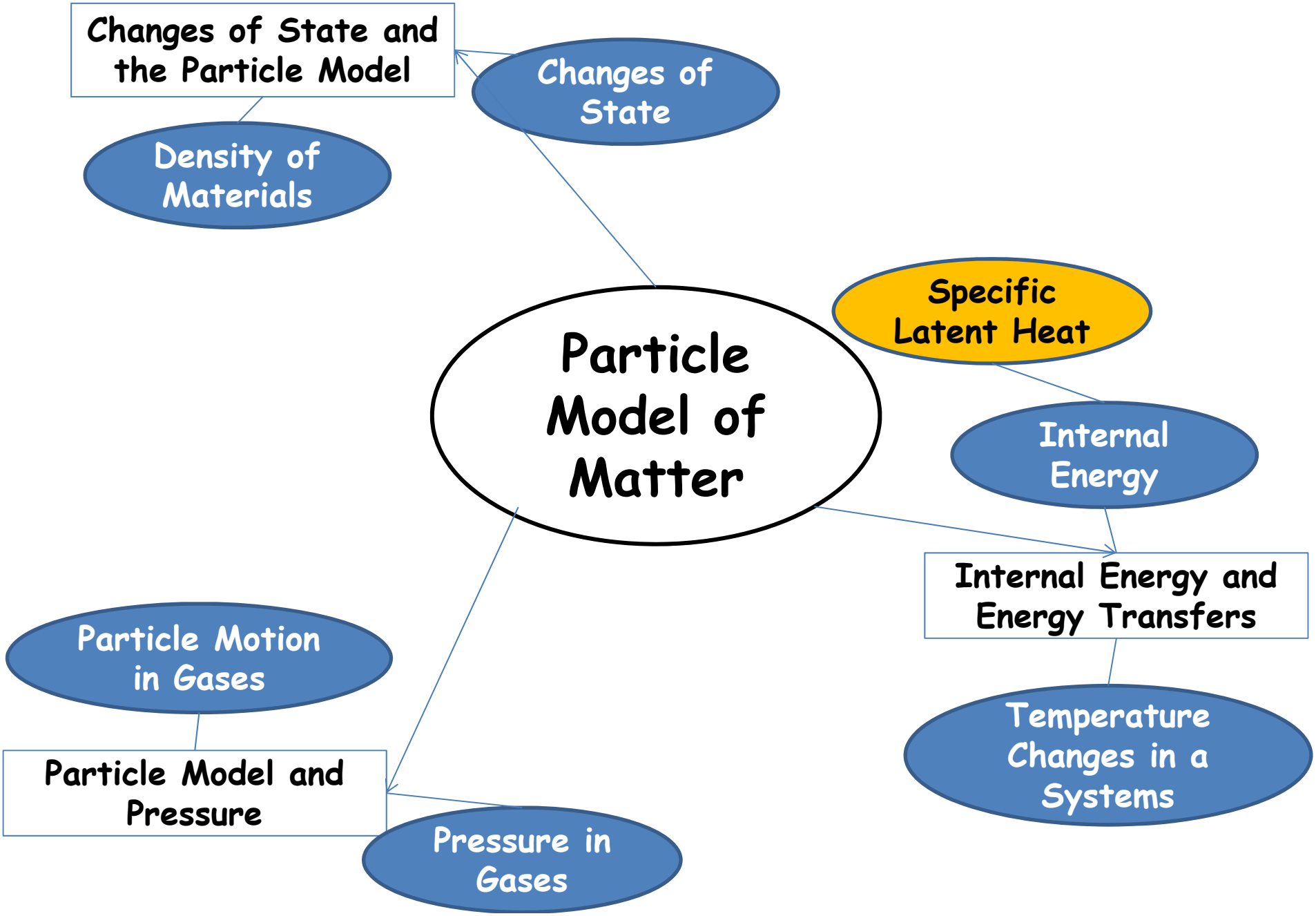
# Unit 3: Particle Model of Matter

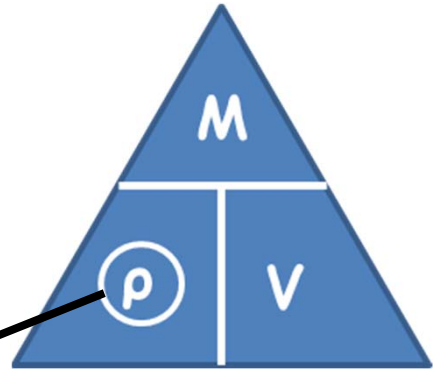


# Density of Materials - Regular Shapes

To find the density of any substance, we use the equation:

$$\text{Density (kg/m}^3\text{)} = \frac{\text{Mass (kg)}}{\text{Volume (m}^3\text{)}}$$

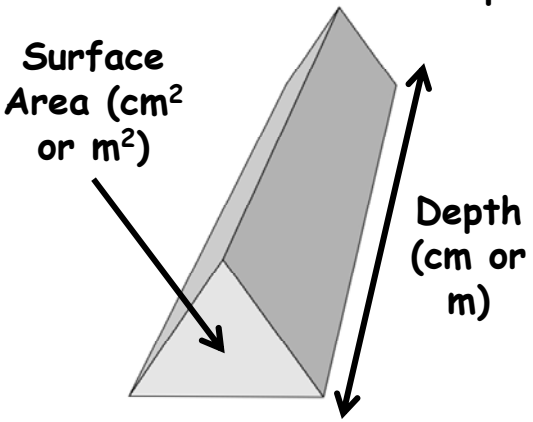
$$\text{Density (g/cm}^3\text{)} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}}$$




You may be asked to find the volume of the shape you are given!

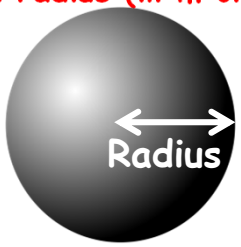
This strange p without a flick is the Greek letter rho, and is used by scientists to represent density

To find the volume of a shape, you need to find the product of the surface area and the depth of the shape.




Sphere's are special! You must use a different equation!

Volume of a sphere (cm³ or m³) = 4/3 x π x radius (in m or cm)²

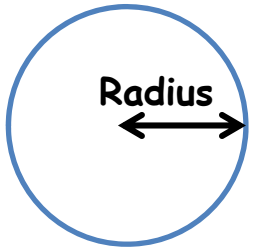


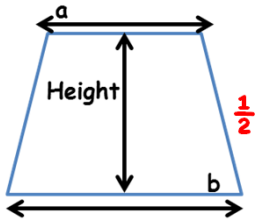

Volume (cm³ or m³) = Surface area (cm² or m²) x depth (cm or m)

Remember how to find the surface area of a range of shapes. You may need to know this to find out the volume of a shape as part of a question.

Circle

π x radius²



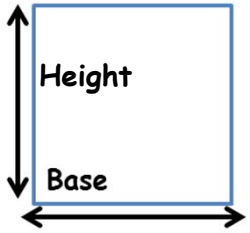



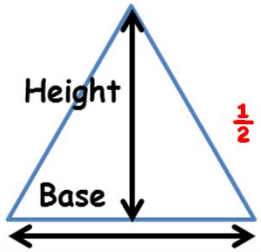

Trapezium

$\frac{1}{2}$ x (a+b) x height

Square/Oblong

base x height




Triangle

$\frac{1}{2}$ x base x height

| Which two of these statements are true? | |
|---|---|
| Helium is less dense than air | All materials are most dense in solid form |
| Particles of a substance have more mass in solid form | All metals are solids at room temperature |

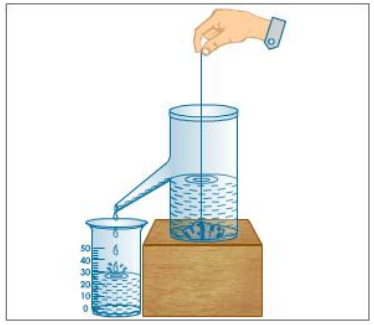
| Which of these statements best describes density? | |
|---|---|
| The number of particles per metre cubed | The amount of weight per metre cubed |
| The amount of mass per metre cubed | The amount of solid per metre cubed |

| A regular cuboid of 5g/cm$^3$ measures 0.4m X 0.2m X 0.1m. What is its mass? | |
|---|---|
| 40kg | 1.6kg |
| 0.04g | 0.0016g |

| Match the statements to the consequences | |
|---|---|
| Air is less dense than water | The titanic floated before its hull was filled with water |
| Steel is more dense than water | Parts of an iceberg can always be seen above the sea line |
| Ice is less dense than water | Once partially filled with water, the Titanic sank |
| Wood is less dense than water | Survivors from the Titanic were able to support themselves on furniture from the ship |

# Density of Materials - Irregular Shapes

It is a little more difficult to find the density of an irregular shape. It would be almost impossible to find an accurate value for the volume of an irregular shape if we were to try and calculate it in the same way as a regular shape. This is where the Eureka can comes in!



Archimedes first discovered the idea of the eureka can when taking a bath. He realised that the volume of his body displaced the same volume of water when he got into the bath.

A Eureka can works in this way to find the volume of an irregularly shaped object. You simply:

- Fill the can to the line
- Carefully place the object into the can
- Measure the volume of water the object displaces using a measuring cylinder.

Density (kg/m$^3$) = $\frac{\text{Mass (kg)}}{\text{Volume (m}^3\text{)}}$

Density (g/cm$^3$) = $\frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}}$

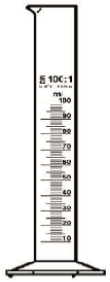
You need to remember that…

"…density is a property of a particular substance, and not just a particular object."

Remember what equipment is required to complete this practical!

Eureka Can

Measuring Cylinder



Top Pan Balance

Tripod to place Eureka can on

| A student sets up an experiment to measure the density of an irregular shape. Put the steps in order, 1-4, where 1 is the first step and 4 is the final step | |
|---|---|
| Place the shape into the water and measure the volume of water that has been displaced | |
| Repeat the reading of the volume of water that has been displaced to get an average | |
| Use the mass and the average volume of water displaced to calculate the density of the object | |
| Weigh the dry shape using a finely calibrated top pan balance | |

| What are the units of density? | |
|---|---|
| $N/m^2$ | m/s |
| $kg/m^2$ | $kg/m^3$ |

| Which piece of equipment would be best at measuring the volume of an irregularly shaped object? | |
|---|---|
| A ruler | A tape measure |
| A Newton meter | A Eureka can |

| Which scientist is the Eureka can named after? | |
|---|---|
| Newton | Darwin |
| Archimedes | Miller |

| What happens to an object that is less dense than water? | |
|---|---|
| It will sink | It will float in the liquid |
| It will float on the liquid | It will keep moving from the bottom of the liquid to the top |

# Density of Materials - Liquids

To find the density of a liquid, we need a top pan balance and a measuring cylinder.

- Place the measuring cylinder you are going to use onto a top pan balance and tare it (so that it goes back to 0g)
- Pour the required liquid into the measuring cylinder (as the density should not change, the less you use the better as this saves on resources)
- Place the measuring cylinder back onto the balance and record the mass of the liquid
- Read the volume from the side of the measuring cylinder (this will give you the volume of the liquid in $cm^3$)
- Use the density equation:

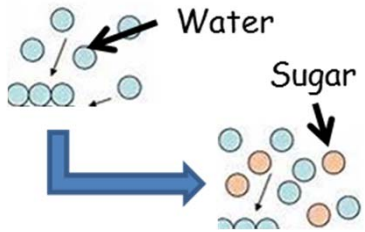
$$\text{Density } (g/cm^3) = \frac{\text{Mass } (g)}{\text{Volume } (cm^3)}$$

Remember…

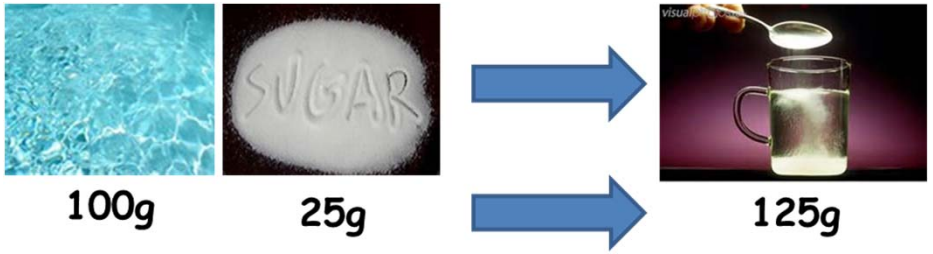
"just like regular, solid objects, the density of a liquid is a property of the liquid itself and not the object."

When a soluble material (like sugar), is added to a solvent (like water), the mass of the substance must increase. This is part of the conservation of mass:

" Mass can neither be created or destroyed during chemical or physical reactions: the mass before the reaction must equal the mass after the reaction."

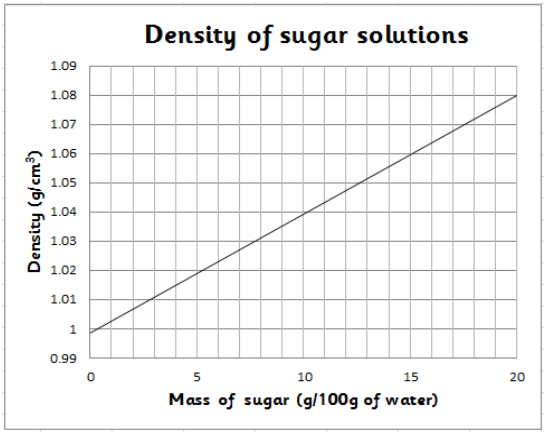



So, if 25g of sugar was added to 100g of water, the total mass of the sugar water must be 125g.



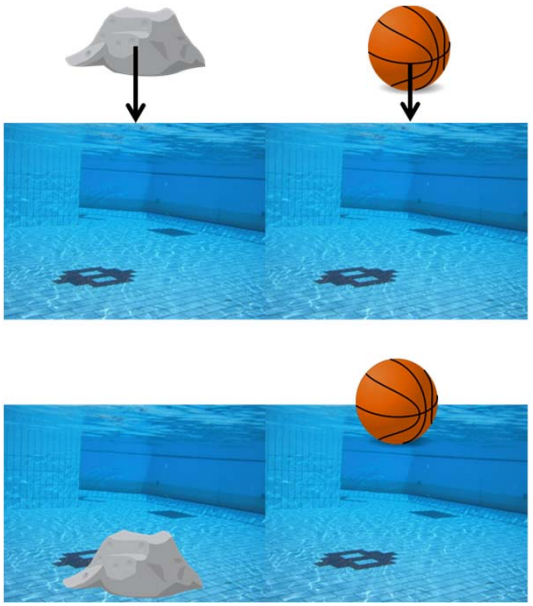
# Density of Materials - Liquids

## Why is the density of a liquid important?




Scientists use the density of a solution so they can work out what is in a solution. For example, drinks can be tested for the sugar content in them by looking at the density of water and comparing it to the density of the drink. This will tell you how much sugar is in the drink.

We can predict if an object will sink or float based on its density. If the density of an object is less than the density of water, then the object will float. If the density of the object is more than the density of water, the object will sink. Let's look at an example:



**Always double check your answers for the correct units! If you have used metre and kilograms, it is kg/m³. If you have used centimetres and grams, it is g/cm³!**

Ships are made out of steel. Although steel has a much larger density than water (7.80g/cm³), ships can still float.

Ships contain a lot of air so that the cabin crew, workers and passengers can breathe. Because of this, the average density of the ship and air is less than the density of water!

| Which of the following will have the greatest mass? | |
|---|---|
| 100g of water and 30g of sugar | 20g of salt with 115g of water |
| 50g of lead and 50g of nitric acid | 150g of salt water, with 30g of salt filtered out |

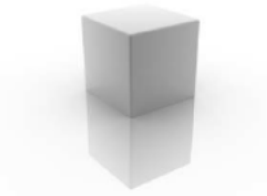
| Which two statements about displacement are correct? | |
|---|---|
| Displacement can be used to measure mass | Displacement can be used to measure volume |
| An object will displace more water if it has a higher density | A solid will displace the same volume of water as its own volume |

| Which two of these things happen when an ice cube melts in room temperature water? | |
|---|---|
| The volume of water increases | The water level stays the same |
| The particles in the ice cube move closer together | The water becomes slightly less dense |

| If a student wanted to measure and compare the density of different liquids, which of these factors should be kept constant? | |
|---|---|
| Mass | Volume |
| Pressure | Temperature |

| Calculate the density of these different objects using their masses and volumes. | | | |
|---|---|---|---|
| Mass = 9kg, Volume = $60cm^3$ | $g/cm^3$ | Mass = 60kg, Volume = $0.4m^3$ | $g/cm^3$ |
| Mass = 45g, Volume = $3cm^3$ | $g/cm^3$ | Mass = 13.5kg, Volume = $9000cm^3$ | $g/cm^3$ |

A student wants to calculate the density of the two objects shown in the figure below.



**Metal cube**



**Small statue**



Describe the methods that the student should use to calculate the densities of the two objects.

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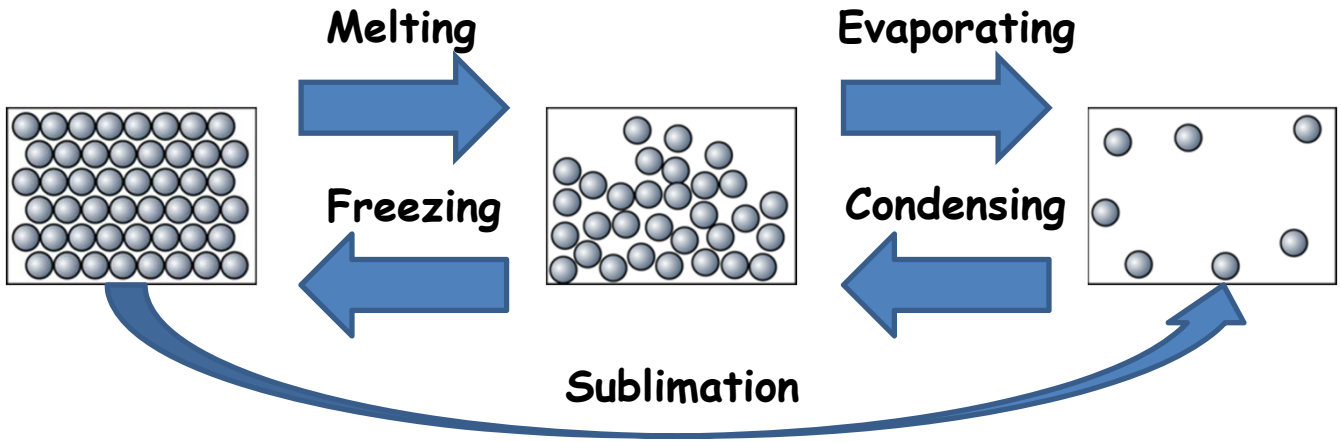
# Density of Materials: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify simple diagrams to model the differences between solids, liquids and gases | | | |
| Describe how to find the density of different materials, including liquids and irregular shapes | | | |
| Calculate the density of a range of different materials, including those that have an irregular shape and liquids | | | |
| Explain the differences in density between the different states of matter in terms of the arrangement of atoms or molecules | | | |

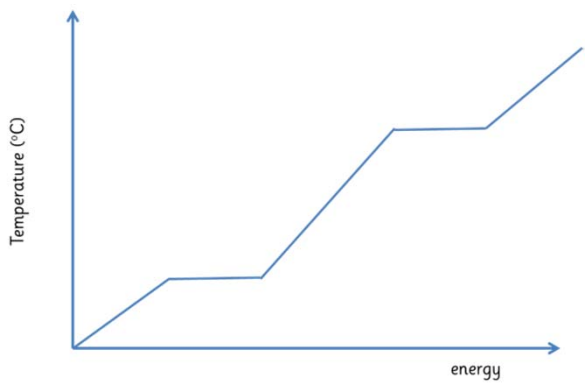
# Changes of state

When a substance is heated enough, it will change state.

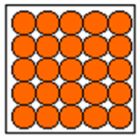



Sublimation is rare and only happens with certain materials. These materials have extremely weak bonds between particles.

We can tell when a substance changes state by looking at a cooling or heating curve.



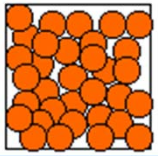

Where the graph is flat (gradient is 0), all of the energy going into the system is used to break the bonds between the particles. This is where the substance is changing state, and the potential energy of the particles is increasing.



**Solid**

Particles are close together

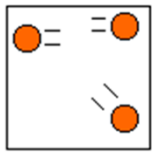
Strong bonds between particles



**Liquid**

Particles are close together

Weak bonds between particles



**Gas**

Particles are far apart

No bonds between particles

| Which word means the change from a liquid to a gas? | |
|---|---|
| Evaporation | Melting |
| Freezing | Condensation |

| When ice melts, which of the following is <u>not</u> true? | |
|---|---|
| The mass increases | The density increases |
| The volume decreases | The number of particles stays the same |

| Match each word to the change of state | |
|---|---|
| Melting | Gas to liquid |
| Freezing | Solid to liquid |
| Sublimation | Solid to gas |
| Condensation | Liquid to solid |

| Which two of these processes release energy? | |
|---|---|
| Condensation | Freezing |
| Evaporation | Sublimation |

| Which two of these things happen as a liquid's freezing point? | |
|---|---|
| Particles gain energy | Heat energy is transferred to the environment |
| Weak bonds are formed between particles | The temperature decreases during the process |

**In this question you will be assessed on using good English, organising information clearly and using specialist terms where appropriate.**

The information in the box is about the properties of solids and gases.

| |
|---|
| Solids:<br>• have a fixed shape<br>• are difficult to compress (to squash).<br>Gases:<br>• will spread and fill the entire container<br>• are easy to compress (to squash). |

Use your knowledge of kinetic theory to explain the information given in the box.

You should consider:

- the spacing between the particles
- the movement of individual particles
- the forces between the particles.

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# Changes of State: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify the names of the different states of matter | | | |
| Identify the names of the different changes of state | | | |
| Describe that, when substances changes state, the mass of the substance does not change | | | |
| Explain that changes of state are a physical change because the material recovers its original properties if the change is reversed. | | | |

# Specific Heat Capacity (Recap from Unit 1)

You need to know the definition of the specific heat capacity of a substance:

"Specific heat capacity is how much energy is required to increase the temperature of 1kg of a substance by 1°C."

Different substances have different specific heat capacities. For example, it takes more energy to raise the temperature of 1kg of water than 1kg of aluminium.

There are 3 key factors that affect how much energy is required to heat a material up:

- The mass of the substance (in kg) — m
- The type of substance that you are heating (J/kg°C) — c
- How much the temperature changes (in °C) — ΔT

We use the specific heat capacity equation to find out how much energy this would require:

$$\text{Energy required (J)} = m \times c \times \Delta T$$

You have completed a practical on finding the specific heat capacity of different materials.

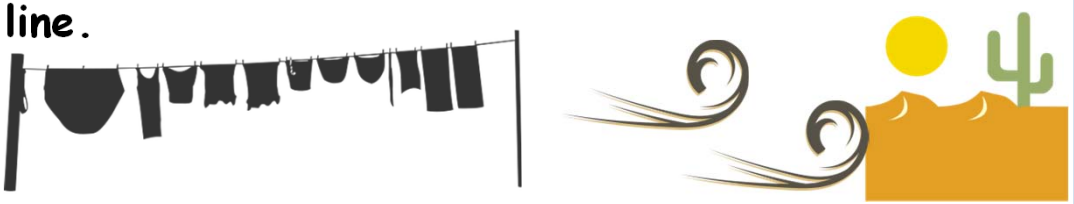
- Your independent variable was the material that the block was made of.
- Your dependent variable was the change in temperature that was measured.
- Your control variables included the type of heater you used, the time you heated the block and the potential difference supplied to the heater.

# Specific Heat Capacity (Recap from Unit 1): Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify that the specific heat capacity of a substance is the amount of energy required to raise 1kg of substance, by 1°C | | | |
| Describe all of the changes that happen in a system heating a block of a material | | | |
| Calculate the amount of energy that is transferred to or from a system using the equation for specific heat capacity | | | |
| Explain how to investigate the specific heat capacities of different materials. | | | |

# Cooling by Evaporation

We can change how quickly a liquid evaporates. Think about drying off your clothes on a washing line.



The ideal conditions needed for your clothes to dry quickly would be:

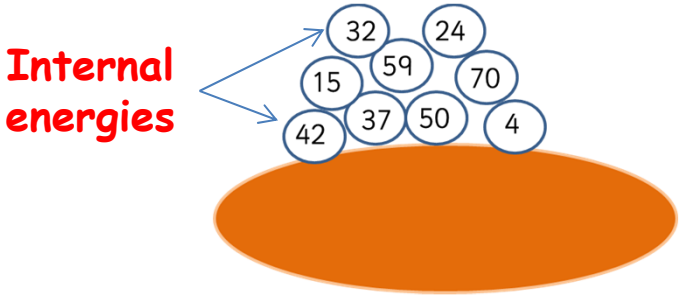
- Dry (little humidity)
- Hot
- Windy

These conditions allow particles to move from the surface of the clothes into the air as water vapour easily. These conditions also allow water particles (sweat) to be taken away from your skin easily.

Remember the conservation of mass:

" Mass can neither be created or destroyed during chemical or physical reactions: the mass before the reaction must equal the mass after the reaction."

Imagine that we could see each individual water particle that made up our sweat. Each water particle would have a different amount of energy. The higher the energy, the more likely it is that molecule of water would evaporate.

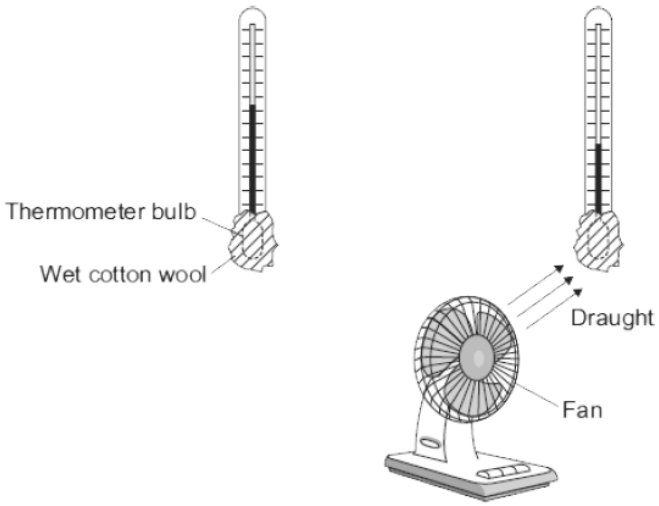



Here, the water particles with the highest energy (70, 59 and 42) are most likely to evaporate. Once they have evaporated, the <u>*average*</u> energy of the particles left behind would be less. This means that the temperature of the group of particles would be less; it has less energy.

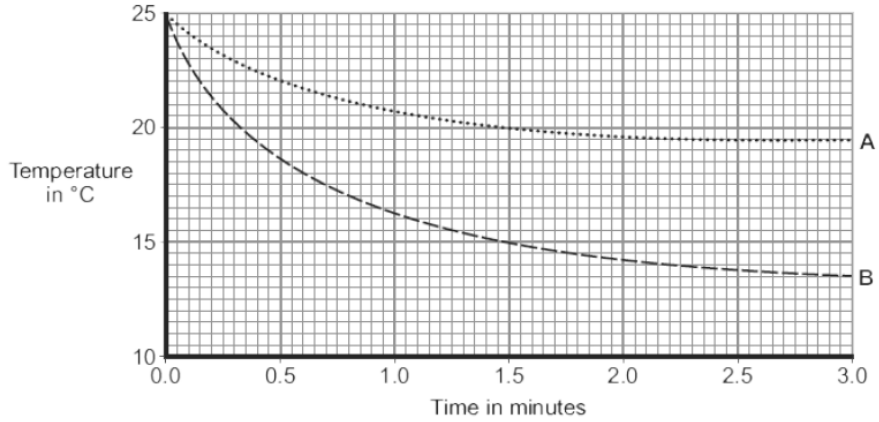
| Complete the sentences below. | |
|---|---|
| Animals sweat in hot weather because evaporation has … | A cooling effect |
| Wind helps to dry clothes because the evaporation rate is increased when evaporating particles are … | Large clouds |
| Huge thunderstorms are experienced in tropical climates because high solar energy leads to lots of evaporation which produces … | Carried away quickly |
| Puddles can evaporate below the boiling point of water because some particles in a liquid have enough energy to escape liquid bonds, even at … | Low temperatures |

| Internal energy is the… | |
|---|---|
| Average thermal energy of the particles in a liquid | Total kinetic energy of all of the particles in a system |
| Total kinetic energy and potential energy of all of the particles in a system | Average kinetic energy of some of the particles in a substance |

The diagram shows two thermometers. The bulb of each thermometer is covered with a piece of wet cotton wool. One of the thermometers is placed in the draught from a fan.




The graph shows how the temperature of each thermometer changes with time.




(a) Which of the graph lines, **A** or **B**, shows the temperature of the thermometer placed in the draught?

Write the correct answer in the box. ☐

Explain, in terms of evaporation, the reason for your answer.

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(b) A wet towel spread out and hung outside on a day without wind dries faster than an identical wet towel left rolled up in a plastic bag.

Explain why.

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# Cooling by Evaporation: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify that a system is made up of particles (atoms and molecules) | | | |
| Describe internal energy of a system as being the total kinetic and potential energy that makes up a system | | | |
| Describe the changes of energy store that take place when a system is heated | | | |
| Explain that a transfer of energy in a system can lead to either a change in temperature or a change in state | | | |

# Specific Latent Heat

Energy is required to change the state of a material. The energy that is put into a system increases the potential energy of the particles in that system, by breaking apart the bonds that are keeping the substance as a solid or a liquid. Specific latent heat of a material is…

" the amount of energy required to change the state of a given mass of a type of substance."

Specific latent heat is the reason why we use ice in drinks to keep them cool! It takes more energy to break the bonds in the ice to turn them to water than it does to heat cold water.

To find the energy required to change the state of a substance, we find the product of the mass of the substance and the specific latent heat of the substance.

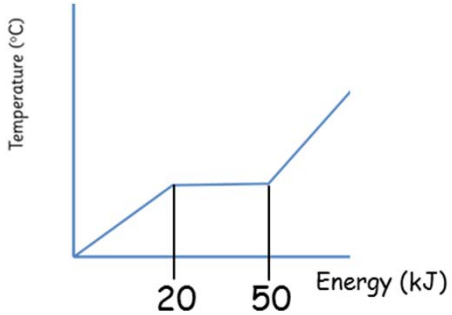
Energy = Mass x Specific latent heat

The energy (in J) required to change the state of a substance…

…is equal to the mass of the original substance (in kg)…

…multiplied by the value of the specific latent heat of the substance (in J/kg).

You can also find the energy that is required to change the state of a substance.




To find the energy that is required to change the state of a substance, read off the values from when the line flattens out to when the line starts to go up again.

In this example, the difference amount of energy is 30kJ

| Ice with a mass of 600g is place in a container and heated. 204kJ is required to change the state from solid to liquid. During this, the temperature does not change. What is the specific latent heat of fusion? | |
|---|---|
| $340 \times 10^3$ J/kg | $34 \times 10^3$ J/kg |
| $3.40 \times 10^3$ J/kg | 340 000 000 J/kg |

| What are the units for the following quantities? | |
|---|---|
| m | |
| L | |
| $\Delta\theta$ | |
| E | |

| Select the incorrect statement. | |
|---|---|
| During a change of state there is no temperature increase | Heat and temperature are not the same |
| The specific latent heat of fusion is the same for all liquids | The specific latent heat of vaporisation is greater than fusion |

| Some students make the following statements about specific latent heat. Which statement is incorrect? | |
|---|---|
| The latent heat of vaporisation relates to evaporation | The latent heat of fusion relates to melting |
| Latent heat is the heat stored when the temperature rises | Latent heat is the energy per kilogram needed to change state without changing temperature |

(a) A company is developing a system which can heat up and melt ice on roads in the winter. This system is called 'energy storage'.

During the summer, the black surface of the road will heat up in the sunshine.

This energy will be stored in a large amount of soil deep under the road surface. Pipes will run through the soil. In winter, cold water entering the pipes will be warmed and brought to the surface to melt ice.

The system could work well because the road surface is black.

Suggest why.

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(b) (i) What is meant by specific latent heat of fusion?

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(ii) Calculate the amount of energy required to melt 15 kg of ice at 0 °C.

Specific latent heat of fusion of ice = $3.4 \times 10^5$ J/kg.

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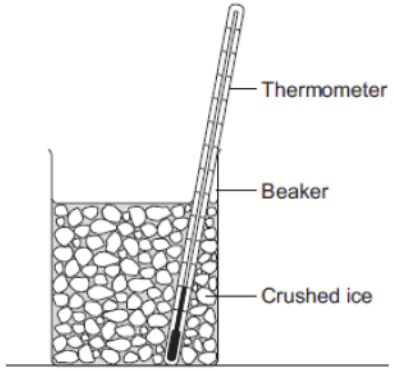
Energy = ..... J

(c) Another way to keep roads clear of ice is to spread salt on them. When salt is added to ice, the melting point of the ice changes.

A student investigated how the melting point of ice varies with the mass of salt added.

The figure below shows the equipment that she used.




The student added salt to crushed ice and measured the temperature at which the ice melted.

(i) State **one** variable that the student should have controlled.

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(ii) During the investigation the student stirred the crushed ice.

Suggest **two** reasons why.

Tick (✓) **two** boxes.

| | **Tick (✓)** |
|---|---|
| To raise the melting point of the ice | |
| To lower the melting point of the ice | |
| To distribute the salt throughout the ice | |
| To keep all the ice at the same temperature | |
| To reduce energy transfer from the surroundings to the ice | |

(iii) The table below shows the data that the student obtained.

| **Mass of salt added in grams** | 0 | 10 | 20 |
|---|---|---|---|
| **Melting point of ice in °C** | 0 | -6 | -16 |

Describe the pattern shown in the table.

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(d) Undersoil electrical heating systems are used in greenhouses. This system could also be used under a road.

A cable just below the ground carries an electric current. One greenhouse system has a power output of 0.50 kW.

Calculate the energy transferred in 2 minutes.

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Energy transferred = ..... J

(e) **In this question you will be assessed on using good English, organising information clearly and using specialist terms where appropriate.**

A local council wants to keep a particular section of a road clear of ice in the winter.

Describe the advantages and disadvantages of keeping the road clear of ice using:

- energy storage
- salt
- undersoil electrical heating.

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# Specific Latent Heat: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify the specific latent heat as the amount of energy required to change the state of 1kg of a substance | | | |
| Describe that, when a change of state occurs, the temperature stays the same | | | |
| Describe the difference between the specific latent heat and the specific heat capacity | | | |
| Calculate the energy required to change the state of a substance, the specific latent heat and the mass of substance that has changed state using the equation | | | |
| Explain the different states of a substance from interpreting a cooling curve | | | |
| Apply data from heating and cooling curves to find the melting and boiling point of a substance | | | |

# Particle Motion in Gases

To change the gas pressure, there are 3 things we can do. Think about going shopping in a busy high street, and you bump into people quite often. We could change how often you bumped into someone by…

- Going somewhere quieter (*reducing the number of particles*)
- Walk slower to stop bumping into people in front of you (*reduce the energy of the particles – this is done by cooling the gas*)
- Increase the size of the high street (*increasing the size of the container*)

If we increase the amount of collisions each particle has, we would be increasing the pressure. If we decrease the amount of collisions each particle has, we would be decreasing the pressure of the gas.

Imagine each person as a particle!

Gases are able to create a pressure. When a gas particle hits a surface, it exerts a tiny force. There are billions of gas particles that bounce of surfaces every second, creating a much larger force.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Gases are able to do this as they move in all directions at a fast speed. We can show the speed of a particle by drawing an arrow on it. The larger the arrow, the faster it is moving.

| Particles in which state of matter have the highest energy? | |
|---|---|
| Solid | Condensation |
| Liquid | Gas |

| Which of these states of matter are classed as fluids? | |
|---|---|
| Solids liquids and gases | Solids and gases |
| Gases only | Liquids and gases |

| Which of the statements best describes the motion of gas particles? | |
|---|---|
| Fast in one direction | Slow in one direction |
| Fast in all directions | Slow in all directions |

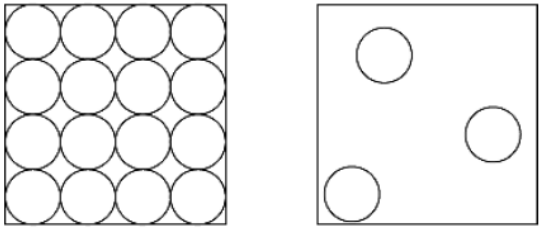
| Which of these would <u>not</u> increase the pressure of a gas in a container? | |
|---|---|
| Increasing the number of gas particles in the containers | Increasing the temperature of the gas |
| Decreasing the size of the container | Decreasing the amount of collisions that gas particles have with the container every second |

| What happens to gases in a fixed container when their temperature increases? | |
|---|---|
| Their volume increases | Their volume decreases |
| Their pressure increases | Their pressure decreases |

(a) The diagrams show the arrangement of the particles in a solid and in a gas.

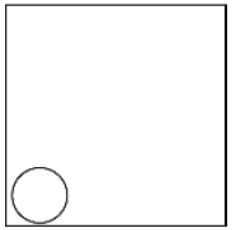
Each circle represents one particle.

**Solid** **Gas**



(i) Complete the diagram below to show the arrangement of the particles in a liquid.

**Liquid**



(ii) Explain, in terms of the particles, why gases are easy to compress.

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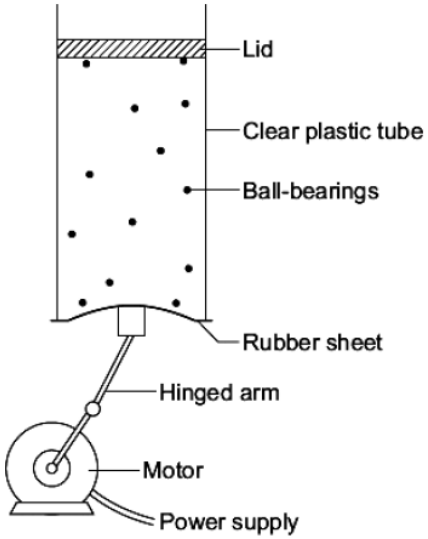
(b) The diagram below shows the model that a science teacher used to show her students that there is a link between the temperature of a gas and the speed of the gas particles.

The ball-bearings represent the gas particles. Switching the motor on makes the ball-bearings move around in all directions.




(i) How is the motion of the ball-bearings similar to the motion of the gas particles?

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**(1)**

(ii) The faster the motor runs, the faster the ball-bearings move. Increasing the speed of the motor is like increasing the temperature of a gas.

Use the model to predict what happens to the speed of the gas particles when the temperature of a gas is increased.

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**(1)**

# Particle Motion in Gases: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify that there is a relationship between the temperature of a gas and the kinetic energy of the particles in a gas | | | |
| Describe that changing the temperature of a gas of a constant volume will increase the pressure of the gas | | | |
| Explain how the motion of the molecules in a gas is related to both its temperature and its pressure | | | |
| Explain qualitatively the relationship between the temperature of a gas and its pressure for a constant volume | | | |

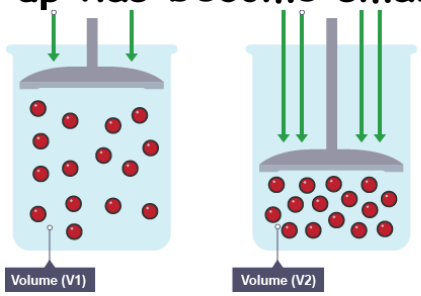
# Increasing the Pressure of a Gas – Physics Only

## Boyle's Law

Boyle's law states that…

"…decreasing the volume of a gas increases the pressure of the gas, proviing that the gas is kept at the same temperature."

An example of this is when a gas is trapped in a cylinder by a piston. If the piston is pushed in, the gas particles will have less room to move as the volume the gas takes up has become smaller.




Because the volume has decreased, the particles will collide more frequently with the sides of the container; each time they collide, they exert a force on them. More collisions mean more force, so the pressure will increase.

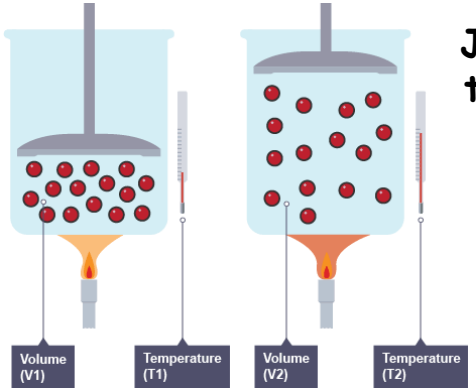
$$P_1V_1 = P_2V_2$$

## Charles' Law

Charles' law states that…

"…increasing the temperature of a gas increases the volume of the gas, as long as the gas is kept at the same pressure."

An example of this law would be the observations made when a balloon is placed in liquid nitrogen. The temperature decreases, so the volume of the gas decreases. This is why a balloon shrinks when placed in liquid nitrogen.




Just remember, if the temperature increases and no more gas is added, the volume must also increase!

$$V_1 = V_2 \times \frac{T_1}{T_2}$$

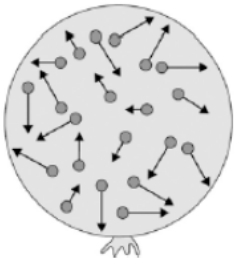
| Students make these statements about temperature. Select the incorrect statement | |
|---|---|
| Temperature is a measure of the average kinetic energy of the particles | The higher the temperature the more kinetic energy the particles have |
| Temperature is equivalent to the total amount of heat energy | Particles move slower in cold water than in hot water |

| What two things happen when we heat a gas inside a container with a constant volume? | |
|---|---|
| The particles gain mass | The particles gain kinetic energy |
| The pressure increases | The pressure remains constant |

| Why is the pressure in a car tyre lower in winter than in summer? | |
|---|---|
| The air in the tyre begins to freeze | The tyre shrinks in the cold |
| The average kinetic energy of the air is lower | Air leaks out of the tyre |

| Why do some aerosol cans carry warnings to keep them away from high temperatures? | |
|---|---|
| The can will melt | The contents will become inert |
| The contents are flammable | The heat will increase the pressure in the can causing it to explode |

The figure below shows a balloon filled with helium gas.



(a) Describe the movement of the particles of helium gas inside the balloon.

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(b) What name is given to the total kinetic energy and potential energy of all the particles of helium gas in the balloon?

Tick **one** box.

External energy ☐

Internal energy ☐

Movement energy ☐

(c) Write down the equation which links density, mass and volume.

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(d) The helium in the balloon has a mass of 0.00254 kg.

The balloon has a volume of 0.0141 $m^3$.

Calculate the density of helium. Choose the correct unit from the box.

| | | |
|---|---|---|
| **$m^3$ / kg** | **kg / $m^3$** | **kg $m^3$** |

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Density = ..... Unit .....

# Increasing the Pressure of a gas – Physics Only: Checklist

| For your exam, you must be able to… | I have looked at this once | I have reviewed this | I have mastered this |
|---|---|---|---|
| Identify that work is the transfer of energy by a force, and that doing work on a gas increases the internal energy of the gas | | | |
| Identify that work is done on a gas when it is compressed or expanded | | | |
| Describe, using the particle model, how an increase in the volume of a gas with a constant temperature can lead to a decrease in pressure | | | |
| Calculate the change in pressure of a gas if the volume of a gas is changed | | | |
| Explain how doing work on an enclosed gas leads to an increase in the temperature of a gas | | | |