Unit 8I Heating and cooling

About the unit

In this unit pupils:

- recognise the need for a temperature scale
- learn to distinguish between heat (as energy) and temperature
- learn about mechanisms of heat transfer: conduction, convection and radiation, and apply this to familiar contexts
- learn about expansion and change of state in solids, liquids and gases
- use the particle model to explain conduction, convection and change of state

In scientific enquiry pupils:

- draw and interpret line graphs from data collected
- carry out a survey of people's perceptions of common temperatures
- investigate the effectiveness of different forms of insulation, controlling relevant variables

Note on the teaching of energy

This unit considers the idea that energy transfer results from a difference in temperature. This is an important concept, as most changes are a result of differences and energy changes are associated with them, *eg a raised object falls, transforming its potential energy to kinetic energy*. The unit also helps pupils distinguish heat (energy) from temperature. There has been much debate about the use of the word 'heat' for energy. The risk is that it might support the idea of a separate kind of stuff – as was current in science before the work of James Joule in the nineteenth century. It is used here in contexts which should avoid that misconception. The unit applies ideas of moving particles to explain the transfer of heat (energy) by conduction and convection, thus clarifying that, in this context, heat is a kind of movement. Particle models are also used to explain how matter changes state when energy is added or removed, so this unit needs to follow unit 7G 'Particle model of solids, liquids and gases' and unit 7H 'Solutions'.

This unit is expected to take approximately 10 hours.

Where the unit fits in

This unit uses ideas developed in the key stage 2 programme of study. It builds on ideas introduced in unit 4C 'Keeping warm' and unit 5D 'Changing state' in the key stage 2 scheme of work.

In unit 7I 'Energy resources', pupils will have identified that when fuels burn they release energy and have noted the consequent rise in temperature.

In unit 7G 'Particle model of solids, liquids and gases', pupils will have encountered the particle model of matter.

In unit 9I 'Energy and electricity', pupils will study energy transformation and energy conservation.

Expectations

At the end of this unit

in terms of scientific enquiry

most pupils will: plan a survey of perceptions of temperature, using an appropriate sample; plan an investigation into methods of reducing heat loss; carry this out using ICT for recording temperature data and relate findings to practical implications; select effectively information from secondary sources to compare methods of preventing heat loss in houses; collect and interpret temperature data from a substance changing state

some pupils will not have made so much progress and will: use thermometers safely; present survey data using a chart or table; identify and control key variables in an investigation of insulators for reducing heat loss and draw practical conclusions; select information to report on ways of reducing heat loss in houses; draw a graph of temperature changes when a substance changes state

some pupils will have progressed further and will: make systematic measurements of temperature changes with a precision which enables reliable conclusions to be drawn in an investigation of insulators; evaluate different sources of information on domestic heat loss prevention methods; extrapolate from temperature data on change of state

in terms of physical processes

most pupils will: give examples of common temperatures on the Celsius scale; distinguish between heat and temperature, describe energy flow as the result of temperature difference; describe some uses of good conductors and insulators and examples of conduction in solids and convection in liquids and gases; explain conduction and convection, expansion and change of state in terms of the particle model

some pupils will not have made so much progress and will: give examples of some common temperatures; describe some uses of good conductors and insulators; describe how insulators can reduce heat loss; describe how substances expand and change state

some pupils will have progressed further and will: give examples of a wide range of temperatures on the Celsius scale; compare conductivity of materials and relate this to their uses; use the particle model to explain change of state relating this to the forces between particles

Prior learning

It is helpful if pupils:
- know that temperature is a measure of how hot an object is
- can use a thermometer
- know that metals are good thermal and electrical conductors
- recall that evaporation occurs at the surface of a liquid
- know about the particle model of matter
- can describe differences between solids, liquids and gases

Health and safety

Risk assessments are required for any hazardous activity. In this unit pupils:
- use hot water and electrical heaters
- observe heated metals, liquids and air
- use flammable and oxidising materials

Model risk assessments used by most employers for normal science activities can be found in the publications listed in the *Teacher's guide*. Teachers need to follow these as indicated in the guidance notes for the activities, and consider what modifications are needed for classroom situations.

Language for learning

Through the activities in this unit pupils will be able to understand, use and spell correctly words:
- relating to heat transfer, *eg conduction, convection, radiation, insulator, conductor*
- with similar but distinct meanings, *eg heat (as energy), temperature*
- relating to scientific enquiry, *eg sample size, trial measurements, evaluation, prediction*

Through the activities pupils could:
- organise information in an appropriate sequence
- show relationships between ideas in writing by using link words, *eg so that*, and reservation words, *eg although, if*

Resources

Resources include:
- a range of thermometers
- temperature sensors and dataloggers
- range of insulating materials, *eg felt, expanded polystyrene, duvet filling, cork, thermal lining for curtains*
- 'energy houses' – lidded boxes which can be insulated using a variety of materials of varying thicknesses, using Velcro pads
- information on insulation in the home
- vacuum pump
- radiant heater
- 'ball and ring' or other expansion demonstration apparatus
- salol (phenyl salicylate)

Out-of-school learning

Pupils could:
- consider why different clothes are worn at different times
- think about how to keep food and drink warm or cool

Learning objectives Pupils should learn:	Possible teaching activities	Learning outcomes Pupils:	Points to note
What's the temperature?			
• that temperature is a measure of how hot things are • that the Celsius scale of temperature is used in science • the values of the boiling point and freezing point of water on the Celsius scale and of some typical temperatures • how to plan a survey, considering the importance of sample size	• Use two introductory activities to help pupils recall previous measuring experience and to raise the issue of scales. • Two pupils put their hands in water, one in cold and the other in warm, then both simultaneously put their hands in lukewarm water and report how it feels; one claims it's warm, the other that it's cold. Ask them to check the temperature with a thermometer. • Ask pupils to suggest values for common temperatures, *eg freezing water, boiling water, room temperature, outside temperatures during different seasons, body temperature, the coldest place on Earth, the hottest place on Earth, hot oven temperature, safe (hygienic) fridge and freezer temperature*. Then pupils: – measure or otherwise find out about these temperatures and produce a chart of temperatures such as a 'temperature line' or bar chart; or – conduct a survey of perception of temperature values with adults or other class groups, and work out how much those surveyed estimate values too high or too low	• explain why using their senses is not a reliable way to measure temperature • understand the need for a scale of temperature and use the Celsius scale of temperature • combine results to produce a larger sample size • present information in chart form so that it is easily assimilated	• A temperature line is an example of a number line, and should include negative values. • Pupils could find out about these temperature values for homework. ⚠ **Safety** – water must not be too hot
• that there are different kinds of thermometer	• Demonstrate or arrange for groups to use different thermometers to measure a range of temperatures.	• select an appropriate thermometer for a set of measurements	• Possible examples include sensors with dataloggers, digital display, bimetal strip, thermocouple, as well as liquid-in-glass.
How do things get hotter or colder?			
• to recognise heat as energy • to use a model which associates energy flow with temperature change • to make predictions and compare these with observations • that heat flows as a result of temperature differences	• Remind pupils of year 7 work on the heating effect of burning fuels, where energy was released to cause temperature rise. Discuss the energy flow associated with the cooling of boiling water and the warming of ice in the classroom. • Elicit pupils' ideas about how heat and temperature are linked and establish that they are not the same thing. Ask pupils to predict and observe how the temperatures change when they, *eg mix volumes of hot and cold water, boil different quantities of water with the same heater.* • Through questioning, help pupils explain why their predictions matched or did not match the observations they made.	• describe the flow of heat (energy) in an everyday situation of temperature change, *eg the cooling of hot food* • relate a flow of heat to change in temperature • relate a difference in temperature to a flow of heat • give reasons for their predictions and for any differences between the predictions and observations	• Pupils often confuse heat and temperature. The distinction required is that heat is a quantity of energy and that temperature is the response of a material to the input of energy. Heat capacity can be left to key stage 4. The principle of energy conservation is covered in unit 9I 'Energy and electricity'. • Pupils should understand that heat naturally flows from a higher to a lower temperature. The fridge needs a power supply to make heat go the opposite way (details of its mechanism are not required here). ⚠ **Safety** – care is needed with hot and boiling water

Learning objectives Pupils should learn:	Possible teaching activities	Learning outcomes Pupils:	Points to note
• that heat energy will flow more easily through good thermal conductors and less well through poor conductors	• Ask pupils to touch a number of materials, *eg wool, metal, polystyrene, rubber, wood, glass, etc,* and decide which feels coldest/warmest. Summarise opinions. Point out that all materials are at the same temperature – room temperature. Explain that the sensation of coldness is caused by the best conductors of heat conducting their body heat away most quickly. The temperature difference causing this flow of energy is between the pupils themselves and the object they touched. Remind pupils that we have a near-constant body temperature of about 37°C. Ask how this compares with the objects touched.	• explain that whether things feel warm or cold to the touch will depend on their conductivity as well as their temperature	• Pupils may have investigated thermal insulators for keeping things warm or cool at key stage 2. Some may think that thick clothes 'make them warm', as if the material is active rather than preventing the loss of heat generated by the body. • Pupils should be dissuaded from talking about 'the cold getting in' when discussing the purpose of insulation.
• that most metals are good thermal conductors • that poor thermal conductors are called insulators • how to use ICT to monitor temperatures	• Ask pupils to work in pairs to suggest why certain materials are used in cooking utensils, *eg a wooden spoon (or saucepan handle) and a metal saucepan base.* Demonstrate the difference in rate of conduction of heat, *eg using temperature probes and dataloggers to determine temperature of the tip of a rod and monitor the rate of temperature rise; temperature probes along length of rod.* Use the demonstration to classify materials as good or poor thermal conductors.	• classify materials as conductors or insulators of heat • interpret temperature data from datalogger	• Pupils find out about the properties of elements in unit 8E 'Atoms and elements' and more about metals in unit 9E 'Reactions of metals and metal compounds'. • Extension: compare the conductivity of a range of metals, *eg aluminium, copper, steel*, and relate this to claims made for different metal cooking utensils. ⚠ **Safety** – take care to leave time for rods to cool before handling
• that liquids and gases are poor thermal conductors	• Demonstrate poor conductivity of water by trapping an ice cube at the bottom of a tube of boiling water using a small piece of gauze. Heat the top of the water to boiling point and show that the ice remains unmelted at the bottom. Temperature sensors linked to a computer could monitor different positions in the tube. • Show highly effective insulating materials, *eg expanded polystyrene, filling for duvets,* and demonstrate that they are mostly trapped air, *eg evacuate a sample with a vacuum pump.*	• describe evidence that gases and liquids are poor conductors of heat	• This arrangement prevents transmission of heat by convection, which is covered in the next section. • There is no transfer by convection in these materials because the air is trapped in small pockets.
• that evidence of conduction in solids, liquids and gases can be explained using the particle model	• Recall with pupils the idea that solids are made of particles called atoms and molecules. Introduce the idea that when energy as heat is absorbed by a solid, the particles move around their position in the solid more. This movement can be passed on to adjacent particles. Get pupils to enact this model of conduction: ask them to link arms firmly in a line (simulates a solid), then one pupil provides energy ('heats the line') by gently pushing and pulling the end of the line. The energy (movement) is conducted along the line. This happens less well if they are merely holding hands (liquid) and not at all if they are not linked (gas).	• simulate the conduction of thermal energy through a solid, liquid or gas • apply the particle model to explain why metals are good conductors and why fluids are poor conductors of heat	• This is the first of three uses of the particle model (kinetic theory) in this unit. It builds on the introduction of particles in unit 7G 'Particle model of solids, liquids and gases' and unit 7H 'Solutions'. • The use of the particle model in explaining chemical reactions is covered in unit 8E 'Atoms and elements' and unit 8F 'Compounds and mixtures'.

Learning objectives Pupils should learn:	Possible teaching activities	Learning outcomes Pupils:	Points to note
How do materials change when they are heated and cooled?			
• that movement of particles in solids, liquids and gases increases with increasing temperature and the particles move further apart • to use the particle model to make predictions and to compare these with observations • that expansion of a material will reduce its density	• Remind pupils of the different ways in which particles are arranged in solids, liquids and gases. • Carry out a quick demonstration of expansion of a solid on heating, *eg 'ball and ring', or by heating a horizontal metal rod clamped at one end, with the other end free to roll over a pin with a small paper flag attached.* Discuss with pupils and get them to model, in terms of particles, why the rod/solid expands and contracts. Ask them to use the particle model to predict what would happen if a liquid or gas were heated or cooled, and check the prediction by demonstration or pupil practical work, *eg* – *warm in a water bath a boiling tube filled with oil, with a bung placed in the top, into which has been placed a narrow vertical glass tube with the oil level part way up* – *warm with hands a large round flask containing water with a bung in the top, into which a narrow vertical glass tube has been inserted; either insert a small bead of oil in the glass tube, or invert the open tube into the water and watch the air bubble out* • Ask pupils to use the observations to explain why it would be dangerous to heat a completely sealed container of a liquid or gas.	• describe the expansion of all three states of matter on heating (in terms of particles moving more and taking up more space) and contraction on cooling (in terms of particles slowing down and taking up less space) • relate different states to the different motion and arrangement of particles	• It is important to encourage pupils to apply the particle model themselves. • A very common misconception is that particles themselves expand on heating. It is not obvious from the experimental results that this is incorrect and pupils will need to be given the scientific explanation, ie in terms of increasing separation of particles. ⚠ **Safety** – ensure that containers of liquid and gas allow for expansion and can be heated safely
• that hot fluids rise due to expansion and cooler ones sink to take their place • that expansion of fluids causes a change in density	• Review pupils' ideas of upthrust and density by showing a helium balloon rise or by using similar stimulus material. • Build a (tethered) hot-air balloon using 'night lights' as the source of hot air, or build a windmill suspended from a thread to be driven by the hot air rising from a 100W light bulb. Establish that these work because heated air moves upwards since it is less dense than cooler air, and point out that the air will come down as it cools. • Use forceps to drop a crystal of potassium manganate (VII) down a glass tube into water, which is then warmed over a Bunsen burner, and observe the trail of purple water formed due to the convection current. Alternatively, place a bottle containing cold, colourless water on top of a bottle containing hot coloured water, so that the contents can mix. Repeat with the bottle containing the cold colourless water on the bottom.	• recognise common hazards and work safely with flames and hot light bulbs • choose apparatus to undertake a successful design-and-build exercise • describe how air or water moves when part is heated or cooled	• Upthrust and density are covered in unit 7K 'Forces and their effects'. • Beware of the incorrect statement 'heat rises'. This is often used instead of 'hot air rises'. • Better results are obtained if the crystal is dropped down a narrow glass tube to prevent colouring the water from the top. ⚠ **Safety** – flammable materials; potassium manganate (VII) is a harmful oxidiser (handle with forceps)
• how to organise information about a scientific topic into a coherent sequence	• Offer pupils a mixed-up written explanation of what they have just seen, including reference to energy transfer, and ask them to sequence it chronologically to describe convection currents.	• produce coherent text explaining how a convection current transfers heat	

Learning objectives Pupils should learn:	**Possible teaching activities**	**Learning outcomes** Pupils:	**Points to note**
• to apply the particle model to explain convection in fluids	• Remind pupils that in a solid the particles are closely packed, while in fluids they can move past each other. Encourage them to speculate how the absorption of heat by fluids will cause movement of these particles. • Present a model in which some pupils acquire energy, *eg coloured paper resembling banknotes,* from the source at the front of the room. Explain that those with the most money move fastest, but when they meet the others they give money away. So pupils move from the source towards the back of the classroom (top of the container) distributing money/energy on the way. Others take their place to be provided with energy until they are all warm.	• work with others to simulate convection, *eg describe their role as a particle gaining and losing energy*	• This is a complex model, which uses several elements of the kinetic theory; for some pupils a description of an example of convection would be more appropriate.
• that radiation energy (infrared) can travel through a vacuum	• Conduction and convection both need particles to carry energy when heat is transferred. Ask pupils if heat can travel through nothing at all (a vacuum). • Draw connections between the behaviour of heat and light from the Sun, *eg both radiate from the source.* Demonstrate focusing (use of burning glass) and reflection of infrared radiation using radiant heaters or hot light bulbs.	• distinguish between transfer of thermal energy via conduction and convection and transfer by radiation, with reference to requirement for a medium	• Make the distinction from sound, which does need a medium to travel. Beware of pupils confusing thermal radiation with radioactivity (often called radiation). **Safety** – beware of trailing leads if using mains equipment. Ensure that pupils cannot touch heating elements
How can we reduce energy waste?			
• that insulation can reduce unwanted energy transfer	• Review pupils' key stage 2 work on insulators, where they may have investigated keeping cups of liquid warm or preventing ice cubes melting. • Recap year 7 work on the need to conserve energy resources. Ask groups to discuss the ways used to prevent energy escaping from homes, *eg loft insulation, heavy curtains, cavity-wall insulation.* • Use models to explain how these methods work, *eg double glazing, draught excluders*.	• describe and explain how a house can be fitted out to reduce heat loss	
• to frame a question that can be investigated • to use preliminary work to decide what to measure and the range of measurements to be made • to decide whether it is appropriate to use ICT for collecting data • to decide how best to present the data and to draw conclusions from this • to evaluate their conclusions	• Ask pupils to devise a way to compare the effectiveness of different insulation techniques, using a small lamp as a heating source in an 'energy house', *eg use dataloggers to produce on-screen graphs of heating or cooling*. Help pupils to decide what factors to consider, *eg the starting temperature of the house and thickness, nature and positioning of insulation material.* • Encourage pupils to make some trial measurements and to consider how to present their data and draw conclusions. Ask pupils to evaluate their work and draw inferences for use in everyday contexts.	• devise a plan in which they make fair comparisons • collect and present data • draw conclusions which they relate to practical, everyday situations • evaluate conclusions by considering how good (valid) a model their house is	• This activity may be done as a complete investigation. Home insulation usually prevents a combination of conduction, convection and radiation. Pupils may confuse the various processes and methods, *eg putting shiny foil on the wall behind a radiator reduces loss by reflection of radiation and, consequently, loss by conduction through the wall, even though the foil is a thermal conductor.* **Safety** – teachers should check any heating set-up before use

Learning objectives Pupils should learn:	Possible teaching activities	Learning outcomes Pupils:	Points to note
Checking progress			
• to locate information from text and identify key points • to show relationships between ideas by using links that show purpose and reservation	• Provide pupils with information sources so that they can discuss the pros and cons of different ways of insulating a typical home, *eg using manufacturers' claims for double glazing.* They should attempt to explain their ideas using particle explanations and the concept of heat transfer through materials.	• produce a report explaining the way different 'heat-saving' methods work and comparing effectiveness	• Extension: pupils could consider the environmental impacts of the materials used to make and install insulators, *eg cavity-wall foam, upvc window frames, etc.*
How can we explain change of state?			
• to use the particle model to explain changes of state • that solids, liquids and gases can change when energy is added or removed and these changes are reversible • that changes of state occur at fixed temperatures • to draw an appropriate curve/line to fit quantitative data on a graph	• Ask pupils to use the particle model to predict what might happen if heating of a solid or a liquid *eg wax, water,* continued indefinitely. • Use ICT simulations to illustrate the particle model explanation for melting, boiling, freezing/solidifying. • Invite pupils in groups to measure and record every half minute the temperature of one (or more) material as it changes state, *eg* *– ice as it melts* *– water as it boils* *– salol (phenyl salicylate) as it melts* *– salol (phenyl salicylate) as it freezes* • Ask pupils to plot their data on a graph and show them how to draw an appropriate curve, or use temperature probes with a datalogger, to produce a real-time graphic display. Ask pupils to describe or tell the story of what happens to the temperature. Establish through discussion of their data and some data from secondary sources that changes of state occur at a fixed temperature. Challenge pupils to tell the story of what would happen if their particular substance were cooled or heated again.	• collect data and draw graphs with an appropriate curve to show what happens to the temperature as a material changes state • use the terms 'melting point' and 'boiling point' and give some important examples • describe what happens to the temperature of the substance, *eg the salol got warmer and the temperature stayed the same for three minutes. When it had all melted, the temperature started to go up again* • describe, with reasons, what would happen if the liquid/solid were cooled/heated again • use the particle model to associate heating and cooling with changes of state	• At key stage 2, pupils will have had experience of changes of state and will have used scientific terms for these. They are unlikely to have discussed explanations in terms of particles. • Negative numbers are introduced in key stage 1. By the end of key stage 2, pupils should be able to say that -100°C is lower than 50°C. However, they may need practice in adding and subtracting negative numbers. • Some pupils may need help in choosing appropriate scales for the axes of their graphs. **Safety** – salol (phenyl salicylate) can be safely heated using a water bath; it is not hazardous
Reviewing work			
• to use their ideas about the effects of heat transfer and particle explanations • to communicate their ideas to a variety of audiences • to interpret information	• Bring together pupils' ideas developed in this unit by: – asking them to produce a leaflet which gives an example and an explanation of heat transfer in a situation of interest to them, *eg on a mountaineering expedition above the snowline; on a beach holiday; cooking on a barbecue*. Encourage imagination and ask for explanation. The audience for their leaflet may be parents, younger pupils, the general public – providing a large picture of a seaside scene including sea, sand, Sun, sunbather, beach barbecue, parasol, swimmer, balloonist and onshore wind. Ask pupils to identify all the situations of energy transfer and which mechanism is responsible, and to label and explain each item briefly	• show by their writing that they have assimilated the key ideas behind conduction and insulation • synthesise the key ideas about heat transfer in their responses to the picture	