CONTENTS

CHEMISTRY PACK 1

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WHAT IS CHEMISTRY?

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Chemistry is the science that deals with:

- the properties, composition, and structure of substances (defined as elements and compounds),
- the transformations that they undergo,
- the energy that is released or absorbed during these processes.

Every substance consists of one or more of the hundred and ten or so types of atoms that have been identified as elements. Although these atoms are composed of more elementary particles, they are the basic building blocks of chemical substances; there is no quantity of oxygen, mercury, or gold, for example, smaller than an atom of that substance. Chemistry is concerned not with the subatomic domain but with the properties of atoms and the laws governing their combinations and with how the knowledge of these properties can be used to achieve specific purposes.

Chemistry also is concerned with:

- the utilization of natural substances,
- the creation of artificial ones.

Cooking, fermentation, glass making, and metallurgy are all techniques which utilise and alter chemicals which have been used since earliest times. Today, vinyl, Teflon, liquid crystals and semiconductors represent the advances of chemical technology. Modern chemistry, aided by increasingly sophisticated instruments, studies materials as small as single atoms and as large and complex as DNA (deoxyribonucleic acid), which contains millions of atoms. New substances can even be designed to bear desired characteristics and then synthesized. The rate at which chemical knowledge continues to accumulate is remarkable. Over time more than 8 million different chemical substances, both natural and artificial, have been characterized and produced. The number was less than 500,000 as recently as 1965.

Questions...

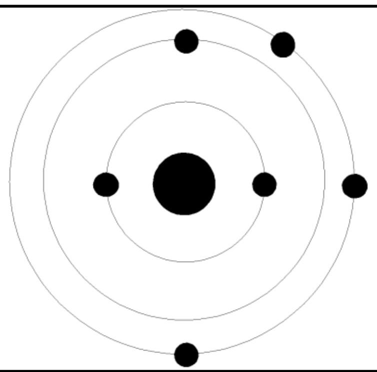
1. In your own words write a definition of chemistry.
2. How does chemistry differ from biology and physics?
3. Make a list of artificial substances which have been created and are in everyday use.

THE ATOM

The atom is the smallest unit into which matter can be divided without the release of electrically charged particles. It also is the smallest unit of matter that has the characteristic properties of a chemical element. As such, the atom is the basic building block of chemistry.

Most of the atom is empty space. The rest consists of a positively charged nucleus of protons and neutrons surrounded by a cloud of negatively charged electrons. The nucleus is small and dense compared to the electrons, which are the lightest charged particles in nature. Electrons are attracted to any positive charge by their electric force; in an atom, electric forces bind the electrons to the nucleus.

It is easier to describe an atom mathematically than conceptually, and so physicists have developed several models to explain its various characteristics. In some respects, the electrons in an atom behave like particles orbiting the nucleus. In others, the electrons behave like waves frozen in position around the nucleus. Such wave patterns, called orbitals, describe the distribution of individual electrons. The behaviour of an atom is strongly influenced by these orbital properties, and its chemical properties are determined by orbital groupings known as shells.



Label the illustration. Find the nucleus and identify the electrons. Where would you find the protons and neutrons?

Nucleus

Protons

Neutrons

Electrons

Questions...

1. What is an atom?
2. Is it possible to talk of smaller units than atoms? Explain.
3. How do atoms relate to one another to pass on energy?

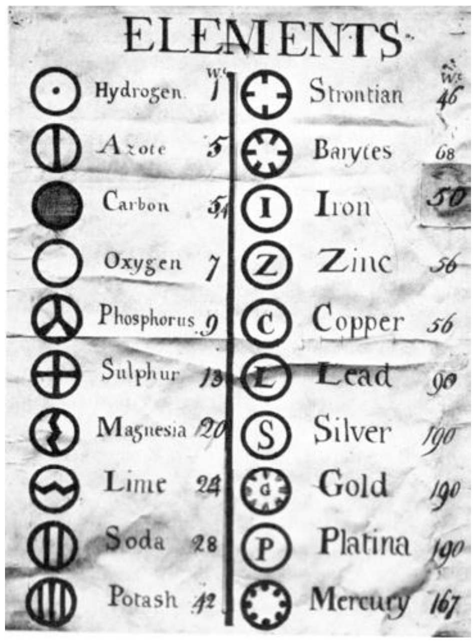
JOHN DALTON - ATOMIC THEORY

John Dalton was born in a village in Cumberland, England, in 1766. His parents were poor. He went to the village school and showed great potential in science and mathematics. He joined Manchester College in his early twenties and researched into science and mathematics for the rest of his life. In 1808 he published his '**Atomic Theory**', the main points of which were:

- The elements are made up of tiny particles of matter called atoms;
- Atoms are indivisible and indestructible;
- Atoms of the same element are identical and have the same mass;
- Atoms of different elements have a different mass;
- When elements come together to form compounds the atoms of the individual elements which join, remain whole.

John Dalton said that when elements join together to form compounds the original atoms of each element do not change their structure, but by joining with the atom of another element the nature of the joining gives the compound new qualities. In some cases the compound is simply the joining of one atom from one element to another atom from another element. But in some cases it is much more than the joining of two atoms; it may be that one atom joins three or more atoms from the other element, and of course the joining together of atoms happens millions of times.

John Dalton also wrote up the elements in a chart, (shown opposite), to make it easier for people to relate their findings to each other. This system was not really used much and was replaced by the Periodic Table which is used today.

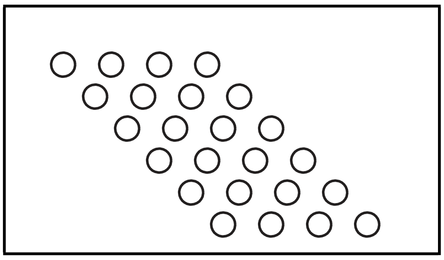


Questions...

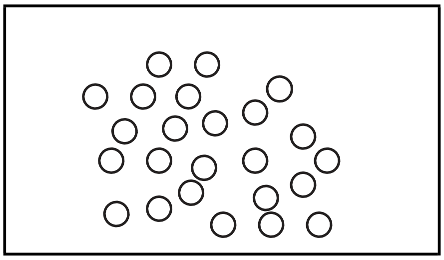
1. What is an element?
2. Are atoms indivisible and indestructible?
3. Write a short biography of John Dalton.

PARTICLE THEORY

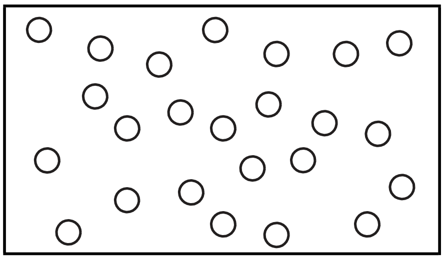
Particle theory is concerned with the way particles are arranged. The nature of the particles in a solid, liquid or gas state remain the same. This can be seen to be the case if water is frozen and then melted. The water after melting is the same as before it was frozen. The difference between solid, liquid, and gas states is the way the particles are arranged.



In a solid the particles are positioned closely to each other and there is a strong force of attraction between them. The particles in a solid do not move much and so keep a definite shape. Because the solids are already closely packed they do not easily change shape and force is required to work solids into other shapes.



Liquids have particles which are not so closely packed and therefore are fluid. Particles in liquids have some forces of attraction but not as much as in solids. The particles move in all directions and flow easily. Liquids keep the same volume and are not easily compressed.



Gas particles have very little attraction to each other and separate very easily. The particles move very fast and collide and disperse away from each other. Gas particles can be easily compressed because there is so much space between them and they have a very low density.

Questions...

1. What are particles in terms of the chemistry definition?
2. Draw illustrations like the ones above to show:
   - what happens when a solid is hit with a hammer,
   - what happens when liquid is poured into a vessel,
   - what happens when a gas is compressed.

ELEMENTS

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An element is any substance that cannot be decomposed into simpler substances by ordinary chemical processes.

Chemical elements constitute the fundamental materials of which all matter consists. Today, roughly 110 elements are known. Of these, 90 are found in nature either chemically free or in combination with other elements. The others are artificially produced.

Only 10 of the elements, carbon, sulphur, copper, antimony, iron, tin, gold, silver, mercury, and lead, were known in the uncombined state in ancient times. Although they were recognized as distinct varieties of matter, they were not classified as elements. In ancient and medieval times, the elements were thought of as:

- **earth, air, fire,** and **water,** the four simple substances of which all material bodies were supposed to be compounded.

The modern use of the concept dates from the early 1660s, when the English chemist Robert Boyle described elements as primitive and simple, or perfectly unmixed, bodies that are not made of any other bodies or of one another. From this time the term 'element' was reserved for material substances.

Roughly one-third of the elements found in nature occur in a chemically free state on Earth. These elements, which are not very active chemically, include nitrogen, gold, platinum, copper, and the noble gases.

The five most abundant elements in the Earth's crust are:

- oxygen,
- silicon,
- aluminium,
- iron,
- calcium.

Hydrogen is by far the most abundant element in the universe, accounting for more than 90 percent of the total number of atoms and for about three-fourths of the mass. Helium is next in abundance, constituting about 7 percent of the number of atoms and nearly one-fourth of the total mass.

Questions...

1. How did people understand chemistry and elements in the middle ages?
2. What is the difference between an atom, an element and a compound?

MIXTURES

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Mixtures are substances which are not chemically joined up. There are many examples of mixtures including sea water. It is quite easy to separate mixtures because they are not chemically joined. Whilst they mix to form a new substance their individual properties are maintained. Chemically joined substances, on the other hand, change their nature because they physically join up with other substances. When a solid is dissolved into a liquid it is called a solution.

Experiment...

This experiment looks at how to separate a mixture - rock salt. Rock salt is a mixture of salt and sand. In themselves they are each compounds. To separate the two substances a method has to be found which affects one substance whilst not affecting the other.

Sand does not dissolve in water whilst salt does. The easiest way to separate the two is by using water:

- Grind up the rock salt into tiny particles.
- Dissolve the solution in water.
- Filter the solution through filter paper into a container.
- Evaporate the water.

When the substance is mixed with water, the salt dissolves but the sand does not. When the solution is then filtered, the sand remains in the filter whilst the salt passes through into the container with the water. When the water is heated and evaporated off the salt is left. In this way the sand and salt are easily separated.

Think of ways of separating other mixtures:

- sea water, (salt and water),
- oil and water,
- mud, (soil and water),
- iron filings and soil.

COMPOUNDS

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Atoms of different elements can combine with one another to form chemical compounds.

Water, which is a chemical compound of hydrogen and oxygen in the ratio two hydrogen atoms for every oxygen atom, contains H O molecules.

The atoms of the various chemical elements can be likened to the letters of the alphabet: just as the letters of the alphabet are combined to form thousands of words, the atoms of the elements can combine in various ways to form a myriad of compounds. In fact, there are millions of chemical compounds known, and many more millions are possible but have not yet been discovered or synthesized. Most substances found in nature, such as wood, soil, and rocks, are mixtures of chemical compounds. These substances can be separated into their constituent compounds by physical methods, which are methods that do not change the way in which atoms are assembled within the compounds. Compounds can be broken down into their constituent elements by chemical changes.

Chemical compounds show a bewildering array of characteristics. At ordinary temperatures and pressures, some are solids, some are liquids, and some are gases. The colours of the various compounds span those of the rainbow. Some compounds are highly toxic to humans, while others are essential for life. Substitution of only a single atom within a compound may be responsible for changing the colour, odour, or toxicity of a substance. So that some sense can be made out of this great diversity, classification systems have been developed. Compounds are also classified as organic or inorganic. Organic compounds, so-called because many of them were originally isolated from living organisms, typically contain chains or rings of carbon atoms. Because of the great variety of ways that carbon can bond with itself and other elements, there are more than nine million organic compounds. The compounds that are not considered to be organic are called inorganic compounds.

Questions...

1. What is a chemical compound?
2. How is a compound made?
3. Make a list of compounds which are in everyday use.

PURIFYING COMPOUNDS

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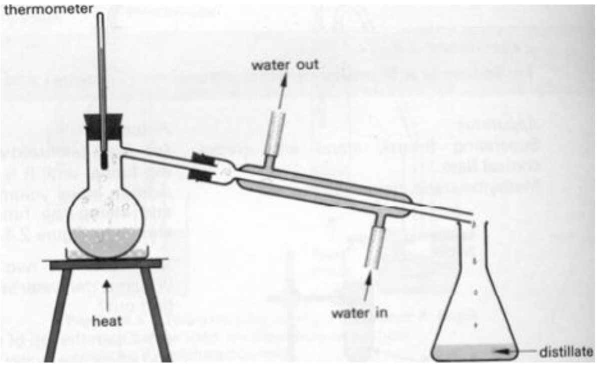

The problem faced by the scientist when wanting to investigate the qualities of a substance is that the substance has to be pure otherwise the validity of any findings would not be acceptable. It is often necessary to separate substances until only that part is left which is required. In order to achieve this type of substance, purifying, or separating methods are used.

The example above shows a simple distillation process. The mixture used is ethanol and water. The method is simple. Most liquids evaporate at different temperatures. When the mixture of ethanol and water are heated, the ethanol reaches its evaporation point before water does. The gas of the evaporating liquid is collected and cooled. The cooled gas becomes liquid ethanol again and the solution left is water.

There are many methods of separation and purification including:

- solution, filtration and crystallization,
- decolourization,
- distillation,
- sublimation.

Questions...

1. What does purification mean?
2. Why is it important to purify a substance before conducting an experiment with it?
3. Taking the list above write short descriptions on each of the methods of separation and purification.

SOLIDS

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The simple definition; a solid is generally thought of as being hard and firm.

Upon inspection, however, the definition becomes less straightforward. A cube of butter, for example, is hard after being stored in a refrigerator and is clearly a solid. After remaining on the kitchen table for a day, the same cube becomes quite soft, and it is unclear if the butter should still be considered a solid. Many crystals behave like butter in that they are hard at low temperatures but soft at higher temperatures. They are called solids at all temperatures below their melting point. A possible definition of a solid is **an object that retains its shape if left undisturbed**. The important issue is how long the object keeps its shape. A highly viscous fluid retains its shape for an hour but not a year. A solid must keep its shape longer than that.

Solids exhibit certain characteristics that distinguish them from liquids and gases. All solids have, for example, the ability to support loads applied to a surface. Their properties depend on the properties of the atoms that form the solid, on the way those atoms are arranged, and on the forces between them.

Solids are generally divided into three broad classes:

- **Crystalline** solids have a very high degree of order in a periodic atomic arrangement. Practically all metals and many other minerals belong to this class.
- **Noncrystalline** solids are those in which atoms and molecules are not organized in a definite lattice pattern. They include glasses, plastics, and gels.
- **Quasicrystalline** solids are metal alloys with novel symmetries in which the atoms are arranged in patterns that do not repeat at regular intervals. They exhibit symmetries, such as fivefold symmetry, that are forbidden in ordinary crystals. Quasicrystal structures are common in alloys in which aluminium is combined with another metal, such as iron, cobalt, or nickel.

Questions...

1. Define a solid.
2. Choose two contrasting solids and describe their qualities.
3. What has to happen to make most solids change into their liquid forms?

SOLIDS - AN EXPERIMENT

Experiment...

Try the following experiment:

We say that a solid is defined as an object which is hard and firm and maintains its solidity over a period of time. But some solids keep their solidness for longer than others. Compare Iron with butter, for instance. All solids are subject to change into liquid or gaseous states if they are subjected to heat. Make a list of solidness. Consider different solids and prioritise them in order of their solidity, and say how heat affects their ability to remain solid. Think about why the solids behave in the way they do and what this might say about their molecular make-up.

NAME OF SOLID	TEMPERATURE APPLIED	HOW DOES THE SOLID CHANGE, AND WHAT DOES THIS TELL US ABOUT ITS MAKE UP?
1. **BUTTER**		
2. **PLASTIC**		
3. **WOOD**		
4 **METAL**		

LIQUIDS

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The physical properties of a liquid are its retention of volume and its conformation to the shape of its container.

When a liquid substance is poured into a vessel, it takes the shape of the vessel, and, as long as the substance stays in the liquid state, it will remain inside the vessel. Furthermore, when a liquid is poured from one vessel to another, it retains its volume (as long as there is no vaporization or change in temperature) but not its shape. These properties serve as convenient criteria for distinguishing the liquid state from the solid and gaseous states. Gases, for example, expand to fill their container so that the volume they occupy is the same as that of the container. Solids retain both their shape and volume when moved from one container to another.

Liquids may be divided into two general categories: pure liquids and liquid mixtures. On Earth, water is the most abundant liquid, although much of the water with which organisms come into contact is not in pure form but is a mixture in which various substances are dissolved. Such mixtures include those fluids essential to life, blood, for example, beverages, and seawater. Seawater is a liquid mixture in which a variety of salts have been dissolved in water. Even though in pure form these salts are solids, in oceans they are part of the liquid phase. Liquid mixtures contain substances that in their pure form may themselves be liquids, solids, or even gases.

The liquid state sometimes is described simply as the state that occurs between the solid and gaseous states.

Questions...

1. Define liquid.
2. Is liquid a distinct state, or is it just a stage between solid and gas?
3. What features do the atoms in liquids show which are not apparent in solids?

LIQUIDS - AN EXPERIMENT

Experiment...

The physical properties of a liquid are its retention of volume and its conformation to the shape of its container.

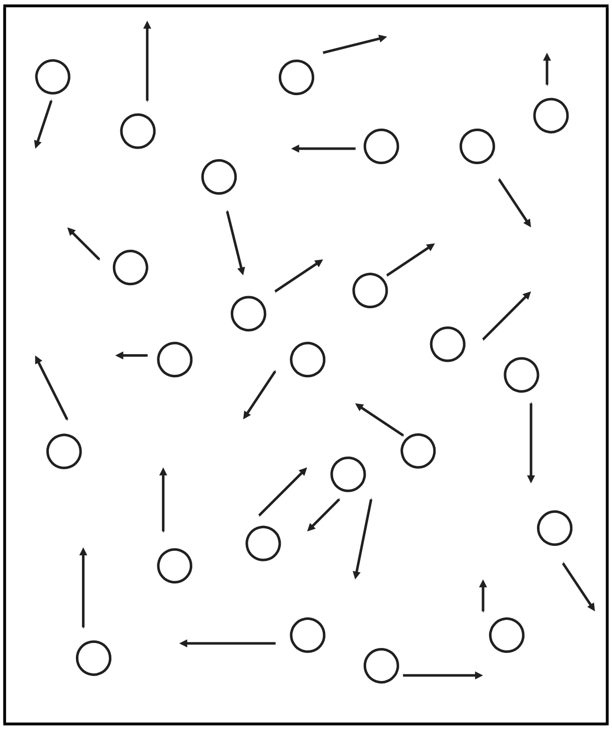
If we accept the definition of a liquid as expressed above, we can undertake an experiment to find out how a liquid can change either into a gas or into a solid, and find out which liquids are more or less resistant to change. Take two liquids, water and ethanol, (you could choose two others if required - consult with the teacher or facilitator), and note the effects on these if cooled or heated. First try cooling the liquids; try different temperatures and be very accurate in your measurements. Then see what effect heating has on them. What does this tell you about liquids and the properties of different liquids.

NAME OF LIQUID	TEMPERATURE APPLIED	HOW DOES THE LIQUID CHANGE, AND WHAT DOES THIS TELL US ABOUT ITS MAKE UP?
1. **WATER** COOLING		
2. **WATER** HEATING		
3. **ETHANOL** COOLING		
4. **ETHANOL** HEATING		

GASES

A gas has no definite shape and exhibits high fluidity. It tends to expand indefinitely and readily fills any container into which it is introduced. Gases are highly compressible, and under ordinary conditions they have a density approximately 1,000 times less than that of liquids. A small change in temperature or pressure generally produces a substantial change in the volume of a gas. The relationships between the temperature, pressure, and volume of gases have been deduced and expressed in the form of equations known as the gas laws, (see page 15).

- Gas particles have very little attraction to each other.
- They separate very easily.
- The particles move very fast and collide.
- They disperse away from each other.
- Gas particles can be easily compressed because there is so much space between them.
- They have a very low density.



Questions...

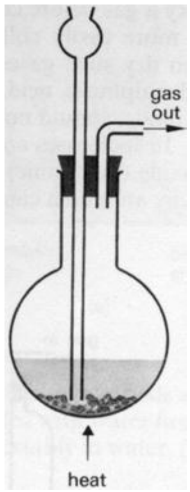
1. Write a definition of a gas.
2. How do the properties of a gas differ from those of a liquid?
3. How can a gas be turned into a liquid? Give examples.

COLLECTION OF GASES

There are four stages to remember when collecting gases:

- **The reaction vessel** - some type of vessel is needed which will allow the gases to mix, allows the gases to be produced at a controlled rate, and allows the gases to escape by a separate route.
- **The purification stage** - Usually gases are passed through other substances, often water, to purify them. This stage depends on the type of gas in question.
- **The drying stage** - gases must be dried using an agent which does not react with the gas or influence the gas in any way. The drying agent is often concentrated sulphuric acid.
- **The collection stage** - The first part of any gas collection should be allowed to escape because it is probably a mixture of gas and the air present in the vessel used. Gas is collected by upward delivery if it is lighter than air, and downward delivery if it is heavier than air. The main concern with collecting gas is that it should not escape into the air or become impure by inward leakage.

The illustration shows a simple gas collection method. The substance from which gas is to be formed is heated in a vessel, and is collected by a pipe which passes through the bung and onto a collecting vessel, (not shown).



Questions...

1. Draw illustrations of different types of vessels which can be used to collect gases.
2. What is the drying stage and why is it important?
3. Why should the first part of any gas collection be allowed to escape? How do you know when to stop the escape?

SIMPLE GAS LAWS

In order to have general gas laws it is necessary to have a general gas. All gases are different and react differently under certain conditions so in order to write up general gas laws scientists imagine an ideal gas. This gas does not exist but allows scientists to highlight laws that apply generally to all gases. An ideal gas is a gas that conforms, in physical behaviour, to a particular, idealized relation between pressure, volume, and temperature called the general gas law. This law is a generalization containing both Boyle's law and Charles's law as special cases and states that for a specified quantity of gas, the product of the volume v and pressure p is proportional to the absolute temperature t; i.e., in equation form, pv = kt, in which k is a constant. Such a relation for a substance is called its equation of state and is sufficient to describe its gross behaviour.

The general gas law can be derived from the kinetic theory of gases and relies on the assumptions that:

- the gas consists of a large number of molecules, which are in random motion and obey Newton's laws of motion;
- the volume of the molecules is negligibly small compared to the volume occupied by the gas;
- no forces act on the molecules except during elastic collisions of negligible duration.

The behaviour of real gases is described quite closely by the general gas law at sufficiently high temperatures and low pressures, when relatively large distances between molecules and their high speeds overcome any interaction. A gas does not obey the equation when conditions are such that the gas, or any of the component gases in a mixture, is near its condensation point.

Questions...

1. What is a general gas law?
2. Is a general gas law useful bearing in mind that gases behave differently?
3. Make a list of the common features of all gases.

THE PROPERTIES OF METALS

There are 88 metal elements in the Periodic Table, compared with 21 non metals. Some of the properties of metals are easily understood and can be seen in everyday use. They:

- are very good conductors of electricity - all electrical circuits use wires made of metals, often copper,
- are usually very strong - bridges and metal girders are good examples,
- can be shaped without breaking - think of car body parts,
- conduct heat - because the atoms are tightly packed they are efficient at passing on heat along the length of the metal,
- are shiny when polished - metals have very smooth surfaces which reflect light effectively,
- are heavy in relation to many other objects of the same size - this is because the atoms are so tightly packed and regularly distributed.

Other properties of metals include:

- They have very high melting points - Iron 1540^{o}C, Copper 1084^{o}C, Aluminium 660^{o}C.
- They are ductile - this means they can be drawn out into wires without breaking easily.
- Some metals are magnetic.
- Metals can be combined to make a different metal - these mixtures are called alloys.
- Metals are sonorous - this means they make a sound when hit. Ideal for musical instruments among other things.
- Metals make metal oxides when they come in contact with oxygen in the air. These metallic oxides are alkaline and have a pH value more than 7.

Questions...

1. How does the ordinary understanding of what a metal is differ from the chemistry definition?
2. What is an alloy?
3. Make a list of alloys which are in everyday use.
4. What does **alkaline** mean and what is a **pH** value?

THE PROPERTIES OF NON-METALS

There are 21 non-metals in the Periodic Table. The properties of these non-metals vary much more than those of the 88 metals. Their properties include:

- they are poor conductors of electricity - they make ideal insulators, (e.g. plastic covers for wiring),
- they are not strong - the bonds of their atoms are weaker than metals and they break or wear easily,
- they don't reflect heat very well and are dull in colour,
- they are not magnetic,
- they are poor conductors of heat,
- they react with oxygen to make oxides which are acidic,
- they have low boiling points - Neon -249^{o}C, Sulphur 113^{o}C.

Questions...

1. Write a short definition of a non-metal.
2. Do non-metals always have qualities which are opposite to metals?
3. Why are non-metals often brittle and weak?

METALS AND NON-METALS - EXCEPTIONS TO THE RULE

There are four exceptions to the general rules of properties of metals and non-metals.

- **Diamond** is made from Carbon and is a non-metal. Diamonds are very hard indeed, unlike all the other non-metals. The reason for this is that the atoms are bonded to each other in a very strong way which makes the diamond very hard. It also has a very high melting point, 3500^{o}C. Diamonds make ideal material for drills to cut stone and other hard substances, as well as being sought after as fashion items.
- **Graphite** is a non-metal but it is a conductor of electricity. Graphite is made from Carbon atoms but its structure is layered. This allows electrons to move between layers. This type of structure makes graphite quite weak and slippery. It can be used as a lubricant because of this quality.
- **Sodium** is a metal but it is very soft and can float in water. It can be cut with a knife unlike any other metal. Sodium is a very reactive substance and should always be handled with care.
- **Mercury** is a metal but at room temperature it is liquid. For mercury to become solid it has to be cooled to -39^{o}C. Mercury readily expands when heated and so it is often used in thermometers and other measuring equipment.

Questions...

1. Why is it important to consider these four exceptions to the general rules of how metals and non metals behave?
2. Find out how mercury is used in thermometers and what other chemicals can also fulfil this role.
3. Find out more about graphite and make a list of its everyday uses.

WATER

- Water is a very important substance and is often used as a catalyst in experiments.
- It is a substance composed of the chemical elements hydrogen and oxygen.
- It exists in gaseous, liquid, and solid states.
- Water is one of the most plentiful and essential of compounds.
- It is vital to life, participating in virtually every process that occurs in plants and animals.
- Temperature measurements use the freezing point, $0^{o}C$ and boiling point $100^{o}C$ of water as a reference point.
- When water freezes it becomes ice which is lighter than the water it has changed from. Solids usually weigh more than their liquid equivalents but water expands when it freezes, reducing its mass.
- At $100^{o}C$ water turns into a vapour.

Questions...

1. Is water the most important chemical on Earth? Why?

2 Draw an illustration showing the complete process of change from ice to water to vapour, then back to water and then ice again. Include how you would capture and keep the vapour.

3. Make a list of chemicals which are directly affected by water.

SOAPS AND DETERGENTS

Soaps and detergents are substances that, when dissolved in water, give it the ability to remove dirt from surfaces such as the human skin, textiles, and other solids. The seemingly simple process of cleaning a soiled surface is, in fact, complex, and consists of the following physical-chemical steps:

- **Wetting of the surface**, (and, in the case of textiles), penetration of the fibre structure by the detergent. Detergents (and other surface-active agents) increase the spreading and wetting ability of water by reducing its surface tension, that is, the affinity its molecules have for each other in preference to the molecules of the material to be washed.
- **Absorption** of a layer of the soap or detergent between the water and the surface to be washed.
- **Dispersion** of soil from the fibre or other material into the wash water. This step is facilitated by mechanical agitation and high temperatures.
- **Preventing the soil from being deposited again** onto the surface cleaned. The soap or detergent accomplishes this by suspending the dirt in a protective colloid, sometimes with the aid of special additives.

Surprisingly, water on its own is not enough to adequately wet a surface that needs to be cleaned. Try it yourself. Pour some water into a test tube and then pour it back out. When you look closely at the inside of the test tube you will see that some parts of the test tube are dry. This is because the surface tension in the water pulls back the droplets to form drops. If you add detergent or soap to the water and repeat the experiment you will see that more of the inside of the test tube is wet than before. Detergents reduce the surface tension in the water.

Detergents collect the dirt from a surface and hold them in their droplets. One important feature of detergents is that they do not allow the dirt back on to the surface, and so when the detergent and water are washed out of the surface the dirt is also carried away, leaving the surface clean.

Questions...

1. What is a detergent?
2. What is the difference between a detergent and a soap?
3. Draw an illustration to show how a detergent works.