Learning objectives
After this topic, you should know:
- which materials make the best conductors
- which materials make the best insulators
- how the thermal conductivity of a material affects the rate of energy transfer through it by conduction
- how the thickness of a layer of material affects the rate of energy transfer by conduction through it.

When you have a barbecue, you need to know which materials are good conductors and which ones are good insulators. If you can’t remember, you’re likely to burn your fingers!

Testing rods of different materials as conductors
The rods need to be the same width and length for a fair test. Each rod is coated with a thin layer of wax near one end. The uncoated ends are then heated together.

Look at Figure 1. The wax melts fastest on the rod that best conducts energy.

- Metals conduct energy better than non-metals.
- Copper is a better conductor than steel.
- Glass conducts better than wood.

Testing sheets of materials as insulators
Use different materials to insulate identical cans (or beakers) of hot water.

When choosing your materials, consider which properties will make the materials good thermal insulators, for example, the thickness of the material or the colour of the material.

The volume of water and its temperature at the start should be the same.

Use a thermometer to measure the water temperature after a fixed time.

Use your results to work out which is the best insulator.

The table below gives the results of comparing two different materials using the method above.

<table>
<thead>
<tr>
<th>Material</th>
<th>Starting temperature in °C</th>
<th>Temperature after 300 s in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>paper</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>felt</td>
<td>40</td>
<td>36</td>
</tr>
</tbody>
</table>

Safety: Take care if you are using very hot water.

Figure 1 Comparing conductors

Thermal conductivity
In Figure 1, each rod has the same temperature difference between its ends. Each rod is the same length and diameter. The energy transfer by conduction through a material depends on its thermal conductivity. The greater the thermal conductivity of a material, the more energy per second it transfers by conduction. So, in Figure 1, if

- A conducts better than C, and
- C conducts better than B, then
- the thermal conductivity of A is higher than the thermal conductivity of C, and
- the thermal conductivity of C is higher than the thermal conductivity of B.
Insulation matters
Materials that are good insulators are necessary to keep you warm in winter, whether you are at home or outdoors. Good insulators need to be materials that have low thermal conductivity, so energy transfer through them is as low as possible.

The energy transfer per second through a layer of insulating material depends on:
- the temperature difference across the material
- the thickness of the material
- the thermal conductivity of the material.

To reduce the energy transfer as much as possible in any given situation:
1. the thermal conductivity of the insulating material should be as low as possible
2. the thickness of the insulating layer should be as thick as is practically possible.

Figure 2 shows a layer of insulating material being fitted in the loft of a house. The insulating material chosen has a much lower thermal conductivity than the roof material. Several layers of this material fitted on the loft floor will reduce the energy transfer through the roof significantly. Insulating buildings is covered further in Topic P2.5.

1 a Explain why steel pans have handles made of plastic or wood. [2 marks]
   b Suggest which material, felt or paper, is the better insulator. Give a reason for your answer. [2 marks]

2 a Choose a material you would use to line a pair of winter boots. Give a reason for your choice of material. [2 marks]
   b Describe how you could carry out a test on three different lining materials. Assume you have a thermometer, a stopwatch, and you can wrap the lining round a container of hot water. [3 marks]

3 Describe an investigation you would carry out to find out how the thickness of a layer of insulating material affects the energy transfer through it. [5 marks]

4 In Figure 1, A is a copper rod, B is a glass rod, and C is a steel rod. Determine which rod keeps its wax in the solid state for the longest time. Explain your answer. [2 marks]

Key points
- Metals are the best conductors of energy.
- Non-metal materials such as wool and fibreglass are the best insulators.
- The higher the thermal conductivity of a material, the higher the rate of energy transfer through it.
- The thicker a layer of insulating material, the lower the rate of energy transfer through it.
Learning objectives
After this topic, you should know:
● what infrared radiation is
● how infrared radiation depends on the temperature of an object
● what is meant by black body radiation
● what happens to the temperature of an object if it absorbs more radiation than it emits.

Energy from the Sun
When you are in sunlight, you are absorbing infrared radiation from the Sun. Infrared radiation and visible light are parts of the electromagnetic spectrum. So too are radio waves, microwaves, ultraviolet rays and X-rays. Electromagnetic waves are electric and magnetic waves that travel through space. The wavelength of light increases across the visible spectrum from blue to red light. Infrared waves are longer in wavelength than visible light waves.

The Sun emits all types of electromagnetic radiation. Fortunately, the Earth’s atmosphere blocks most of the types of radiation that are harmful to people. But it doesn’t block infrared radiation or light from the Sun.

Detecting infrared radiation
You can use a thermometer with a blackened bulb to detect infrared radiation. Figure 1 shows how to do this.

The glass prism splits a narrow beam of white light into the colours of the spectrum.

The thermometer reading rises when it is placed just beyond the red part of the spectrum. Some of the infrared radiation in the beam goes there. Your eyes can’t detect it, but the thermometer can.

Infrared radiation is beyond the red part of the visible spectrum.

Suggest what would happen to the thermometer reading if you moved it away from the screen.
Radiation and surface temperature

If you want to see animals and people in the dark, you need to use special cameras. These cameras detect infrared radiation. All objects give out (emit) infrared radiation.

The higher the temperature of an object, the more infrared radiation it emits in a given time.

All bodies (objects), no matter what their temperature is, emit and absorb infrared radiation. A body at constant temperature emits infrared radiation at the same rate as it absorbs it.

A perfect black body is an object that absorbs all the radiation that hits it. It doesn’t reflect any radiation, and it doesn’t transmit any radiation (i.e., no radiation passes through it). A good absorber is also a good emitter, so a perfect black body is also the best possible emitter. The radiation emitted by a perfect black body is called black body radiation. No other object emits or absorbs radiation as effectively as a black body.

An object that has a constant temperature emits radiation across a continuous range of wavelengths.

Figure 4 shows how the intensity of black body radiation varies with wavelength. The intensity of the radiation is highest at a certain wavelength, which depends on the temperature.

If the temperature of the object is increased, the intensity of the radiation it emits is greater at every wavelength – as shown in Figure 4. Figure 4 also shows that the peak of the higher radiation curve is at a shorter wavelength than the peak of the lower curve. This is because the shorter the wavelength of the radiation, the greater the increase in intensity at that wavelength. Therefore, the peak intensity is at a shorter wavelength than it was at the lower temperature.

1 Explain what infrared radiation is. [1 mark]

2 a An infrared camera on a satellite shows that more infrared radiation is emitted at night from a city than from the surrounding rural area. Explain what this tells you about the city compared with the rural area. Give a reason for your answer. [2 marks]

b Explain how you could tell if an electric iron is hot without touching it. [1 mark]

3 a When an iron nail was heated in the flame of a Bunsen burner, the colour of the nail became dull-red then orange-red. Explain why the colour of the nail changed in this way. [2 marks]

b The colour of a star depends on its surface temperature. A student notices that three stars, X, Y, and Z, near to each other have different colours. X is yellow, Y is red, and Z is white.

i Write down and explain which star is hottest. [2 marks]

ii Write down and explain which star is coolest. [2 marks]
**Learning objectives**

After this topic, you should know:

- what happens to the temperature of an object if it absorbs more radiation than it emits
- how the temperature of the Earth is affected by the balance of absorbed and emitted radiation.

**Absorption and emission of infrared radiation**

Every object absorbs and emits infrared radiation, whatever its temperature is. If an object has a constant temperature, the object emits infrared radiation at the same rate as it absorbs it. When an object absorbs radiation faster than it emits radiation, its temperature increases.

Rescue teams use light-coloured, shiny blankets to keep accident survivors warm (Figure 1). A light, shiny outer surface emits a lot less radiation than a dark, matt (non-glossy) surface. This keeps the patient warm, as less infrared radiation is emitted than if an ordinary blanket had been used.

**Study tip**

Remember that all objects emit *and* absorb infrared radiation.

**Radiation and the Earth’s temperature**

The temperature of the Earth depends on lots of factors, such as the rate that light and infrared radiation from the Sun are:

- reflected back into space or absorbed by the Earth's atmosphere or by the Earth's surface
- emitted from the Earth's surface and from the Earth's atmosphere into space.

*Figure 1 An emergency blanket in use*
If the Earth had no atmosphere, the temperature on the surface would plunge to about −180 °C at night, the same as the Moon’s surface at night. This would happen because the surface would not be receiving any radiation from the Sun – it would be emitting radiation into space.

Some gases in the atmosphere, such as water vapour, methane, and carbon dioxide (greenhouse gases) absorb longer wavelength infrared radiation from the Earth and prevent it escaping into space. These gases absorb the radiation and then emit it back to the surface (Figure 2). This process makes the Earth warmer than it would be if these gases were not in its atmosphere.

1. Infrared radiation from the Sun warms the ground.

2. Ground becomes warm and emits longer-wavelength infrared radiation.

3. CO₂ molecules absorb and re-emit infrared radiation back to the ground.

**Figure 2 The absorption and emission of infrared radiation**

1. The surface of the Earth absorbs radiation from the Sun and it emits radiation.
   a. State one similarity and one difference in the radiation the Earth emits and the radiation it absorbs from the Sun. [2 marks]
   b. Describe what happens to the radiation the surface of the Earth emits on a very clear night. [2 marks]

2. On a hot day in summer, the interior of a parked car in sunlight with its windows closed becomes unbearably hot.
   a. Explain why the temperature inside the car becomes much higher than the outside temperature. [3 marks]
   b. Explain why the inside of the car would not become as hot if it had been parked in a shaded area. [2 marks]

3. Explain why the presence of greenhouse gases in the atmosphere makes the Earth warmer than it would be if there were no greenhouse gases in the atmosphere. [3 marks]

**Key points**

- The temperature of an object increases if it absorbs more radiation than it emits.
- The Earth's temperature depends on a lot of factors, including the absorption of infrared radiation from the Sun, and the emission of radiation from the Earth's surface and atmosphere.
Learning objectives

After this topic, you should know:

- what is meant by the specific heat capacity of a substance
- how to calculate the energy changes that occur when an object changes temperature
- how the mass of a substance affects how quickly its temperature changes when it is heated
- how to measure the specific heat capacity of a substance.

A car in strong sunlight can become very hot. A concrete block of equal mass would not become as hot. Metal heats up more easily than concrete. Investigations show that when a substance is heated, its temperature rise depends on:

- the amount of energy supplied to it
- the mass of the substance
- what the substance is.

The following results were obtained using two different amounts of water. They show that:

- heating 0.1 kg of water by 4 °C required an energy transfer of 1600 J
- heating 0.2 kg of water by 4 °C required an energy transfer of 3200 J

Using these results, you can say that:

- Increasing the temperature of 1.0 kg of water by 4 °C requires a transfer of 16 000 J of energy
- Increasing the temperature of 1.0 kg of water by 1 °C involves a transfer of 4000 J of energy.

More accurate measurements would give 4200 J per kg per °C for water. This is its **specific heat capacity**.

The specific heat capacity of a substance is the energy needed to raise the temperature of 1 kg of the substance by 1 °C.

The unit of specific heat capacity is the joule per kilogram degree Celsius (J/kg °C).

For a known change of temperature of a known mass of a substance:

\[
\Delta E = m \times c \times \Delta \theta
\]

where:

- \(\Delta E\) is the energy transferred, in joules (J)
- \(m\) is the mass, in kilograms (kg)
- \(c\) is the specific heat capacity, in joule per kilogram per degree Celsius (J/kg °C)
- \(\Delta \theta\) is the temperature change, in degrees Celsius (°C)

The energy transferred to the substance increases the thermal energy store of the substance by an equal amount.

To find the specific heat capacity of a substance, rearrange the above equation into the form:

\[
c = \frac{\Delta E}{m \Delta \theta}
\]

**Measuring specific heat capacity**

Use the arrangement shown in Figure 1 to heat a metal block of known mass. You will need to use a thermometer and a top-pan balance.

Use the energy meter (or joulemeter) to measure the energy supplied to the block. Use the thermometer to measure its temperature rise.

What changes to energy stores occur as result of the transfer of energy to the block?
To find the specific heat capacity of aluminium, insert your measurements into the equation:

\[
c = \frac{\Delta E}{m \Delta \theta}
\]

Replace the block with an equal mass of water in a suitable container. Measure the temperature rise of the water when the same amount of energy is supplied to it by the heater.

Your results should show that aluminium heats up more quickly than water.

**Safety:** Wear eye protection and take care with a hot immersion heater.

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**Storage heaters**

A storage heater uses electricity at night (off-peak) to heat special bricks or concrete blocks in the heater. Energy transfer from the bricks keeps the room warm. The bricks have a high specific heat capacity, so they store lots of energy. They warm up slowly when the heater element is on, and cool down slowly when it is off.

**Table 1 The specific heat capacity for some other substances**

<table>
<thead>
<tr>
<th>Substance</th>
<th>water</th>
<th>oil</th>
<th>aluminium</th>
<th>iron</th>
<th>copper</th>
<th>lead</th>
<th>concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat capacity in J/kg °C</td>
<td>4200</td>
<td>2100</td>
<td>900</td>
<td>390</td>
<td>385</td>
<td>130</td>
<td>850</td>
</tr>
</tbody>
</table>

---

1. A small bucket of water and a large bucket of water are left in strong sunlight. Which one warms up faster? Give a reason for your answer. [2 marks]

2. Use the information in Table 1 above to answer this question.
   a. Explain why a mass of lead heats up more quickly than an equal mass of aluminium. [2 marks]
   b. Calculate the energy needed:
      i. to raise the temperature of 0.20 kg of aluminium from 15 °C to 40 °C [2 marks]
      ii. to raise the temperature of 0.40 kg of water from 15 °C to 40 °C [2 marks]
      iii. to raise the temperature of 0.40 kg of water in an aluminium container of mass 0.20 kg from 15 °C to 40 °C. [3 marks]
   c. A copper water tank of mass 20 kg contains 150 kg of water at 15 °C. Calculate the energy needed to heat the water and the tank to 55 °C. [5 marks]

3. State two ways in which a storage heater differs from a radiant heater. [2 marks]

4. Design an experiment to measure the specific heat capacity of oil using the arrangement in Figure 1. [6 marks]

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**Key points**

- The specific heat capacity of a substance is the amount of energy needed to change the temperature of 1 kg of the substance by 1 °C.
- Use the equation \( \Delta E = m c \Delta \theta \) to calculate the energy needed to change the temperature of mass \( m \) by \( \Delta \theta \).
- The greater the mass of an object, the more slowly its temperature increases when it is heated.
- To find the specific heat capacity \( c \) of a substance, use a joulemeter and a thermometer to measure \( \Delta E \) and \( \Delta \theta \) for a measured mass \( m \), then use \( c = \frac{\Delta E}{m \Delta \theta} \).
P2.5 Heating and insulating buildings

Learning objectives
After this topic, you should know:
● how homes are heated
● how you can reduce the rate of energy transfer from your home
● what cavity wall insulation is.

Reducing the rate of energy transfers at home
Houses are heated by electric or gas heaters, oil or gas central heating systems, or by solid fuel in stoves or in fireplaces. Whichever form of heating you have in your home, the heating bills can be expensive. When your home heating system is transferring energy into your home to keep you warm, energy is also transferring to the surroundings outside your home. Figure 1 shows some of the measures that can be taken to reduce the rate of energy transfer from a home, and so reduce home heating bills.

Go further!
A duvet is a bed cover filled with ‘down’ or soft feathers, or some other suitable insulator such as wool. Because the filling material traps air, a duvet on a bed reduces the rate at which energy is transferred from you as you sleep. The tog rating of a duvet depends on the thickness of the material and on its thermal conductivity. It tells you how effective it is as an insulator. The thicker the material, or the lower its thermal conductivity, the better it is as an insulator, and so the higher its tog rating.

Figure 1 Saving money

● Loft insulation such as fibreglass reduces the rate of energy transfer through the roof. Fibreglass is a good insulator. The air between the fibres also helps to reduce the rate of energy transfer by conduction. The greater the number of layers of insulation, the thicker the insulation will be. So the rate of energy transfer through the roof will be less.

● Cavity wall insulation reduces the rate of energy transfer through the outer walls of the house. The cavity of an outer wall is the space between the two layers of brick that make up the wall. The insulation is pumped into the cavity. It is a better insulator than the air it replaces. It traps the air in small pockets, reducing the rate of energy transfer by conduction.

● Aluminium foil between a radiator panel and the wall reflects radiation away from the wall and so reduces the rate of energy transfer by radiation.
Double-glazed windows have two glass panes with dry air or a vacuum between the panes. The thicker the glass and the lower its thermal conductivity is, the slower the rate of transfer of energy through it by conduction will be. Dry air is a good insulator, so it reduces the rate of energy transfer by conduction. A vacuum also prevents energy transfer by convection.

If the external walls of a warm building have thicker bricks and lower thermal conductivity, the rate of transfer of energy from the inside of the building to the outside will be lower and the cost of heating will be less.

**Solar panels**

Heating a home using electricity or gas can be expensive. Solar panels absorb infrared radiation from the Sun and are used to generate electricity directly (solar cell panels) or to heat water directly (solar heating panels). In the northern hemisphere, a solar panel is usually fitted on a roof that faces south so that it absorbs as much infrared radiation from the Sun as possible.

Electric and/or gas heaters and gas or oil-fired central heating or solid-fuel stoves are used to heat houses.

The rate of energy transfer from houses can be reduced by using:
- loft insulation
- cavity wall insulation
- double-glazed windows
- aluminium foil behind radiators
- external walls with thicker bricks and lower thermal conductivity.

Cavity wall insulation is insulation material that is used to fill the cavity between the two brick layers of an external house wall.
P2 Energy transfer by heating

Summary questions

1. a. i. Explain why a white hat is better to wear outdoors in summer than a black hat. [2 marks]
   
   ii. Describe the type of surface that is better for a flat roof: matt or smooth, dark or shiny. Explain your answer. [2 marks]

   b. A solar heating panel is used to heat water. Some panels have a transparent cover and a matt black base. Others have a matt black cover and a shiny base.

   Suggest which of these two designs, Panel X or Panel Y, is better. Give reasons for your answer. [4 marks]

2. A heat sink is a metal plate or clip fixed to an electronic component to stop it overheating.

   a. When the component becomes hot, how does energy transfer from:
      
      i. where the component is in contact with the plate to the rest of the plate? [1 mark]
      
      ii. the plate to the surroundings? [1 mark]

   b. Describe the purpose of the metal fins on the plate. [2 marks]

   c. Heat sinks are made from metals such as copper or aluminium. Copper is approximately three times more dense than aluminium, and its specific heat capacity is about twice as large. Discuss how these physical properties are relevant to the choice of whether or not to use copper or aluminium for a heat sink in a computer. [4 marks]

3. a. Explain why woolly clothing is very effective at keeping people warm in winter. [3 marks]
   
   b. Wearing a hat in winter is a very effective way of keeping your head warm. Describe how a hat helps to reduce the rate of energy transfer from your head. [3 marks]
   
   c. Keeping your ears warm is important too. Explain why energy transfer from your ears to the surroundings can be significant in winter. [3 marks]

4. Marathon runners at the end of a race are often supplied with a shiny emergency blanket to stop them becoming cold. These silvery blankets are very light in weight because they are made from plastic film with a reflective metallic coating inside.

   a. Name the form of energy transfer that is reduced by the reflective coating inside the emergency blanket. [1 mark]

   b. Explain why an emergency blanket helps to stop the runners becoming cold. [2 marks]

5. A meteorite loses about 60 MJ/kg of energy from its kinetic and gravitational potential energy stores when it falls to the ground from space. The specific heat capacity of a meteorite is about 400 J/kg °C.

   a. Estimate its maximum temperature rise if just 1% of the kinetic and gravitational potential energy is transferred as thermal energy of the meteorite. [4 marks]

   b. The melting point is about 2500 °C. Discuss whether or not the 1% assumption in a is realistic. [2 marks]

6. A 5 kW electric shower heats the water flowing through it from 15 °C to 40 °C when the water flow rate is 1.5 kg per minute.

   a. Calculate the energy per second used to heat the water. The specific heat capacity of water is 4200 J/kg °C. [2 marks]

   b. Calculate the percentage efficiency of the shower heater. [3 marks]

7. Penguins huddle together to keep warm. Design an investigation to model the effect of penguins huddling together. Use beakers of hot water to represent the penguins. [5 marks]
Practice questions

01 A student had read about an outdoor ice container. The article described ways of slowing down the rate at which the ice melts on hot summer days. She decided to investigate using the apparatus in Figure 1.

**Figure 1**

A is copper  
B is glass  
C is plastic

01.1 Why did the student use an infrared heater in the investigation? [1 mark]

01.2 Name two control variables in the investigation. [2 marks]

01.3 The student used a temperature probe attached to a data logger instead of a thermometer. Suggest how this improved the investigation. [2 marks]

01.4 A politician has suggested glaciers should be covered in insulation to slow down their rate of melting. Do you agree with this suggestion? Explain your answer [2 marks]

02 Table 1 shows the thermal conductivity of three metals used in the manufacture of saucepans.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Thermal conductivity in W/m²°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>380</td>
</tr>
<tr>
<td>stainless Steel</td>
<td>54</td>
</tr>
<tr>
<td>aluminium</td>
<td>250</td>
</tr>
</tbody>
</table>

02.1 Choose one metal for the base of a saucepan that would give the best thermal efficiency. Give a reason for your choice. [2 marks]

02.2 Describe how to check a saucepan is hot without touching it or using a thermometer. [2 marks]

03.1 A hot water bottle made of rubber is filled with 0.65 kg of hot water. The temperature of the water is 90 °C. Calculate the temperature of the hot water bottle after 163 800 J of energy are transferred during the night. Specific heat capacity of water is 4200 J/kg °C [3 marks]

03.2 A new type of bed warmer is sealed, filled with polymer gel, and heated using an electric insert. The bed warmer can control the temperature of the polymer gel. Suggest two advantages of using the new bed warmer rather than a traditional hot water bottle. [2 marks]

04 A student investigated the insulation properties of two materials, A and B. The apparatus she used is shown in Figure 2.

**Figure 2**

Her method was as follows:
1. Wrap a 2 cm layer of material A around the beaker.
2. Fill the beaker with 200 ml of hot water and record the temperature of the water.
3. Record the temperature of the water after 10 minutes.
4. Wrap a second 2 cm layer of material A around the beaker.
5. Repeat stages 2 and 3.
6. Replace material A with material B and repeat stages 1–5.

Table 2 shows the results of the investigation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Number of layers</th>
<th>Water temperature at the start, in °C</th>
<th>Water temperature after 10 mins, in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>82.5</td>
<td>66.0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>83.0</td>
<td>71.5</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>81.5</td>
<td>72.0</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>75.0</td>
<td>67.5</td>
</tr>
</tbody>
</table>

04.1 Calculate the temperature change for each test. [2 marks]

04.2 Which material was the better insulator? Give a reason for your answer. [2 marks]

04.3 Suggest two ways the student could have improved the investigation. [2 mark]