A2 Level Physics

Chapter 12 – Thermal Physics

12.2.1 Solid, Liquid and Gas

Notes

Solids, Liquids and Gases

All matter, according to Kinetic Theory, is made up of tiny, identical particles called molecules, which are made up of Atoms. The atoms are made up of protons, neutrons, and electrons. The protons and neutrons are built up of smaller particles called Quarks.

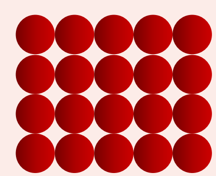
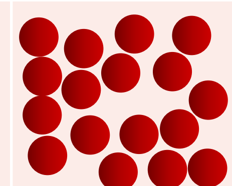
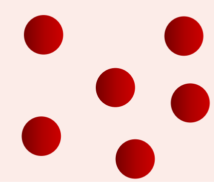
An atom is the smallest particle of an element that uniquely defines a chemical element (for example, an atom of Argon (Ar) has 18 protons, 22 neutrons, and 18 electrons).

An element is a substance made up of only one type of atom. Gold, for example, is an element with only gold atoms in a pure gold piece.

When two or more atoms form chemical bonds with each other, a molecule is formed. A molecule is the smallest particle of a pure substance that has its own unique properties.

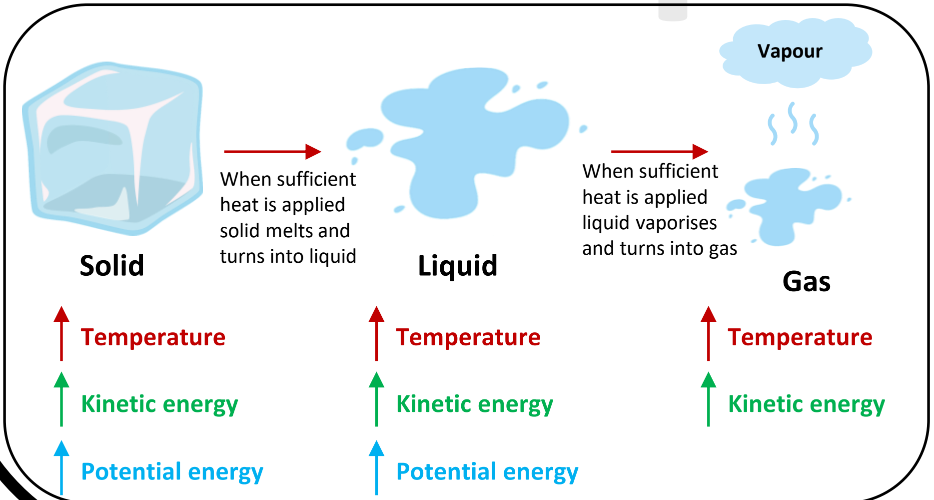
For example, C is the symbol for a single carbon atom, while O is the symbol for a single oxygen atom. CO_2, on the other hand, is the symbol for a carbon-dioxide molecule with two oxygen atoms and one carbon atom.

The table on the right summarises the arrangement and movement of particles in solids, liquids, and gases, as well as showing simplified illustrations of their arrangement.

	Solid	Liquid	Gas
Arrangement of particles	- Molecules are relatively close together and are arranged in a regular 3-D framework. - Regular pattern. - Atoms and molecules are held together by strong forces of attraction between particles. This is due to the electrical charges of the electrons and protons in the atoms.	- They're still close together. - They're arranged in a random order. - Because the molecules are free to move, the liquid flows freely and has no defined structure. - In comparison to a solid, the attractive forces between molecules are weaker.	- The molecules are far apart. - They have essentially no attracting force between them. - Gases have a random arrangement.
Movement of particles	- Vibrate randomly on the spot in simple harmonic motion.	- Free to move around randomly.	- Rapid random motion
Properties	- They have a fixed shape and cannot flow since the particles are unable to move from one place to another. - They can't be compressed or squashed because the particles are so close together that there's no room for them to move.	- Since the molecules in liquids are free to move around each other, they can flow and take the shape of their container. - They can't be compressed or squashed because the particles are so close together that there's no room for them to move.	- Since the particles can move in all directions, they flow and entirely fill their container. - Because the particles are far apart and have room to move, they can be compressed or squashed together.
Diagram			

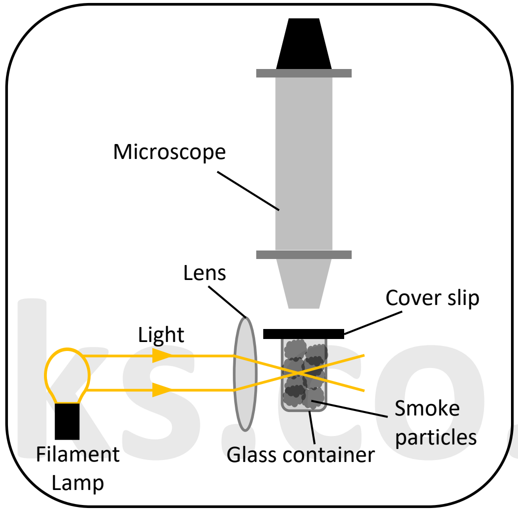
Solids, Liquids and Gases

- The particles in a solid begin to vibrate when the solid is heated. The more the molecules vibrate, the higher the temperature of the solid. The energy used to raise a solid's temperature also increases the molecules' kinetic energy. The solid melts if it reaches a sufficient temperature. This occurs because the substance's molecules vibrate so much that they break from one another, causing the substance to lose its structure. The molecules' potential energy increases at this point, and the substance transitions from a solid to a liquid.
- When a liquid is heated, the molecules begin to move rapidly. The faster a liquid's molecules move, the higher its temperature. The amount of energy used to raise the temperature of a liquid also increases the kinetic energy of the liquid molecules. Heating the liquid more and more causes it to vaporise. This is because the molecules have enough kinetic energy to break free and travel away from one another. The molecules' potential energy increases at this point, and the substance transitions from a liquid to a gas.
- When a gas or vapour is heated, the molecules gain kinetic energy and speed up.



Brownian Motion

In 1827, Robert Brown investigated pollen grains in water. He observed that the grains seemed to be moving in jerky patterns all the time, but he couldn't figure out why. Albert Einstein answered the problem about 80 years later, and his explanation helped to persuade many sceptics of the kinetic theory's accuracy.



The arrangement shown in the diagram opposite can be used to observe and study Brownian motion.

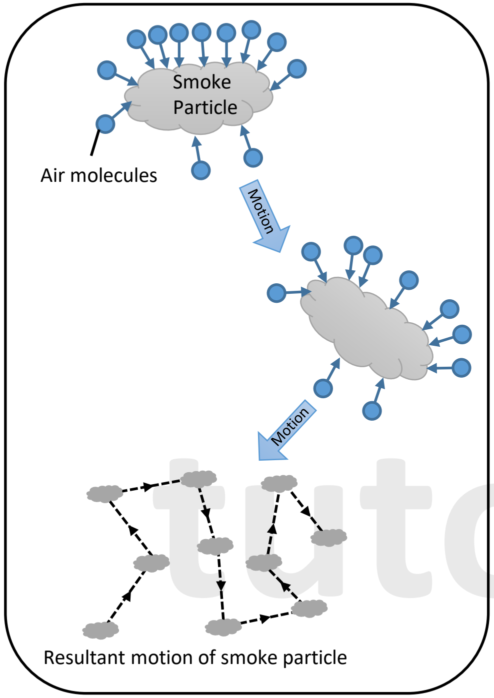
Fill a tiny glass container halfway with smoke and immediately cover it with a cover slip.

Using a filament lamp and a lens to focus the light, illuminate the glass container.

Using the microscope, examine the motion of the smoke particles in the glass container.

Brownian Motion

Conclusions from Brownian motion:



The observations can be explained by considering what happens to a single smoke particle.

1) The smoke particle moves in a jerky motion. The particle has a jerky motion because it is being impacted by randomly moving air molecules. As a result, the smoke particle also moves randomly, just like the air molecules.

2) Since air molecules are constantly moving, smoke particles are constantly moving.

3) Smoke particles are visible, but air molecules are not, implying that air molecules are very small.

4) Smoke particles move slowly due to a large number of air molecules.

Internal Energy

The molecules within a substance have two forms of energy:

- Kinetic energy (KE) because of the molecules random motion/vibration.
- Potential energy (PE) because of the bonds between the molecules.

These two types of energy combine to make up the substance's internal energy. As a result, internal energy can be defined as:

The internal energy of an object is the sum of the random distribution of the kinetic energy (KE) and potential energies (PE) of its molecules.

Increasing a substance's internal energy increases the KE and/or PE associated with the random motion and positions of its molecules.

Both the KE and PE components are present in roughly equal proportions.

When a substance is heated, the kinetic energy of the molecules usually increases as well. The average kinetic energy of the molecules is related to the temperature of the material. The average speed (KE) of the molecules is proportional to the temperature of a gas.

The KE will stop increasing when the substance reaches a specific temperature, and the heat will be transferred to potential energy, breaking the bonds between the molecules and changing the state of the material. For example, at this point, a solid (such as ice) transforms into a liquid (such as water).

When the state of a substance changes:

- The PE of molecules increases, causing the bonds between them to break.
- The KE remains the same, meaning that the temperature will remain the same, even though the substance is still being heated.

As a result, there is a continuous interchange between the KE and PE components of the total internal energy forming the foundations of internal energy. Also, as the KE increases, the PE remains constant, and as the PE increases, the KE remains constant, which is why the KE and PE are roughly equal in proportion.

Internal Energy

Internal energy and heat (thermal) energy are closely related, although they do not have the same meaning.

Heat (thermal) energy is the energy transferred between two points due to a temperature difference between them.

A systems internal energy:

Increases by:

1) Supplying heat energy to the system, and/or
2) Doing work on the system.

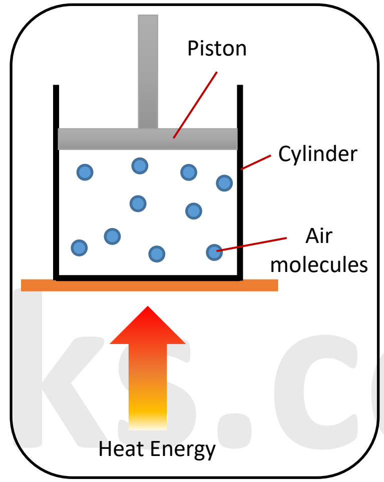
Decreased by:

1) Transferring heat energy out of the system and/or
2) Letting the system do work on the surrounding.

Internal Energy

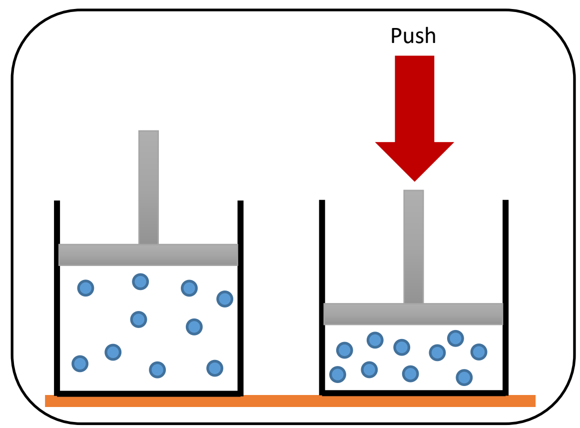
To better understand how the internal energy of a system can be changed, consider the system to be the air confined by a piston and cylinder.

The internal energy of the air (and thus its temperature) is increased by:



Supplying the system with heat from the outside (with the piston held in position).

As a result, the KE of the molecules increases.



The piston is pushed down into the cylinder (reducing the volume in which the air is contained).

This does work on the air and causes an increase in the KE of the molecules. This is because the collision of the downward moving piston with the gas molecules causes the gas molecules to move faster.

Absolute Zero

The absolute or kelvin scale is based on absolute zero, and is also known as the thermodynamic scale of temperature.

The absolute zero is the lowest limit for temperature.

$$Absolute\ zero = 0K = -273.15°C$$

A temperature of less than absolute zero is impossible.

Regardless of the substance that makes up the object, an object at absolute zero has minimum internal energy.

You can learn more about absolute zero from the 12.1 Temperature Pack.

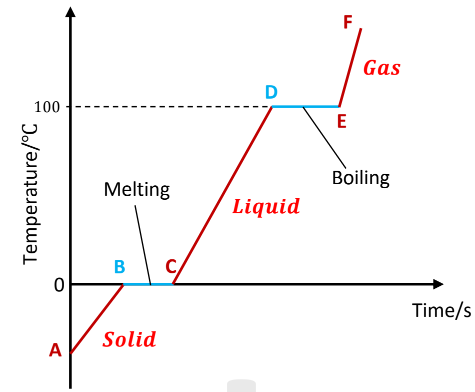
Change of State

When substances are heated or cooled, they can change state. When liquid water is heated enough, it turns into steam, and when it is cooled enough, it turns into ice. Ice may be melted and then frozen again, indicating that state changes are reversible.

Ice to Steam

Consider melting some ice and then heating the water until it boils and turns to steam.

If you plot the temperature against time for the entire process, you'll get something like the graph opposite.



Interpretation of the graph:

- **AB –** The ice starts at a temperature below 0℃. Increasing the temperature causes the molecules to gain energy and vibrate more strongly about their fixed positions. The molecules' ***kinetic energy (KE) rises***.
- **BC –** The ice melts at the melting point. Even though heat energy is still supplied, the temperature remains constant at 0°C until all of the ice has melted. This is because the molecules have gained enough KE to break the bonds which hold them together. The molecules become increasingly disordered, with a slight increase in separation. This is where the molecules' ***potential energy (PE) rises***. This is the point at which ice becomes liquid water.
- **CD –** The water temperature climbs to 100°C with continued heating. The molecules are moving faster and faster. ***KE increases***.
- **DE –** The water eventually boils and reaches the boiling point. Even if heat energy is still being supplied, the temperature remains constant at 100°C until all of the water has converted to steam. This is because the molecules have gained enough KE to completely break free of each other. The separation of the molecules increases dramatically and they are moving quickly in all directions. ***PE increases***. This is the point at which liquid water becomes a gas or vapour.
- **EF –** The temperature of steam exceeds 100°C. The molecules are now very far apart and in a state of rapid, random motion. ***KE rises***.

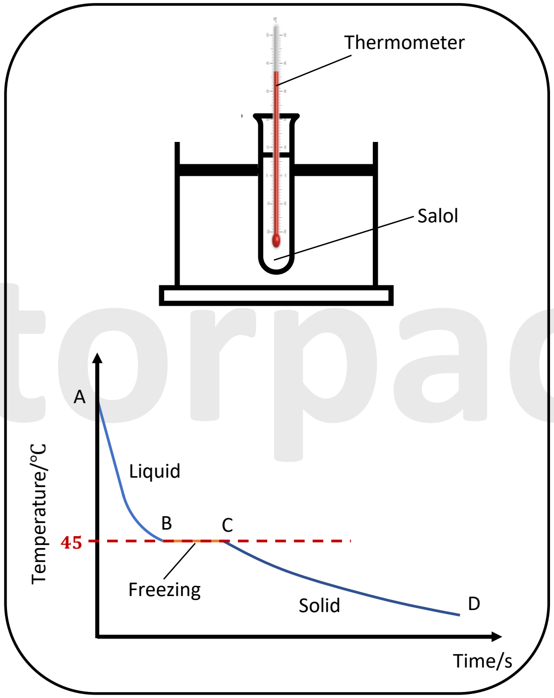
Change of State

Cooling curve for Salol

When a substance cools down and transforms from a liquid to a solid, changes in state can be measured.

Allowing a substance to cool down is generally easier. Salol is a solid that is used in this study. In order to investigate its cooling curve:

1) Fill a boiling tube with salol and place a thermometer in the tube. Then place the tube in a hot water bath.
2) Allow the salol to melt and reach the boiling water's temperature.
3) Remove the boiling tube from the hot water and set it on a cooling rack to cool.
4) For about 20 minutes, measure and record the temperature of the salol every minute, stirring slightly to evenly mix the hot and cold parts.
5) Using the recorded temperatures, plot a graph of temperature against time.



A cooling curve for salol is shown in the diagram above. The freezing point of the salol is found at section BC, where the temperature remains constant during the state change.

The motion of the molecules slows down during the freezing phase, and new bonds are formed. As a result, the molecules' KE and PE are reduced.

Change of State

Summary

When a substance is heated and melts or evaporates to turn from liquid to gas, its internal energy increases as the movement of its particles increases, and bonds between particles break.

When a substance is cooled and condensation occurs to turn a gas into a liquid, its internal energy decreases as the movement of its particles decreases, and bonds between particles form.

During a change of state:

- Energy must be supplied or extracted.
- The temperature remains constant.
- Molecules are either breaking free (PE increases) or coming together (PE decreasing)

In between changed of state:

- Energy supplied raises the temperature of the substance, while energy extracted lowers it.
- The molecules move faster (or slower), and the KE increases (or decreases).

Please see '12.2.2 Solid, Liquid and Gas worked examples' pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.