Energy
Work *and* Heating and cooling

Ideas you have met before

Energy stores and transfers

Energy is transferred when changes happen, and this transfer can happen in different ways. Energy may be transferred from place to place in a material or from one form of storage to another.

The quantity of energy transferred in a change can be measured.

When elastic materials are stretched or squashed they have more energy stored in them.

Using simple machines

Levers enable a small force to have a greater effect. For example, you could use a screwdriver to lever a lid off a paint can, applying a greater force than with your bare hands.

Pulleys and gears also allow us to transfer forces in much more effective ways.

Thermal energy

Conduction and radiation are important ways of moving energy from place to place.

In this chapter you will find out

Doing work

- Work is done and energy transferred when a force moves an object. The bigger the force or distance, the greater the work.

Using machines

- Machines make work easier by reducing the force needed. Levers and pulleys do this by increasing the distance moved, and wheels reduce friction.
- A lever works through a fulcrum to multiply a force.
- By working out the size of turning forces we can make sure that structures balance.

Thermal energy

- The thermal energy of an object depends upon its mass, its temperature and what it's made of.
- Fuels are chemicals that transfers energy by burning.
- Different fuels store and transfer different amounts of energy.

Transfer of thermal energy

- When there is a temperature difference, energy transfers from the hotter to the cooler object.
- Thermal energy is transferred through different pathways, by particles in conduction and convection, and by radiation.

Doing work

We are learning how to:

- Recognise situations where work is done.
- Describe the relationship work done = force × distance.
- Apply the equation for work done to different situations.

Ancient Egyptians used a 'shadouf' to lift heavy buckets of water from deep rivers. A shadouf is a type of **lever** – a simple machine that uses a force to transfer energy. Machines help us to do work.

FIGURE 2.3.1a: A shadouf, lifting water from a lake.

Linking energy and force

A force can transfer **energy**. If you were pulling a heavy load along, you would need to use a large force. Energy stored in your body would be transferred to the kinetic energy store of the object and some energy is transferred to the surroundings by heating. **Work** is done when a force is used to transfer energy. You would be doing work, for example, if you squashed a piece of foam rubber. The **deformation** of the material involves the transfer of energy.

The work done is equal to the energy transferred, and is measured in joules (J).

1. Which situation in the photos needs the biggest force?
2. Draw an energy transfer diagram for both situations in Figure 2.3.1b.

FIGURE 2.3.1b: Which forces are doing work in these situations?

It's not only about the force

If you push a trolley around a supermarket you are, scientifically speaking, doing work. Energy is being transferred from you. The amount of work you do will be affected by a number of factors. Choosing a trolley with rusty wheels will need more force to push it and if you stack the trolley up with shopping that will increase the force needed as well.

The amount of work also depends on the distance covered. If the distance from the entrance of the supermarket to the check-outs is greater, that will increase the work done as well. So the amount of work done depends upon the force applied and the distance moved. We have to be careful with measuring the distance, though. We use what is called the **displacement**, which is the shortest distance from the start point to the end point, not allowing for wandering around the displays several times.

FIGURE 2.3.1c: This shopper is doing work – possibly in ways he hasn't thought about.

3. How could you measure the force needed to move the trolley?
4. Why might this change during the shopping trip?
5. When measuring the distance, could you just measure the total distance of all the aisles and use that?

Defining work done

The further you pull or push a load, the more work you do. If two people were pushing identical boxes along a floor but one person pulls their box twice the distance, that person will do twice as much work. Or if one box is much heavier and needs double the force to push, then double the amount of work will be done. The work done depends on the size of the force applied and the distance a load is moved.

work done (J) = force (N) × distance (m)

6. Calculate the work done in the following situations.
   a) A man uses a force of 50 N to push a box 1 m along a smooth floor.
   b) A striker at a fairground uses a force of 100 N to raise a puck a height of 6 m.
7. How much work is done by the engine of a car that applies a force of 20 000 N to move the vehicle 1 kilometre?

Did you know...?

Just as work is done in making a car move, it is also done in making it stop. In some racing cars so much energy is transferred by the brakes that the brake disks glow.

Know this vocabulary

lever
energy
work
deformation
displacement

Making work easier

We are learning how to:

- Understand what simple machines are.
- Explain why they are useful.
- Compare and contrast different machines.

We sometimes think of machines as being things like tractors and power drills. These are machines but they are powered using sources of energy other than us. They make jobs easier because we don't supply the energy needed. However, there are other machines that are entirely human powered, that still make life easier.

Simple machines

There are different types of simple **machines**, but they have one thing in common – they make work easier. They reduce the **force** needed. There is a limit to the size of force we can apply, so machines are useful. People have been using machines for thousands of years and we still make use of them every day. We may not even realise when we're using them.

One of the most common types of machine is a **lever**. We have them all over the house. Figure 2.3.2a shows four examples of levers.

With the first three, if there was no handle there, there would simply be a rod to try to twist. Even if we could grip it, applying enough force would be really difficult. Having a lever magnifies the force we can apply.

1. If the handle was longer, would that make it easier or harder to turn?
2. With the tap, we use two (or more) of the levers at once. Why?
3. The pedal bin is an odd one out, though it's still a lever. Compare the distance the pedal moves with the distance the lid moves. What is being magnified in this case?

FIGURE 2.3.2a: Simple machines.

Why machines are helpful

A lever is an example of a machine that reduces the force needed by increasing the distance. If the lid is stuck on a tin of paint it can take a lot of force to move it. By using a screwdriver as a lever and the side of the can as a turning point, a lot of force can be applied.

It's partly that it's difficult to grip the lid but it's also that the lever is much longer on the side the person is pushing down on. This multiplies the force, turning a smaller force into a bigger one. The **input force** (from the person) is much less than the **output force** (applied to the lid).

Another example of a simple machine is to use wheels. This doesn't increase the size of the force applied but it reduces friction and so makes the opposing force less.

The boxes in Figure 2.3.2c would be difficult to lift or drag but by putting them on a small trolley the force needed to move them is much less.

4. Give another example of using a machine to lever something.
5. Jo is trying to undo a bolt that is rusted into place and can't turn it with a spanner. She then gets a piece of steel tubing that is much longer than the spanner, puts it over the spanner and pushes on the far end. Why is it now possible to undo the nut?
6. Alex says that levers give you something for nothing because they turn a little force into a big one, but Tom says they don't because although they reduce the force needed to do a job, that force has to be applied over a greater distance. Who is right, and why?

Did you know...?

Work is also done when an elastic object is deformed. A cyclist sitting on a bike and compressing the springs is also considered to be doing work.

FIGURE 2.3.2b: Using a lever.

FIGURE 2.3.2c: Using wheels.

Applying ideas about machines

You might think a bicycle is a machine too. In fact, it's several machines bundled into one. One kind of machine is the lever and there are several on a bike; gears are also a kind of machine and even the wheels themselves are a machine as they reduce friction.

7. Explain, using sketches to assist, how both the handlebars and the pedal cranks are levers.
8. Why should we also regard gears as a machine?
9. Some bicycles are more effective machines than others. What do you think makes them better?

FIGURE 2.3.2d: A bicycle is several machines combined.

Know this vocabulary

machine
force
lever
input force
output force

Explaining thermal energy

We are learning how to:

- Describe how temperature differences lead to energy transfer.

The hottest temperature ever recorded on Earth was 56.8 °C in Death Valley, USA in 1913. The coldest was −89 °C in Vostock, Antartica in 1983. What do we actually mean by how hot or how cold something is?

Temperature

We use a scale of **temperature** to measure how hot or how cold something is. The common unit is **degrees Celsius** (°C). The instrument we use to measure temperature is called a thermometer. Standard thermometers measure temperatures from 0 °C (the temperature at which water freezes) to 100 °C (the temperature at which water boils).

1. Put the following objects in order of temperature, with the hottest first.

   A the Sun's surface, B boiling water, C volcanic lava, D glacier of ice.

2. Using Figure 2.3.3a to help you, match up the objects and their corresponding temperatures in Table 2.3.3.

TABLE 2.3.3

Object	Temperature (°C)
1 body temperature	a) 20
2 hot bath water	b) 5
3 temperature of a hot sunny day	c) 57
4 highest air temperature recorded	d) 30
5 room temperature	e) 37
6 cold drink from the fridge	f) 40

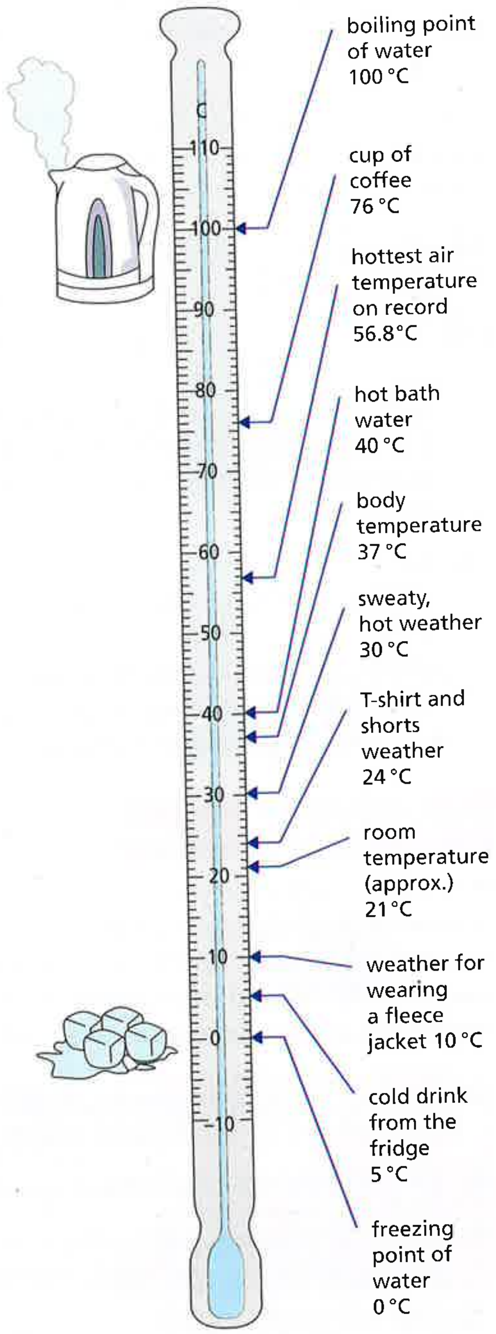

FIGURE 2.3.3a: A temperature scale.

Energy flow

If there is a difference in temperature between two objects in contact, or between an object and its surroundings, there is a transfer or flow of **energy**. Energy always flows from the hotter object to the colder object. Energy will continue to flow in this direction until the two objects reach the same temperature. The greater the difference in temperature, the faster the flow of energy.

We use this principle of energy transfer to heat and cool objects or our surroundings. If you put some food at room temperature (20 °C) in a fridge (at 5 °C), energy from the warmer food will transfer to the colder surroundings of the fridge. This will reduce the temperature of the food and cool it down.

Did you know...?

The coldest temperature possible is called 'absolute zero'. It is −273.15 °C. Some scientists have won the Nobel prize for finding ways to cool matter to within billionths of a degree of absolute zero.

3. Look at the diagrams in Figure 2.3.3b. State the direction of energy transfer in each situation.
4. Put the diagrams in order of the quickest to transfer energy to the slowest. Explain your answer.
5. If you wanted to cool a container of water as quickly as possible, would you put it in a fridge or in a freezer? Explain your answer.

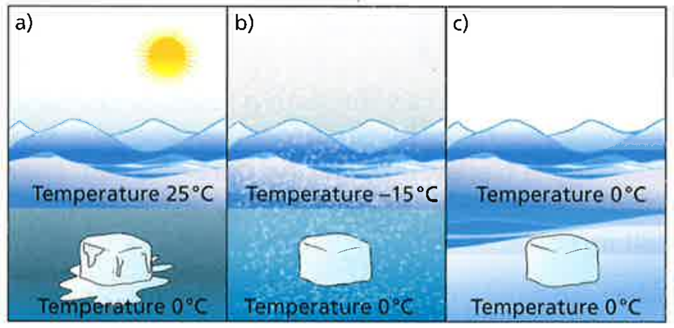

FIGURE 2.3.3b: Will the energy flow from the ice cube or to the ice cube?

Energy and temperature

Think about a cup of hot water and a big bucket of warm water. You know that the water in the cup has a higher temperature. But which **thermal energy** store is the greater?

Although the water in the cup is hotter, there is much less of it.

- Temperature is a way of comparing two objects and measuring how much hotter one is than the other.
- The water has thermal energy. This is the total energy of all the particles – a measure of not only how fast particles are moving but also the total number and type of particles.

6. Which would have most energy – a cup of boiling water or a gigantic iceberg? Explain your answer.
7. Suggest another example of a situation in which energy flows from a hotter to a cooler object.

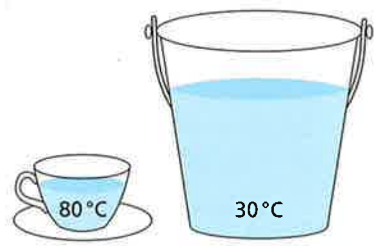

FIGURE 2.3.3c: The water in the cup has a higher temperature. But which has more energy?

Know this vocabulary

temperature
degrees Celsius
energy
thermal energy

Heating

We are learning how to:

- Explain how energy can travel by conduction, convection and radiation.
- Give examples of each of these happening.

Energy sometimes travels, whether or not we want it to. We might want to keep hot food hot and cold food cold. However, sometimes we want energy to be transferred. We want it to spread around our home on a cold day and to travel out of our body on a hot day. It's got more than one way of being transferred though.

Conduction

Energy is transferred through a solid, or through two solids that are touching, by the process of thermal **conduction**. If energy is transferred to one part of a saucepan it will all soon get hot. The thermal energy store of the whole object will increase.

If the thermal energy store of a solid increases, energy is transferred to its particles. They vibrate faster and transfer energy as they continually collide with their neighbours. Some materials are not as good as others at transferring the energy from particle to particle. Ones that are good are good conductors.

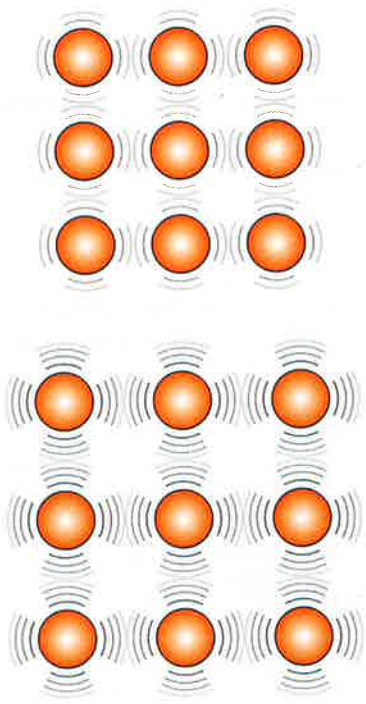

FIGURE 2.3.4a: The hotter a solid, the more its particles vibrate and collide.

1. Explain why a metal teaspoon left in hot tea is soon hot throughout, even the part of the handle sticking out into the air.
2. Explain why a saucepan might have a cast iron body and a wooden handle.
3. Suggest why the arrangement of particles explains why conductors are solids.

Convection

Energy is transferred in a different way in materials that flow, for instance fluids. If energy is transferred to a liquid or gas, the substance will expand as the particles move around more. This area becomes less dense and will rise. For example, the hot water tank in a house has the heating element at the bottom. Energy is transferred to the water, which rises to the top. Cold water falls to take its place and energy is transferred into this too.

Did you know...?

Many years ago, before ventilation fans were introduced, fresh air would be drawn into mines by using convection currents. This arrangement needed two vertical shafts linked by a tunnel. A fire would be lit at the bottom of one shaft and hot air would rise up it. This would draw cold air down the other shaft and through the tunnel.

This means that the water circulates. We call these movements **convection** currents. The same thing happens with air – hot air rises. This is what makes a hot air balloon rise up. It happens with a bonfire too – you can often see bits of ash being carried upwards. Convection only works with fluids as the material has to flow, and it only works if the fluid lower down is hotter than that higher up. As soon as all the tank gets hot, the circulation stops.

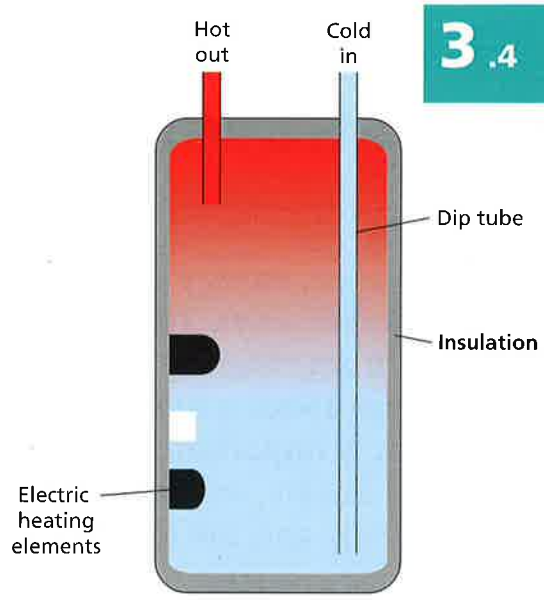

FIGURE 2.3.4b: The heating elements are in the lower part of this water heater.

4. An electric kettle has the heating element at the bottom. This is partly in case you only want to heat up a small amount of water, but it is also a good way of heating up a larger amount. Explain why.
5. If a water heater had the element at top instead of the bottom, what do you think would happen?
6. A refrigerator has heat exchanger coils on the inside; their job is to chill the air. Why are they near the top?

Radiation

Energy is also transferred by **radiation**. Any hot object will radiate energy. We can feel this from an open fire or from a radiant heater, but the object doesn't need to be glowing – it just needs to be hot.

Unlike conduction and convection, radiation doesn't need a medium to carry it. It travels as waves. Waves have a range of frequencies and wavelengths. Energy can be transferred by infrared radiation. This has frequencies lower than that of red light and cannot be seen by the eye. However, it transfers energy by heating – the infrared waves are emitted and absorbed. A hot object in a cool room will emit more radiation than it absorbs. It cools down until all the materials in the room are at the same temperature.

FIGURE 2.3.4c: A radiant heater emits thermal radiation.

7. How does a bonfire transfer energy to the surroundings?
8. Do we transfer energy to our surroundings and, if so, how?
9. What happens to objects that absorb infrared radiation?

Know this vocabulary

conduction
convection
insulation
radiation

Energy

How to stop energy from travelling

We are learning how to:

- Explain the difference between conductors and insulators.
- Explain how insulation works.
- Apply ideas about insulation to practical applications.

As we've seen, **energy** can be transferred in three quite different ways. This means that if we want to stop it from entering or leaving, we have to be quite clever about it and understand how it moves. Insulation is important in the home; as well as coats and duvets, we have insulation in cookers, fridges, walls and the loft.

Conductors and insulators

We might think we can divide materials into **conductors** and **insulators**, but it's not as simple as that. **Energy** is transferred through materials at different rates. If it moves slower we tend to regard the material as an insulator and if it travels faster, it's considered to be a conductor.

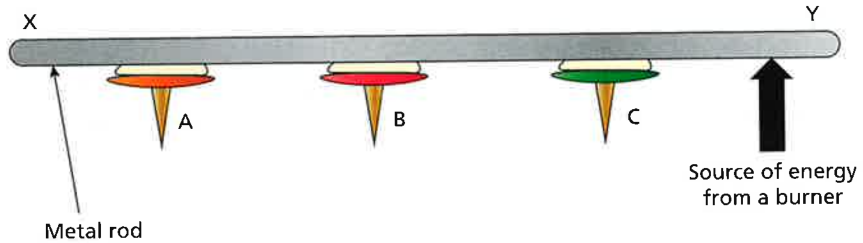

FIGURE 2.3.5a: Investigating conduction.

In the experiment shown in Figure 2.3.5a, a **metal** rod has drawing pins stuck on it with wax. One end of the rod is heated.

1. What will happen as time goes by?
2. What will this show?
3. How could we use this experiment to compare different types of metal to see which was the best conductor?
4. Could we use this method with **non-metals**?

Did you know…?

Thermal imaging cameras form images from radiated energy. A thermal image of your face would show that your cheeks are radiating more energy than the tips of your nose and ears.

Making insulation work

Remember that for a material to stop energy from being transferred it has to stop all three methods of transfer. Metals tend to be good conductors so we should avoid those, and if fluids are allowed to flow they will carry energy by convection. Air is a good insulator, as long as it's held still. Stopping radiation is trickier because any hot object will radiate and it doesn't need anything to carry it, but it's worth remembering that shiny objects are good at reflecting waves and not good at radiating.

Would bubble wrap make a good insulator? If we put hot water in a beaker surrounded by bubble wrap, would it stay hot? It's not a metal so it won't be good at conducting and bubble wrap holds air in pockets so it can't move in convection currents. It's pale and slightly shiny so it won't be great at radiating energy.

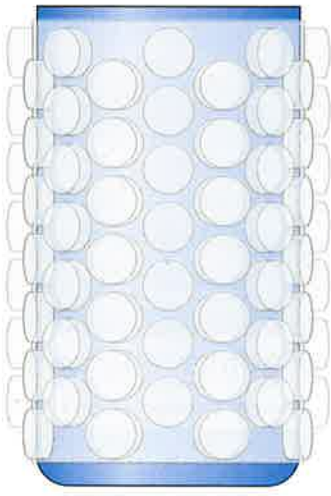

FIGURE 2.3.5b: Insulating a beaker.

5. How could we investigate this to see if bubble wrap was effective insulation?
6. Why might the lack of a lid limit its effectiveness?
7. What else might be a good way of insulating a beaker of hot water?

Applying ideas about insulation

Modern houses have to have large amounts of insulation built in. As a result, they use relatively little energy to keep them warm in the winter. The insulation is used in a variety of ways; one of them is wall insulation.

This builder is fitting wall insulation to a house extension – you can see the thick layers being fitted. The only gaps are for doors and windows.

FIGURE 2.3.5c: Insulating a house.

8. Why would this material not be a good conductor?
9. Energy is also transferred by convection, which carries warm air up to the ceiling. Explain whether you think this type of material would also make a good loft insulator.
10. If the walls and roof are well insulated, what should be true about the temperature of the outside walls on a cold day when the heating is running?

Know this vocabulary

conductor
insulator
energy
metals
non-metals

Energy and temperature

We are learning how to:

- Describe the warming and cooling of objects.
- Explain the relationship between energy transfer and temperature change.

If you want to keep a drink hot or cold you can use an insulated flask or a vacuum flask (often called a thermos flask), which is more efficient but more expensive. What are the differences between the two? Which one would be the best value for money?

FIGURE 2.3.6a: An insulated flask is useful for slowing down temperature changes.

Cooling and warming

The warmer something is, the higher its **temperature**. Monitoring temperature changes is a useful way to measure how quickly energy is being transferred. The rate of cooling of a material may be investigated by measuring how its temperature changes over time and plotting a graph of temperature against time. This is often called a cooling curve.

1. Describe the relationship between how hot something is and its temperature.
2. Look at the graph in Figure 2.3.6b. Describe what is happening.

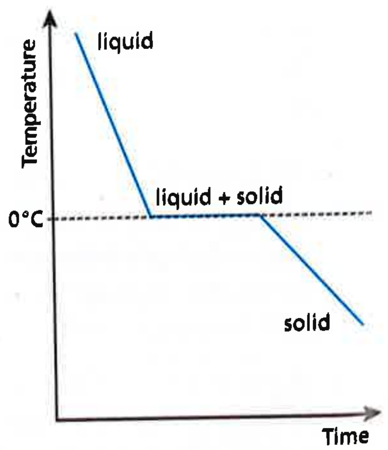

FIGURE 2.3.6b: A cooling curve for a test tube of water put in a mixture of ice and salt and cooled to –20 °C.

Energy transfer and temperature change

Energy will transfer from a warm object (higher temperature) to a colder one (lower temperature).

If you pour hot water into a cold saucepan, the temperature of the water decreases and the temperature of the saucepan increases. Energy is transferred from the water to the saucepan.

If nothing else interfered, the temperature of the water and the saucepan would become the same. However, the saucepan is standing on something and is surrounded by air. Energy is transferred to its surroundings until the saucepan and the surroundings, including the water, reach the same temperature. We say that thermal equilibrium has been reached.

Materials that transfer energy well (quickly) are called **thermal conductors**. Materials that do not are called **thermal insulators**.

3. Describe what happens to the temperature of cold water if it is put into a hot metal can.
4. Describe the direction of energy transfer when a metal worker plunges a red hot piece of metal into cold water.
5. Think about the situation shown in Figure 2.3.6c and try to explain the meaning of 'open system'.

FIGURE 2.3.6c: The water, saucepan and surroundings are an 'open system'. Energy transfers happen in all parts of it.

Vacuum flask

The vacuum flask is a very effective way of insulating its contents from the surroundings. It stops energy from being transferred in or out.

The actual flask is made of glass and has two layers. The air has been removed from between the two layers. The layers have been silvered; they have a highly reflective surface, like a mirror. There is a plastic cap in the top.

Vacuum flasks aren't the only way of keeping hot drinks hot (or cold drinks cold). We could compare them with other types of insulated container to see which performs the best.

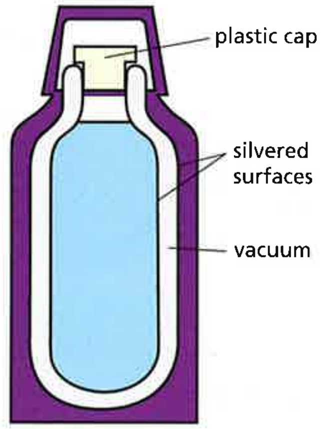

FIGURE 2.3.6d: A vacuum flask.

6. Describe how you could run a comparative test between two different insulated flasks to see which was the most effective.
7. From the data gathered you could draw temperature/time graphs of the flasks being compared. Sketch the shape of one of the graphs you might expect to get from one of the flasks. Annotate it to show key features.
8. Why do you think the vacuum flask has:
   - **a)** a vacuum between the two glass layers?
   - **b)** silvered surfaces?
   - **c)** a plastic cap?

Did you know…?

Double glazing works because a gas is sandwiched between two panels of glass. Originally it was air, but nowadays argon is often used because it is a better insulator than air.

Know this vocabulary

temperature
thermal conductor
thermal insulator

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

- Explain how work done is related to force and distance.
- Compare work needed to move objects different distances.
- Calculate work done from force applied and horizontal distance moved.

- Know that work done is measured in joules.
- Explain that doing work involves the transfer of energy.
- Explain how different situations in which work is done involve different amounts of energy being transferred.

- Identify input and output forces from machines and know that they make work easier by reducing the force needed.
- Explain using a diagram how a lever makes a job easier.
- Compare and contrast different levers in terms of forces required and distances moved.

- Recognise levers, pulleys and wheels as examples of machines.
- Identify how different types of machines make work easier.
- Suggest which type of machine would be suitable to make work easier in a particular context.

- Know that the thermal energy store is the amount of energy stored in a material due to the vibration of its particles.
- Know that the thermal energy store of an object depends upon its mass, temperature and material.
- Explain why an object's temperature may change if it is heated or cooled.

- Know that when there is a temperature difference, energy is transferred from the hotter to the cooler object.
- Use ideas about energy transfer to explain observations about changing temperature.
- Explain what a temperature/time graph shows about the energy transferred.

- Know that energy is transferred through different pathways, by particles in conduction and convection, and by radiation.
- Explain how a particular type of insulation works in terms of conduction, convection and radiation.
- Compare and contrast the transfer of energy by conduction, convection and radiation.

- Describe how particles in a fluid move when heated.
- Explain how convection results in energy being transferred.
- Explain, using diagrams, how convection currents flow in unfamiliar situations.

- Explain the difference between conductors and insulators in relation to how quickly energy travels through them.
- Explain how to prevent energy loss by conduction, convection and radiation.
- Evaluate a claim about the effectiveness of insulation in a particular context.

Questions

KNOW. Questions 1–4

See how well you have understood the ideas in this chapter.

1. Work done is measured in: [1]

a) newtons **b)** newton metres squared

c) joules **d)** newtons per metre.

2. Explain how this lever is making the job of lifting the crate easier. [2]

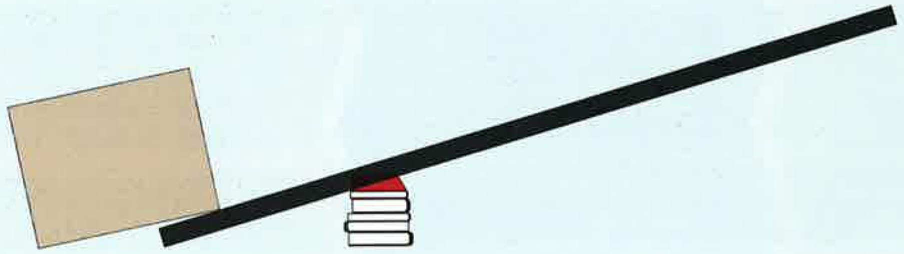

FIGURE 2.3.8a

3. This block has a store of thermal energy store. Which one of the following will not affect the amount of energy? [1]

a) the colour of the surface

b) the mass of the block

c) its temperature

d) the material from which it's made.

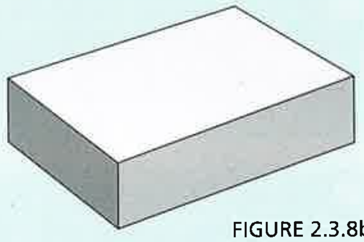

FIGURE 2.3.8b

4. Which of these rows shows the correct definitions? [1]

TABLE 2.3.8

	Conduction	Convection	Radiation
A	Transfer of energy by the vibration of particles.	Transfer of energy when particles in a heated fluid rise.	Transfer of energy as a wave.
B	Transfer of energy as a wave.	Transfer of energy by the vibration of particles.	Transfer of energy when particles in a heated fluid rise.
C	Transfer of energy when particles in a heated fluid rise.	Transfer of energy as a wave.	Transfer of energy by the vibration of particles.
D	Transfer of energy when particles in a heated fluid rise.	Transfer of energy by the vibration of particles.	Transfer of energy as a wave.

APPLY. Questions 5–6

See how well you can apply the ideas in this chapter to new situations.

5. People sometimes use pedestrian ramps if they have a child in a pushchair or pram.

a) Explain why the ramp makes work easier. [1]

b) Explain why the wheel is an example of a simple machine. [1]

FIGURE 2.3.8c

6. This food was bought hot from a café and wrapped up before being carried home. Explain how the insulation reduces energy loss by conduction, convection and radiation. [3]

FIGURE 2.3.8d

EXTEND. Questions 7–8

See how well you can understand and explain new ideas and evidence.

7. This freezer pack has been kept in the freezer overnight and is now put in a lunch box. Explain how it will help to keep the food colder during the next day. [2]

FIGURE 2.3.8e

8. Jules is moving house and has packed all her books into a crate. She's pushing the crate from one side of the room to the other. If she has to apply a force of 150 N and is sliding it 5 m, how much work will she have done? [2]

FIGURE 2.3.8f