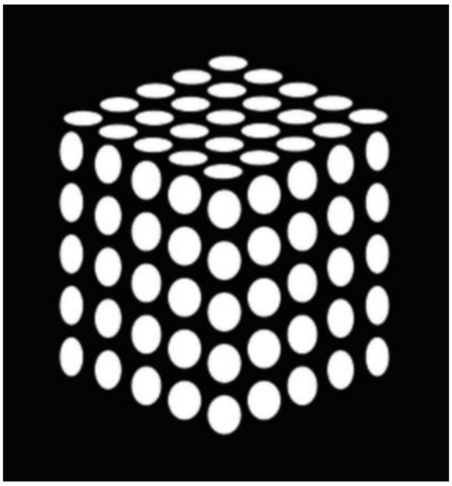
Physics 6.3

Particle Model



	Question	Answer

1	What do we mean by "particle"?	An atom or molecule
2	Describe the particle arrangement in a solid	Particles have a regular arrangement, have a fixed position, touch each other and small spaces
3	Describe the particle arrangement in a liquid	Particles touch each other but have no fixed position and slide past each other. Some small spaces.
4	Describe the particle arrangement in a gas	Particles are separated and move freely. Large spaces.
5	What formula relates density, mass and volume?	Density = Mass / volume
6	Define "physical change"	A change in which intermolecular forces are overcome or enabled but no chemical bonds are broken or made.
7	Give a particle explanation for melting	Particles are given enough energy (through heating) to overcome the intermolecular forces that hold them in a fixed position.
8	Give a particle explanation for freezing	Particles lose kinetic energy and move more slowly, reducing spaces between particles and allowing intermolecular forces to hold particles together
9	What is condensing?	When a gas cools to form a liquid
10	What is boiling?	When a liquid is heated to form a gas
11	What is evaporation?	When a liquid slowly forms a gas due to kinetic energy of individual particles at the surface
12	What is sublimation?	When a solid turns straight to a gas or a gas turns straight to a solid

13	Define internal energy of an object	The total kinetic and potential energy of the particles in an object
14	Define "specific heat capacity"	The amount of energy needed to raise the temperature of 1kg by 1 degree C.
15	Define "latent heat"	The energy needed to change state "up"
16	Describe the relationship between gas temperature and pressure at constant volume	The higher the temperature the higher the pressure
17	What is "potential energy of particles"?	Energy particles have because they've had work done on them
18	What is "kinetic energy of particles"?	Energy particles have because they are moving
19	What does "to do work on particles" mean?	To move them further apart against their intermolecular attraction
20	How would you find the specific heat capacity of a material?	Find its mass, time how long it takes to raise temp of sample, find energy as power X time, then use shc formula (given)
21	How would you calculate the density of a cuboid?	Volume = length X base X height. Find mass using a mass balance, then use density = mass / volume
22	How would you find the density of an irregular object?	Volume = displaced water into a measuring cylinder. Find mass using mass balance, then use density = mass/volume

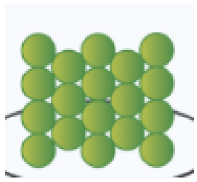
Name	**Symbol**	**Factor**	**To convert to standard units:**
Tera	T	10^{12}	× by
Giga	G	10^{9}	× by

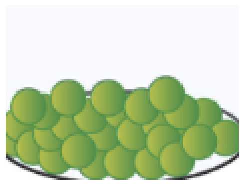
Mega	M	10^6	× by 1,000,000
kilo	k	10^3	× by 1,000
centi	c	10^{-2}	÷ by 100
milli	m	10^{-3}	÷ by 1,000
micro	μ	10^{-6}	÷ by 1,000,000
nano	n	10^{-9}	÷ by 1,000,000,000

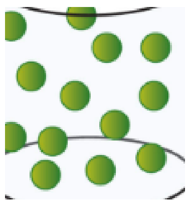
Kinetic theory

All matter (solids, liquids and gases) is made of atoms. In many substances these atoms are joined as molecules or giant structures of ionic lattices. For the purposes of this unit, we will refer to all of these constituents of matter: atoms, molecules and ions, as "particles".

Particles in materials are held together by attractive forces. In a solid, the particles are held firmly together because these forces are strong. If we want to melt a solid to turn it into a liquid, we must put energy in in order to do work against these forces and overcome them, to separate the particles from their fixed positions in rows. This is why you need to heat a solid to melt it. A similar situation arises if you want to boil a liquid to create a gas: you must put energy in in order to overcome the forces holding the particles together in a liquid. This energy is transferred to the substance by heating.







You have already learned about energy stores. You will have seen how energy is stored when objects move and also in the thermal store of objects. In fact thermal energy stores are just a special version of kinetic energy stores. When you heat a material, its particles gain energy.

Scientists talk about internal energy of an object or material. This is the energy stored because of the arrangement and motion of the particles. These two aspects are called potential energy and kinetic energy respectively.

Consider a block of ice at -20°C. If we put it in a sealed tin and heat it with a Bunsen flame, its temperature will increase until it reaches 0°C. At this point it will melt. After all the ice has melted to form liquid water, the water temperature now increases until it reaches 100°C – at this point it will begin to boil and become a gas (water vapour). At each of these stages, energy is stored in the internal energy of the ice/water/steam.

Time (m)	0	1	2	3	4	5	6
Total energy added	0	1,000J	2,000J	6,000J	12,000J	20,000J	25,000J
Pic							
Temp	-20°C	-10°C	0°C	40°C	80°C	100°C	120°C
State	Solid	Solid	Solid melting to liquid	Liquid	Liquid	Liquid boiling to gas	Gas
Particle diagram							
Arrangement of particles	Orderly rows	Orderly rows	Departing from orderly rows and beginning to slide past each other	Touching but no fixed positions or rows	Touching but no fixed positions or rows	Some particles are escaping the liquid to move freely on their own	Large spaces between particles
Attractive forces between the particles	Strong	Strong	Some strong, some weaker	Weak but still attractive	Weak but still attractive	Beginning to become very weak	Very weak
Motion of particles	Vibrating in fixed positions	Vibrating in fixed positions	Some beginning to move away from fixed positions	Constant movement, no fixed positions	Constant movement, no fixed positions	Some sliding past each other, some moving rapidly on their own, not touching any others	Random and fast
How is the added energy being stored?	Kinetic energy of particles	Kinetic energy of particles	Potential energy of particles	Kinetic energy of particles	Kinetic energy of particles	Potential energy of particles	Kinetic energy of particles

Questions for thinking:

1. What things are included in the term "particles" for this unit?
2. Why are the particles in a solid held firmly together?
3. Why must we heat a solid if we want to melt it?
4. Why are the particles in a liquid held together?
5. Why can liquids flow whereas solids can't?
6. Why must you heat a liquid in order to boil it?
7. Compare the arrangement of particles in a solid, liquid and gas.
8. Compare the motion of particles in a solid, liquid and gas.
9. What are the two components of internal energy called?
10. Which component is to do with the temperature of the material?
11. Which component is to do with the state of the material?
12. State three possible temperatures for a block of ice
13. State three possible temperatures for a beaker of water
14. State three possible temperatures for a can of water vapour.

Density

All matter is made of atoms and molecules. We can use the term "particles" to include atoms and molecules.

Density is a measure of how heavy a certain volume of a material is. Iron is more dense than wood and wood is more dense than air. The equation for density is:

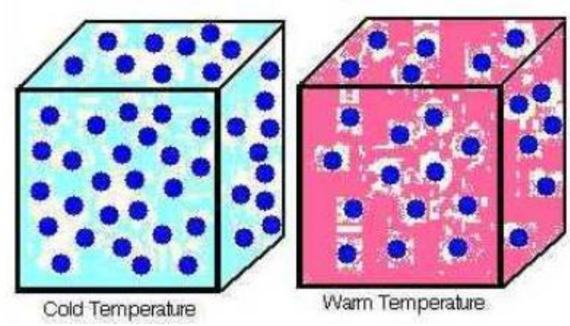
$$\rho = \frac{m}{V} \qquad \text{density} = \frac{\text{mass}}{\text{volume}}$$

density, ρ, in kilograms per metre cubed, kg/m^3

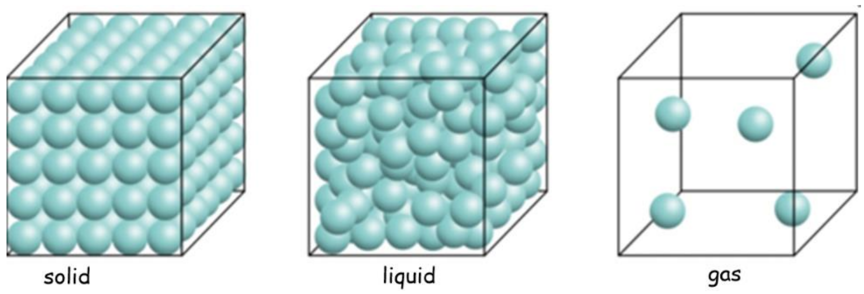
mass, m, in kilograms, kg

volume, V, in metres cubed, m^3

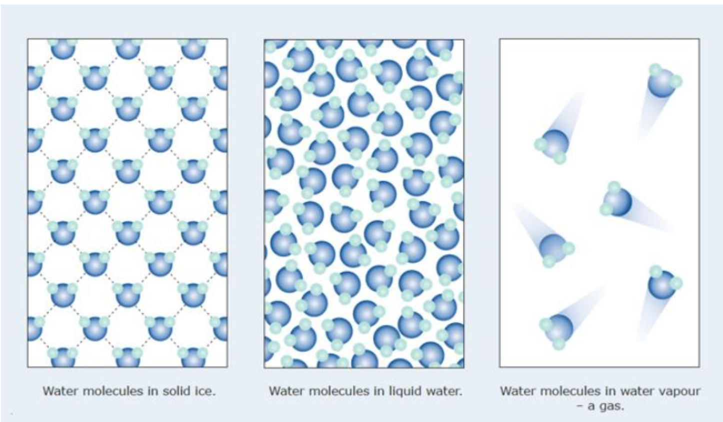
Most materials become less dense as they are heated. Heating gives particles more kinetic energy, and as they move faster particles become further apart from each other, effectively decreasing the density of the material as a higher proportion of it is empty space.



Different states of a material have different densities because of particle arrangement:



Most materials are most dense when they are in a solid form. For example, solid iron is more dense than liquid iron, and liquid iron is more dense than gaseous iron. The main exception to this rule is water, which because it has unusually shaped molecules, actually forms a less dense crystal when it is in solid state (frozen) than when it is a liquid:



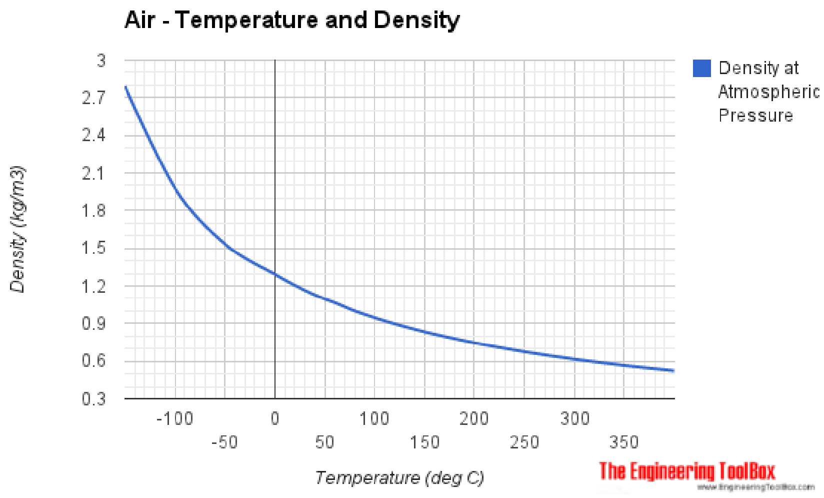
Questions:

1. What is the formula for density?
2. Draw the particle arrangements for solids, liquids and gases.
3. Describe the particle arrangements for solids, liquids and gases.
4. Explain why most materials are more dense in their solid form.
5. Explain why heating a block of metal causes it to become less dense.
6. Calculate the density of a block of metal with mass 1.2kg and volume $0.3m^3$.

7. If a volume of $5.6m^3$ a liquid has mass 6.9kg, find its density.
8. If the density of aluminium is 2,712kg/m^3, find the volume of 13,800kg.
9. Calculate the volume of 240,000kg of barium if the density of barium is 3594kg/m^3.
10. What mass of germanium takes up $4570m^3$ of space if the density of germanium is 5323kg/m^3?
11. If the density of manganese is 7440kg/m^3, find the mass of 35,000 m^3.

Extension:

1. Find the number of particles in the box labelled "solid" on the previous page.
2. Estimate the number of particles in the cube labelled "liquid" above.
3. The graph shows how the density of air varies with temperature.

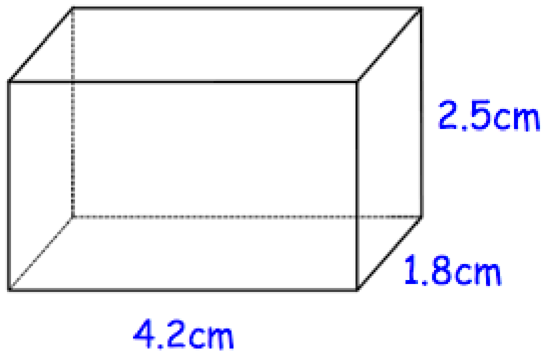


a. Describe the relationship between temperature and density for air.
b. Find the density of air at -50°C.
c. What is the mass of $5m^3$ of air at 150°C?
d. What is the volume of 15kg of air at 50°C?

Practical techniques: Finding the density of objects

To find the density of any object you need to know the value of two things: the mass and the volume. The mass should always be found using digital scales – be sure to press "TARE" to avoid zero errors on the scales.

The method for measuring volume depends on the type of object you have. If you have a regular shaped solid, you can use your formulas for 3D shapes to find the volume:



2.5 x 1.8 x 4.2 = 18.9cm^3

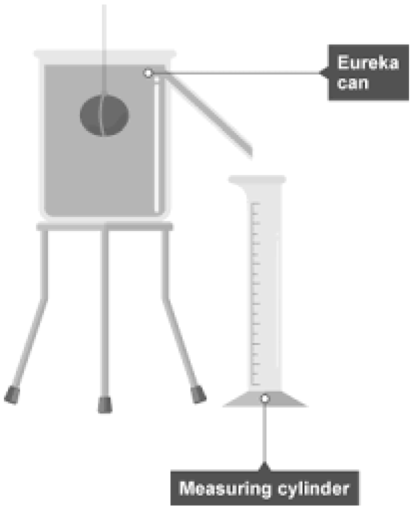
Then just use the formula:

Density = mass/ volume

Density = 5.67/18.9 = 0.3g/cm^3

If you have an irregularly shaped object, you need to use the displacement method to find volume:

Fill a eureka can with water up to the spout hole. Place carefully onto a tripod and top up the water if necessary. Place a measuring cylinder underneath the spout and gently lower the object in, collecting the displaced water in the measuring cylinder. Read the volume of water at eye level to find the volume of the object.



= 30 ml = 30cm

Then just use your formula with the mass you measured using the digital scales:

Density = mass/volume

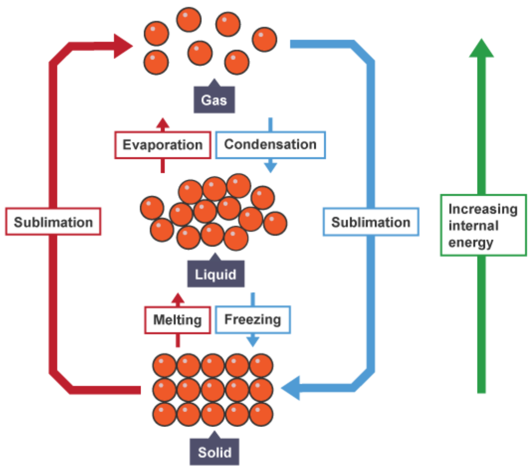
Density = 5.67/30 = = 0.189g/cm^3

Questions:

1. Describe the method for finding the density of a block of metal.
2. Describe the method for finding the density of a chess piece.
3. If you don't press TARE on your digital scales and there is some dust on there, what kind of error will you get?
4. If you don't bend down to read measuring cylinder at eye level, what kind of error do you get?
5. If a leak from the ceiling drips water into your measuring cylinder, what kind of error do you get?

Changes of State

There are three main states of matter: solid, liquid and gas. A substance can be in the solid, the liquid or the gaseous state depending on the energy its particles have. For example, oxygen is a gas at room temperature but if we remove energy from its particles by cooling it, it will condense into a liquid and then freeze into a solid. Different substances do this at different temperatures.



Mass is conserved when a substance changes state. If you start with 1kg of oxygen gas and cool it, you will have 1kg of liquid oxygen.

Changes of state are physical changes as opposed to chemical changes. An example of a chemical change is combustion. Combustion is a chemical change because chemical bonds are broken and formed during the change. It is impossible to reverse combustion and recover the original properties of the reactants. In a physical change such as melting or freezing however, no chemical bonds are broken or formed. Rather, intermolecular forces are overcome or experienced as particles are moved further or closer together as a result of their kinetic energy. If the process is reversed then the properties of the material are identical to those before the state change.

Questions:

1. State the three main states of matter.
2. Copy and complete the table:

State change	From __ to __	Add or remove energy?	What happens to particle movement?	What happens to intermolecular forces?
Melting	From solid to liquid			
Freezing		Remove		
Boiling			Increases	
Condensing				Increased

3. What does it mean when we say "mass is conserved" in a state change?
4. Grace has 2.5kg of ice and melts it in a sealed container. What is the mass of the water when she has finished?

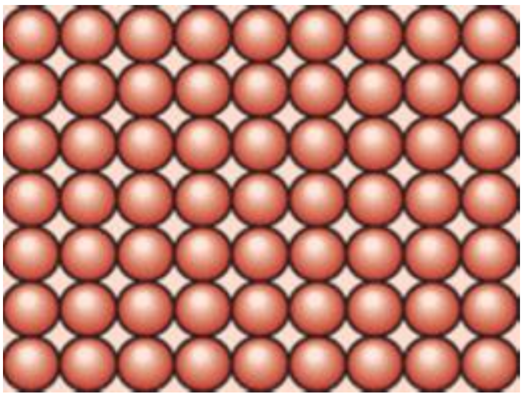
5. Define a physical change.

6. Anish boils 18g of water and collects the gas but 12% of the water remains in the beaker as droplets. What is the mass of the collected gas?
7. Is photosynthesis a chemical or physical change? Explain your answer.
8. What is “sublimation”?
9. Which of the following is not a physical change: sublimation; burning; evaporating
10. An ice cube is dropped on the floor and first melts, then evaporates. Describe what happens in terms of particle arrangement and motion.
11. Why does the bathroom mirror get cloudy when we have a shower?
12. Some houses have heated bathroom mirrors that do not get cloudy when you have a shower. Explain why heated mirrors do not get cloudy.
13. A liquid is poured into a tray and then frozen. Noah thinks the mass of the frozen solid will be greater than the mass of the liquid. Ajay thinks the masses will be the same. Who is right? Explain your answer.

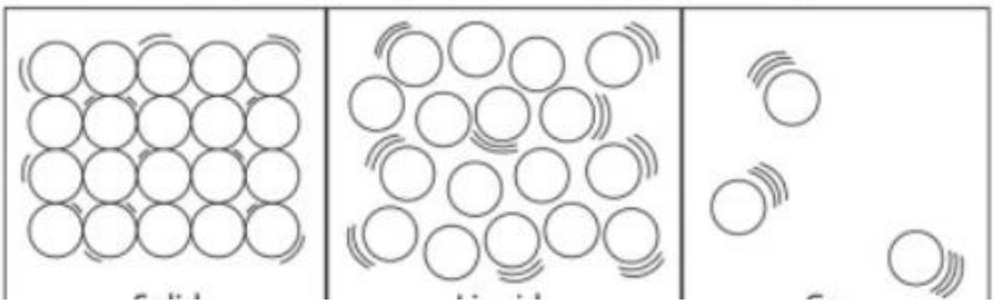
<u>Internal energy and changes of state</u>

-273°C is absolute zero: the coldest temperature possible: particles have no motion whatsoever and are as close together in the solid arrangement as it is possible to be. Scientists have actually never been able to achieve absolute zero, because vibrations just from somebody walking down the street a mile away can transfer energy to the particles and cause them to vibrate slightly, causing the temperature of the material to rise.

Consider a solid at absolute zero: -273℃. If the particles have absolutely no motion and they are as close together as possible, then they have zero energy.



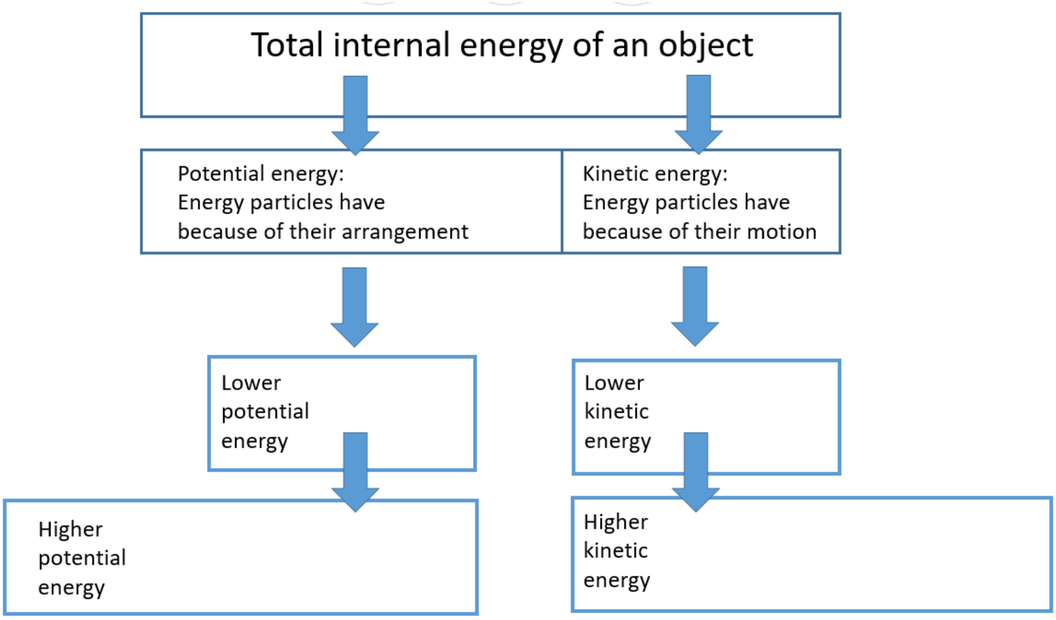
In reality, nothing is ever at absolute zero. All objects have particles that are moving and are not as close as possible, although they may still be touching.



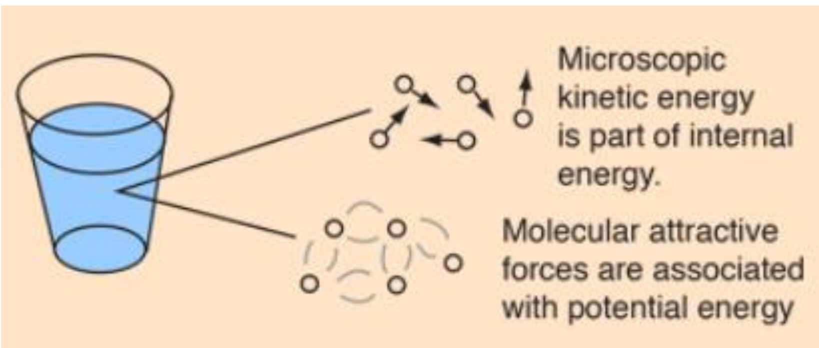
This applies to all solids, liquids, and gasses: in other words, all the matter in the universe.

The total internal energy stored by the particles in an object has two components:

1) Energy the particles have because of their arrangement. This is called potential energy.
2) Energy the particles have because of their motion. This is called kinetic energy.



At all temperatures higher than absolute zero, particles have kinetic energy and move. Their motion depends on how much energy they have and the state of matter they are in. The particles also have potential energy. When a liquid turns into a solid, heat energy is given out – this is called latent heat. So the fact that a liquid can be turned into a solid means the particles in a liquid have potential energy. Another way of saying this is that particles in, for example, a liquid have had work done on them for them to change state from a solid: an object that has had work done on it has potential energy.



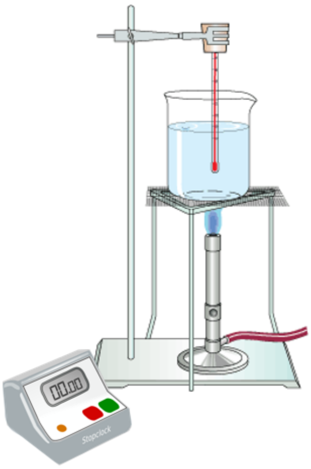
Questions for thinking

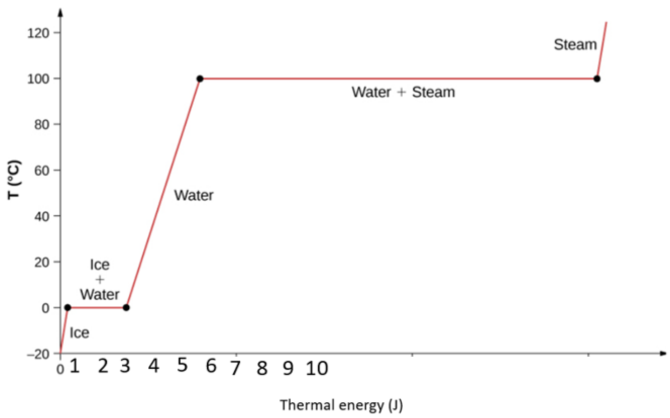
1. What is absolute zero?
2. Why do all objects and materials above absolute zero have an internal energy store?

3. What is kinetic energy store of particles?
4. What is potential energy store of particles?
5. Which energy does increasing temperature affect?
6. Which energy store of particles does changing state (e.g. melting) affect?
7. Why are melting and boiling classed as “doing work” on the particles?

Heat and temperature

When we heat ice over time, we might expect its temperature to increase. However what we actually find is a bit more complicated than that:





Thermal energy (J)	Temp-erature (C)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

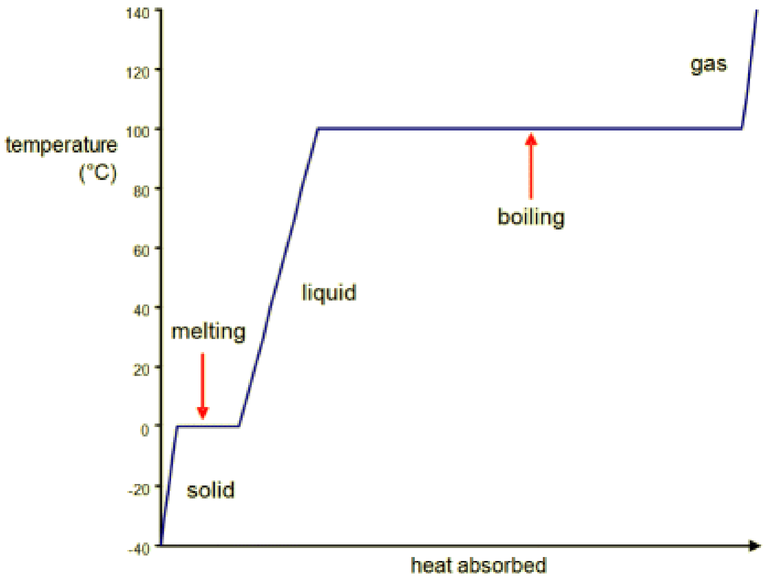
Initially, as the ice is heated, its temperature does increase. The thermal energy is causing the particles in the solid ice to vibrate about their fixed positions faster. In other words, the energy is being used to increase the particles’ kinetic energy. However, when we get to 0̊C, the temperature ceases to rise: instead it remains constant at 0 even though we continue to add thermal energy. This is because the solid ice is melting: the energy is being used to change the arrangement of the particles – in other words, it is being used to increase their potential energy.

Questions:

1. Explain the difference between heat and temperature.
2. Copy the graph above and explain its shape
3. Heating an object can increase its temperature. State three things that the increase in temperature depends on.
4. Jade says that “thermal energy is just one version of kinetic energy”. Explain what she means by this.

Specific Latent Heat

The graph shows the temperature changes when ice is heated:



In the topic “Energy” we looked at specific heat capacity. Specific heat capacity is related to the principle that if you add heat energy to a material, its temperature will rise. There are some special cases where this does not apply: during changes of state. The graph shows how the temperature of water changes as heat energy is added to it. The water starts off at -40°C (ice) and its temperature increases until it reaches 0°C. Here it remains constant while more energy is added to it. This is melting: the heat energy that is being added is being used to overcome the intermolecular forces of attraction that hold the water particles in their solid arrangement. So the heat energy cannot be used to increase the temperature. After the right amount of energy has been added, all the intermolecular forces have been overcome and the ice has fully melted into liquid water. So the temperature increases again as more heat energy is added. A similar thing happens at the next state change: boiling.

The energy used in the state change is called **latent heat**.

The specific latent heat of a material is the energy absorbed or released when 1kg of the material changes state without a change in temperature.

The energy supplied for the state change does increase the internal energy of the material but it doesn't increase the temperature. This is because the particles do not move faster (gain kinetic energy) but because they are changing their arrangement to a higher state they are gaining potential energy.

Energy required for change of state = mass x specific latent heat

This formula is on the physics equation sheet.

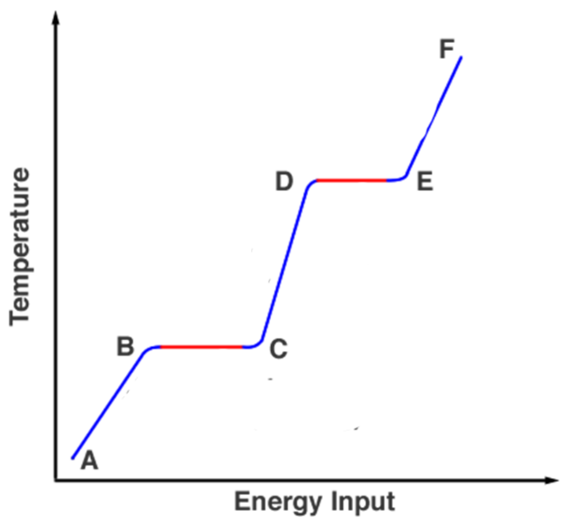
Specific latent heat of fusion = energy needed for melting

Specific latent heat of vaporisation = energy needed for boiling

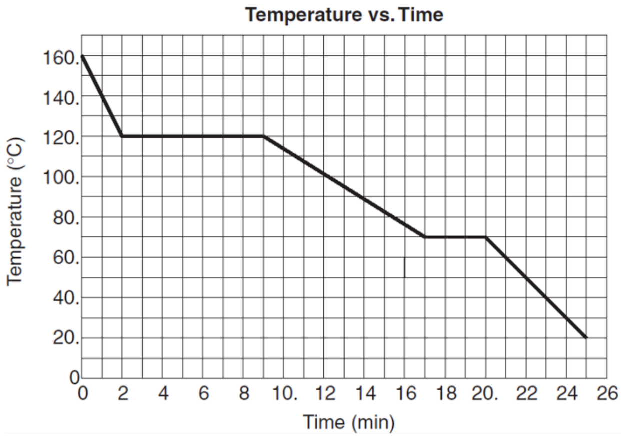
<u>Questions:</u>

1. Define specific latent heat.
2. What is specific latent heat of fusion?
3. What is specific latent heat of vapourisation?

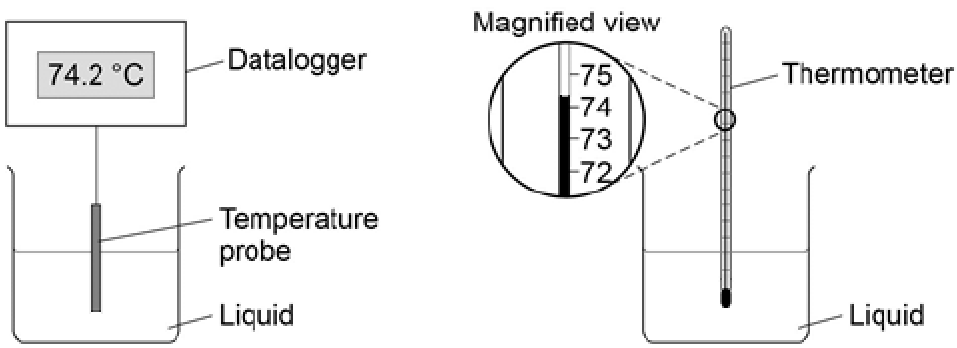
4. Copy the graph and explain what is happening at stages A-B; B-C; C-D; D-E, E-F. Use the following words: solid, liquid, gas, state change, melting, boiling, particles, internal energy, kinetic energy, potential energy, latent heat of fusion, latent heat of vaporisation.
5. Calculate the energy needed to melt 0.49kg of aluminium . The specific latent heat of fusion of aluminium is 399,000 J/kg.



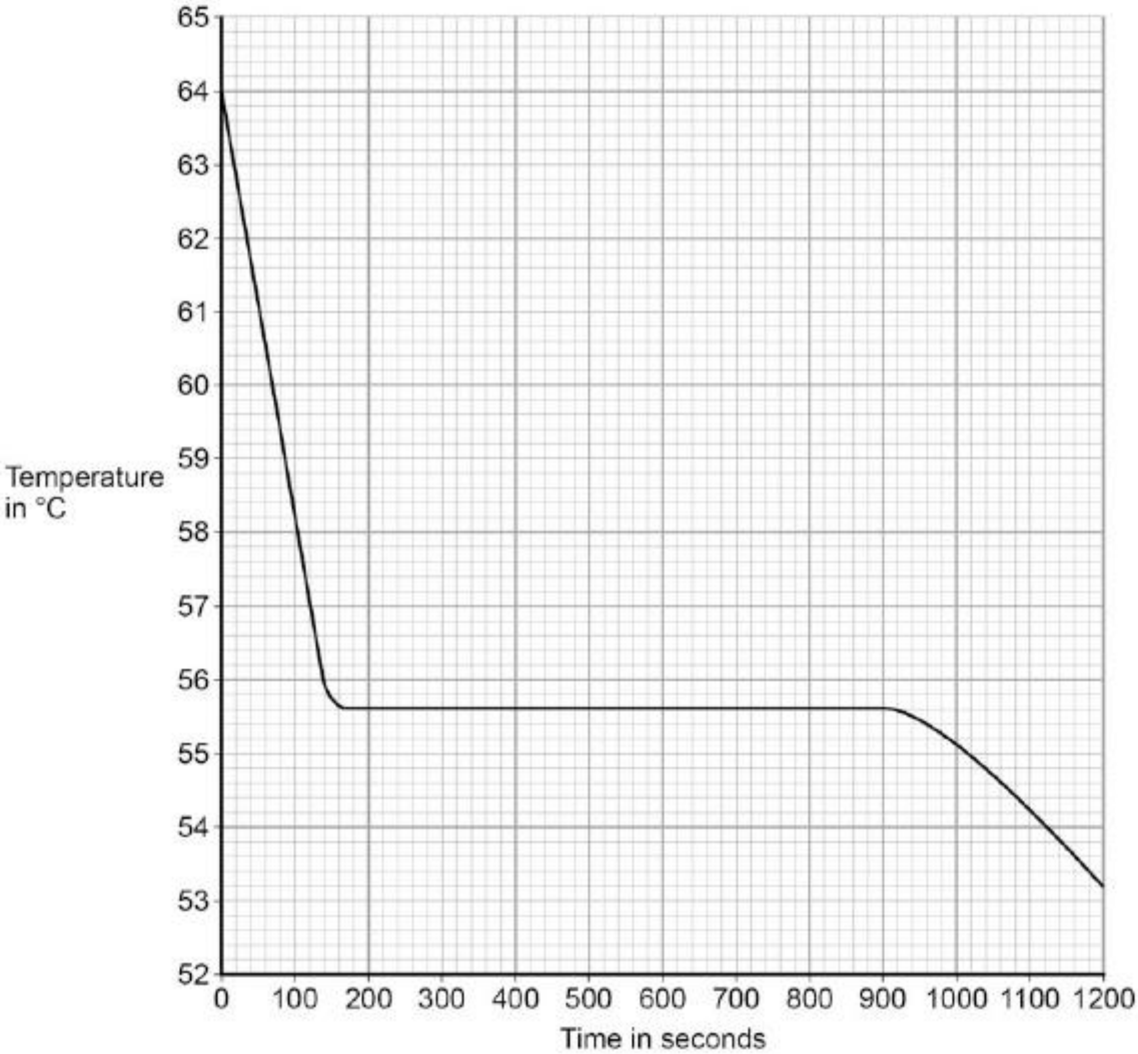
6. If the specific latent heat of vaporisation of aluminium is 10,500,000 J/kg, find the energy needed to vapourise 0.49kg of aluminium.
7. Find the specific latent heat of fusion of element Y if 405,000J of energy are used to melt 0.6kg of the element.
8. What is the specific latent heat of vaporisation of element Z if 2,670J of energy are needed to boil 510g of the element?
9. What mass of lead can be melted using 58kJ of energy? The specific latent heat of fusion of lead is 25,000 J/kg.
10. What mass of helium can be boiled using 84,000J of energy? The specific latent heat of vaporisation of helium is 21,000J/kg.
11. Explain the difference between specific heat capacity and specific latent heat. Do not just write the definitions.
12. A gas was cooled and its temperature recorded over time. The graph shows the results: Explain what is happening at each stage in the graph. Use the words solid, liquid, gas, state change, melting, boiling, particles, internal energy, kinetic energy, potential energy, latent heat of fusion, latent heat of vaporisation.



13. The diagram shows two sets of apparatus for investigating temperature during state change. State which apparatus is better and explain why.



14. The graph shows the temperature for melted stearic acid as it cools. How many facts can you find from this graph?



15. Plot the points to show the change in temperature for element X as it is heated. Label the stages and draw a particle diagram for each one.

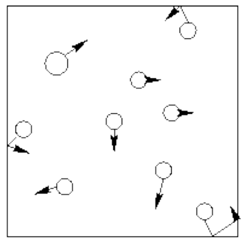
16. The specific latent heat of fusion for element X is 40J/kg, yet this is not shown on the graph. Suggest a reason for this discrepancy.

Energy input (J)	**Temperature (°C)**
0	-60
50	-40
100	-20
150	-20
200	-20
250	+5
300	+30
350	+30
400	+30
450	+30
500	+50

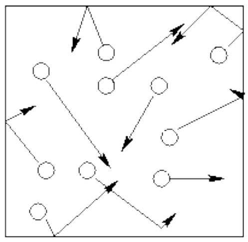
Gas Pressure

The particles of a gas are in constant random motion. The temperature of a gas is determined by the average kinetic energy of the particles.

All gases exert a pressure on the walls of their container. This is caused by the particles colliding with the container walls.



Cool gas, fewer and less energetic collisions



Hot gas, more and more energetic collision

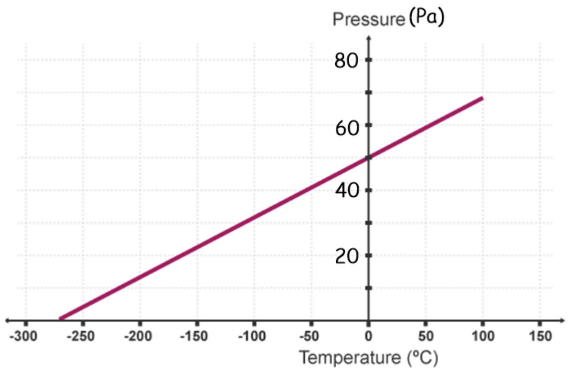
If the volume of a gas is kept the same, for example by keeping it in a sealed container of constant size, and the temperature is increased, for example by holding the container over a heat source, then the gas pressure will increase. This is due to the particles gaining kinetic energy and therefore colliding with the container walls more frequently and with greater force. If you took a sealed can with a gas, e.g. water vapour, and heated it, the increasing pressure would cause it to explode.

The explanation of phenomena using the motion of particles is known as kinetic theory. When we examine the relationship between two variables, such as temperature and pressure, we keep all other variables, such as volume, fixed (constant) so that the relationship is clear to see.

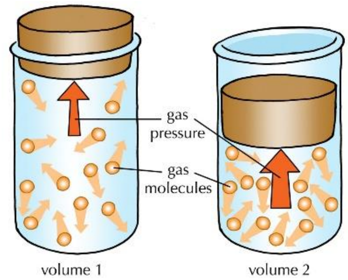
<u>Questions:</u>

1. What is temperature a measure of?
2. What causes gas pressure? Copy the diagram that shows this and label it with: gas particle, container wall, collision
3. At a constant volume, what is the relationship between a gas' pressure and temperature?
4. Use kinetic theory to explain why the relationship is as you have described. Use the words kinetic energy, collisions, frequent, forceful, pressure.
5. In the diagram above for "hot gas", why are the arrows bigger? Copy the diagram for cool and hot gas.
6. Consider a balloon filled with helium gas. If the balloon bursts, what will happen to the volume of the gas? Explain why.
7. If you put an inflated balloon in the freezer, it shrinks. Explain why.
8. Explain why gases are easy to compress.

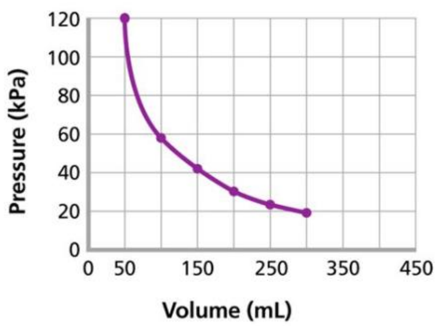
9. Why can heating a sealed container cause it to explode? Use the words kinetic energy, collisions, frequent, forceful, pressure.
10. What is the relationship between temperature and pressure at constant volume?
11. The graph shows how pressure varies with temperature for a gas, X. Copy the graph and use it to support your answer to (7).



12. If you kept the mass of a gas the same but decreased its volume, what would happen to its pressure? Copy the diagram and describe and explain what would happen.



13. The graph shows how pressure of a gas varies with volume at constant temperature. Write a quantitative description of the relationship between pressure and volume and give evidence from the graph. Use kinetic theory to explain why this relationship exists.



14. Sketch a graph to show the relationship between temperature and volume of a gas at constant pressure. Use kinetic theory to explain why this relationship is as it is. Consider the frequency of collisions but not their force.