Physics Factsheet

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Key Preparation - Particle Theory

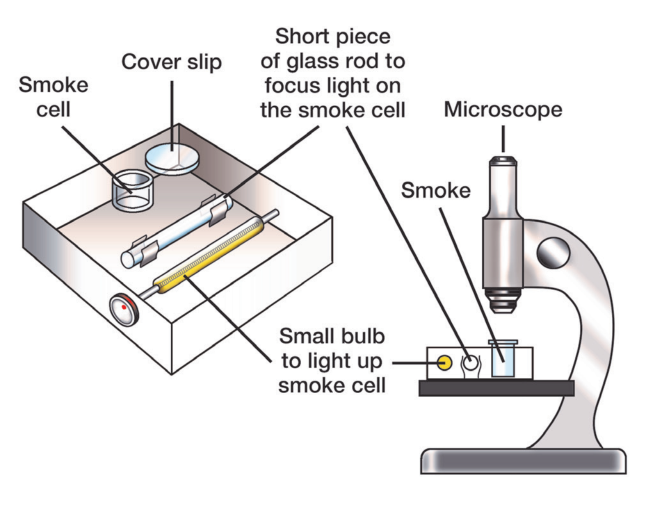
Introduction

In previous studies you will have learnt something about "Particle Theory" – the idea that the different properties of solids, liquids and gases can be explained by different arrangements of the particles of the substance. In order to progress in your studies, you now need to be sure that these ideas are clear, with no misunderstandings, so as to form a sound platform for the greater depth of understanding required at a higher level of study.

Evidence for Particles

The usual evidence quoted for the existence of particles is Brownian Motion, investigated with the apparatus as shown in **Figure 1**.

Figure 1 Usual apparatus to demonstrate Brownian Motion of smoke particles in air.



Viewed through the microscope, illuminated from the side, the particles of smoke can be seen moving about in a rapid, randonm motion. The explanation is that the much smaller (therefore invisible) air particles are also moving in rapid, random motion and buffeting the smoke particles about.

Table 1 General properties of solids, liquids and gases

Solids	Liquids	Gases
Keep their own shape	Can flow, but have a surface	Fill the whole container
Are difficult to compress	Are difficult to compress	Are easily compressed

Particle Explanation

Figure 2 Arrangement of particles in solids, liquids and gases

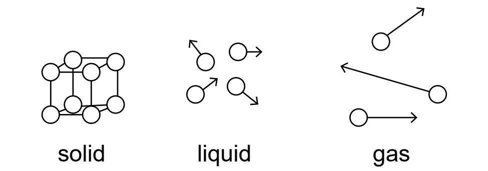


Figure 2 illustrates how Particle Theory explains these differences:

Solids keep their shape because the particles are held by bonds and can only vibrate, not move freely. They are difficult to compress because the particles are close together.

Liquids do not hold their shape and can flow because the particles are not held together by bonds, they can move; however, they are still close together and exert attractions on each other, which makes them difficult to compress and gives rise to the surface.

The particles in a gas are completely free to move and are far apart (typically 80 times further apart than in solids or liquids) and moving quickly, so gases can fill the container completely and are easy to compress.

Key Points:

1) *Some students wrongly assert that the particles in a solid are close together, those in liquids further apart, and those in gases even further apart, implying that it is evenly stepped.*
2) *The particles in a liquid are only slightly further apart than in a solid – indeed, the particles in liquid water are closer together apart than in solid water (ice).*

Internal Energy

The internal energy of a substance is the sum of the P.E and K.E of the particles. Heating increases the internal energy, which can result in a rise of temperature, or a change of State.

Test your understanding:

1) *Explain how Brownian Motion supports the idea that matter is made up of particles.*
2) *Use your knowledge of ParticleTheory to explain why ice floats on water.*
3) *Explain, in terms of Particle Theory, why the internal energy of a solid is mainly PE., whereas that of a gas is almost all KE.*

Particle Theory to Explain Observed Phenomena

Particle Theory satisfactorily explains many observed phenomena; a few are reviewed here.

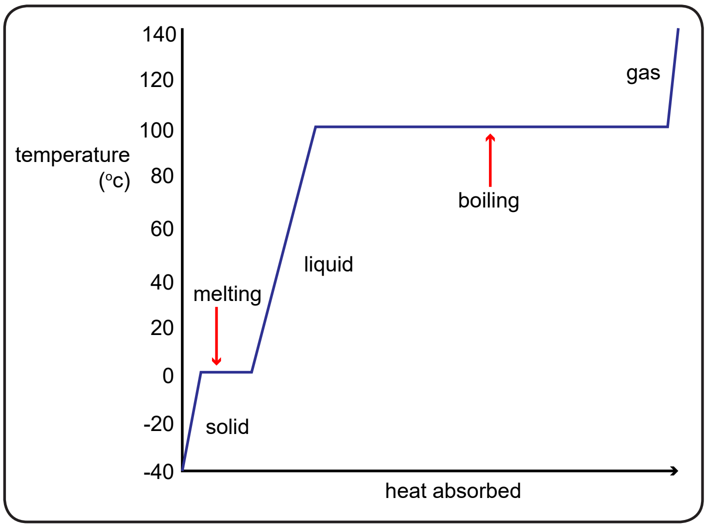
Density

The density of a material will depend on the mass of the individual particles and on how closely they are packed. On the whole, solids will be slightly denser than liquids and gases will be far less dense.

Change of State

You should be familiar with heating curves such as the one below for water.

Figure 3 Heating curve for water



When a solid is heated, the energy input increases the internal energy of the particles and they vibrate more vigorously as the temperature increases. The quantity of heat needed to change the temperature of 1kg of the solid by 1°C is the ***Specific Heat Capacity***.

$$Q = mc\Delta\theta$$

Heat input/J, Mass/kg, SHC/Jkg^{-1}C^{-1}, Change in temperature/°C

At a certain point the energy input increases the internal energy without a change in temperature until all of the solid has changed into a liquid. The energy input during this change of state goes to breaking the bonds. The quantity of heat energy needed to change 1kg of a solid into liquid at its melting point is the ***Specific Latent Heat of Fusion***.

A similar process happens at the transition from liquid to gas and the energy needed to change 1kg of liquid to gas at its boiling point is the ***Specific Latent Heat of Vaporization***.

$$Q = mL$$

Heat input/J, Mass/kg, SLH of fusion (solid to liquid) or vaporization (liquid to gas) Jkg^{-1}

> ***Key Points:***
>
> *1) At this level of study, you will be expected to:*
> *a) Be able to explain that during a change of state the energy input is changing the internal energy of the substance without increasing the temperature.*
> *b) Know and use the equations above.*
> *c) Understand the difference and be careful to use the terms "heat" and "temperature" correctly.*

Behaviour of Gases

For A Level, study of Particle Theory is largely concerned with gases and is extended to "***Kinetic Theory***".

- The internal energy of a gas is KE and the temperature of the gas is related to the average KE of the particles.
- The pressure of a gas arises from the collisions of the particles with the walls.

Experimental Results

You will carry out investigations into the volume, temperature and pressure of gases, which lead to the relationships between them. *Factsheet 99 "Gas Law Practicals and Absolute Zero"* gives more detail of the experiments and the handling of the results.

1.

Figure 4 Apparatus to investigate P v V

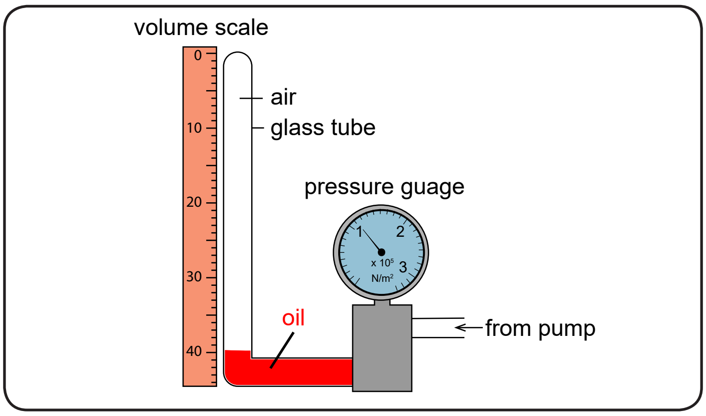
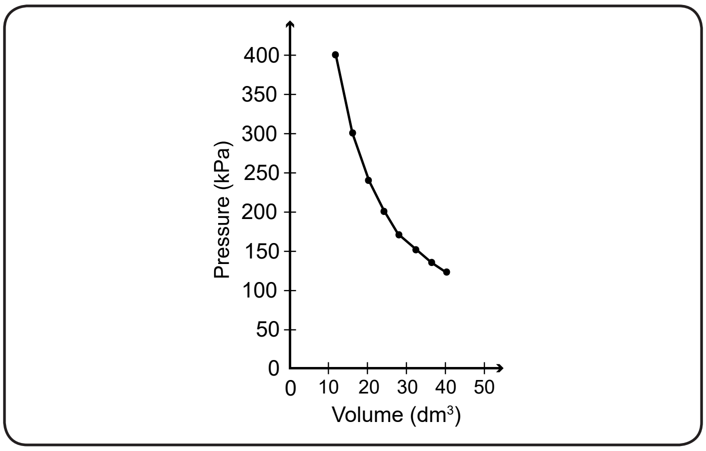


Figure 5 Typical results



If **temperature** is constant: ***volume is inversely proportional to pressure***

2.

Figure 6 Apparatus to investigate P v t

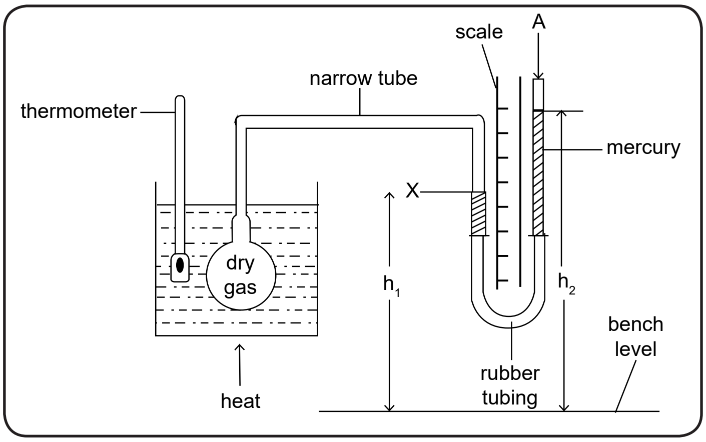
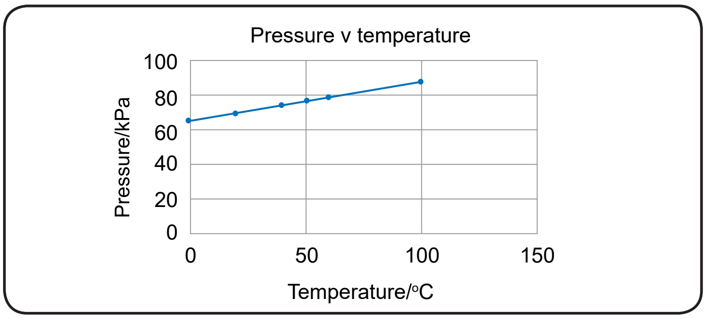


Figure 7 Typical results



If **volume** is constant: ***pressure increases with temperature***

3.

Figure 8 Apparatus to investigate V v t

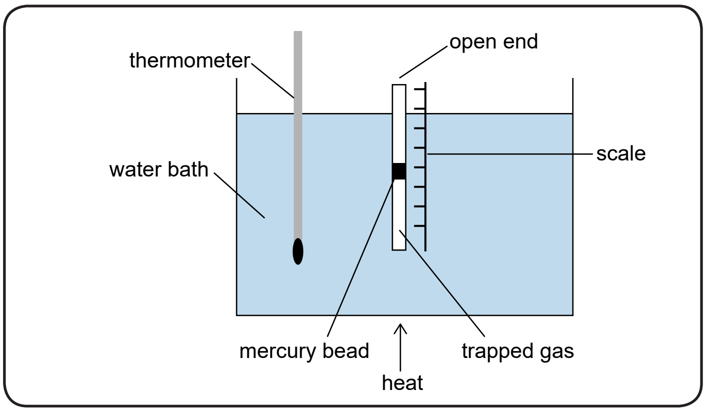
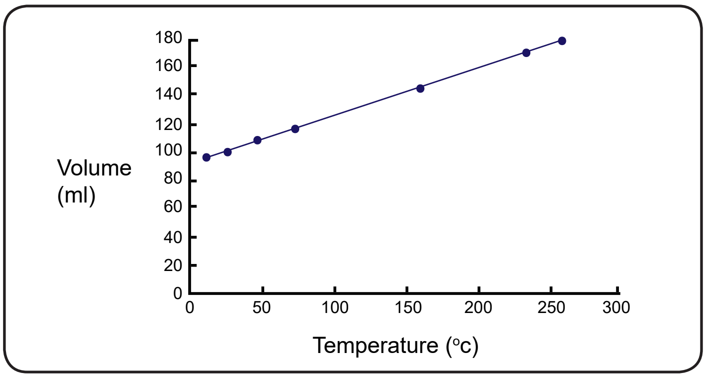
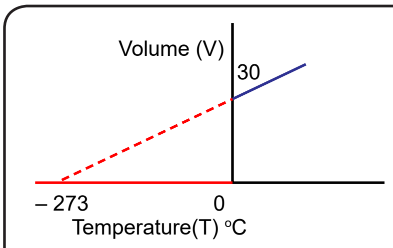


Figure 9 Typical results



If **pressure** is constant: ***volume increases with temperature***.

Figure 10 Typical results redrawn and extrapolated to show intercept on x-axis



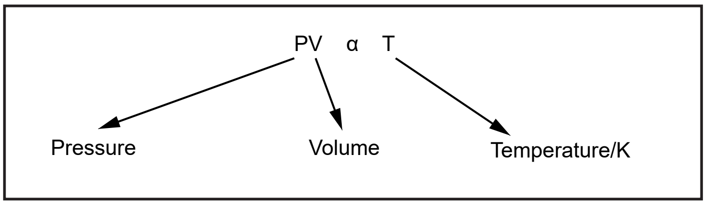
Volume (V)	Temperature (T) °C
20	0
21.8	25
23.7	50
25.4	75
27.3	100

If the volume v temperature graph is extrapolated to give an intercept on the temperature axis, the intercept is close to -273°C and this temperature is known as "Absolute Zero".

This redrawing of the results to show the intercept on the x-axis led to the formulation of a new temperature scale – the "Absolute Scale" or "Kelvin Scale", which has Absolute Zero as its zero, so zero on the K scale is -273°C. The advantage of this scale is that it is now possible to say that volume is proportional to temperature, and pressure is also proportional to temperature, whereas on the Celsius scale, although the quantities give a straight line on the graphs, they **CAN NOT** be described as proportional since the line does not pass through the origin.

Combined Gas Laws

Putting the 3 gas laws together gives:



Key Points:

As stated above: This holds only if temperature is in Kelvin. In any calculations you must remember to change °C to Kelvin.

Particle Theory Explanations

These are experimental results, but you will be expected to be able to explain them in terms of Particle Theory.

Pressure and Volume

If the temperature of the gas is kept constant, then the average KE remains the same, but if the volume is reduced then the pressure will increase because the particles hit the walls more often.

Pressure and Temperature

If the volume is fixed, then as the temperature rises and the average KE of the particles increases, then they will hit the walls more often and harder increasing the pressure.

Volume and Temperature

As the temperature of a gas is increased, the average KE of the particles increases, so they would hit the walls more often and harder increasing the pressure as above. If the pressure is to remain constant, then the walls must be free to move, so that the particles hit no harder and/or no more frequently than before.

Test Your Understanding:

4) *Why is it incorrect to say that the volume of a gas is directly proportional to temperature on the Celsius scale?*
5) a) *Explain how a gas exerts a pressure on its container.*
   b) *Explain, in terms of the particles, why the pressure of a gas will increase if the temperature increases and it is not allowed to expand.*

Ideal Gases

The Laws above are experimental, in order to progress to a more mathematical treatment in terms of particles – "***Kinetic Theory***" - scientists introduce a simplifying concept of an "***Ideal Gas***". It is useful, because, although no gas is actually ideal, virtually all gases are a good approximation to it under normal conditions. There are a number of key assumptions of Ideal gases:

1. Large numbers of particles are in constant, rapid, random motion.
2. All collisions between particles and the walls are perfectly elastic – i.e. no KE is lost, and the time of collisions is small compared to the time between the collisions,
3. That other than during collisions, the forces between particles are negligible.
4. The volume of the particles themselves is negligible compared to the volume of the whole gas.

In order to derive the mathematical formula, the collision of a particle with a wall is treated as a change of momentum from $\longrightarrow$ to $\longleftarrow$ (i.e. 2mv), where m is the mass and v the velocity of the particle. (Remember momentum is a vector quantity) The number of collisions per second is calculated and thus the rate of change of momentum i.e. force on the walls can be derived. The expressions are then averaged over the whole population of particles.

Key Points:

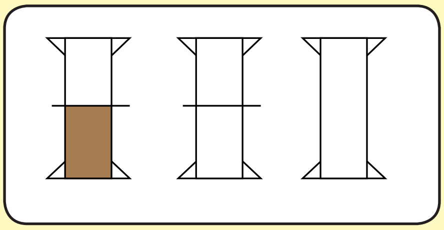
1) *The temperature of a gas is related to the average KE of the particles.*
2) *Particle theory satisfactorily explains much of gaseous behaviour.*
3) *For A Level, Kinetic Theory is a more mathematical treatment which makes simplifying assumptions of an "Ideal Gas".*

Test Your Understanding:

6) *Give the key assumptions of Kinetic Theory.*
7) a) *Convert 62°C to the Kelvin scale.*
   b) *Convert 350K to °C.*
8) a) *A gas occupies 5m^3 at 25°C, what would be its volume at 40°C if the pressure remains the same?*
   b) *If the volume were not allowed to increase, explain in terms of particles why the pressure would increase.*

Test Your Understanding (continued):

9) *Explain why the change of momentum occurring if a particle of mass m hits the wall at right angles with velocity is 2mv.*
10) *The diagram represents a gas jar into which a small quantity of bromine has been introduced and allowed to evaporate, with a gas jar of air inverted over the top of it separated by a piece of cardboard.*
    a) *Complete the second diagram to show how particles are distributed and moving in the bromine and in the air above.*
    b) *Complete the third diagram to show how the particles are distributed and moving a short time after the cardboard has been removed.*



Answers to 'Test Your Understanding':

1) *Brownian Motion supports the ideas of Particle Theory, because only if the air particles (too small to see) are in rapid, random motion could they cause the observed motion of the smoke particles.*
2) *Ice floats on water because it is less dense. Since the particles of ice are the same as those of liquid water, they must be further apart in the solid (ice) than they are in the water.*
3) *In a solid the particles are joined by bonds and not free to move. They can only vibrate i.e. possess PE. The particles in a gas are totally free (no PE) and moving rapidly (KE).*
4) *The graph of volume v temperature on the Celsius scale is a straight line, but it does not pass through the origin, so volume cannot be described as proportional to temperature.*
5) a) *A gas exerts a pressure on its container through the momentum change when the particles hit the walls.*
   b) *If the temperature increases, the speed of the particles increases and if the volume does not increase, the particles will hit the walls more frequently and the momentum change at each hit will be greater.*
6) • *That gases consist of a large number of particles in constant, rapid, random movement.*

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- *That all collisions are perfectly elastic and that the collision time is negligible compared to time between collisions.*
- *Other than during collisions the particles exert negligible forces on each other.*
- *That the volume of the particles themselves is negligible compared to the volume of the gas.*

7) a) 62°C = 62 + 273 = 335K
b) 350K = 350 - 273 = 77° C

8) a) $5m^3$ at 25°C i.e. 298K
So at 40°C i.e. 313K is 313/298 x 5 = $5.25m^3$
b) If the gas were not allowed to expand the pressure would increase because the particles travel faster, so hit the walls more often and there is a greater change of momentum at each impact.

9) The change of momentum is 2mv because momentum is a vector quantity, so there is a change from + mv to -mv, i.e. 2mv.

10) a) Look for drawing of particles with arrows of different length and different directions to indicate rapid random motion; brown in the bottom half and white in the top half.
b) Look for randomly distributed brown and white particles still with their arrows to indicate speed and direction.

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