Chapter 2: Phases of Matter

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1 What is Matter?

The term matter can be used to describe any substance present within our universe and can be categorised into the aforementioned states of matter: solid, liquid and gas.

Solids are definite in volume and shape, both properties being susceptible to modification with changes in temperature. Solids end to expand when heated and contract when cooled to extreme temperatures.
Liquids at a constant temperature have a fixed volume and take the shape of whatever container they are housed in. The volume of a liquid can be influenced with changes in temperature.
Gases have neither a definite shape nor volume at any given temperature. A gas takes the shape of whatever container and the affect of temperature on its volume is substantial.

What makes something a solid or a liquid or a gas? It all has to do with the space between the particles of the substance and the types of bonds that hold to molecules together

In a solid the particles are very close together (regular arrangement) due to strong forces of attraction which only gives them the freedom to vibrate at a fixed point.

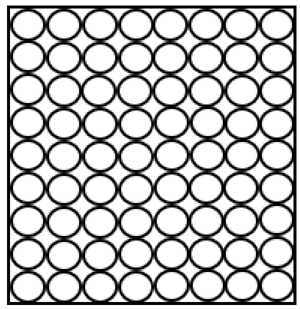

Figure 1: Particle placement within a solid substance.

In a liquid the forces of attraction between particles weaker therefore being further apart from one another. This means that they are free to roam about, allowing them to collide with one another. Energy is given off when this occurs, causing liquid particles to have more energy.

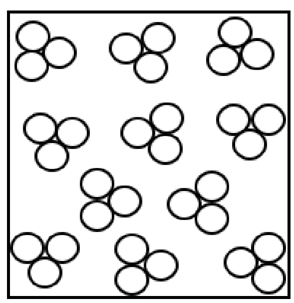

Figure 2: Particle placement within a liquid substance.

In a gas the forces of attraction between particles are negligible, this means that they are free to move about as they please at very high velocities. When gas particles collide with one another, they do so less rapidly than those in a liquid.

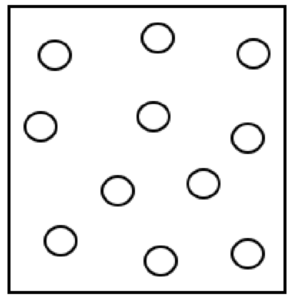

Figure 3: Particle placement within a gas substance.

1.1 The Kinetic Molecular Theory of Matter

This theory aims to explain why matter truly exists in different phases and how it is able to change from one state to another. the theory outlines the microscopic properties of atoms (or molecules) and their interactions which in turn uncovers observable macroscopic properties such as temperature, pressure and volume.

Atom: An atom is the smallest unit of ordinary matter.
Molecule: A molecule is a group of two or more atoms held together by chemical bonds

The kinetic molecular theory of matter states that:

- The particles which make up matter are constantly moving or vibrating, their velocity depending on which state they are in
- All existing particles posses energy, the amount of which varies depending on the state as well as the temperature the matter is exposed to.

  The temperature of a substance can be explained as the measure of the average kinetic energy of the particles.
- A change in the state of matter can occur when the energy of the particles increases or decreases. This can be done by adjusting the temperature of the substance at hand
- There are attractive forces present between atoms and molecules. As

these intermolecular forces strengthen, the particles move closer together and their motion becomes more restricted.

– Spacing between particles can vary depending on their intermolecular forces attraction.

1.2 Changing through States of Matter

The kinetic model can be used to explain how a substance changes from one state to another. The following diagram simply depicts what we are about to delve into:

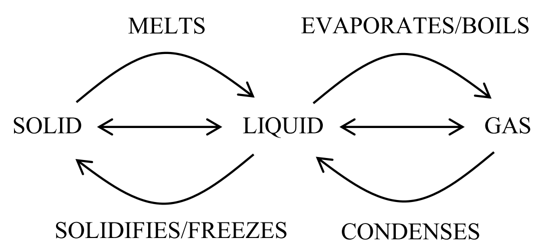

Figure 4: Transitioning from states of Matter.

Solid to Liquid

When heat is applied to a solid, the tightly packed particles vibrate faster and start to gain energy. As a result the temperature of the solid continues to increase gradually with time. There comes a point when the particles would have gained enough energy to overcome all forces of attraction (intermolecular) present between them and a change in state occurs. Every Substance has a unique heat tolerance, also known as the melting point.

Intermolecular Forces: The forces of attraction found between the molecules.

Note: *Once the temperature of the melting point is reached and the intermolecular forces in the substance starts to break down the temperature stays constant throughout the rest of the melting process and does not increase.*
For Example, if we were to place an ice cube in a glass and watch it melt, the temperature at the start of melting until the ice cube turned completely into water remained constant and did not increase.

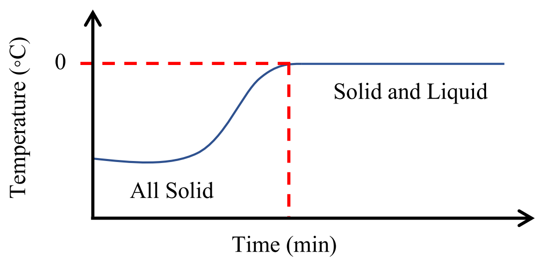

Figure 5: Change from solid to liquid state.

When the solid changes state into its liquid form, there are still some forces of attraction present between the particles but they are much weaker than in it's original state. Solids with high melting points have stronger forces of attraction between their particles then those with lower melting points and therefore would take more time to melt.

Liquid to Gas

When liquid particles warm up, the particles start to move around even faster as their overall energy increases. Particles at the surface which have enough energy to overcome the weaker intermolecular forces of attraction are released into the air to form a gas. This is called evaporation.

Note: *Evaporation and boiling are two different things even though evaporation occurs in the process of boiling. For example, Water can evaporate naturally with time whereas boiling water is an excellerated process of evaporating the water. Evaporation takes place only at the surface of a liquid, whereas boiling may occur throughout the liquid. In boiling, the change of state takes place at any point in the liquid where bubbles form. The bubbles then rise and break at the surface of the liquid.*

When a heat is applied to a liquid, the warmer particles rise up to the surface as they are lighter than the cooler particles. This happens because when particles are heated and they gain energy they vibrate more rapidly and create more space between each other. This makes warmer particles less dense then cooler ones, allowing them to rise to the surface. Once the boiling point of the liquid is reached and the temperature of the liquid is constant throughout the container this no longer happens. The liquid particles closest to the heating source are now the ones with the highest temperature and form into gas instantly releasing vapour pressure, shooting bubbles to the surface of the liquid. This is when you know the boiling point has been reached.

Note: *The vapour pressure has to be equal to greater than atmospheric pressure to be able to burst through the surface of the liquid and escape in it's gaseous form.*

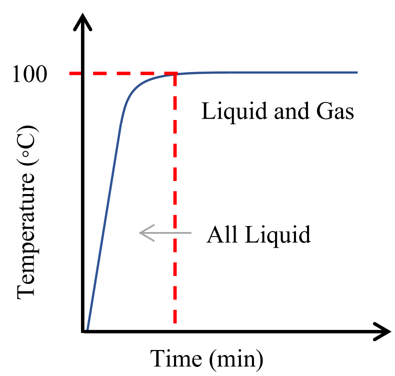

Figure 6: Change from liquid to gaseous state.

The same rules still apply:

- The particles need to overcome the weak intermolecular forces of attraction.
- The temperature does not change until these forces have been broken down completely, even though heat is constantly supplied. The temperature of a pure boiling liquid will not rise until it has completely evaporated.

Note: *Changes of state are examples of physical changes as they do not involve the formation of new substances. Whenever a physical change of state occurs, the temperature remains constant during the change.*

Changes in state of Water

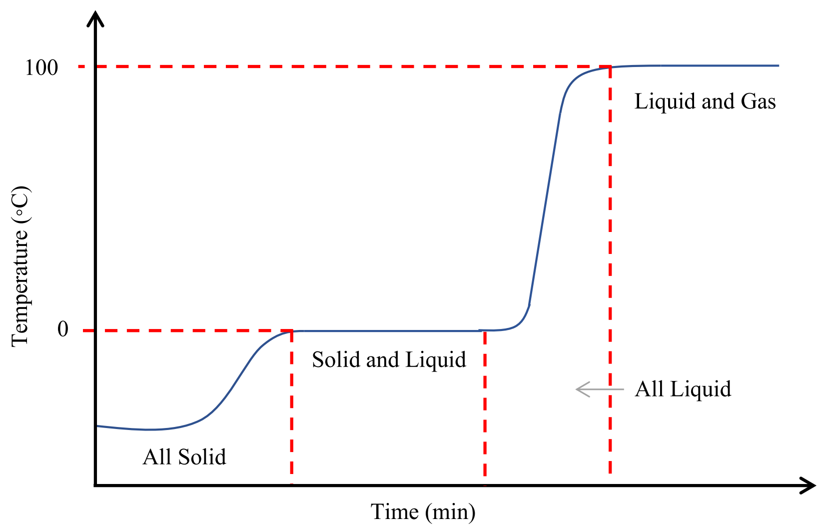

Figure 7: Changes in state of water.

Gas to Liquid

When the molecules in a gas cool down, the movement of particles also slows down as they being to loose their energy. This causes the gaseous particles to enter their original state as liquid particles. This process is called condensation. An example of this is when you leave a glass of cold water in room temperature and drops of water start to form around the glass. This occurs because the cold glass starts to cool down the gaseous water molecules present in the air start to collect together and turn into water droplets.

Liquid to Solid

Liquids can turn into their solid state if they are cooled down to their freezing point. Similar to condensation, when particles start to cool down they get slower, start loosing their energy and releasing it into the atmosphere (exothermic). In order for freezing to take place heat must be removed from the substance throughout the process. If not, the freezing process will stop. The heat energy released during freezing is called latent heat and is equal to the energy required to melt the same amount of the same substance.

Sublimation: The Unusual Change of State

There are a few substances which change from solid state to gaseous state directly, skipping the liquid state entirely. This unusual process is called sublimation where the cooling of the gas changes it into its solid form and the heating of the gas changes it back into its gaseous form. Examples of substances that behave in this way are: carbon dioxide, all ammonium salts, iron (III) chloride, aluminium chloride and iodine.

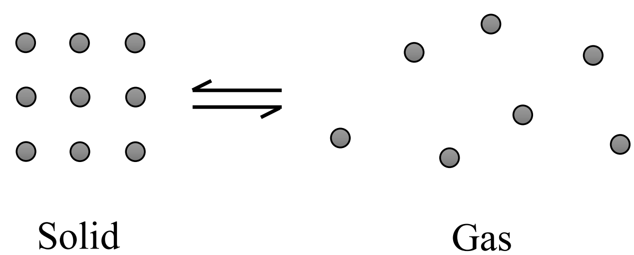

Figure 8: The Reversible Process of Sublimation.

1.3 Diffusion: The Evidence of Movement of Particles in Gases

When somebody wearing a nice perfume walks by, you can smell the perfume. For this to happen gas particles must be leaving the person and spread out through the air. This spreading out of gas is called diffusion and it takes place rapidly. All gases diffuse to fill the space available for them. For example, Although bromine is heavier than air, after a day the brown fumes of the gaseous bromine could be seen to have spread out evenly throughout both gas jars from the liquid present in the lower gas jar.

The rate at which gases diffuse depending on the gas in question. A good example for this is the ammonia and hydrogen chloride diffusion experiment where the liquid forms of these two acids are used to soak two separate pieces of cotton wool. Each cotton ball is fitted on either side of a dry glass tube

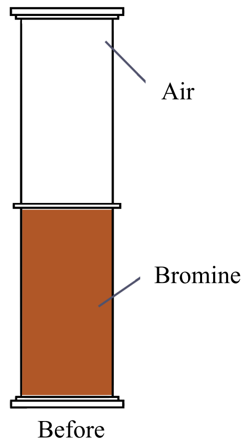

Figure 9: After 24 hours the bromine diffuses throughout both cylinders.

and stoppered with a rubber tab on each side. When the two gases react they form a white gas called ammonium chloride.

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(g)$$

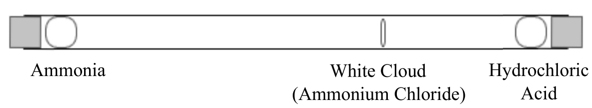

Figure 10: Cotton ball Diffusion Experiment.

As shown in the diagram, the white cloud is formed closer to the cotton soaked in the hydrochloric acid which indicates that the hydogen chloride gas particles moved (diffused) slower than the ammonia particles. Generally, the lighter the particles are, the faster they move at a given temperature and vice versa. Diffusion can also take place in liquids but it is a much slower process than that in gases. This is because the particles of the liquid move much more slowly. Such diffusion could be seen to take place when the purple colour of a crystal of potassium permanganate eventually spreads throughout water in which it is placed. Diffusion between gases and liquid can also take place. This process is called intimate mixing which can be explained using the principles of kinetic theory which were covered in Section 1.1, Kinetic Theory states that collisions take place continuously between particles present in both liquids and gases and that there is sufficient space between the particles of one substance for the particles of the other substance to move into.

1.4 Brownian motion: The Evidence of Movement of Particles in Liquids

In 1827 the renound botanist, Robert Brown, made an observation which provided evidence of particle movement in liquids. While looking through his microscope he noticed fine pollen grains on the surface of water were not stationary but were in random motion. Brown concluded that the pollen grains were moving as a result of the constant collision of the fast-moving much smaller water particles with the pollen grains. Brownian movement in gases can be observed in a smoke cell.

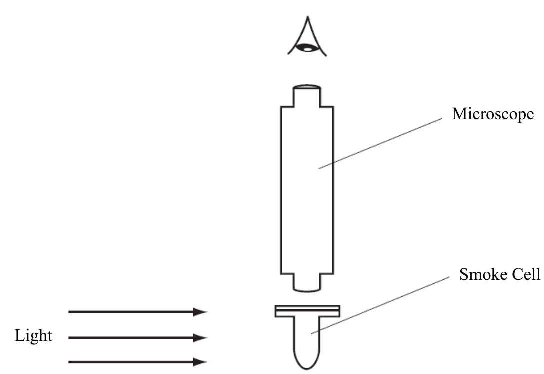

Figure 11: Smoke Cell Diagram.

When looking through the eye-piece one could see tiny illuminated specks of smoke particles which are in continuous random motion. The smoke particles are being pushed around by the continuous movement of gaseous particles presenting the air which are not visible to the human eye, even under a microscope! However, we can still see their movement through the movement of the smoke particles.

2 Purity of Substances

If you need to know if a substance is pure, one method is to investigate it's melting point or boiling point. These two temperatures are characteristic and unique to each substance.

Note: *No two pure substances have the same boiling and boiling points.*

The presence of impurities causes the boiling and the melting points to increase or decrease, depending on the impurity present.