping your home warm is not just about turning on the central heating or lighting a fire. It's also about reducing the amount of energy transferred from inside your home to the air outside (Figure 1.32).

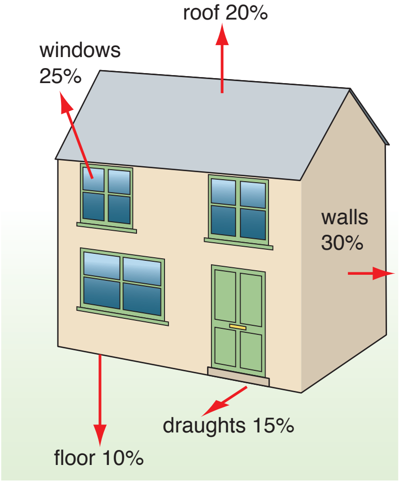

Figure 1.32 The proportions of thermal energy lost from an uninsulated house through the roof, the walls, the windows, the floor and as draughts around the doors and windows.

Reducing energy loss involves trying to stop conduction and convection. Figure 1.33 shows some of the methods used to reduce the energy loss from our homes.

Most methods of reducing energy loss work by trapping air. If air is trapped in small pockets, it cannot move far, so energy loss by convection is greatly reduced. This trapped air is also a good insulator, so energy loss by conduction is reduced (Figure 1.34).

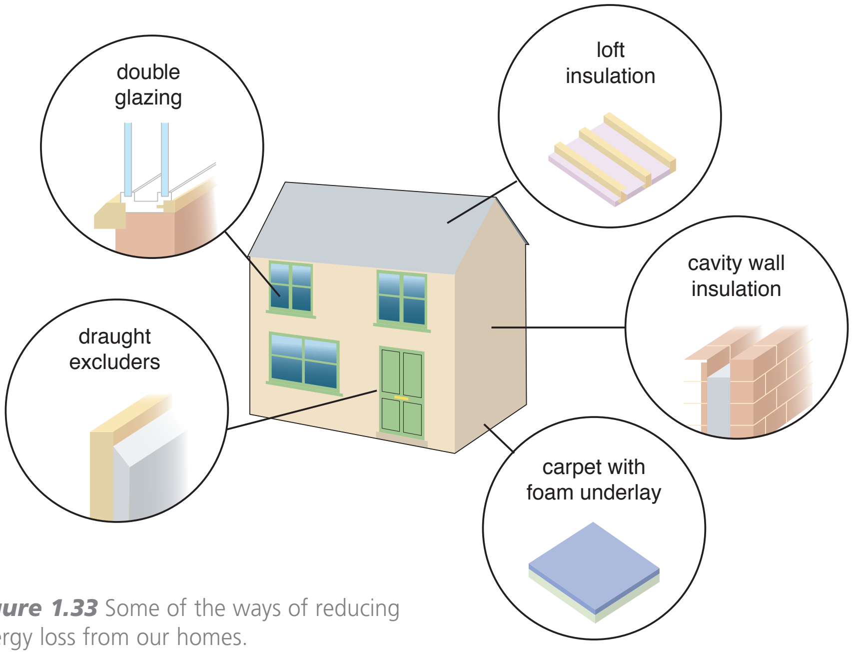

Figure 1.33 Some of the ways of reducing energy loss from our homes.

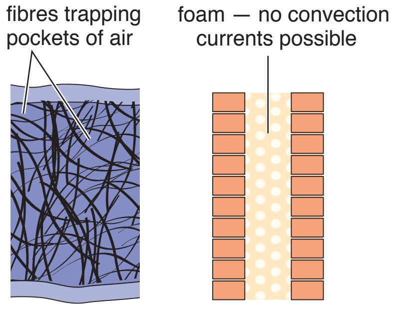

Figure 1.34 Air trapped by fibre wool and by foam reduces energy loss by convection and conduction.

Double-glazed windows have two sheets of glass with air, or an air and argon mixture, in between. The air, argon and glass are good insulators, so very little energy is lost by conduction. To keep energy loss by convection low, the gap between the two sheets of glass must be thin. Some types of glass are given a special coating that reflects infra red radiation back into the house.

Draught excluders keep warm air inside the house and stop cold air getting in.

Table 1.3 Typical U-values. The lower the U-value, the better the insulation provided by the material.

	U-value in W/m² °C
Solid brick wall	2.0
Wall with cavity insulation	0.3
Single-glazed window	5.0
Double-glazed window	1.8
Tiled roof, no insulation	2.0
Tiled roof with insulation	0.2

Boost your grade

Don't try to remember any U-values or the unit for U-value. If you need to compare materials, U-values will be given to you in the question.

Figure 1.36 This house has solar panels fitted to the roof. They are used to provide hot water. Why is it better if the solar panels face south rather than north?

U-value

U-values measure how good a material is as an insulator. A material with a low U-value provides good insulation, helping to keep thermal energy inside the building.

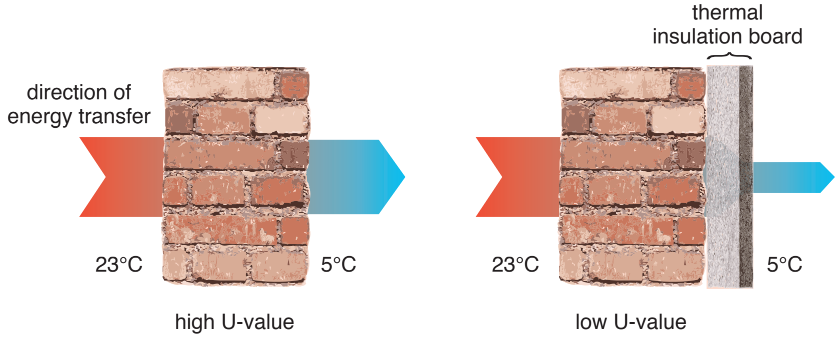

Figure 1.35 A high U-value means that energy will be transferred rapidly through the wall.

Solar panels

Solar panels use energy radiated by the Sun to provide hot water. Even in the UK a solar panel can provide all the hot water needed by the average family during the summer, and in the winter it still helps to heat the water. Large solar panels can also provide hot water for a central heating system. Unfortunately in the UK, this is usually only in the summer when you don't need the heating on.

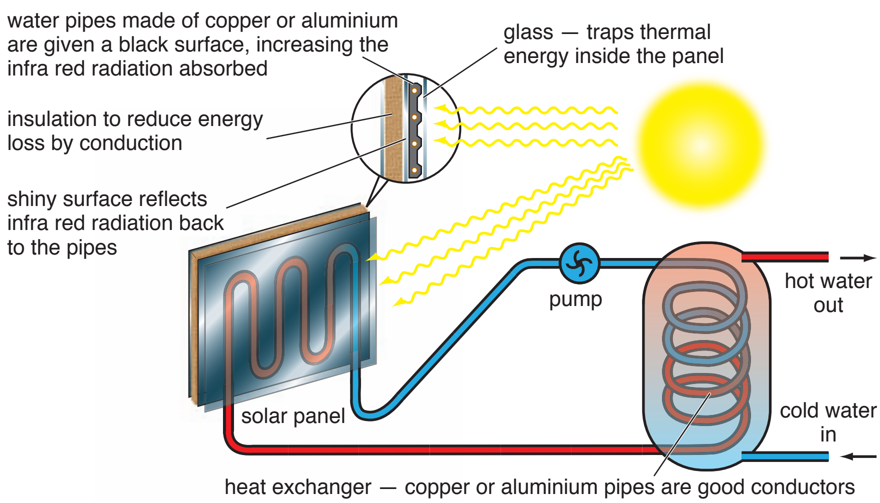

Figure 1.37 Important features of one type of solar panel water heater.

Test yourself

24 Give three ways of reducing the energy transfer from a house.
25 By what method does energy transfer through glass?
26 Why are the heat exchanger pipes inside hot water tanks made from copper or aluminium?
27 Why is the pipe inside a solar panel as long as possible?
28 Why is it usual for hot water tanks to have an electric immersion heater fitted, or to be connected to a boiler?

P1 1.10

Learning outcomes

- Know that the same mass of different substances at the same temperature store different amounts of energy.
- Understand that different materials have different uses depending on their specific heat capacity.

Boost your grade

There is a definition of specific heat capacity but you do not need to know it for the exam. You do need to know the unit: J/kg °C.

Table 1.4 The specific heat capacity of some common substances

Substance	Specific heat capacity in J/kg °C
Water	4200
Oil	1800
Brick	840
Aluminium	900
Steel	500
Copper	380

Boost your grade

In the exam all the equations will be given to you on a sheet so you do not need to learn them. But you must be able to find the right equation to use.

Test yourself

29 What is the specific heat capacity of concrete?

Specific heat capacity

Water needs a lot more energy to increase its temperature by 1°C than the same mass of concrete. This also means that when water cools by 1°C, it will give out more energy than the same mass of concrete cooling by 1°C.

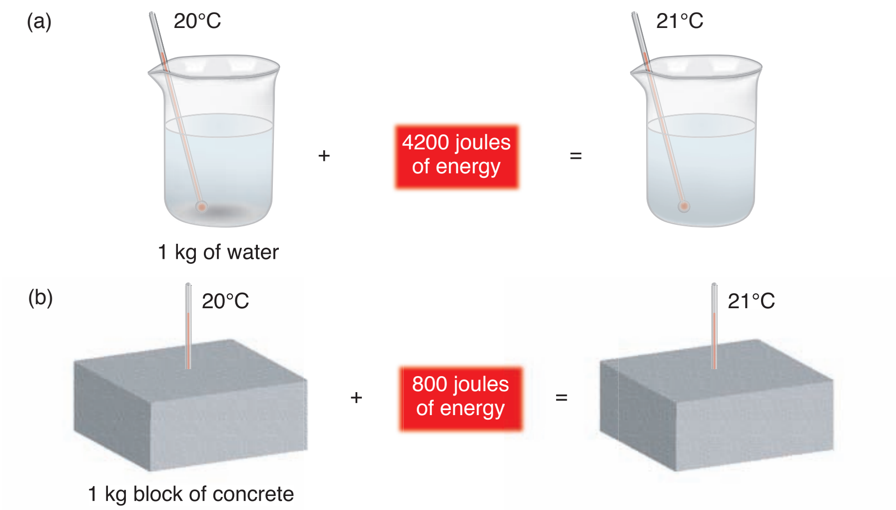

Figure 1.38 (a) 4200 joules of energy are needed to increase the temperature of 1 kg of water by 1°C. (b) 800 joules of energy are needed to increase the temperature of 1 kg of concrete by 1°C.

We say that water has a higher **specific heat capacity** than concrete. The specific heat capacity of water is 4200 joules/kilogram degree Celsius (J/kg °C).

This means that, to increase the temperature of 1 kilogram of water by 1° Celsius, you need to transfer 4200 joules of energy to the water.

The high specific heat capacity of water is the reason why water is so good at storing energy. The higher the specific heat capacity of a substance, the more energy it absorbs to give a 1°C rise in temperature.

The amount of energy needed to increase the temperature of an object can be calculated using the equation $E = m \times c \times \theta$:

E	=	m	×	c	×	θ
energy transferred	=	mass	×	specific heat capacity	×	temperature change
(joules, J)		(kilograms, kg)		(J/kg °C)		(degrees Celsius, °C)

This equation can also be used to calculate the energy lost when an object cools down.

Worked example

An electric kettle is used to boil 0.5 kg of water. The temperature of the water starts at 20°C and the kettle switches off as soon as the water reaches 100°C. Calculate the amount of energy transferred to the water.

temperature change (θ) = 100 – 20 = 80°C

$E = m \times c \times \theta$

$E = 0.5 \times 4200 \times 80$

$E = 168\,000$ joules

Measuring the specific heat capacity of a metal block

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You can use the equipment shown in Figure 1.39 to measure the specific heat capacity of a substance, in this case a block of metal. The block has holes to take the immersion heater and thermometer. Before switching the heater on, take the temperature of the block and measure its mass. Switch the heater on for 15 minutes and then take the temperature of the block again. Write down how much energy has been transferred to the heater in the 15 minutes it was switched on.

You should now have all the data you need to calculate the specific heat capacity of the metal.

1 Give two reasons why the value you get for the specific heat capacity is not going to be very accurate.

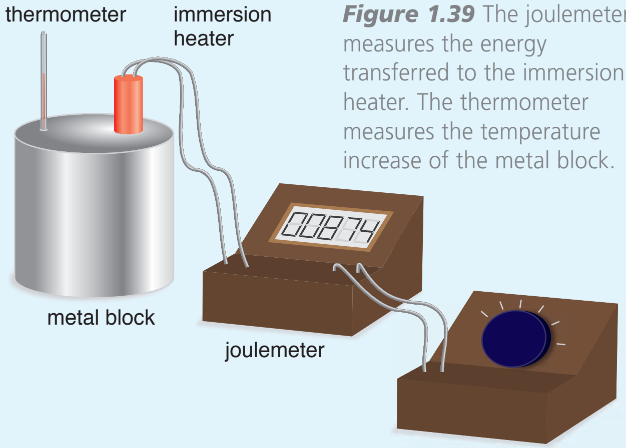

Figure 1.39 The joulemeter measures the energy transferred to the immersion heater. The thermometer measures the temperature increase of the metal block.

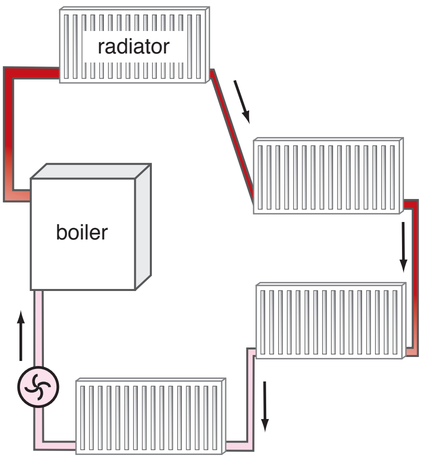

Figure 1.40 In a central heating system water is used to transfer energy from the boiler to the radiators.

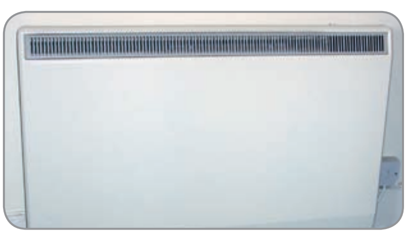

Figure 1.41 Electric night storage heaters containing concrete store energy as they heat up overnight. During the daytime, the concrete cools down, transferring thermal energy to the room.

Making use of specific heat capacity

In a central heating system water is heated in a boiler then pumped through pipes to the radiators (Figure 1.40). As the water cools in a radiator, energy is transferred into the room. The high specific heat capacity of water means that when the water reaches the last radiator in the system it is still hot enough to heat that radiator and the room it is in.

Electric night storage heaters use concrete, not water, to store energy (Figure 1.41). Concrete has a lower specific heat capacity than water so it stores less energy than the same mass of water heated to the same temperature. So why use concrete?

Because concrete has a higher density than water, it takes up less space than the same mass of water. So the heaters can be made smaller and take up less space in a room.

The cooling system for a car engine uses circulating water to remove energy from a hot engine. From the car engine the heated water passes to the radiator where the energy is transferred to the air. The cooler water now goes back to the engine. The high specific heat capacity of the water means that each time the water circulates through the engine it absorbs and removes a lot of energy.

Test yourself

30 Portable electric radiators are often filled with oil and not water. How fast would an oil-filled radiator heat up compared with a radiator of the same size containing water?

31 How much energy must be transferred to a 2 kg block of aluminium to increase its temperature from 20°C to 70°C?

32 In cooling from 100°C to 20°C a block of copper transfers 15 200 joules of energy to the surrounding air. Calculate the mass of the copper block.