7. Phases of Matter

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Learning Outcomes

(a) Define the term density.

The density of a substance is defined as the ratio of the mass to the volume

$$\rho = \frac{m}{V}$$

Where density is represented by the symbol rho (ρ) and is usually measured in $g.cm^{-3}$ or kgm^{-3}.

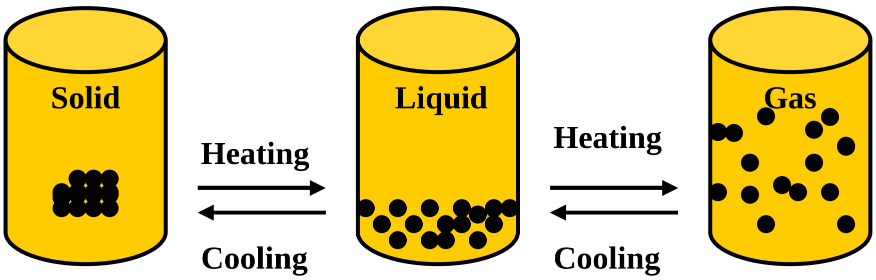
HANDY TIP

It is very important to realise that these units are not equivalent, as $1kgm^{-3}$ is equivalent to $\frac{1000g}{1000000cm^3} = \frac{1}{1000} g.cm^{-3}$, so a unit of $1g.cm^{-3}$ is 1000 times as large as the same density given in $kg.m^{-3}$.

If a substance has a large density it implies that there is a large amount of matter condensed into a very small space, if a substance has a low density it implies that the particles are either lower mass or are spaced further apart.

(b) Relate the difference in the structures and densities of solids, liquids and gases to simple ideas of the spacing, ordering and motion of molecules.

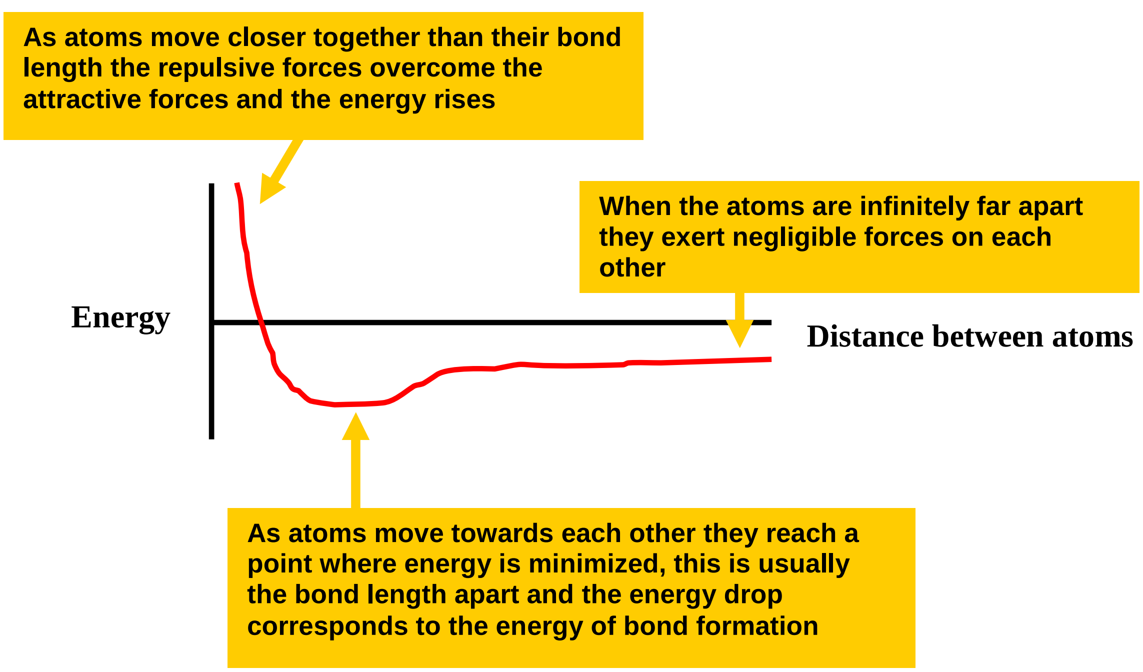
The existence of three states or phases of matter is due to the relative strength of the interatomic or intermolecular forces and the motion which atoms or molecules have because of their internal energy.



Solids

Attractive interatomic forces are present within a solid, however interatomic repulsion is also found to take place, otherwise the solid would collapse.

For distances greater than one atomic diameter the attractive force exceeds the repulsive force, while for distances smaller than one atomic diameter the opposite is true.



In a solid the only motion of the atoms is to vibrate about their equilibrium positions. The atoms occupy fixed positions and solids have shape

Liquids

As the temperature is increased, the vibrations increase and the kinetic energy increases so that atoms are able to overcome the interatomic forces with their immediate neighbours and there is a phase change (melting).

There is less order as the solid melts. The atoms or molecules of a liquid are only slightly further apart than in a solid. But they have greater speeds, due to the increased temperature and kinetic energy and move randomly in the liquid while continuing to vibrate.

There are still forces of attraction between the molecules; these attractive forces cause surface tension and viscosity. A huge amount of energy is required to break all of the intermolecular forces and cause a phase change from a liquid into a gas

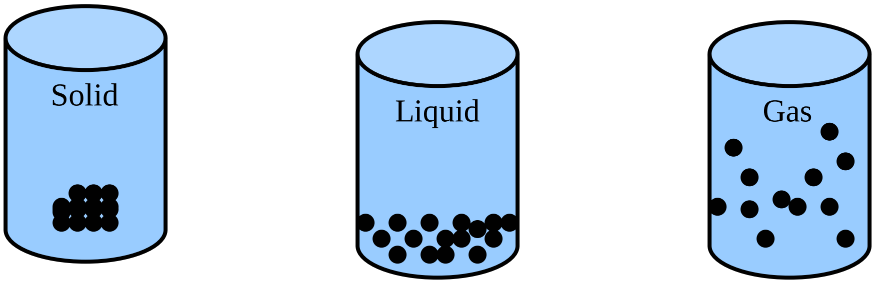
Gases

In a gas or vapour the atoms and molecules move randomly with high speeds through all the space available and the particles are very far apart.

Molecular interaction only occurs for the brief instants when molecules collide and large repulsive forces operate between them.

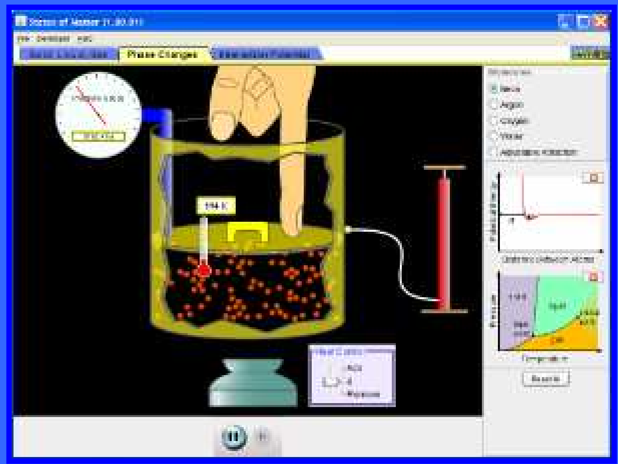
Gases can be compressed because of the huge spaces which exist between the particles.

(c) Describe a simple kinetic model for solids, liquids and gases.



The kinetic model of matter looks at all particles as being round balls, these particles are attracted to each other, when molecules form intermolecular bonds there bonds can be modelled as springs.

This simulation looks at the phase changes occurring in different substances, under different conditions. The attention to detail and accuracy is great, look carefully at water to see the effect of hydrogen bonds
http://phet.colorado.edu/simulations/sims.php?sim=States_of_Matter



The hotter the substance is the faster all of the molecules move and the more space each molecule occupies – not because the actual molecule is bigger but because it moves more it occupies a larger space even if it is not filling the entire space all of the time.

HANDY TIP

Imagine a person dancing on a dance floor, if they move faster they tend to take up more space, not because the person themselves in bigger but because they move to cover more space more quickly.

Initially, in the solid phase the molecules are all close together, and firmly in a position, all that they can do is vibrate. As they gain energy and the temperature is increased some of the molecules gain enough energy to break free of their bonds and move off by themselves, they have changed phase into a liquid.

Now that the particles are a liquid they can move but are still close to their neighbouring molecules. Liquids have the ability to flow because the molecules are no longer in fixed positions. The closer the molecules and the stronger the bonds between the molecules the more viscous (sticky and thick) the liquid will be.

Most viscous liquids become less viscous as they are heated because the molecules gain kinetic energy and break some of the intermolecular bonds and are able to move past each other more easily.

Water has very low viscosity and is easy to pour, more viscous liquids such as oil and honey are much thicker and harder to pour.

When the molecules have gained enough energy to break all of the forces between the molecules, the individual molecules move off and fill the entire container, this is the gas phase. The hotter the gas is the faster the molecules move and the more space the gas occupies. This is why gases expand upon heating.

Gases can be compressed because of the large spaces between molecules, because there are negligible forces between neighbouring particles the particles are light enough to "float" and thus a gas can occupy an entire container and not just the base of the container.

(d) Describe an experiment which demonstrates Brownian motion and appreciate the evidence for the movement of molecules provided by such an experiment.

Brownian motion is the random motion which dust particles and pollen grains are seen to have when placed in a medium of air or water

An experiment which demonstrates Brownian motion can be carried out using pollen grains. When observed under a microscope, the pollen grains are in a state of continual motion. The motion is both random and jerky.

Brownian motion can be observed when small particles of any kind are suspended in a fluid.

The constant and random bombardment of the suspended particles by the molecules of the surrounding medium cause the larger molecule to appear to be in continuous random jerky motion.

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This video looks at a simple experiment used to simulate the effect of Brownian motion but using larger marbles which move at a rapid rate to represent air and a large hockey puck to represent pollen or dust particles
http://www.youtube.com/watch?v=lCmbLbXWAbA&feature=related

This link also looks at a "brownie in motion" -literally– well worth a laugh but not likely to be examined
http://www.youtube.com/watch?v=IgxG1I7L51A&NR=1

The motion can be made more pronounced by:

1. **Increasing the temperature of the fluid so that the air particles move faster and have more vigorous and more energetic collisions with the suspended particles**

2. **Decreasing the size and mass of the suspended particles so that when they collide with air molecules they experience a larger acceleration.**

This simulation allows you to watch a recorded path of a large particle as it is bombarded with smaller air particles, I strongly recommend performing this experiment with N=10 as it gives a more pronounced motion
http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=24

(e) Distinguish between the structure of crystalline and non-crystalline solids with particular reference to metals, polymers and amorphous materials.

There are two general classifications of solids: Crystalline and amorphous

Most solids, all metals and many minerals are crystalline. In a crystalline solid all of the molecules or ions are arranged in regular repetitive units, crystalline solids have a very ordered structure.

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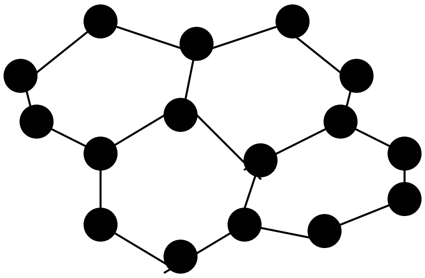
Photograph of metal surface [20]

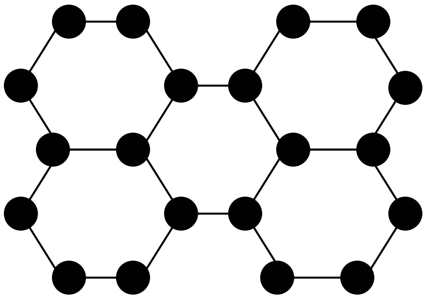
Metals are made up of tiny crystals called 'grains' at various angles to one another. This is called polycrystalline. The crystalline structure of a metal can be revealed by polishing the surface, treating it with an etching chemical (sometimes a dilute acid) and then viewing it under the microscope.

In an amorphous solid the particles are arranged in a more disordered way and show a small amount of order over a short distance and no order over a large distance.

Amorphous solid

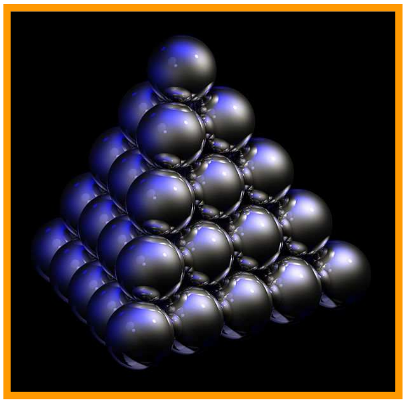


Crystalline solid



Polymers are materials with giant molecules, containing about 1000 to 100 000 atoms, and usually contain carbon. Polymers are made from building blocks called monomers; polymers have regular arrangements of monomers.

The crystalline structure of a solid depends on many factors including the type of bonds and the size and shape of the particles.



Metals always pack in a close packed structure where every atom is surrounded by as many atoms as is possible, this is the reason that metals are very dense.

Photograph of close packed balls [21] © Greg L

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In covalent solids the electron pair is shared between two atoms this results in directional bonding which means that each atoms can only be surrounded by as many other atoms as it is covalently bonded to.

(f) Define the term pressure and use the kinetic model to explain the pressure exerted by gases.

A number of assumptions are made in order to simplify the kinetic theory of gases

1. All of the molecules of a particular gas are identical- This is not true, most gases like air are composed of a number of different kinds of gases and all of the molecules are not identical – however since most gas molecules are relatively small and simple this assumption is allowed.

2. All collisions between the molecules and with the walls of the container are perfectly elastic.

3. The molecules exert no forces on each other except during collisions and the effect of gravity is ignored – This is not true, if gases did not exert forces of attraction upon each other it would not be possible to liquefy a gas- however since most gases have molecules which are very far apart and moving very fast under most conditions the forces of attraction are very small and can therefore be ignored.

Gas particles move randomly in a straight line at a constant speed until they collide with another particle or the walls of the container, after collision they rebound elastically. The size of the gas particles is negligible compared to the size of the spaces between them; this allows gases to be easily compressed.

Pressure is the force exerted per unit of area; it is measured in Pascal (Pa)

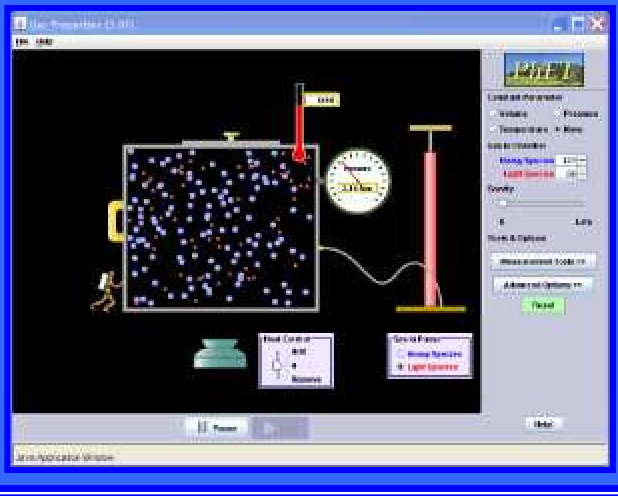
$$P = \frac{F}{A}$$

Where pressure (P) is measured in Pascal (Pa)
Force (F) is measure in Newton (N) and
Area (A) is measured in square metres (m^2)

The pressure which is exerted by a gas on the wall of its container arises because of collisions of the gas molecules with the wall of the container. The pressure depends on both the speed with which the gas molecules collide as well as the number of gas molecules which collide.

The larger the number of mols of gas which are contained in a vessel the higher the pressure will be because collisions will occur more frequently, similarly the higher the temperature the faster the molecules will move and the more frequent and energetic the collisions will be, resulting in a larger pressure being exerted.

This simulation allows you to watch the motion of gas molecules under conditions of different temperatures, you can also control the number of mols of gas in the container by pumping in less gas with the piston.
http://phet.colorado.edu/simulations/sims.php?sim=Gas_Properties

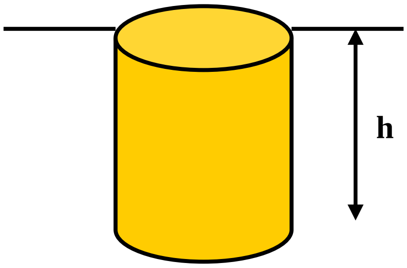


(g) Derive, from the definitions of pressure and density, the equation p= ρgh.

The pressure exerted by a liquid is experienced by any surface in contact with it. This can be experienced if you fill a plastic bag with water, the pressure is exerted everywhere on any surface in contact with the base or sides. The pressure at a point in a liquid acts equally in all directions and the force is always exerted perpendicularly to the surface.

The pressure at a point in a liquid is defined as the force per unit area on a very small area around the point.

The pressure varies with depth because at a greater depth there will be a greater weight of water pushing down than at a shallow depth.



An expression for the pressure (P) at a certain depth (h) in a liquid of density (ρ) can be found be considering a small horizontal area (A)
The force (F) acting vertically downwards on this areas will be equal to the weight of the column of liquid

The volume of liquid column can be calculated using the equation:

V= hA

Since the volume of a cylinder is always the base area multiplied by height

The mass of liquid column can be calculated using the equation

M = hAρ

Since mass is equal to density multiplied by volume

Weight of liquid column can be calculated by multiplying mass by the acceleration of free fall

W= hAρg

Hence, since weight is the force acting downwards,

F_g = hAρg

And pressure is force divided by the area

$$p = \frac{F}{A} = \frac{hA\rho g}{A}$$

This can be simplified to

$$\boxed{P = \rho g h}$$

The pressure at a point in a liquid depends only on the depth and the density of the liquid. Where height (h) is measured in metres (m), Density (ρ) is measured in kilograms per cubic metre (kgm^{-3}) then pressure is in Pa.

(h) Use the equation P = pgh.

Calculate the pressure which is exerted on a diver, at a height 10m below the surface of the water; assume density of sea water is 1030 $kg.m^{-3}$

$$P = \rho g h$$

$$P = (1030)(9.81)(10)$$

$$P = 101043 Pa$$

This pressure is only the pressure due to the water, in order to determine the total pressure acting on the person we have to include atmospheric pressure as well
Therefore the total pressure is 202kPa – roughly twice atmospheric pressure.

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This link is for a web page which looks in detail at hydrostatic pressure
http://www.ac.wwu.edu/~vawter/PhysicsNet/Topics/Pressure/HydroStatic.html

(i) Distinguish between the processes of melting, boiling and evaporation.

When a solid substance is heated it may **melt** and change its state from a solid to a liquid. A pure substance melts at a definite temperature, called the melting point, it solidifies at the same temperature when cooled and this is called the freezing point.

A liquid **boils** when its temperature is such that it changes from a liquid to a gas, and bubbles of vapour form throughout the liquid, these bubbles usually originate nearer to the source of heat. The pressure inside these bubbles is the saturated vapour pressure (SVP) of the liquid at that specific temperature. This pressure must be at least as large as the pressure outside the bubbles otherwise the vapour bubbles would collapse.

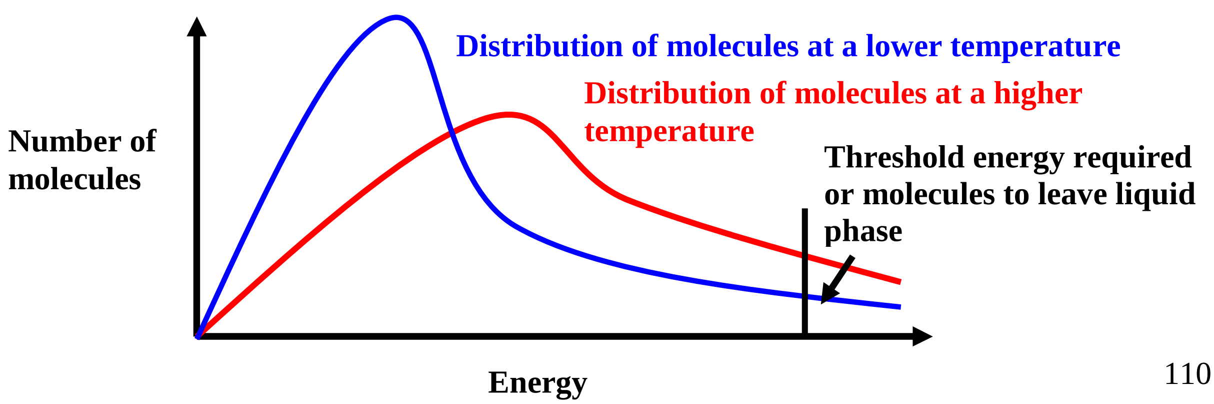
The boiling point of a liquid is that temperature at which its saturated vapour pressure (SVP) is equal to the external pressure. (The external pressure is the sum of the atmospheric pressure,

In a saturated vapour pressure system the vapour and liquid phases are in equilibrium, this means that the vapour is condensing back to liquid at the same rate as the liquid is turning into gas.

Evaporation is another process by which a liquid can become a vapour, but unlike boiling evaporation can take place at any temperature, it occurs at a greater rate when the liquid is at its boiling point.

At any temperature certain molecules of the liquid will be moving fast enough and have enough energy to overcome the attractive forces around it enabling it to escape from the surface of a liquid and enter the gas phase.

This concept is best explained using a Boltzman's Distribution,



The higher the temperature the more likely more molecules are to have sufficient energy and the greater the rate of evaporation. Since gas molecules can only evaporate at the surface of a liquid the greater the surface area of a liquid the greater the rate of evaporation. If there is a draught the rate of evaporation is also increased because vapour molecules are removed before they return back to the liquid phase. In fact any factor which reduces the density of molecules above where a liquid is evaporating will speed up the rate of evaporation as the molecules are less likely to be bounced back into the liquid phase.

When a liquid evaporates it loses the molecules which have the greatest kinetic energies, and therefore when a liquid evaporates it cools.