UNIT 6 Thermal Energy and Matter

Recommended Prior Knowledge
Pupils should have encountered some basic ideas concerning heat and temperature and the difference between them needs to be made clear e.g. a spark has a high temperature but can emit only a little thermal energy whilst the polar sea is cold but the internal energy of all its molecules is large. Many pupils will not distinguish between electrical and thermal conduction and will, also, need to be put straight. Pupils will need to know terms like insulation and radiation (applied to I.R. radiation). Some elementary kinetic theory is also needed for this unit.

Context
This unit introduces the topic of thermodynamics – another hugely significant area of physics. Many large industries rely on its being understood. This unit could be fitted into a course almost anywhere since it is, to some extent, independent of many of the concepts on which the other units rely. Energy, however, ought to have been properly defined before it is taught. Heat is often referred to as thermal energy.

Outline
The early ideas of conduction and convection are fairly easy to explain and to understand and many pupils will already be aware of these two energy transmission mechanisms. Radiation is likely to prove harder and it is worth ensuring that pupils have a clear understanding of this topic before moving on. The effective insulation of buildings is dealt with and the manner in which a thermometer functions will be introduced here. Pupils will meet these phenomena: expansion, boiling, melting and evaporation. The definitions of heat capacity, specific heat capacity and specific latent heat are included in this unit.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
9(a)	Describe how to distinguish between good and bad conductors of heat.	There are many simple examples. Stir hot tea with plastic, wooden, glass, aluminium, stainless steel and silver spoons/rods. Poke a fire with iron, brass and copper rods. Give practical examples: a saucepan should be made from a good conductor whilst its handle is made from a poor one. There are many others.		There are several types of simple equipment which show comparative thermal conduction properties.
9(b)	Describe in molecular terms how heat transfer occurs in solids.	Use a model of a solid structure (balls joined by springs) and show that shaking one end leads to vibrations at the other. In a metal, a vibrating atom can propel electrons a very long distance at high speed. They collide with other atoms far off and set them vibrating. This is a much faster process.	Heat transfer: http://www.lanly.com/heating.htm or: http://www.mansfieldct.org/schools/mms/staff/hand/convcondrad.htm or: http://sol.sci.uop.edu/~jfalward	Pupils can be linked together in a line using their arms and vibrations can be sent along the line. Compare metallic conduction with kicking a football the entire length of the pitch.

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			/heattransfer/heattransfer.html Thermal conduction: http://phun.physics.virginia.edu/topics/thermal.html	
9(c)	Describe convection in fluids in terms of density changes.	Use a Bunsen burner to heat a beaker of water at one side, on the bottom. The convection current can be seen using a few tiny crystals of potassium permanganate at the bottom. Special tubes which link back on themselves in a square shape can be used to illustrate convection. There is a clear series of events which take place in convection: hot water expands → its density falls → it rises → it pushes away the liquid above it and sucks in the liquid next to it → a circulation is set up.		Illustrate convection with specific examples: • wind • heat transmitted around a room • the ice-box in a refrigerator cools the area below it.
9(d)	Describe the process of heat transfer by radiation.	Hot objects emit I.R. radiation (unit 6). The hotter the object, the more radiation it emits. At equilibrium, an object absorbs just as much as it emits. Be careful to distinguish between absorption and emission. Absorption experiment: set up a black can of water and a white can of water in direct sunlight. Determine the temperature rises. Wear a black T-shirt and a white one in direct sunlight. What happens? Emission experiment: set up the two cans filled with boiling water in the shade. Record the temperature drop with time.	IR radiation: http://www.gcse.com/energy/radiation.htm or: http://k12.ocs.ou.edu/teachers/reference/overrad.html Absorption/emission: http://sol.sci.uop.edu/~jfalward/physics17/chapter7/chapter7.html	Examples include: • energy from Sun to Earth • electric fires (not radiators) • thermal imaging. **Trick question:** Why are polar bears white? **Answer:** Camouflage.

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9(e)	Describe how to distinguish between good and bad emitters and good and bad absorbers of infra-red radiation.			
9(f)	Describe how heat is transferred to or from buildings and to or from a room.	Simple experiments measuring the temperature drop of a can of water, a warm piece of metal, or even a thermometer itself, lagged in different ways or given a thin black coating from a sooty candle can be used to illustrate the processes.		
9(g)	State and explain the use of important practical methods of heat insulation for buildings.	The poor conductivity of air does not itself explain insulation, as most buildings are surrounded by many metres of air. Most heat is transferred to or from buildings and rooms by convection in the air. The principle of most insulation mechanisms is to suppress convection. This is done by trapping the air. It is **then** important that air is a poor conductor of heat.	Insulation: http://www.sei.ie/content/content.asp?section_id=1111	A few insulation techniques are not designed to suppress convection. Why is white a popular colour for houses in hot countries? Consider the day and the night.
10(a)	Explain how a physical property which varies with temperature may be used for the measurement of temperature and state examples of such properties.	Make it clear that the property chosen must change significantly, measurably and always in the same direction (prevents ambiguity). Any property which behaves in this way this will do.	Thermometric parameters: http://www.cartage.org.lb/en/themes/Sciences/Physics/Thermodynamics/AboutTemperature/Development/Development.htm	Mention the: • volume of mercury/ ethanol, • resistance of platinum, • thermoelectric e.m.f. of a thermocouple.
10(b)	Explain the need for fixed points and state what is meant by the ice point and the steam point.	Two points are needed to draw a straight line and two fixed points are needed to specify exactly every particular, intermediate point. Give some idea of how they are obtained in practice. Calibrate a thermometer on which no scale has been marked (use rubber bands or a permanent pen to mark the fixed points), or check a laboratory thermometer.	Fixed points: http://honolulu.hawaii.edu/distance/sci122/Programs/p20/p20.html#4.%20Temperature%20Scales	Emphasise that the ice point is the only temperature at which ice and water can co-exist and the steam point is the only temperature at which water and steam may co-exist – both at standard atmospheric pressure.

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10(d)	Describe the structure and action of liquid-in-glass thermometers (including clinical) and of a thermocouple thermometer, showing an appreciation of its use for measuring high temperatures and those which vary rapidly.	Let pupils see a variety of liquid-in-glass thermometers with different ranges and sensitivities. Get them to explain why one thermometer has a greater range than another or why the graduations on one thermometer are closer than on another. Let them see that the bulbs have different volumes, the bores are different, the lengths are different and the liquids might well be different. Will these thermometers be linear? How were the points marked on the scale?	Thermometers: http://honolulu.hawaii.edu/distance/sci122/Programs/p20/p20.html#4.%20Temperature%20Scales Thermocouples: http://www.efunda.com/designstandards/sensors/thermocouples/thmcple_intro.cfm	Describe and show a thermocouple. Discuss its advantages and disadvantages. Will its readings (between 0 °C and 100 °C) agree with hose on the liquid-in-glass thermometer? Use a thermocouple to observe the cooling of a beaker of hot water.
10(c)	Discuss sensitivity, range and linearity of thermometers.	Consider the difficulty of reading a temperature when the thermometer is in someone's mouth. How can this be solved? How would the pupils design a clinical thermometer – one that maintains its maximum reading?	Range and sensitivity: http://kr.cs.ait.ac.th/~radok/physics/j7.htm	
11(a)	Describe a rise in temperature of a body in terms of an increase in its internal energy (random thermal energy).	State the increasing speed of the molecules as the temperature rises as a fact but try to justify it, e.g. as temperature rises: • Brownian motion becomes more violent, • chemical reactions speed up, • the speed of sound in gases rises.	Kinetic theory: http://www.bcpl.net/~kdrews/kmt/kmt.html or: http://www.falstad.com/gas/	
11(b)	Define the terms heat capacity and specific heat capacity.	Emphasise that a rise in temperature is a consequence of the transfer of thermal energy (cause and effect). Heat and temperature are not the same thing. Heat water in a beaker with an immersion heater or use an electric kettle.	Heat capacity: http://www.westga.edu/~chem/courses/chem1211d/lecture/Chapter6/sld008.htm Specific heat capacity: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html	Emphasise that heat capacity is measured for a particular object whereas specific heat capacity is the property of a substance. Specific heat capacity deals with temperature changes and it unit includes that of temperature.

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11(c)	Calculate the heat transferred using the formula *thermal energy = mass x specific heat capacity x change in temperature*.	Plot ΔT → t (temperature rise → time). The initial straight line reveals that ΔT α Q (heat supplied) since Q = Pt. Kettles often have a rated power marked on them. Using this value, determine the specific heat capacity of water.		
11(d)	Describe melting/solidification and boiling/condensation in terms of energy transfer without a change of temperature.	Cool a test-tube of molten wax and plot T→ t. Notice the shape of the graph and where the wax becomes solid. **Do not melt candle wax or any other inflammable substance with or near a naked flame.** Measure the temperature of water as it is brought to the boil and keep measuring it as it boils.	Melting and boiling: http://stweb.peel.edu.on.ca/ssweb/SNC1D/Edmatters/Gr9_Introduction/Handouts/Chemistry/Changes%20of%20State.htm	Specific heat capacity is defined for a single phase changing temperature whilst melting and boiling are phase changes occurring at a single temperature.
11(e)	State the meaning of melting point and boiling point.	Define melting point and boiling point.		
11(f)	Explain the difference between boiling and evaporation.	Leave various dishes of water in direct sunlight. Record their maximum temperature. Do they ever reach 100 °C? Tabulate the differences between the two terms.	Evaporation and boiling: http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/vappre.html#c2	See 12(e) and 12(g) in unit 9.
11(h)	Explain latent heat in terms of molecular behaviour.	Explain that melting/boiling involves pulling the molecules apart against an attractive force which is holding the molecules together. Use a few small balls held together by doubled-sided sticky tape or adhesive strips. Energy is needed to separate the balls.	Vaporisation: http://en.wikipedia.org/wiki/Evaporation	

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11(g)	Define the terms latent heat and specific latent heat.	The latent heat of steam can be used to transfer heat. Consider a "Bain Marie" or a traditional porringer in cooking.	Latent heat: http://www.physchem.co.za/Heat/Latent.htm#fusion Specific latent heat: http://www.irish-energy.ie/content/content.asp?section_id=1165&language_id=1	
11(i)	Calculate heat transferred in a change of state using the formula *thermal energy = mass x specific latent heat.*	Measure the specific latent heat of evaporation of water. Use an electric kettle whose power rating is known and let the water boil for five or six minutes. Measure the mass of water which escaped. Leaving the lid off as it boils should prevent an automatic kettle switching itself off at the boiling point.		
11(j)	Describe qualitatively the thermal expansion of solids, liquids and gases.	Demonstrate specific examples. • Solids: ball and hoop, and the bimetallic strip. • Liquids: completely fill a flask with coloured water, insert a bung with a narrow tube and immerse the flask in hot water. At first the water level in the tube falls as the glass expands but then the level rises. • Gases: use the flask with the bung and tube empty and invert the equipment and put free end of the tube under water. Bubbles emerge when the flask is held in warm hands.	Expansion of solids, liquids and gases: http://www.physchem.co.za/Heat/Effects.htm	
11(k)	Describe the relative order of magnitude of the expansion of solids, liquids and gases.	In a liquid-in-glass thermometer, both the liquid and the glass expand. It is possible sometimes to see a fall in the liquid level before it rises since the glass expands first. Eventually the liquid expands more and the liquid rises in the tube even though the tube has expanded. All ideal gases expand at the same rate as each other which is much larger than the rate at which liquids expand.	Thermal expansion: http://www.physchem.co.za/Heat/Effects.htm or http://www.wpbschoolhouse.btinternet.co.uk/page03/3_52states.htm Expansion: http://www.revision-notes.co.uk/revision/148.html	Galilean thermometers work on the same principle. As the temperature rises, the liquid expands more than the solid and so the density of the liquid falls faster. The balls sink.

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11(l)	List and explain some of the everyday applications and consequences of thermal expansion.	Ask pupils to collect photographs or make drawings of anywhere that thermal expansion is good or bad. All of these are used: the bimetallic strip is the basis of the thermostat, riveting and fitting metal rims on train wheels, expansion has to be allowed for in tall buildings, overhead power cables, bridges, roads and railway lines. The thermal expansion of liquids is the basis of the liquid-in-glass thermometer.	Expansion of bridges: http://www.dimages.ca/expansion_of_solids.htm	Fuel is cooled so that more can be put into a racing-car's tank of a given volume.
11(m)	Describe qualitatively the effect of a change of temperature on the volume of a gas at constant pressure.	Demonstrate this effect by trapping air in a capillary tube with an index of oil or concentrated sulphuric acid. Put the tube into a beaker of hot water and as the gas expands, it pushes the index up. If a class set is available pupils can plot a graph of the length of the air column against temperature and extrapolate the graph backwards to zero length.		