4.3 Particle model of matter

The particle model is widely used to predict the behaviour of solids, liquids and gases and this has many applications in everyday life. It helps us to explain a wide range of observations and engineers use these principles when designing vessels to withstand high pressures and temperatures, such as submarines and spacecraft. It also explains why it is difficult to make a good cup of tea high up a mountain!

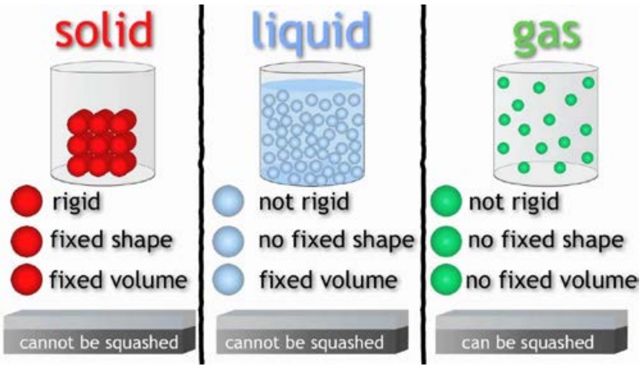
4.3.1 Changes of state and the particle model

4.3.1.1 Density of materials

Content	Key opportunities for skills development
The density of a material is defined by the equation: density = $\frac{\text{mass}}{\text{volume}}$ [$\rho = \frac{m}{V}$] density, ρ, in kilograms per metre cubed, kg/m^3 mass, m, in kilograms, kg volume, V, in metres cubed, m^3 The particle model can be used to explain • the different states of matter • differences in density.	MS 1a, b, c, 3b, c Students should be able to recall and apply this equation to changes where mass is conserved.
Students should be able to recognise/draw simple diagrams to model the difference between solids, liquids and gases.	WS 1.2
Students should be able to explain the differences in density between the different states of matter in terms of the arrangement of atoms or molecules.	WS 1.2

Required practical activity 5: use appropriate apparatus to make and record the measurements needed to determine the densities of regular and irregular solid objects and liquids. Volume should be determined from the dimensions of regularly shaped objects, and by a displacement technique for irregularly shaped objects. Dimensions to be measured using appropriate apparatus such as a ruler, micrometer or Vernier callipers.

Particle Model is just what you are used to drawing. You need to be able to draw the diagrams and relate the properties of solids, liquids and gases to the movement, position and bonds between the particles. You should also know that solids tend to be denser than liquids (although this is not always true – take ice and water for instance) and both are much more dense than gases.



Density

You need to **learn the equation** and know what units things are measured in.

The required practical is in several stages but none are very difficult. With all of these practicals it is important to state very clearly what measurements need to be taken, what equipment should be used for taking them and what you do with the data once you have got it.

Regular objects e.g. a wooden block –

- Measure, using **a ruler** or **Vernier callipers**, the height, length and width of the block. Multiply these together to get the **volume**.
- Determine the **mass** of the object using **scales**.
- Divide the mass by the volume to determine the density.

Irregular objects e.g. a funny shaped metal thing

- Use a displacement can to find the volume.
- Fill the can up with water and place on a flat surface. Wait until the can stops dripping.
- Carefully place object into can.
- Catch the water displaced through the spout in a measuring cylinder.
- The volume of water displaced is equal to the volume of the object placed in the water.
- Determine the mass using scales.
- Divide the mass by the volume to find the density.

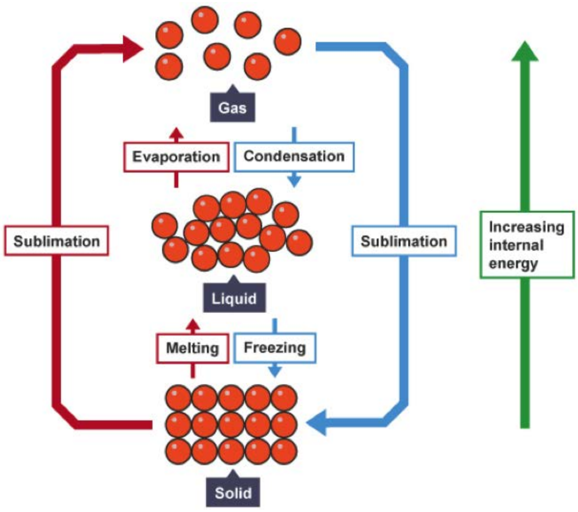
Liquids e.g. water

- Find the mass of an empty measuring cylinder using scales.
- Fill the measuring cylinder with a known amount of water e.g. 100ml
- Put it on the scales again. Find the mass of the water by subtracting the mass of the empty cylinder.
- Divide the mass by the volume to find the density.

4.3.1.2 Changes of state

Content	Key opportunities for skills development
Students should be able to describe how, when substances change state (melt, freeze, boil, evaporate, condense or sublimate), mass is conserved. Changes of state are physical changes which differ from chemical changes because the material recovers its original properties if the change is reversed.	

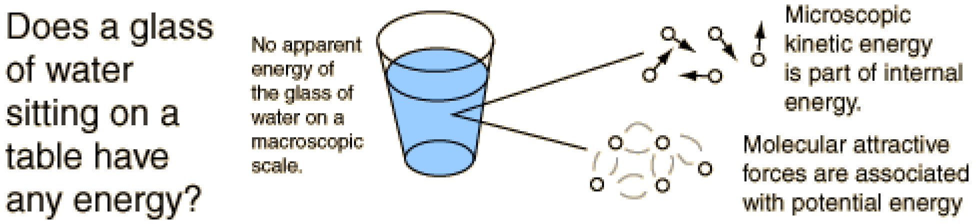
You need to know the meaning of the key words in the diagram below and know that any physical change in state can be reversed. Remember, anything can be a solid, liquid or gas, it just depends on the temperature. (There are a couple of exceptions to this e.g. Carbon dioxide sublimes so it does not have a liquid state at atmospheric pressure).



4.3.2.1 Internal energy

Content	Key opportunities for skills development
Energy is stored inside a system by the particles (atoms and molecules) that make up the system. This is called internal energy. Internal energy is the total kinetic energy and potential energy of all the particles (atoms and molecules) that make up a system. Heating changes the energy stored within the system by increasing the energy of the particles that make up the system. This either raises the temperature of the system or produces a change of state.	

Internal energy (as it states quite clearly above) is the sum of the kinetic energy and the potential energy of the particles. So, if you heat something up you give the particles more kinetic energy so that they move faster. This will increase the internal energy of the system. The other way is to increase the potential energy which you do by stretching the object i.e. making the particles move further away from each other. This will also increase the internal energy of the object.



4.3.2.2 Temperature changes in a system and specific heat capacity

Content	Key opportunities for skills development
If the temperature of the system increases, the increase in temperature depends on the mass of the substance heated, the type of material and the energy input to the system.	
The following equation applies: change in thermal energy = mass × specific heat capacity × temperature change $[\Delta E = m\,c\,\Delta\theta]$ change in thermal energy, ΔE, in joules, J mass, m, in kilograms, kg specific heat capacity, c, in joules per kilogram per degree Celsius, J/kg °C temperature change, $\Delta\theta$, in degrees Celsius, °C. The specific heat capacity of a substance is the amount of energy required to raise the temperature of one kilogram of the substance by one degree Celsius.	MS 1a, 3b, c, d Students should be able to apply this equation, which is given on the *Physics equation sheet*, to calculate the energy change involved when the temperature of a material changes. This equation and specific heat capacity are also included in Energy changes in systems.

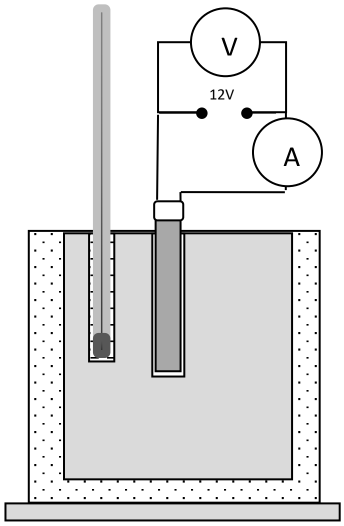
The equation for specific heat capacity is included on the equation sheet that you will be given in exams. Therefore you do not need to learn it. However, you do need to rearrange it. See website for additional questions to check you know how to do this. Something with a high specific heat capacity, such as water, needs a lot of energy to increase its temperature. Metals tend to have fairly low specific heat capacities so take much less energy to increase the temperature. This means that water is used in lots of places where you need to remove or transfer heat such as car radiators or heating systems in the home.

Required Practical

What is the specific heat capacity of copper?

Materials

In addition to access to general laboratory equipment, each group needs:



- 1 kg copper block with two holes – one for the heater and one for the thermometer
- 1 kg iron, aluminium or lead blocks for comparison
- thermometer
- pipette to put water in the thermometer hole
- 30 W heater
- 12 V power supply
- insulation to wrap around the blocks
- ammeter and voltmeter
- 4mm leads
- stop watch or stop clock
- balance (capable of measuring more than 1 kg) to determine the mass of the blocks
- heatproof mat.

Method

- Measure and record the mass of the copper block in kg.
- Place a heater in the larger hole in the block.
- Connect the ammeter, power pack and heater in series.
- Connect the voltmeter across the power pack.
- Use the pipette to put a small amount of water in the other hole.
- Put the thermometer in this hole.
- Switch the power pack to 12 V. Switch it on.
- Record the ammeter and voltmeter readings. These shouldn't change during the experiment.
- Measure the temperature and switch on the stop clock.
- Record the temperature every minute for 10 minutes.

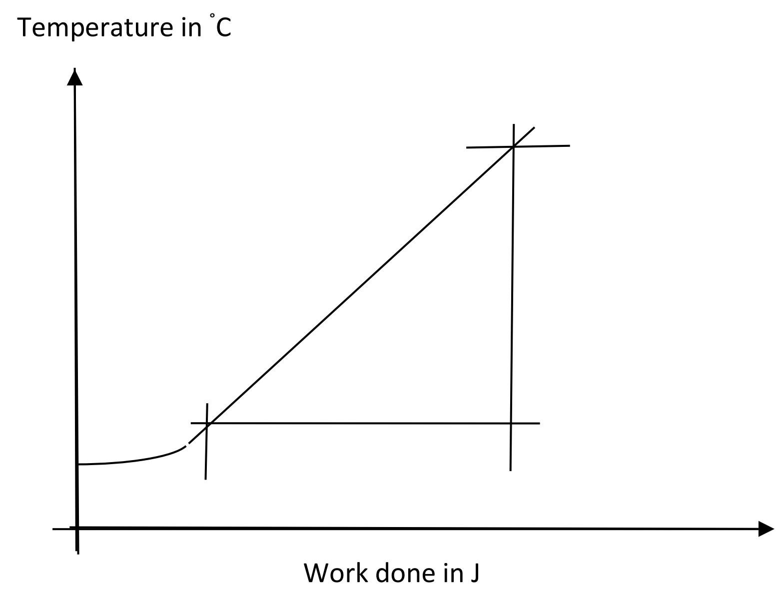
Add your results to a table such as the one below.

Time in seconds	Work done in J	Temperature in ˚C
0		
60		

Calculate the power of the heater in watts.

To do this, multiply the ammeter reading by the voltmeter reading.

1. Calculate the work done by the heater. To do this, multiply the time in seconds by the power of the heater.
2. Plot a graph of temperature in °C against work done in J.



3. Draw a line of best fit. Take care as the beginning of the graph may be curved.

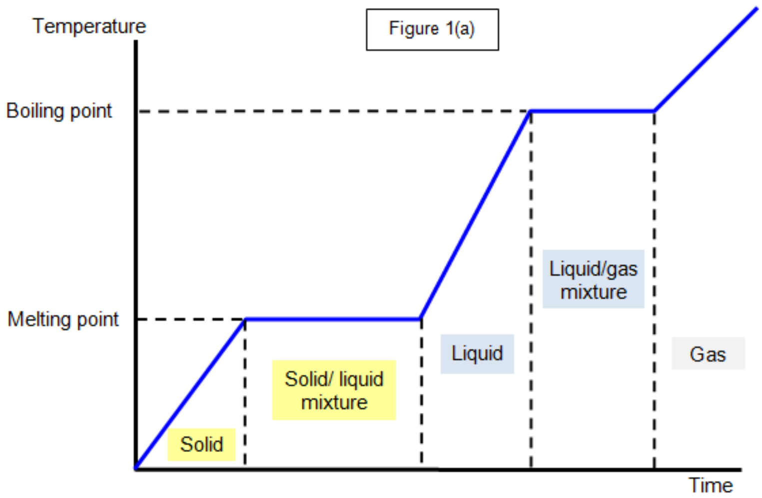
4. Mark two points on the line you have drawn and calculate the change in temperature *(ϑ)* and the change in work done *(E)* between these points

5. Calculate the specific heat capacity of the copper (*c*) by using the equation $c = \frac{E}{m \times \vartheta}$ where *m* is the mass of the copper block

4.3.2.3 Changes of heat and specific latent heat

Content	Key opportunities for skills development
If a change of state happens: The energy needed for a substance to change state is called latent heat. When a change of state occurs, the energy supplied changes the energy stored (internal energy) but not the temperature. The specific latent heat of a substance is the amount of energy required to change the state of one kilogram of the substance with no change in temperature.	
energy for a change of state = mass × specific latent heat [$E = m\,L$] energy, E, in joules, J mass, m, in kilograms, kg specific latent heat, L, in joules per kilogram, J/kg Specific latent heat of fusion – change of state from solid to liquid Specific latent heat of vaporisation – change of state from liquid to vapour	MS 1a, 3b, c, d Students should be able to apply this equation, which is given on the *Physics equation sheet*, to calculate the energy change involved in a change of state. MS 4a AT 5 Perform an experiment to measure the latent heat of fusion of water.
Students should be able to interpret heating and cooling graphs that include changes of state. Students should be able to distinguish between specific heat capacity and specific latent heat.	WS 3.5

This equation is given on the equation sheet as well. You basically need to know what it says above. Don't worry too much, or at all really, about the bonds. You will notice that they are not mentioned in the specification at all which probably means that they are not going to ask you questions about them. Knowing that they are made of energy is probably enough. You do need to know the fusion and vaporisation business as detailed above and to explain the shape of the curve below, labelling where the specific latent heat of fusion and vaporisation come in to it i.e. fusion is the flat bit when it changes from a solid to a liquid and vaporisation is the flat bit where it changes from a liquid to a gas.



4.3.3.1 Particle motion in gases

Content	Key opportunities for skills development
The molecules of a gas are in constant random motion. The temperature of the gas is related to the average kinetic energy of the molecules. Changing the temperature of a gas, held at constant volume, changes the pressure exerted by the gas.	WS 1.2
Students should be able to: • explain how the motion of the molecules in a gas is related to both its temperature and its pressure • explain qualitatively the relation between the temperature of a gas and its pressure at constant volume.	WS 1.2

The fact that the temperature of a gas is a measure of the KE of the molecules is important. So if you heat something up you are giving the particles more KE and they move faster. This will make the gas hotter.

Gases exert pressure on the container they are held it because the molecules hit the walls and bounce back in the other direction. This puts a force on the walls. Pressure is force divided by area so there must be a pressure. If the temperature increases then the particles are moving faster so they will hit the walls **more often** so the pressure will increase. This is what the last statement in the specification above means.

4.3.3.2 Pressure in gases (physics only)

Content	Key opportunities for skills development
A gas can be compressed or expanded by pressure changes. The pressure produces a net force at right angles to the wall of the gas container (or any surface).	WS 1.2
Students should be able to use the particle model to explain how increasing the volume in which a gas is contained, at constant temperature, can lead to a decrease in pressure. For a fixed mass of gas held at a constant temperature: pressure × volume = constant [$p V = constant$] pressure, p, in pascals, Pa volume, V, in metres cubed, m^3 Students should be able to calculate the change in the pressure of a gas or the volume of a gas (a fixed mass held at constant temperature) when either the pressure or volume is increased or decreased.	MS 3b, c Students should be able to apply this equation which is given on the *Physics equation sheet*.

This is known as Boyle's law which you don't have to know but it helps if you want to look stuff up about it. The first statement means that if you squash a gas the pressure increases. This is because the walls of the container are now closer together so again the particles will hit them more often so the pressure will increase.

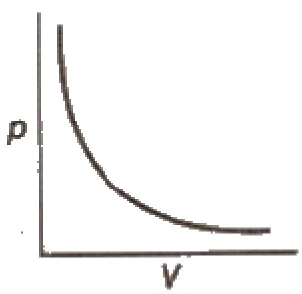
The opposite is also true. If you increase the volume then the particles will have further to travel between hitting the walls so will do so less often, thus the pressure will decrease.

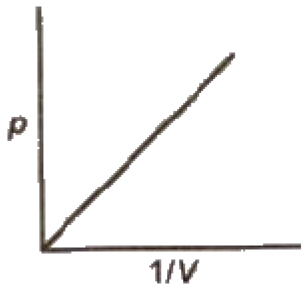
The equation $pV = constant$ is given on your sheet. However, you do need to realise that this means that it is also true that

$$p_1V_1 = p_2V_2$$

Because they both equal the same constant providing that the temperature and the mass of the gas have not changed. You will also need to be able to rearrange this formula. A typical question will be when you are given a pressure and a volume of a gas before something happens then either a pressure or a volume after the event and you have to find the missing one. See workbook or website for examples.

You also should be familiar with the two graphs that arise from this equation.





Physicists always like to plot straight line graphs for several reasons. Firstly it is much easier to draw a straight line of best fit accurately than it is to do a curve. This also makes anomalous results much easier to spot. The second, and indeed main, reason is that you can find the gradient of a straight line graph. This means that you can find the constant from the equation above and therefore use it to work out other pressures and volumes that you cannot find out experimentally.

4.3.3.3 Increasing the pressure of a gas (physics only) (HT only)

Content	Key opportunities for skills development
Work is the transfer of energy by a force. Doing work on a gas increases the internal energy of the gas and can cause an increase in the temperature of the gas.	
Students should be able to explain how, in a given situation eg a bicycle pump, doing work on an enclosed gas leads to an increase in the temperature of the gas.	WS 1.2

When you push on any gas in a container you are doing work on it. You are applying a force over a distance (e.g. the distance that the container squashes). Work done is an energy as we all know. Thus you are adding energy to the gas which becomes part of the internal energy of the gas. This means that it has more internal energy and therefore must have got hotter.