**THE CHEMICAL EARTH**

**What is this topic about?**

To keep it as simple as possible, (K.I.S.S.) this topic involves the study of:

1. The Composition of Matter... MIXTURES
2. The ELEMENTS
3. COMPOUNDS... Ionic & Covalent
4. Physical & Chemical Changes
5. Bonding, Structures & Properties

...all in the context of the Earth’s chemical nature & our use of resources

**but first, an introduction...**

**What is Chemistry?**

Chemistry is the study of matter and its properties, and the ways that it can be changed or transformed.

To successfully study this subject it is essential that you grasp **3 vital concepts**, as early as possible.

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**Types of Matter**

**Pure Substances**

- Elements
- Compounds

**Mixtures**

All substances can be classified into just a few different types...

It is essential for you to understand the differences!

**Atoms**

All matter, whether Element, Compound or Mixture, is made of atoms.

Structure of an ATOM

- electron (-)
- Nucleus contains PROTONS (+) and NEUTRONS (0)

Although there are millions of different substances, they are all composed of relatively few types of atoms.

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**Physical Changes v Chemical Changes**

**Physical Changes**

Physical changes do NOT produce any new substances.

- Things may change their state (e.g. melt) or might dissolve in a liquid, but it's still the same stuff.

**Chemical Changes**

Chemical changes make new substances during chemical reactions.

- In a chemical reaction the atoms do not change, but they are rearranged in new combinations, forming new “products”, different to the “reactants” you started with.

This topic covers these things and more...
CONCEPT DIAGRAM ("Mind Map") OF TOPIC

Some students find that memorising the OUTLINE of a topic helps them learn and remember the concepts and important facts. As you proceed through the topic, come back to this page regularly to see how each bit fits the whole. At the end of the notes you will find a blank version of this "Mind Map" to practise on.
1. THE COMPOSITION OF MATTER... MIXTURES

Every substance is either an element, a compound, or a mixture. In this section you will study mixtures, but it is essential that you understand clearly how each type of matter is different.

**Elements**

Pure.
Only one type of atom present.
Each has a unique set of properties.
Listed on the Periodic Table, with its own symbol and Atomic Number.
Cannot be separated into parts by any physical or chemical process.

**Examples of Elements**

Oxygen, Iron, Copper, Lead, Chlorine

**Compounds**

Pure.
Only one type of particle present.
Each has a unique set of properties.
Contains 2 or more elements, chemically bonded together in a fixed ratio.
Cannot be separated into parts by any physical process.
Can be separated into its elements by chemical decomposition.

**Examples of Compounds**

Water, Salt, Copper sulfate, Ethanol

**Mixtures**

Not pure.
(Different particles within.)
Variable composition and properties.
Can be separated into parts by physical processes.
(filtering, distilling, etc)
May contain elements and/or compounds within the mix.

**Examples of Mixtures**

Air, Concrete, Sea water

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We are Surrounded by Mixtures
The Earth is often thought of as being made up of several “spheres”. All are mixtures of compounds and elements.

Lithosphere
This is the solid, rocky part of the Earth.
Rocks are mixtures of minerals which are, in turn, crystalline compounds. Each type of rock is a different mixture, with different minerals, in varying proportions.

Hydrosphere
This is the watery part of the Earth, mainly the oceans, but also rivers and lakes. Most of it is a mixture of water with suspended solids (e.g. dirt), dissolved compounds (especially salt) and dissolved elements such as oxygen and nitrogen.

Atmosphere is the gaseous part of the Earth... the air. Air is a mixture of elements (e.g. nitrogen (N₂), oxygen (O₂) and Argon (Ar)) and compounds such as carbon dioxide (CO₂) and water vapour (H₂O).

Biosphere technically refers to those parts of the Earth where living things are found, and so includes parts of the Lithosphere, Hydrosphere and Atmosphere.
Living things themselves are complex mixtures of (mainly) water, proteins, carbohydrates, fats and so on. These “life chemicals” include the most complex compounds known, such as DNA, which may have millions of atoms bonded together in each molecule.

Separating Mixtures
Since the different particles within a mixture are not all chemically bonded together, and since each has different properties, they can be separated fairly easily by simple physical processes.

It is important that you can identify the “Difference in Properties” (D.I.P.) which allows each process to separate the fractions of the mixture.

Solids of Different Grain Size
Imagine a mixture of dry sand and pebbles you have scooped up from a beach. How could the sand be separated from the pebbles?

Using a sieve.
Fine material (sand) falls through the mesh.
Coarser pebbles are caught

D.I.P = grain sizes

Solids and Liquids (when NOT a solution)
If a solid is suspended in a liquid (such as sand mixed with water) it will often separate by itself if allowed to stand. When a solid settles-out of a suspension like this, it is called sedimentation.

In the laboratory or in industry, the separation can often be achieved faster and more efficiently by filtration.

A filter paper is like a “sieve” of paper fibres, with many small holes. Water molecules can pass through the holes, but the larger particles of the suspended solid are caught.

D.I.P = particle size.
**Dissolved Solids in Liquids**

When a solid is dissolved in a liquid, such as when salt dissolves in water, the mixture is called a “solution” and filtration will not work to separate the parts.

Later in this course you will learn in detail what happens when solids dissolve. At this point just be aware that in a solution the particles of the dissolved solid (“solute”) are similar in size to the molecules of the liquid (“solvent”). If the water molecules can get through the filter paper, the dissolved solute particles will too.

The commonest ways to separate the parts of a solution are:

- **Evaporation**... to collect the solid solute, and
- **Distillation**... to collect the liquid solvent.

For example, with a salt-water solution, the water boils (and vaporises) at 100°C. The salt however, wouldn’t even melt until 770°C and so it stays in the basin or flask.

As the water evaporates away the salt solution becomes more and more concentrated, until solid salt crystals begin to separate from the remaining solution. In a distillation, it is time to stop heating before the flask over-heats and breaks!

**Separating Liquid Mixtures**

If 2 liquids can mix together and dissolve in each other (like alcohol in water, or oil in petrol) they are said to be “miscible”. If 2 liquids will not mix with each other (like oil and water) they are “immiscible”.

Separating immiscible liquids can be easily done with a separating funnel.

**D.I.P. = immiscible and different density**

If the liquids are miscible, separation is more difficult.

If their boiling points are quite different, distillation will work.

**D.I.P. = different boiling points.**

However, if the b.p.’s are similar, it might be difficult to get total separation into really pure “fractions”. For example, when distilling alcohol-water mixtures it is impossible to collect pure alcohol, and in the industrial distillation of (say) wine to make brandy, the distillate is about 40% alcohol, 60% water.

**Separating Gas Mixtures**

For example, how could you separate air into its different gases?

The technique used is called “**Fractional Distillation**”.

**D.I.P. = different boiling points.**

Basically, air can be turned to liquid, by cooling and compressing it. Then, if allowed to gradually warm up, each different gas “fraction” boils off at its particular b.p., and can be collected separately... pure oxygen, pure argon, etc.

**Fractional Distillation** is also used to separate crude oil (petroleum) into petrol, kerosene, diesel fuel, etc.
Practical Work... Separating a Mixture

You may have done a practical exercise in the laboratory to separate a simple mixture into its fractions.

A common task is to begin with a mixture of sand, salt and water and collect clean, dry sand, pure solid salt and pure water.

A flow-chart of a suitable procedure is shown.

You need to be able to interpret, and to construct, similar flow charts of procedures.

A Point of Good Technique

It is important to add small quantities of extra, pure water to the residue to wash all the dissolved salt through with the filtrate.

Case Study of an Industrial Separation: Gold Mining

In alluvial gold deposits, small nuggets and flakes of gold are mixed with gravel and silt deposited over the ages by rivers. Typically, there might be just a few grams of gold in each tonne of dirt and stones.

D.I.P. = density difference

To separate the gold, the deposits are scooped up by mechanical excavators and processed through a sluice, in which large amounts of water (from a river) are washed over the mixture while it is vibrated, or rotated, down a series of steps or “traps”. Gold is very dense, and tends to settle and collect in the traps, while the lower density stones, sand and silt are washed away.

Useful Product of Separation

Obviously the purpose of this process is to collect gold, which is used for jewellery, in electronics, and is still used as a medium of storing and exchanging wealth.

Issues Associated with Waste Products

This process produces huge quantities of loose silt and gravel which was traditionally discharged back into the rivers with the water. This caused enormous ecological damage due to dirty water, silting up of channels, burying of fish breeding pools and wetlands, and so on.

Modern operations discharge waste into “settling ponds”, where silt collects, allowing only clean water to return to the rivers. Eventually the collected waste is used to refill the excavation sites, and the original environment is helped to regenerate.
Gravimetric Analysis

To separate the parts of a mixture is one thing, but very often in industry or science it is important to measure the quantities or percentages of each fraction.

Examples of where this might be important:
- Measuring the amount of a mineral within an ore deposit to determine if it is economically worth mining it.
- Measuring quantities of pollutant chemicals in effluent, or in water or air.
- To check that manufacturers' claims are correct regarding the chemical composition (e.g. fat or salt content) of food.

Gravimetric Analysis involves separating the parts of a mixture and accurately measuring the masses along the way, so that you can calculate the composition of the mixture.

Practical Work...

A Simple Gravimetric Analysis

You may have carried out a practical exercise similar to the following:

If you were given a solid mixture of sand and salt, how could you determine the percentage of each in the mixture?

Outline of Procedure

1. Weigh a sample of the mixture.
2. Add pure water & stir well. (Salt dissolves, sand doesn't)
3. FILTER to collect the sand.
4. DRY the residue and weigh accurately. (Subtract the mass of the filter paper)
5. EVAPORATE the water from the filtrate until completely dry.
6. Weigh the dried salt (subtract mass of basin)

Sample Results

Mass of Sample = 3.45 g
Mass of Sand = 1.27 g
Mass of Salt = 2.08 g

Analysis of Results

% Sand in sample = \( \frac{\text{mass of sand}}{\text{mass of sample}} \times 100 \)
= \( \frac{1.27}{3.45} \times 100 \)
= 36.8%

% Salt in sample = \( \frac{\text{mass of salt}}{\text{mass of sample}} \times 100 \)
= \( \frac{2.08}{3.45} \times 100 \)
= 60.3%

Notes:
1. These percentages add to only 97.1%, so there must have been some other substance(s) present, or this represents the experimental error. (Possibly there was moisture in the mixture which doesn't get accounted for. Need to dry the mixture sample thoroughly, before starting.)
2. It is appropriate to round-off the final answers to 3 significant figures as shown, since that matches the precision of the experimental measurements.

Some Points of Good Technique

- Dry the filter paper in the oven and weigh it accurately first!
- Don't forget to wash the residue with small amounts of extra pure water, to wash all salt through.
- For maximum accuracy, you should weight it, dry it more and re-weigh. Repeat, until the mass does not change; then you know it's fully dried.
- Dry the evaporating basin in the oven and weigh it accurately first!
- Heat gently near the end. A major source of error is when rapid heating causes “spattering” of salt, so you end up losing some.
- For maximum accuracy, you should weight it, dry it more and re-weigh. Repeat, until the mass does not change; then you know it's fully dried.
Worksheet 1  Mixtures & Separations

Fill in the blank spaces

Elements are a).................. substances composed of b)....................................... of atom. They c).................. be separated into any simpler substances by either d)................................. nor e)......................... are f)................. substances which contain 2 or more types of atoms, which are g).......................... bonded together in a h)................. ratio. They cannot be separated by any i)............................... process, but can be chemically separated into the j)........................... they contain.

Mixtures are k)............................... substances which may contain various l)......................... and m)............................... to each other. The proportions of each part of the mixture may n)............................... enormously.

The “Lithosphere” is the o)............................... part of the Earth. It is mostly made of rocks, which are p)............................... of minerals.

The q)............................... is the liquid part of the Earth. It is a mixture of r)........................... and various dissolved s)................................... and t)........................... notably t)............................... The Atmosphere is a mixture of u)............................, the most abundant being v)........................ and w)............................... Living things are mixtures of (mostly) w)........................ and many complex x)............................... such as y)............................ and z)............................... Every mixture contains different parts, each with different z)............................... This makes it fairly easy to a)................................. the "fractions" by simple ab)................................. processes such as ac)................................., ad)................................. and ae)................................. Analysis is the method of finding the composition of a mixture, by separating a mixture and ae)................................. the fractions accurately as they are collected.

Worksheet 2 Practice Problems

1. For each of the following mixtures, suggest a simple way to collect the specified fraction(s) in the laboratory.
   a) Collect pure water from a copper sulfate solution.
   b) Collect clear water from muddy water.
   c) Collect copper oxide (insoluble) from a water suspension.
   d) Collect solid nickel chloride from a water solution.
   e) A can of lawn mower petrol has accidentally got some water in it... this could damage the engine. How to remove the water? (These liquids are immiscible)

2. Fred has accidentally mixed flour (insoluble) and icing sugar (soluble) together.
   a) Use a simple flow chart (answer on reverse) to describe a laboratory procedure to separate them again.
   b) Which simpler procedure might have been possible if the sugar had been coarse-grained?

3. (Answer on reverse, showing working)
   A dry mixture of soluble potassium sulfate and insoluble manganese dioxide was analysed gravimetrically as follows:
   A weighed sample was thoroughly stirred into pure water, then filtered through a pre-weighed filter paper. The collected residue was oven dried and weighed. Meanwhile, the filtrate was boiled in a pre-weighed evaporating basin until a dry solid formed, then weighed.

   Results:
   Mass of mixture sample = 4.96g
   Mass of filter paper = 0.16g
   Mass or paper + dried residue = 3.04g
   Mass of evap.basin = 28.62g
   Mass of basin + dry solid = 30.70g

   a) Name the substance collected in the filter paper.
   b) Calculate the mass of this substance collected.
   c) Calculate the % of this substance in the mixture.
   d) Name the substance collected in the evap.basin.
   e) Calculate the mass of this substance collected.
   f) Calculate the % of this substance in the mixture.
   g) What evidence is there that this analysis may be quite accurate?
   h) Describe one technique, not mentioned in the outline above, which might have been done by the experimenter to help ensure accuracy.
Worksheet 3  Test Questions section 1

Multiple Choice

1. The diagram shows the particles within a substance.

Which of the following is the best description of this substance?

A. a pure mixture of 2 elements.
B. a pure compound of 2 elements.
C. an impure mixture of 2 elements.
D. an impure compound of 2 elements.

2. The Earth's atmosphere is predominantly:
A. mixture of elements.
B. a mixture of compounds.
C. a compound of oxygen and nitrogen.
D. unbonded atoms.

The following information refers to Q3 & Q4.

A dry mixture of pebbles, sand and salt was separated as follows:
Step 1: Dry mix was shaken in a sieve
Step 2: The material that passed through the sieve was stirred into water.
Step 3: The water mixture was filtered.
Step 4: Part of the filtrate was evaporated
Step 5: The remainder of the filtrate was distilled.

3. The material collected at Step 4 would have been:
A. water only.
B. sand only.
C. a mixture of sand & salt.
D. salt only.

4. The "difference in properties" which allows a separation to occur at step 3 and at step 4, respectively, is:
A. particle size and boiling point.
B. solubility and melting point.
C. melting point and boiling point.
D. particle size and melting point.

Longer Response Questions

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate. Answer on reverse if insufficient space.

5. (4 marks)
You have been given a mixture of potassium chloride (which is highly soluble in water) and insoluble copper(II) oxide. Your task is to use simple laboratory procedures to prepare pure, dry samples of each chemical.

Construct a flow chart of the procedure you would use.

6. (8 marks)
A soil sample was subjected to gravimetric analysis as follows:
Step 1: An evaporating dish was weighed accurately. mass of basin = 42.85g
Step 2: The soil sample was placed in it and weighed. mass soil+basin = 54.27g
Step 3: Then placed in oven at 80°C until mass was constant. mass after drying = 52.66g
Step 4: Then into oven at extremely high temperature. (this burns away all the organic (plant) matter, leaving only the minerals.) Cooled, re-weighed. final mass = 46.72g

a) Calculate the mass of:
i) the soil sample.
ii) the water in the sample.
iii) the organic matter in the sample.
iv) the minerals in the sample.
b) Showing working, calculate the percentage composition of the soil sample.
c) Which step in the analysis involved a chemical change?
d) Why was it important, in Step 3, for the dish to be left in the oven until the mass was constant?
2. THE ELEMENTS

Elements in Nature?
In the billions of years since the Earth formed, most atoms on Earth have chemically reacted with each other to form compounds. That’s why most of the Earth is a mixture of compounds, and with few uncombined elements.

However, there are a few notable exceptions. Some elements have such low chemical reactivity (i.e. they tend not to react with other atoms) that they are found uncombined.

Examples:
- Gold... is a very low activity metal, found in very small amounts in the Lithosphere.
- The “Inert Gases” are a group of elements which do not chemically react at all. They do not form compounds and are always found as single atoms. Being gases, they are mainly in the atmosphere. The most common is Argon which makes up about 0.9% of the air.
- Nitrogen (N₂) gas is an element which makes up about 78% of air. Nitrogen atoms are highly reactive, but when 2 of them join to form diatomic (2-atom) molecules of N₂, the molecules are very unreactive.
- Oxygen (O₂) gas makes up about 21% of the air. O₂ is chemically active, and should all be combined into compounds. So why isn’t it? Simple... plants constantly produce oxygen during photosynthesis. If there was no life on Earth, there would not be any elemental oxygen... it would all be combined into compounds.

Classifying the Elements
There are about 100 different elements, although many are quite rare. Over 99% of the Earth is made up of only a dozen of the most common elements.

Each element has its own type of atom, and its own unique set of properties. However, most elements fall into just 2 general categories...

**METALS**

- Shiny
- Most hard solids
- High conductivity (of electricity)
- Malleable (can be rolled into sheets)
- Ductile (can be pulled into wires)

**NON-METALS**

- Dull (most)
- Some solids, many gases
- Low (except carbon)
- Brittle... shatter
- Brittle... snap

The Semi-Metals (or “Metalloids”)
There is also a small group of elements which have properties that are “in-between” and do not fit clearly into the metal or non-metal classification. This group includes Silicon and Germanium which have properties as follows:

- Shiny appearance, but glass-like rather than metallic.
- Hard solids at 25°C (i.e. high melting point)
- Semi-conductors of electricity (in-between)
- Brittle (non-malleable, non-ductile)

Because their properties are a mixture of those of the metals and non-metals (or in-between), the “Semi-Metals” are usually considered as a small, separate group.

Position of Metals, Non-Metals & Semi-Metals on the Periodic Table

**Metals**

**Non-Metals**

**Semi-Metals**

Hydrogen does not easily fit this scheme. Physically, it has properties like a non-metal, but chemically it often acts like a metal. It is usually shown detached from the table, as above.

These metals actually belong in the table where shown, but are usually detached so the table fits a page easily.
What Determines the State?
You need to understand that whether a substance is solid, liquid or gas is determined by its melting point (m.p.) and boiling point (b.p.).

For example, consider these:

<table>
<thead>
<tr>
<th>Element</th>
<th>m.p.(°C)</th>
<th>b.p.(°C)</th>
<th>State at 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>1535</td>
<td>3000</td>
<td>solid</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>-39</td>
<td>357</td>
<td>liquid</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>-219</td>
<td>-183</td>
<td>gas</td>
</tr>
</tbody>
</table>

Changing the pressure changes the m.p. and b.p., so that's why we specify “normal atmospheric pressure” as well as 25°C as being “normal conditions”. In fact, 25°C and normal (average) atmospheric pressure is known as “Standard Laboratory Conditions” (SLC) and is the set of conditions under which chemical measurements are usually made and formally declared.

A Note about the Gases
On the Periodic Table, the extreme right-hand column contains the “Inert Gas” group of elements. This group do not react chemically and so they exist as single atoms. Therefore, you can just use their chemical symbols as shown. e.g. Helium (He), Argon (Ar), etc.

**ALL OTHER GASEOUS ELEMENTS**
always bond together in pairs, forming “diatomic molecules”. Therefore, when dealing with these in their pure element form, you must use formulas as follows:

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Symbol</th>
<th>Pure Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>H₂(g)</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>N₂(g)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>O₂(g)</td>
</tr>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>F₂(g)</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>Cl₂(g)</td>
</tr>
</tbody>
</table>

The Properties of Elements Determine Their Uses
You need to realise that we make use of very few elements in their pure form.

When we do use an element, its usage is related to its properties.

**Metal Examples**
Metal usefulness is based on physical properties.

- Copper is used for electrical wiring, because of its good electrical conductivity, and because it is very ductile (can easily be drawn out into wire).
- Iron (esp. in the form of steel) is used to construct tools, buildings, bridges, vehicles, etc, because of its strength. Its malleability and ductility allow forming into many shapes.
- Aluminium has the same advantages of steel (strong, malleable & ductile) with the added advantage of light weight & corrosion resistance.

**Non-Metal Examples**
Usefulness is based on chemical properties.

- Argon is used to fill light bulbs, and in welding, because it will not react chemically, and so shields metals from corroding while red hot.
- Chlorine is used in industry as a bleach (paper making) and as a disinfectant (swimming pools) because it is chemically very active.
- Oxygen is used in medicine because its chemistry is vital for respiration. In an oxy-acetylene torch, oxygen’s chemical involvement in combustion produces a hot flame.
Worksheet 4  The Elements
Fill in the blank spaces

The Earth is mostly composed of mixtures of a)........................., with very few uncombined b)................... This is because over the billions of years since the Earth formed most atoms have c).......................... with each other, to form d).................... Only a few elements occur e).......................... in nature. Generally these are elements which have low f).......................... such as g).......................... (metal) and “inert gases” such as h).......................... A notable exception is i).......................... which makes up 21% of the atmosphere. It is actually quite j).........................., and would not exist in an uncombined state except that k)..........................

There are about l)............. elements, each with its own unique m)......................... However, most elements can be classified as either n).......................... or o)...................... according to a few simple physical properties. The general differences can be summarized as:

n).......................... (yes or no?)
o)............. Shiny appearance? p)............... q)............. malleable? r)............... s)............. conduct electricity well? t)............... u)............. ductile? v)............... “Malleable” means w).......................... “Ductile” means x)..........................

However, not all elements fit this classification. A few, such as y).......................... and z).......................... have “in-between” properties and considered as a 3rd separate group called the “z).........................”

One element, aa).......................... doesn’t fit easily into any of this. Its physical properties are like a ab).........................., but chemically it often behaves like a ac)..........................

On the Periodic Table, the right-hand corner is where the ad).......................... are located. Over 3/4 of the table, on the ae).......................... side is the af).......................... The small ag).......................... group are found in between.

That weirdo, ah).......................... is usually detached from the table at the top-left corner.

The vast majority of elements are ai).......................... at 25°C and normal atmospheric pressure. (These conditions are known as “aj)..........................”)

Only 2 elements are liquid: ak).......................... and ..........................

The rest are gases, including the “al)..........................” gases located in the am).......................... column of the Periodic Table. These exist as single atoms, but all other gaseous elements, such as an).........................., exist as “ao)..........................” molecules. For these you must use a formula such as ap).......................... to show this.

The usage of an element is always related to its properties. For example, Copper is used for aq).......................... because of its ar).......................... and .......................... Argon is used in light bulbs and in welding, because of its as).......................... .......................... prevents red-hot metals from at)..........................

Student Name..........................

When completed, worksheets become section summaries
Worksheet 5  The Elements - Practice Questions & Problems

1. Rubidium (Rb) is located in the left column, and Neon (Ne) in the right-hand column of the Periodic Table.
   a) One is always found in an uncombined, elemental state, the other never is. Predict which is which, and explain why.

   b) For each of these elements, predict its properties:
   i) general appearance and state at SLC.
   ii) electrical conductivity.
   iii) malleability and ductility, in the solid state.

2. From the following data of m.p., b.p. and electrical conductivity for some elements, predict
   a) their physical state at SLC,
   b) whether each is a metal or non-metal.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>m.p. (°C)</th>
<th>b.p. (°C)</th>
<th>Elect.Cond</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>119</td>
<td>445</td>
<td>poor</td>
</tr>
<tr>
<td>Q</td>
<td>1769</td>
<td>3825</td>
<td>excellent</td>
</tr>
<tr>
<td>R</td>
<td>-7</td>
<td>58</td>
<td>poor</td>
</tr>
<tr>
<td>S</td>
<td>30</td>
<td>2400</td>
<td>v. good</td>
</tr>
<tr>
<td>T</td>
<td>-219</td>
<td>-183</td>
<td>poor</td>
</tr>
</tbody>
</table>

3. For each of the following elements, list the properties which make it suitable for the given use. (You may need to do a little research)
   a) Gold, used in jewellery.
   b) Silicon, used to make computer “chips”.
   c) Lead, used in fishing sinkers.
   d) Helium, used in air-ships and party balloons. (Hydrogen’s better, but not as safe. Why?)
   e) Tungsten, a metal used as the filament in light bulbs.

Worksheet 6  Test Questions  Section 2

Multiple Choice

1. The elements which are found uncombined in nature are:
   A. mostly metals from the left of the Periodic Table.
   B. mainly semi-metals such as silicon.
   C. mostly elements of low chemical activity.
   D. mainly non-metals which need to gain electrons.

2. An element is described as: “solid at SLC, with a shiny appearance. It is hard and brittle and conducts electricity slightly.” This element is probably a member of the:
   A. metals
   B. semi-metals
   C. non-metals
   D. inert gases

Longer Response Questions

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate.
Answer on reverse if insufficient space.

3. (4 marks)
   a) Name an element, other than oxygen, which can be found naturally in an uncombined state on Earth. Also state which “sphere” of the Earth this element is most likely to occur in.
   b) Explain why this element is found uncombined, rather than combined in compounds.
   c) Explain why oxygen is found uncombined. (It makes up approx. 21% of air)

4. (6 marks)
   Answer this entire question by constructing a suitable table.

   You have been given a sample of a pure, solid element.
   a) State 3 simple tests and/or observations you would carry out to classify this substance as a metal or non-metal.
   b) For each test/observation, state the expected result for
      i) a metal
      ii) a non-metal


### Atomic Structure

All atoms have basically the same general structure:

- **In the Nucleus** are Protons & Neutrons.
- **In orbit around the nucleus** are the Electrons.

The atoms of each element are all the same as each other, but different to the atoms of other elements.

How are they different?

The atoms of each element have different numbers of **Protons, Neutrons** and **Electrons**. Examples:

- **Hydrogen**:
  - 1 proton
  - 1 electron
  - 0 neutrons

- **Lithium**:
  - 3 protons
  - 3 electrons
  - 4 neutrons

- **Zinc**:
  - 30 protons
  - 30 electrons
  - 35 neutrons

- **Lead**:
  - 82 protons
  - 82 electrons
  - 125 neutrons

Notice that no matter how many particles there are:

- **No. of Protons = No. of Electrons**

  **THIS IS TRUE FOR ALL ATOMS**

  This number is the **ATOMIC NUMBER**

### The Mass of an Atom

In chemical calculations it is vital to deal with the mass of the substances involved. The atoms of different elements have different masses according to how many protons and neutrons are in the nucleus.

Note that the electrons have such small mass compared to a proton or neutron that, for practical purposes, the electrons can be ignored.

Using the atoms on the left as examples:

<table>
<thead>
<tr>
<th>Atom</th>
<th>No.of Protons</th>
<th>No.of Neutrons</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lithium</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Zinc</td>
<td>30</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>Lead</td>
<td>82</td>
<td>125</td>
<td>207</td>
</tr>
</tbody>
</table>

These “Mass Numbers” are the relative masses of these atoms... obviously one atom has a very small value when measured in grams. (1 hydrogen atom $\cong 1.7 \times 10^{-27}$ kg).

Mass numbers are always whole numbers, since there must be whole numbers of protons and neutrons in each atom.

On the Periodic Table each element is detailed something like this:

- **Atomic Number**: Equal to the number of electrons and the number of protons in each atom
- **Chemical Symbol**: Element Name
- **"Atomic Weight"**: NOT the “Mass Number" (For one thing it is usually NOT a whole number. This will be explained fully in a later topic.)

However, for simplicity (K.I.S.S. Principle) you may **round-off this number to the nearest integer**, and take this as the Mass Number for atoms of this element.

In this example, Argon atoms have:

- **Atomic Number = 18**
- 18 protons and 18 electrons
- **Mass Number $\cong 40$** = sum (protons + neutrons)
- must have 22 neutrons.
**Electron Energy Levels**

Although the mass of an atom is all about protons and neutrons in the nucleus, chemical reactions and the forming of compounds is all about electrons.

The electrons are not just whizzing around the nucleus in any old orbits... they are precisely organised into tightly defined “energy levels”, or “shells”. The 1st energy level, or “inner shell”, can only hold 2 electrons.

The 2nd energy level can hold a maximum of 8 electrons.

Beyond here, things get more complicated, but the thing to know is that, beyond the first energy level, the “magic number” is 8... if an atom has exactly 8 electrons in its outermost energy level it achieves the best possible energy state that an atom can have.

**ALL ATOMS WILL TRY TO ACHIEVE THE BEST POSSIBLE ENERGY STATE, BY HAVING 8 ELECTRONS IN THE OUTER SHELL.**

**Electron Configuration**

Electron Configuration is simply a description of how the electrons are arranged within the energy levels of an atom.

For example, atoms of Aluminium have a total of 13 electrons. They would be arranged as shown:

Firstly, the 1st shell fills with 2 electrons.

Then the 2nd shell fills with 8.

There are 3 left, which must go into the 3rd shell.

The Electron Configuration is: **2.8.3**

---

**Formation of Ions**

Every atom can achieve its best possible energy state if its outer shell of electrons contains 8 electrons. (or 2 electrons for the 1st shell)

Most atoms do not have the correct number of electrons for this to occur automatically. However, atoms will readily lose or gain electrons in order to achieve this. An atom which has gained or lost electron(s) is called an ION.

**Example 1: Formation of a Fluoride Ion**

An atom of Fluorine has 9 protons (+) 10 neutrons 9 electrons (−)

Electron Configuration = 2.7

If this atom gains an electron it becomes a Fluoride ion (F−). (note change in name)

Electron Configuration = 2.8

It still has 9 protons (+ ve charge) but now has 10 electrons (− ve). Overall, it now has a negative charge.

OUTER SHELL IS FULL = BEST ENERGY STATE

**Example 2: Formation of a Sodium Ion**

An atom of Sodium has 11 protons (+) 12 neutrons 11 electrons (−)

Electron Configuration = 2.8.1

If this atom loses an electron it becomes a Sodium ion (Na+/). (note NO change in name)

Electron Configuration = 2.8

It still has 11 protons (+ ve charge) but now has 10 electrons (− ve). Overall, it now has a positive charge.

OUTER SHELL IS FULL = BEST ENERGY STATE

(It has lost the 3rd shell entirely, so the full 2nd shell is now its outermost orbit)
If a sodium atom came near to a fluorine atom, it should be obvious what will happen...

Electron transferred

[Diagram of Na atom transferring electron to F atom]

Both atoms become ions...

Na⁺ F⁻

Opposite electrical charges attract, so these ions must now stick together... this is the COMPOUND Sodium Fluoride (NaF)

**Ionic Lattices**

In fact, of course, you don’t just get 1 sodium atom reacting with 1 fluorine atom. In real situations there are billions of atoms. After all the ions have formed, each positive sodium ion is attracted to every nearby fluoride ion, and vice versa.

The result is that you don’t just get pairs of opposite ions, but huge, 3-dimensional lattices of +ve and -ve ions.

The chemical formula for any ionic compound is an “empirical formula”... it shows only the ratio between the ions, not the actual numbers that are present. In ionic compounds there are no discrete molecules. In the solid state an ionic compound forms a crystal, which is a huge array of billions of ions in a lattice.

Another example...

What if it was magnesium atoms that reacted with fluorine?

Magnesium atoms have 12 electrons, so they are arranged.

2.8.2

To achieve a full outer shell it must lose 2 electrons

[Diagram of Mg atom losing 2 electrons]

Magnesium ion Mg²⁺

Two fluoride ions are formed, each one with an extra electron... F⁻

The formula for magnesium fluoride is MgF₂ because the ratio between the ions is 1:2

**Formation of Ionic Compounds**

Ionic Compounds
form when atoms gain, or lose, electrons creating ions.

METALS always lose electrons forming NEGATIVE ions. The name of the atom changes to end -IDE, for the ion.

NON-METALS always gain electrons forming POSITIVE ions.

The chemical formula shows the ratio between ions not the actual numbers involved. (“Empirical Formula”)
**Valency**

The “valency” of a chemical species refers to its “combining ratio” with other species. For the simple ions, the charge on the ion (including sign) is the same as valency. If you know (or can figure out by the patterns) the valency of species, you can predict the chemical formula of the compound. Study these examples:

- **Potassium** (group 1 metal) Valency = +1
  - Combined with
  - **Sulfur** (group 6 non-metal) Valency = -2
    - Formula for Compound: $K_2S$

You must have same amount of (+) and (-) electric charge, in every case.

- **Aluminium** Valency = +3
  - Combined with
  - **Chlorine** Valency = -1
    - Formula for Compound: $AlCl_3$

**Non-Metals** gain electrons to fill the outer shell to 8 electrons. Ions are negative.

**Main Group Numbers** correspond to the number of electrons in the outer shell.

**Group 1 Metals** all have 1 electron in outer shell, and lose it.

**Group 2 Metals** all have 2 electrons in outer shell, and lose them.

**Group 3 Metals** all have 3 electrons in outer shell, and lose them.

**Semi-Metals** do not normally form ions.

**Group 8** all have FULL outer shell. Do NOT form ions. Do NOT react chemically. INERT GASES

Chemistry contains many details to learn, but there are nearly always patterns involved. Learn the few, simple patterns, rather than memorising masses of detail.
More Than Just Simple Ions
As much as we’d like to keep it really simple, there are a few complications with ions that you must know about.

Multi-Valency Metals
Some of the metals belonging to the “Transition Metal Block” of the Periodic Table can form ions in more than one way.

For example, atoms of Iron (Fe) most commonly have 3 electrons in the outermost electron shell. To form ions, the atoms lose these 3 electrons and thereby form Fe³⁺ ions.

However, sometimes the iron atom can “shuffle” its electrons between its outer shell (the 4th energy level) and the incomplete 3rd shell in such a way that it has only 2 electrons in the outer shell. In this situation the atoms will lose only 2 electrons to form an ion... Fe²⁺ ions form.

![Diagram of iron ions](image)

Polyatomic Ions
As well as the simple ions which form when individual atoms gain or lose electrons, there are a number of more complicated ionic species you must know about because they are very common, and cannot be avoided.

These are the “polyatomic” ions (poly=many) which are composed of a group of atoms which have an ionic charge on the whole group, due to the gain or loss of electron(s). The entire group acts chemically just like a single, simple ion, and can join with other ions forming compounds and ionic crystal lattices.

One common example is the “sulfate” ion, SO₄²⁻.

Somewhere within this group of 5 atoms there are 2 extra electrons, in excess of the total protons these atoms contain. The ion has a valency of -2.

Other examples are:
- Nitrate (NO₃⁻) ion (valency -1)
- Hydroxide (OH⁻) ion (valency -1)
- Carbonate (CO₃²⁻) ion (valency -2)

Most of the common polyatomic ions have (-ve) charge and valency. Only one common example has a (+ve) valency like a metal. This is the ammonium ion (NH₄⁺).

This group consists of a nitrogen atom and 4 hydrogens. Compared to the total protons, this group has one less electron so it acts as an ion with a valency of +1.

Working out a chemical formula is done exactly as before, except names do NOT change and brackets are needed when 2 or more polyatomic groups are involved.

Example:

![Diagram of polyatomic ions](image)
### A Summary: Formulas & Names for Ionic Compounds

**Formulas**
1. Determine the (+ve) and (-ve) ion involved.
2. Work out the **minimum** number of each ion which gives equal amounts of (+ve) & (-ve) charge. Example: you need 3x(-1) to match (+3)
3. Write symbol for the (+ve) ion first.
4. Use sub-scripts to show ratio of ions. Number “1” is not written. e.g. FeBr$_2$
5. If a polyatomic ion is involved:
   - brackets MUST be used if more than one polyatomic ion. e.g. Mg(NO$_3$)$_2$
   - bracket must NOT be used if only one polyatomic ion. e.g. NaNO$_3$

Note: The symbols for an ion must contain electric charge, written as a super-script. e.g. Fe$^{3+}$

The formula for a compound must NOT contain electric charges.

---

**Naming Compounds of Simple Ions**
1. Name the (+ve) ion (metal) first. Its name is always the same as element name.
2. Add the name of the (-ve) ion (non-metal), but altered to end in -IDE. e.g. oxygen becomes “oxide” phosphorus becomes “phosphide”

**Naming Compounds of Metals with Multiple Valencies**
As above, but (in brackets) write the Roman numeral corresponding to the valency number of the metal ion.

- e.g. FeBr$_2$ is “iron(II) bromide” (Fe$^{2+}$ ion) [speak “iron-2-bromide”]
- FeBr$_3$ is “iron(III) bromide” (Fe$^{3+}$ ion) [speak “iron-3-bromide”]

**Naming Compounds With Polyatomic Ions**
1. Name the (+ve) ion first.
2. Add the name of the (-ve) ion. The name of a polyatomic ion does NOT change.

**Examples**
- Fe(NO$_3$)$_2$ is “iron(II) nitrate”
- (NH$_4$)$_2$SO$_4$ is “ammonium sulfate”

---

A Table Summarising Symbols & Valencies is at the end of these notes
A “Lewis Formula” for a chemical species uses dots to represent the outer shell electrons of each atom. The rest of the atom is represented by the chemical symbol for that element.

**Examples:**

- Lithium atom, Li
  - Lewis Formulas: Only the outer shell electron shown
  - Li
- Beryllium atom, Be
  - Lewis Formulas: Add extra electrons in a “box pattern” around the atom
  - Be
- Boron atom, B
  - Lewis Formulas: For Boron atom, B
  - B
- Carbon atom, C
  - Lewis Formulas: For Carbon atom, C
  - C
- Nitrogen atom, N
  - Lewis Formulas: For Nitrogen atom, N
  - N
- Oxygen atom, O
  - Lewis Formulas: For Oxygen atom, O
  - O
- Fluorine atom, F
  - Lewis Formulas: For Fluorine atom, F
  - F
- Neon atom, Ne
  - Lewis Formulas: Outer shell is complete with 8 electrons in 4 pairs.
  - Ne

**Lewis Formulas for Ions**

When a non-metal gains 1 or more electrons to form a negative ion, the extras are shown in a different style, for example:

- Fluorine ion, F⁻: Extra electron gained
  - F⁻

An oxygen atom gains 2 electrons to form the oxide ion:

- Oxygen atom, O
  - Lewis Formulas: An oxygen atom gains 2 electrons to form the oxide ion:
  - O²⁻ + 2 e⁻ → [O²⁻]⁻²⁻

A Lewis Formula is not very useful for showing simple positive ions, but for the record...

- Sodium atom, Na
  - Lewis Formulas: Sodium atom, Na
  - Na⁺

**Lewis Formulas... “Electron-Dot Diagrams”**

Before going any further you need to learn another way to represent atoms, ions and molecules and their electrons.
Here is another example, but more complicated. It demonstrates the importance of balancing chemical equations:

**Formation of an Oxide Ion (from an atom)**

\[
\text{O} + 2e^- \rightarrow \text{O}^{2-}
\]

**Formation of Oxide Ions (from an O_2 molecule)**

\[
\text{O}_2 + 4e^- \rightarrow 2\text{O}^{2-}
\]

Where might the extra electrons have come from? In a chemical reaction, they would normally come from a metal atom which needs to lose electron(s) to achieve its best energy state.

Let’s assume the metal is Lithium:

**Formation of a Lithium Ion**

\[
\text{Li} \rightarrow \text{Li}^{+} + e^-
\]

(Lithium atom \(\rightarrow\) Lithium ion + electron
(Since Li atoms have 1 electron in their outer shell, they must lose it to form the ion with (+1) charge)

However, in a real situation where lithium is reacting with oxygen, each O_2 molecule needs 4 electrons. Therefore, it will take 4 lithium atoms to supply them...

**Previous Equation Multiplied by 4**

\[
4\text{Li} \rightarrow 4\text{Li}^{+} + 4e^-
\]

Now add together the equations together:

**O_2 + 4e^- \rightarrow 4\text{O}^{2-}**

(add these together)

\[
\begin{align*}
4\text{Li} + \text{O}_2 + 4e^- & \rightarrow 4\text{Li}^{+} + 4e^- + \text{O}_2^{2-} \\
\text{There are 4 electrons on both sides, so they cancel out.}
\end{align*}
\]

The correct formula for lithium oxide is \(\text{Li}_2\text{O}\), so this combination of ions is enough to make “2 lots” of ions.

\[
4\text{Li} + \text{O}_2 \rightarrow 2\text{Li}_2\text{O}
\]

This equation is “balanced”... it shows the same number of each atom on both sides of the equation.
Covalent Bonding

The gaining and losing of electrons to form ions is not the only way for atoms to achieve a full outer shell, and the best possible energy state that goes with that. If atoms have 4, 5, 6 or 7 electrons in their outer orbit, they can also achieve a full outer shell by sharing electrons. This is called “covalent bonding”.

Not only do many compounds form this way, but many elements exist as 2 or more atoms covalently bonded together.

Example: the element Fluorine, F₂

Two atoms of fluorine will always bond together by sharing a pair of electrons

Each atom can count the shared electron pair as part of its outer shell, making a total of 8.

A covalent bond is always the sharing of a pair of electrons

These atoms must remain tightly attached to each other in order to share the electrons... they are bonded together very strongly, forming a molecule of F₂.

Atoms of all the non-metals and the semi-metals, (except Group 8 the “Inert Gases”) bond together covalently when in the pure elemental state:

Elements

Group 7
Nitrogen, Oxygen
Sulfur
Phosphorus
Carbon, Silicon and others

Molecules

F₂ Cl₂ Br₂ I₂
N₂ O₂
S₈
P₄
covalent lattices

Hydrogen... the Weirdo

Hydrogen is the smallest atom of all, with only 1 electron.

Sometimes hydrogen loses this electron, forming a hydrogen ion H⁺. When this happens it is behaving chemically like a metal in Group 1.

However, hydrogen atoms can also share electrons covalently. Elemental hydrogen is always H₂ molecules:

Don’t forget that the 1st orbit holds a maximum of 2 electrons, so both atoms achieve a full outer shell by sharing.

Hydrogen, and all the non-metals and semi-metals, not only bond with atoms of the same type in the the element state, but will share electrons with different atoms to form covalent compounds.

A Note About “Molecules”

You need to be aware of the precise definition of the word “molecule”.

Definition: A molecule is the smallest particle of a substance that can have a separate existence, and can move around independently of other particles.

Examples:
Inert gases have “molecules” of just one atom.
Hydrogen has “diatomic” molecules (di=2)

Lattice structures (ionic or covalent) are not molecules.

A Covalent Lattice Element; Silicon

The shape of the lattice is not square as like this 2-dimentional diagram.
In 3-dimensions, the atoms surround each other in a pyramid pattern, called a “tetrahedron”.

Pure silicon forms hard crystals made of billions of atoms covalently bonded in a lattice.
Covalent Compounds

Many common and important substances are formed by covalent bonding between atoms of 2 or more different elements.

### Understanding Covalent Compounds with Lewis Formulas

Everyone knows that water is H₂O. You need to understand exactly how this compound forms.

<table>
<thead>
<tr>
<th>H (1 Hydrogen atom)</th>
<th>H (1 Oxygen atom)</th>
<th>Lewis formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>H O</td>
</tr>
<tr>
<td>2 H (2 Hydrogen atoms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

Look carefully at the Lewis formula above to see how all the atoms involved have achieved full outer shells of electrons by sharing pairs in covalent bonds.

Another well known covalent molecular compound is carbon dioxide CO₂.

<table>
<thead>
<tr>
<th>Carbon atom (1 Carbon atom)</th>
<th>2 Oxygen atoms (2 Oxygen atoms)</th>
<th>CO₂ molecule</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>O:</td>
<td>O=C=O</td>
</tr>
</tbody>
</table>

The CO₂ molecule contains double covalent bonds. These involve atoms sharing 2 pairs of electrons. The structural formula for this would be:

\[
\text{O=C=O}
\]

It's also possible to have a triple covalent bond:

\[
\text{N≡N}
\]

as well as other compounds.

### Predicting Formulas for Covalent Compounds

The formulas of the examples at left are quite predictable if you know how many electrons are in each atom's outer shell, and understand how sharing electrons can achieve a full outer shell.

However, not all covalent compounds are so predictable, because the "rule" about achieving a full shell of 8 electrons is not always followed with covalent bonding.

(It is always followed with ionic bonding.)

For example, if oxygen & sulfur combine covalently, the compound formed is sulfur dioxide (SO₂).

\[
\text{O:S:O}
\]

Study this Lewis Formula and you'll see that the "rule of 8 electrons" has NOT been followed for the sulfur atom!
Naming Covalent Compounds
The first problem you face here is that (for historical reasons) many covalent compounds have “common names” that follow no rule or system, and must be learnt by heart.

Common Names
To keep this as simple as possible (K.I.S.S. Principle!) start with just these three common, important compounds:

Water \( \text{H}_2\text{O} \)

Ammonia \( \text{NH}_3 \)
(Not to be confused with the ammonium polyatomic ion \( \text{NH}_4^+ \))

Methane \( \text{CH}_4 \)
(This is the simplest of a huge range of covalent compounds of carbon... more in later topics)

More Than One Compound
The second problem is that, quite often, there is more than one possible compound formed from the same elements in a covalent compound. Some examples:

<table>
<thead>
<tr>
<th>Elements</th>
<th>Different Compounds Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur &amp; oxygen</td>
<td>( \text{SO}_2 ) and ( \text{SO}_3 )</td>
</tr>
<tr>
<td>Carbon &amp; oxygen</td>
<td>( \text{CO} ) and ( \text{CO}_2 )</td>
</tr>
</tbody>
</table>

To cope with this, a naming system has developed which uses prefixes to state how many atoms of each element are in one molecule.

The Prefixes
1= mono  2= di  3= tri  4= tetra  5= penta  6= hexa

More on Writing Equations
You previously studied examples of equations describing the formation of ions and ionic compounds. The same principles of equation writing apply to the formation of covalent compounds.

If the elements oxygen and hydrogen react with each other, they form the compound water:

Word Equation

\[
\text{Hydrogen + Oxygen} \rightarrow \text{Water}
\]

Symbol Equation

\[
\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}
\]

To write this in chemical symbols, you must recall that both oxygen and hydrogen occur as diatomic molecules.

Balanced Equation

\[
2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O}
\]

How to Name a Simple Covalent Compound From a Molecular Formula

• Name the elements in the order as in the formula.
• Alter the name of the 2nd element to end -IDE.
• Attach a prefix to the front of both names, indicating how many atoms are present in each molecule.
(Important exception: If there is only one atom of the first-named element, do not attach a prefix to it.)

Examples:

\( \text{P}_2\text{O}_5 \) = diposphorus pentoxide
\( \text{SO}_3 \) = sulfur trioxide
\( \text{N}_2\text{S}_3 \) = dinitrogen trisulfide

“Reactants”
(Starting chemicals)

“Product”
Arrow indicates that a change occurred

These elements always occur as molecules of 2 atoms

The formula for water is one you need to memorise

H\(_2\)O\(_2\) is NOT water!
NEVER BALANCE EQUATIONS BY CHANGING A FORMULA

The key is to realise that, since you start with 2 oxygen atoms, you must end up with 2 molecules of water. To do this you must begin with 4 atoms of hydrogen.
(i.e. 2 molecules of \( \text{H}_2 \))
Worksheet 7  Ionic & Covalent Compounds

Fill in the blank spaces

All atoms are composed of 3 types of particles: in the centre of the atom is the a)..................., containing b).................... and ......................... In orbit around this are the c).......................

d).................... have a positive electric charge. Neutrons are e)...................., while f)..................... have a negative electric charge.

The atoms of one element are g)..................... as each other, but differ from atoms of h).............................. in the numbers of i)....................., ..................... and ..................... they contain. In any atom there are always the same number of j)..................... and ..................... This number is called the “k)..............................” and this defines the order of the elements in the l)............................. Table.

The weight or mass of an atom is due to the m)..................... and ..................... (The n)..................... can be ignored because their mass is insignificant) The sum of protons + neutrons is called the “o).............................”

Electrons orbit the nucleus in different p)............................. levels. When an atom’s q)............................. orbit contains r)........... electrons (or 2 electrons in the 1st shell) it achieves maximum stability.

All atoms attempt to achieve this “best energy state” by s)..................... or ..................... electrons to form ions, or by t)............................. electrons. The exception are the elements of Group 8 (the “u)............................. Gases”) which already have complete outer shells.

Generally, metallic elements v)..................... electrons and form w)..................... ions. Non-metals always form x)..................... ions when they y)..................... electrons. Once ions form, the opposite electric charges z)..................... each other, so the ions become “bonded” together. In the solid state, all ionic compounds form aa)..................... lattices of billions of ions.

Generally, the position of an element in the Periodic Table allows easy prediction of the ab)............................. on its ion. This value (including charge) is also known as the “ac).............................” of the element, and indicates its “combining ratio”.

Metals of the “ad).............................” block are not easily predicted, and many can produce more than one ae).....................

Polyatomic ions are af)............................. of bonded atoms which carry electric charges and act like a single ion.

ag)............................. bonding occurs when atoms ah)............................. electrons to achieve full outer shells, and the best energy state. All the non-metals and the ai)............................. elements will form covalent bonds, except (as usual) the gases of group aj).............................

Many non-metals in their elemental state are made up of covalent ak)............................. of 2 or more atoms joined. Some form covalent al)............................. of billions of atoms.

Covalent compounds form when atoms of different elements bond covalently. A single covalent bond always involves am).............................
3. Formation of Ions
a) The electron configurations for various elements are given. State whether each atom would gain or lose electrons, and how many electrons. Also state the charge on the ion formed.

<table>
<thead>
<tr>
<th>Elect. Configuration</th>
<th>Gain/Lose?</th>
<th>How many?</th>
<th>Ion Charge?</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) 2.8.8.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii) 2.8.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii) 2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iv) 2.8.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v) 2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vi) 2.8.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vii) 2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>viii) 2.8.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) From their electron configurations (left) write the electric charge you would expect on an ion of each of the first 20 elements. (Elements blanked out do not normally form ions)

<table>
<thead>
<tr>
<th>Element</th>
<th>Electron Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>He</td>
</tr>
<tr>
<td>Li</td>
<td>Be</td>
</tr>
<tr>
<td>Be</td>
<td>B</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>N</td>
</tr>
<tr>
<td>N</td>
<td>O</td>
</tr>
<tr>
<td>O</td>
<td>F</td>
</tr>
<tr>
<td>F</td>
<td>Ne</td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
</tr>
<tr>
<td>Mg</td>
<td>Al</td>
</tr>
<tr>
<td>Al</td>
<td>Si</td>
</tr>
<tr>
<td>Si</td>
<td>P</td>
</tr>
<tr>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td>S</td>
<td>Cl</td>
</tr>
<tr>
<td>Cl</td>
<td>Ar</td>
</tr>
<tr>
<td>K</td>
<td>Ca</td>
</tr>
<tr>
<td>Ca</td>
<td></td>
</tr>
</tbody>
</table>

b) Describe the pattern apparent in each vertical column.

c) What pattern is apparent in the vertical columns?
### Worksheet 9  Names & Formulas for Ionic Compounds

**1. Simple Ionic Compounds**
Write the name, and predict the formula, for a compound formed from ions of:

<table>
<thead>
<tr>
<th>a) potassium and chlorine</th>
<th>b) magnesium and sulfur</th>
<th>c) oxygen and lithium</th>
<th>d) bromine and zinc</th>
<th>e) calcium and fluorine</th>
<th>f) iodine and aluminium</th>
<th>g) beryllium and oxygen</th>
<th>h) silver and phosphorus</th>
<th>i) hydrogen and sulfur</th>
<th>j) fluorine and sodium</th>
</tr>
</thead>
</table>

**b) Write the name & formula for the compound of:**

<table>
<thead>
<tr>
<th>i) $\text{Fe}^{2+}$ ion with sulfur</th>
<th>ii) $\text{Pb}^{4+}$ ion with chlorine</th>
<th>iii) $\text{Cu}^+$ ion with oxygen</th>
<th>iv) fluorine with the tin(IV) ion</th>
<th>v) nitrogen and the iron(III) ion</th>
</tr>
</thead>
</table>

**3. Polyatomic Ions**

<table>
<thead>
<tr>
<th>a) Name each compound and write symbols for the two ions present.</th>
<th>b) Write the formula for</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) $\text{MgSO}_4$</td>
<td>i) calcium nitrate</td>
</tr>
<tr>
<td>ii) $\text{ZnCO}_3$</td>
<td>ii) copper(II) hydroxide</td>
</tr>
<tr>
<td>iii) $\text{AgNO}_3$</td>
<td>iii) silver sulfate</td>
</tr>
<tr>
<td>iv) $\text{KOH}$</td>
<td>iv) ammonium bromide</td>
</tr>
<tr>
<td>v) $\text{NH}_4\text{Cl}$</td>
<td>v) lithium carbonate</td>
</tr>
<tr>
<td>vi) $\text{Fe(OH)}_3$</td>
<td>vi) aluminium nitrate</td>
</tr>
</tbody>
</table>

### Worksheet 10  Names & Formulas for Covalent Compounds

**1. Write an appropriate name for:**

<table>
<thead>
<tr>
<th>i) $\text{CH}_4$</th>
<th>ii) $\text{H}_2\text{O}$</th>
<th>iii) $\text{SO}_3$</th>
<th>iv) $\text{N}_2\text{O}_3$</th>
<th>v) $\text{PBr}_5$</th>
<th>vi) $\text{OCl}_2$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Student Name...</th>
<th>2. Write a formula for</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) $\text{CH}_4$</td>
<td>i) sulfur difluoride</td>
</tr>
<tr>
<td>ii) $\text{H}_2\text{O}$</td>
<td>ii) phosphorus tri-iodide</td>
</tr>
<tr>
<td>iii) $\text{SO}_3$</td>
<td>iii) nitrogen monoxide</td>
</tr>
<tr>
<td>iv) $\text{N}_2\text{O}_3$</td>
<td>iv) silicon tetrafluoride</td>
</tr>
<tr>
<td>v) $\text{PBr}_5$</td>
<td>v) diboron trioxide</td>
</tr>
<tr>
<td>vi) $\text{OCl}_2$</td>
<td>vi) ammonia</td>
</tr>
</tbody>
</table>
Worksheet 11  Lewis Formulas

Draw a Lewis Formula for
a) an atom of phosphorus
b) a phosphide ion (P^3-) 
c) an atom of calcium
d) a calcium ion (Ca^{2+})
e) an atom of neon
f) a sulfide ion (S^{2-})
g) the covalent compound PH₃ 
h) the covalent compound OBr₂
i) the covalent compound ammonia, NH₃
j) carbon tetrachloride, CCl₄

Worksheet 12  Chemical Equations

1. Equations for Ion Formation
Write an equation to describe the formation of:
a) a lithium ion from a lithium atom.
b) a bromide ion from a bromine atom.
c) bromide ions from a molecule of Br₂.
d) an aluminium ion from an aluminium atom.
e) a sulfide ion from a sulfur atom
f) Combine equations (a) & (c) to form an equation describing the formation of lithium bromide from its elements.
   (hint: the equations must contain the same number of electrons, so when added the electrons will cancel out. This will require one equation to be multiplied by 2 before adding)
g) Combine equations (a) & (e) to describe the formation of lithium sulfide. (similar hint)

2. Balancing Equations
   a) Balance the following equations.
      Ca + O₂ → CaO
      Ag + Cl₂ → AgCl
      Al + O₂ → Al₂O₃
      C + H₂ → CH₄
      S + O₂ → SO₃

3. Write and Balance
   Write equations in words and in symbols (then balance) to describe the formation of:
i) potassium bromide, from its elements (bromine is Br₂)
ii) copper(II) oxide, from its elements (oxygen is O₂)
iii) nitrogen dioxide, from its elements (both diatomic)
iv) silicon tetrachloride, from its elements.

h) Combine equations (d) & (c) to describe the formation of aluminium bromide.
   (need to multiply one equation x2, the other x3, so they have same number of electrons, to cancel out)

i) Combine equations (d) & (e) to describe the formation of aluminium sulfide. (you figure it out!)
Multiple Choice

1. Atoms of silver contain 47 protons, 47 electrons and 61 neutrons. The Atomic Number and the Mass Number, respectively, would be:
   A. 47 & 94     B. 61 & 108
   C. 47 & 108    D. 47 & 155

2. The electron configuration of a certain element is 2.8.6
   You would expect that this element would:
   A. form ions with charge 2+    B. form ions with charge 2-
   C. be unlikely to form ions   D. form ions with charge 6+

3. Which of the following is a correct formula for an ionic compound?
   A. AlBr₃           B. CaCl₃
   C. MgO₂           D. KSO₄

4. The correct name for the compound CuCO₃ is
   A. copper carbon trioxide
   B. copper carbonate
   C. copper(I) carbonate
   D. copper(II) carbonate

5. Which of the following chemical species (A, B, C or D) has exactly the same electron configuration as a chloride ion?
   A. an atom of argon
   B. a fluoride ion
   C. a sodium ion
   D. an atom of chlorine

6. A “double covalent bond” involves:
   A. the transfer of 2 electrons from one atom to another.
   B. the sharing of an electron between 2 atoms.
   C. the sharing of 2 electrons.
   D. the sharing of 4 electrons.

7. A molecular compound with formula N₂O₄ would be best named as:
   A. dinitrogen 4-oxide
   B. nitrogen(II) tetra-oxide
   C. dinitrogen tetra-oxide
   D. nitrogen tetroxide

8. Which of the following equations shows correctly the formation of ammonia (NH₃) from its elements?
   A. N + H₃ → NH₃
   B. N₂ + H₂ → NH₃
   C. N₂ + 3H₂ → 2 NH₃
   D. N₂ + H₂ → N₂H₂

Longer Response Questions

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate. Answer on reverse if insufficient space.

9. (5 marks)
   Find the element potassium on the Periodic Table, and state:
   a) the number of electrons, protons and neutrons in a potassium atom.
   b) the electron configuration.
   c) what this atom would do to form an ion, and the electric charge on the ion.

10. (10 marks)
   a) Give the correct name for each compound.
       i) CaS
       ii) CaSO₄
       iii) Cu(NO₃)₂
       iv) As₂O₃
       v) (NH₄)₂CO₃
   b) Write the formula for:
       i) silver sulfate
       ii) iron(III) iodide
       iii) germanium dioxide
       iv) aluminium hydroxide
       v) lead(IV) sulfide

11. (5 marks)
   Sketch a Lewis formula for:
       a) an atom of neon
       b) an atom of phosphorus
       c) a chloride ion
       d) an oxygen molecule (O₂)
       e) a water molecule

12. (8 marks)
   Write balanced symbol equations for
       a) formation of a chloride ion from a chlorine atom.
       b) formation of chloride ions from a molecule of Cl₂.
       c) formation of a potassium ion from a potassium atom.
       d) formation of the compound potassium chloride from its elements in their normal state.

13. (5 marks)
   a) Sketch a Lewis Formula for a nitrogen atom.
   b) Nitrogen and chlorine can form a compound NCl₃ by sharing electrons so that every atom achieves an outer shell of 8. Sketch the Lewis Formula for a molecule of NCl₃.
   c) Give the name for this compound.
   d) Sketch a structural formula for the molecule.
The Moving Particle Model of Matter

We have good reason to believe that all substances are composed of tiny particles which are always either vibrating or moving around.

The "particles" are, of course, atoms and molecules. Exactly which particles are present is determined by whether a substance is an element, a compound or a mixture. Regardless of this, however, it is known that the particles are constantly in motion.

As an example, consider the familiar compound water. The "particles" in water are molecules of H₂O.

Liquid Water

The molecules are still very close together; that's why it is difficult to compress a liquid.

The inter-molecular forces are still there, but are unable to hold the molecules in one place; that's why liquids have no shape, but take the shape of the container they're in.

As temperature increases, the molecules move faster and faster. They collide harder and push each other apart. That's why substances expand when heated.

Some molecules always have more energy than the average, and these will move fast enough to escape totally from the liquid surface; we say that some of the liquid has evaporated.

At a certain temperature (called the "boiling point") many molecules begin evaporating, not just at the surface, but within the liquid. This forms bubbles of vapour...

We say the liquid is boiling.

Gaseous Water (Water vapour)

The molecules are now very far apart; that's why gases are easy to compress.

They fly rapidly in all directions so gases always totally fill the container.

The high speed collisions occurring cause gas pressure, which increases as temperature rises, because they get faster and faster.
**Physical Changes**

A physical change occurs when (for example)

- a substance changes state.
  (e.g. melts, freezes, condenses, etc)
- objects change their shape or size.
  (e.g. a rock is broken into smaller pieces)
- one substance dissolves in another.
  (e.g. salt dissolves in water)
- the parts of a mixture are separated.
  (e.g. during filtration, or distillation, etc)

In all of these physical changes, no new substances are created. In terms of the particles present, nothing has really changed.

For example, if you melt some ice and then boil the water to vapour, the “particles” within it are still the same H₂O molecules... there’s nothing new been formed.

Imagine the particles within a mixture:

Now you might filter the mixture so that it is separated into 2 fractions,

but notice that these are still exactly the same particles.

The 2 different kinds were mixed together, and now are separated, but they are still exactly the same particles.

**Physical Changes do NOT Create any New Substances, or any New Particles**

---

**Chemical Changes**

A chemical change occurs when (for example)

- a substance burns. (“combustion”)
  (e.g. magnesium burns in air)
- Two elements combine to form a compound
  (e.g. sodium + chlorine $\rightarrow$ sodium chloride)
- A new substance forms
  (e.g. when 2 solutions are mixed and a precipitate forms)
- When a substance “disappears”
  (e.g. when zinc metal is “eaten away” by acid)

... and many other examples.

In all these chemical changes new substances and new particles are formed. The atoms present are still the same, but they have been rearranged into new molecules and/or ion combinations.

For example, consider what happens if an active metal such as sodium, is dropped into water.

**Chemical Changes**

Create New Substances, by Rearranging the Same Atoms into New Combinations of Molecules and/or Ions

$$2 \text{Na} + 2 \text{H}_2\text{O} \rightarrow \text{H}_2 + 2 \text{NaOH}$$
Boiling Water Compared with Electrolysis of Water

The syllabus specifies that you study and compare these two processes. You will have done simple practical work in the laboratory, as follows:

**Boiling Water**

![Image of boiling water](image1)

**Similarities**

- Both these processes
  - Start with the same substance... water
  - add energy to the water... heat in one case, electricity in the other
  - In both cases, bubbles of gas are formed in the liquid

**Differences**

Boiling Water results in a **Physical Change** only.

The bubbles are water vapour forming within the liquid.

The result is a change of state.

\[ \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g) \]

liquid water \( \rightarrow \) gaseous water

No new substances have been produced.

The particles (molecules of \( \text{H}_2\text{O} \)) remain unchanged.

**Electrolysis of Water**

![Image of electrolysis setup](image2)

results in a **Chemical Change**.

You may have collected the gases produced at each electrode and carried out simple flame tests on each. This would clearly establish that the gases are hydrogen (\( \text{H}_2 \)) and oxygen (\( \text{O}_2 \)).

\[ 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g) \]

liquid water \( \rightarrow \) hydrogen gas \( + \) oxygen gas

No new atoms have been formed, but the molecules of water have been broken apart to form molecules of the elements hydrogen and oxygen.

You may have built models to visualise what happened during electrolysis:

![Diagram of electrolysis process](image3)
During this reaction you might have observed:

- a colour change in the solid in the test tube.
- that a gas was produced. This is seen as bubbling and "fluffing-up" of the dry powder solid, and bubbles of gas coming out of the delivery tube.
- that the limewater became cloudy ("milky") when the gas bubbled through it.

The limewater test shows that the gas released is CO₂.

\[
\text{copper(II)} \rightarrow \text{copper(II)} + \text{carbon} + \text{oxide} + \text{dioxide}
\]

\[
\text{CuCO}_3 \rightarrow \text{CuO} + \text{CO}_2
\]

It is the (polyatomic) carbonate ion that has "broken down" into CO₂ gas and left an oxide ion bonded to the copper ion.

Other carbonate compounds follow the same pattern.
Decomposition by Light Energy

Some compounds will decompose if exposed to sunlight.

You may have carried out simple experiments with compounds of silver, such as silver chloride or silver nitrate. A common experiment involves placing a few drops of silver nitrate solution on 2 filter papers. One is placed in a dark cupboard, the other exposed to sunlight.

The dark colours which “develop” on the paper exposed to sunlight are due to a decomposition reaction:

\[
\text{AgNO}_3 \rightarrow \text{Ag} + \text{NO}_2(g) + \text{O}_2(g)
\]

The dark colour is due to microscopic crystals of metallic silver, too small to be seen as shiny and silvery.

Decomposition of Silver Compounds is the basis of Film Photography.

The Photo Image is “Developed” by chemical processing after the light falling on the film has caused changes in the film, by DECOMPOSITION.

Energy Required Relates to Bonding Strength

If you carried out a variety of decomposition experiments, you will have noticed that some compounds decomposed “easily” (e.g. silver compounds needing only a little light) while others required strong heating with a bunsen. There are many compounds that, if you had tried, would not decompose in a bunsen flame because it is just not hot enough.

Why are some easily decomposed, and others more difficult?

It all depends on the strength of the chemical bonds holding the atoms or ions together in the compound.

Atoms or ions in a compound

Ionic or covalent bond holds ions or atoms together

The stronger that bond, the more energy is required to break up the compound.

Therefore, it follows that the bonding within the compound silver nitrate must be quite weak. In copper(II) nitrate it must be stronger, while in (say) sodium sulfate (which cannot be decomposed by bunsen heat) the bonding is very strong.
All substances are composed of “particles” which are constantly a)..................................................................................................................
In a solid, the particles are close together and b)..................................................................................................................
by forces of attraction. This explains why solids have a definite c)..................................................................................
Heat energy causes the particles to d)..................................................................................................................
and as temperature increases the particles e).................................................................................................................. At the “f).................................................................................................................. point”, the vibration is strong enough to allow particles to begin g)..................................................................................................................
In liquids, the particles are still h)..................................................................................................................
(that’s why liquids are difficult to i)..................................................................................................................
but are able to move around freely. This explains why liquids have no fixed j)..................................................................
As temperature increases the particles move k)..................................................................................................................
In a gas the particles are very l)..................................................................................................................
and moving rapidly in m)..................................................................................................................
This explains why gases are easy to n)..................................................................................................................
and always o)..................................................................................................................

Examples of Physical Changes include changes of p)..................................................................................................................
(e.g. melting) or separating the parts of a mixture. New substances q)..........................................................................
(are/are not) formed and new particles r)..................................................................................................................
(are/are not) created.

Chemical Changes include s)..................................................................................................................
(when things burn) or when 2 elements combine to form a t)..................................................................................................................
This u)..................................................................................................................
(does/does not) create any new atoms, but results in new v)..................................................................................................................
being formed as the atoms are rearranged into new w)..................................................................................................................
of molecules and/or ions.

When water is boiled, a x)..................................................................................................................
change occurs. The particles before and after are y)..................................................................................................................
being molecules of z)..................................................................................................................
(formula). In contrast, the aa)..................................................................................................................
of water is a ab)..................................................................................................................
change. The molecules of water are broken up, forming ac)..................................................................................................................
and ..........................................

When chemical changes occur there is usually a lot of ad)..................................................................................................................
either absorbed or released. Commonly, the energy is either ae)..................................................................................................................
or electricity.

In an endothermic reaction, energy is af)..................................................................................................................
so that the product(s) end up with ag)..................................................................................................................
(more/less) energy than the reactant(s). In ah)..................................................................................................................
reactions, energy is ai)..................................................................................................................
so the products contain aj)..................................................................................................................
energy than reactants.

A synthesis reaction is when small, simple chemicals are ak)..................................................................................................................
to make al)..................................................................................................................
products. When, for example, elements combine to form compounds, the reaction often releases energy and so it is am)..................................................................................................................

Decomposition reactions occur when an)..................................................................................................................
This is usually ao)..................................................................................................................
because energy must be supplied. A good example is the heating of carbonate compounds. These will often break down to form ap)..................................................................................................................
gas and the aq)..................................................................................................................
compound. Silver compounds will often decompose if exposed to ar)..................................................................................................................
This is the basis of as)..................................................................................................................

The amount of energy needed for decomposition is related to the at)..................................................................................................................
within the substance.
Worksheet 15  Decomposition Reactions  Practice Problems

For each of the following decompositions, write a word equation AND a balanced, symbol equation.

1. When calcium carbonate is heated, it decomposes into carbon dioxide and calcium oxide.

2. Silver carbonate decomposes (in sunlight) to form silver, carbon dioxide and oxygen gases.

3. Zinc carbonate decomposes into zinc oxide and a gas (?) when heated.

4. If calcium nitrate is heated it decomposes. The products are calcium oxide, nitrogen dioxide gas and oxygen gas.

5. If magnesium sulfate is heated strongly it breaks down. One product is the gas sulfur trioxide. There is one other product which is a white solid.

6. When ammonium carbonate \((\text{NH}_4)_2\text{CO}_3\) is heated it decomposes into 3 gases... water vapour, carbon dioxide and ammonia gas.

Worksheet 16  Test Questions section 4

Multiple Choice

1. Which of the following statements about matter is fully correct?
   A. Substances expand when heated because the particles get bigger.
   B. It is difficult to compress solids & liquids because the particles in both are quite close together.
   C. Heating a solid decreases the forces of attraction, until the particles can move freely as a liquid.
   D. Gases are easily compressed because the particles are moving very quickly.

2. The 4 processes listed (A, B, C and D) are either physical or chemical changes. Which one is the “odd one out”, different to the other 3?
   A. Dissolving sugar in water.
   B. Steam condensing to liquid.
   C. Filtering a liquid mixture.
   D. Steel rusting.

3. The electrolysis of water is:
   A. an endothermic decomposition.
   B. an exothermic decomposition.
   C. an endothermic synthesis.
   D. an exothermic synthesis.

Longer Response Questions

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate. Answer on reverse if insufficient space.

4. (4 marks)
   Explain how a solid melts to become a liquid, with reference to how the particles are arranged in a substance, the forces between them, and the effect of heat on the particles.

5. (6 marks)
   Compare and contrast the boiling of water with the electrolysis of water, in order to explain the difference between physical and chemical changes.

6. (2 marks)
   Differentiate between exothermic and endothermic chemical reactions.

7. (8 marks)
   a) Write a word equation and a balanced symbol equation to describe the decomposition of:
      i) barium carbonate
      ii) silver carbonate, in which the products are 2 different gases and a metal.
   b) Barium carbonate decomposes after strong heating in a bunsen flame. Silver carbonate decomposes on exposure to sunlight. What does this indicate about the relative strength of the bonding in each compound?
Physical and Chemical Properties
How do you recognise things and tell them apart?

How, for example, do you tell an orange from a banana? You look at its colour and shape and (if blindfolded) you’ll go by smell and taste. You are using the properties of different things to identify them.

In Chemistry it’s exactly the same... we identify substances, and classify different chemicals according to their properties. What are the properties we use?

**Physical Properties**
- Melting & Boiling Points (which determine state at SLC)
- Electrical Conductivity
- “Hardness” and Flexibility (e.g. malleability and ductility)

There are many other properties, such as density and colour, but the three above are by far the most useful when surveying and classifying matter in a general way (and using the K.I.S.S Principle!).

**Chemical Properties** include things like
- how reactive the substance is.
- whether it is acidic, basic or neutral.
- which types of reactions it will undergo.
  (e.g. whether it will burn or corrode)

Chemical properties are not so important when surveying and classifying matter in a general way, but will become important in later topics.

Despite mentioning “taste” several times on this page, tasting is NOT safe or appropriate in the laboratory. **Don’t taste the chemicals!!**

You may have done practical work to investigate whether or not the properties of a compound are related to the properties of the elements it contains.

A simple example is to examine a piece of magnesium (element) and note some basic physical properties. Then consider the observable properties of the element oxygen, in the air around us.

Then burn the magnesium in air. The product of the reaction is the compound magnesium oxide, which can be collected and its properties noted.

**Properties of Elements, Compounds & Mixtures**

Elements and Compounds are all pure substances. Each element, and each compound has its own unique properties which are characteristic and do NOT vary.

For example, pure water has a fixed melting point, boiling point, density, acidity, conductivity, etc. It is these unique, fixed properties which allow us to recognise and identify water, and every other pure substance.

Mixtures are not pure. The properties of mixtures are usually a “blend” of the properties of its parts, and vary according to its exact composition. For example, salt water has properties of both water and salt, and its density, boiling point, conductivity (and taste) vary according to the proportions of the mixture.

**Properties of a Compound Compared to its Elements**

You may have examined and considered many other examples. The general conclusion is:

Magnesium: metallic solid... shiny, flexible, conductor.
Oxygen: colourless, odourless, non-conducting gas.

Magneioxide: brittle, powdery, white, non-conducting solid.

Consider the compound sucrose (table sugar) and the elements carbon, hydrogen and oxygen it is made from.

Carbon: black, brittle solid.
Hydrogen: colourless, explosive gas.
Oxygen: colourless, odourless gas

Sucrose: clear, crystalline solid, with a sweet taste.

You may have examined and considered many other examples. The general conclusion is:

**Generally, the properties of a Compound are totally different to the properties of its Elements**
Bonding Within Substances
To survey and understand the general categories of matter, it is important to know the different forces that operate to hold substances together. It is this “bonding” within substances that often determines the general physical properties by which we classify matter into types.

Ionic Compounds
are a lattice of (+ve) and (-ve) ions. The “Ionic Bonds” are actually electrical attractions between opposite charges, and are very strong. Since these bonds are strong, it requires a lot of energy to break them so that the particles can begin moving around. Therefore, the melting and boiling point is usually quite high.

Covalent Lattice Substances
Some elements (e.g. Carbon and Silicon) and some covalent compounds (e.g. silicon dioxide, SiO₂) form a lattice of atoms covalently bonded, in a 3-dimensional crystal structure. Silicon dioxide forms the mineral “silica”, the most common on Earth. A grain of sand is a crystal of silica. The “Covalent Bonds” are formed when a pair of electrons is being shared, and are very strong. Since these bonds are strong, it requires a lot of energy to break them so that the particles can begin moving around. Therefore, the melting and boiling point is usually very high.

Bonding Within Metals
Why are most metals hard, with quite high melting points? There must be some strong bond holding the atoms together, yet allowing them to change shape (malleable & ductile) when hammered or stretched. Metal atoms do not hold onto their outer (valence) electrons. Each atom is actually a (+ve) ion. Loose electrons wander between the ions, in a shifting “sea of electrons”. The “Metallic Bond” is the electrical attraction between the (+ve) ions and the surrounding “sea” of negative charges. In some metals, the bond is very strong, so the metal is very hard and melts at high temperatures. In other metals, the bond is weaker, so some metals are softer and melt at lower temperatures. However, while the metallic bond can be very strong, it is not rigid. The sea of electrons shifts and flows, so the ions can be pushed or pulled to different places without breaking the substance. This is why metals are malleable and ductile, unlike the hard, but brittle ionic or covalent lattices.

Covalent Molecular Substances
Some elements (e.g. oxygen, chlorine) and many compounds (e.g. water, carbon dioxide) are composed of covalent molecules. The Covalent Bonds inside the molecules are very strong and require a lot of energy to break. It may take a lot of energy to decompose the compound. The bonds between molecules are weak, so mp’s & bp’s are low.

"Intra" = inside
"Inter" = between

To understand these substances you must know about “intra-molecular” and “inter-molecular” forces. The forces between the molecules will be explained in a later topic. For now, be aware that they exist and are (generally) very weak. They hold the molecules in place in the solid state but are easily broken by heat energy. This means that the solid melts easily.

Since the “inter-molecular” forces are weak, covalent molecular substances generally have low melting and boiling points, and many are liquids or gases at normal temperature and pressure (SLC).
Comparing the Properties of Different Substances

You may have done practical work to study the properties of a variety of substances.

The properties studied were probably:

- mp & bp (from Chemical Data book or table)
- electrical conductivity, in solid & liquid states, and in solution if possible, by experiment.
- hardness and flexibility of the solid, by expt.

### Typical General Results

<table>
<thead>
<tr>
<th>Category</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Electrical Conductivity</th>
<th>Hardness/Flexibility of solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>Medium to High</td>
<td>High</td>
<td>Good</td>
<td>Most hard, malleable &amp; ductile</td>
</tr>
<tr>
<td>(e.g. Iron, Lead)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionic Compounds</td>
<td>Medium to High</td>
<td>High</td>
<td>Poor</td>
<td>Hard &amp; brittle</td>
</tr>
<tr>
<td>(e.g. Salt NaCl</td>
<td></td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Sodium hydroxide)</td>
<td></td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Covalent Lattices</td>
<td>Very High</td>
<td>Very High</td>
<td>Poor *</td>
<td>Hard* &amp; brittle</td>
</tr>
<tr>
<td>(e.g. Silicon dioxide</td>
<td></td>
<td></td>
<td>Poor</td>
<td></td>
</tr>
<tr>
<td>diamond (carbon)</td>
<td></td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Covalent Molecules</td>
<td>Low</td>
<td>Low to medium</td>
<td>Poor</td>
<td>Solids often soft &amp; waxy</td>
</tr>
<tr>
<td>(e.g. water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>carbon dioxide)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Exceptions & Anomalies:**
* Carbon, in the form of graphite, is a good conductor, and is soft and slippery.

**A Note About the Inert Gases**

On the previous page the bonding in Ionic, Covalent Molecular, Covalent Lattice and Metallic substances was discussed. How do the elements of Group 8, the "Inert Gases", fit into this scheme?

These elements have full outer shells of electrons, so they do not normally form ions, nor share electrons covalently. Therefore, they always exist as **single-atom molecules**.

(Remember the exact definition of a “molecule”)

Technically, therefore, they are molecular substances. When we write “He” for helium this is both the atomic symbol and the molecular formula.

Molecular and Empirical Formulas

When we say that the formula for water is H₂O, we mean that each molecule of water contains 2 atoms of hydrogen and 1 atom of oxygen. “H₂O” is a molecular formula which describes the molecules.

Salt is an ionic compound. Each crystal contains billions of sodium and chloride ions, but they are in the ratio of 1:1. The formula is NaCl, which is an empirical formula. It does not describe molecules (there aren’t any!) but gives the simplest ratio of the elements present.

Similarly, silicon dioxide has the formula SiO₂, but there are no molecules. This compound is a covalent lattice of billions of atoms bonded together. The atoms are in the ratio of 1 silicon atom to every 2 oxygen atoms. SiO₂ is an empirical formula.

In this case there are no covalent bond within molecules. There are, however, some extremely weak inter-molecular forces which can hold the atoms in a solid lattice at extremely low temperatures. Even very tiny amounts of heat can overpower these forces, so helium melts and boils to a gas at a temperature around -270°C.

The forces get stronger as the atoms get bigger, but even so, all the elements of Group 8 are gases at room temperature because of very low m.p.'s and b.p.'s.
Explaining Electrical Conductivity

Any substance will conduct electricity if it contains electrically charged particles which can move independently of each other.

**Metals**
contain metal ions and a mobile “sea” of free electrons. When a voltage is applied, electrical current is carried readily by the electrons flowing among the metal ions.

Metals are good conductors in both solid and liquid states.

**Covalent Lattices and Covalent Molecules** do NOT contain any charged particles that can separate from each other and move independently.

These substances are generally poor conductors whether solid, liquid or in water solution.

(Exceptions: Graphite is a good conductor. The “semi-metal” elements (notably Si & Ge) are semi-conductors)

**Ionic Compounds** are the trickiest to understand! In the solid state the ions are fixed in the lattice and cannot move freely.

Solid ionic lattices will NOT conduct because ions cannot move freely.

However, if an ionic compound is melted, the (+ve) and (-ve) ions can move freely and independently. If a voltage is applied, a current will be carried by the ions migrating in opposite directions.

Many ionic compounds are soluble in water. When they dissolve, the lattice disintegrates and the ions can move freely. (This will be explained fully in a later topic)

**Limitations of Our Models of Substances**
Right through this topic you have used models of atoms, ions, molecules and lattices to help you visualise and understand the structure of matter. These notes have used diagram models, and you may have used physical ball-and-stick models in class.

What are the limitations of these models?

- Ionic and covalent bonds are not stick-like structures, but are invisible forces of attraction.
- Real atoms and ions are not solid balls.
- The proportional sizes of our models are often all wrong.
- We often use colours to distinguish parts of the models, but this is quite unrealistic.

OK, so our models are not very realistic and far from perfect. Despite these limitations, they remain valuable as ways to help us visualise and understand the “particles” of matter which are beyond our direct vision and often beyond the “common sense” of the everyday world.

**Properties Determine Usefulness**
It is the properties of a substance that make it useful for a particular purpose.

Copper is used for electrical wiring, because it is a good conductor of electricity, and is ductile, so can be made into wire easily.

Diamond (a form of carbon, a covalent lattice element) is used for drill bits and high-speed saw blade tips because it is extremely hard and has an extremely high melting point.

Plastics (covalent molecular compounds) are used for electrical insulation, packaging, etc because they are non-conductors of electricity, soft and flexible not soluble in water (and waterproof).
It is the a)................................. of substances that allow us to identify and classify them. Physical properties include b)................................. and ....................... points, c)................................. conductivity, and the hardness and flexibility of each substance.

d)................................. properties include chemical reactivity and the types of e)................................. a substance will undergo.

Each element or f)................................. is a pure substance with a set of properties which are g)................................. and .........................................

Mixtures are not pure, so their properties h)................................. Generally, the properties of a compound are i)................................. when compared to the properties of the j)................................. it is made from.

It is often the k)................................. within a substance that determines its general physical properties:

• Ionic compounds are a l)................................. of ions. The “m)................................. bonds” which hold the ions together are actually n)................................. between opposite electrical o)................................. These bonds are very p)................................. (strong/weak), so these substances generally have high q).................................

• Lattice substances include some elements, such as s)................................., and some compounds, such as t)................................. The lattice is composed of atoms which are u)................................. bonded together. These bonds are very v)................................. (strong/weak) so these substances have very high w).................................

• Metals are held together by “x)................................. bonding”. Each atom is really a y)................................. (charge) ion because it fails to hold its outer z)................................., which wander freely.

The electrical attraction between the ions and this “aa)................................. of electrons” holds the metal together quite strongly and gives it a fairly ab)................................. (high/low) melting point, but also allows flexibility. This is why metals have the properties of ac)................................. and .........................................

• Covalent ad)................................. substances include some elements, such as ae)................................., and many compounds such as af)................................. Each molecule is held together internally by ag)................................. bonds which are very ah)................................. (strong/weak) These are the “ai)................................. -molecular” forces.

However, it is NOT these that must be broken in a change of state. There are also very aj)................................. (strong/weak) forces between the molecules. These are the “ak)................................. -molecular” forces which are broken by heat energy in a change of state. Since these are al)................................., the melting points are generally very am).................................

The property of electrical an)................................. is very important in classifying matter. In general terms, a substance will conduct if it contains ao)................................. which are able to ap)................................. independently of each other.

Covalent lattice and covalent molecular substances aq).................................(do/do not) conduct because they do not contain any ar).................................

Metals are always as)................................. conductors because of the mobile at)................................. within.

Ionic compounds do not conduct in the au)................................. state because the av)................................. cannot aw)................................. However, when they are ax)................................. or when ay)................................. they become conductors because their ions are az).................................
**Multiple Choice**

1. Most covalent molecular substances (e.g. water) have:

A. strong inter-molecular forces only.
B. weak intra-molecular forces only.
C. strong inter-molecular and weak intra-molecular forces.
D. strong intra-molecular and weak inter-molecular forces.

2. The compound silicon disulfide has a very high melting point. Its chemical formula is SiS₂. It is very likely that:

A. this compound has an ionic lattice structure.
B. “SiS₂” is an empirical formula for a covalent lattice.
C. this is a covalent molecular compound.
D. the compound would conduct electricity when liquid.

3. A substance is found to be a good conductor in both solid and liquid (molten) states. You would expect it to:

A. be brittle.
B. have a very low melting point.
C. be malleable
D. be soluble in water.

---

**Longer Response Question**

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate. **Answer on reverse if insufficient space.**

4. (10 marks)

The following are descriptions of 2 elements:

Chlorine: mp = -101°C, poisonous green-yellow gas, highly reactive, valency -1.

Silicon: mp=1,410°C, grey crystalline solid semiconductor, valency -4, does not form ions but will share electrons covalently.

a) List 2 chemical properties of chlorine mentioned above.

b) Silicon and chlorine can combine to form a compound in which each atom achieves an outer electron shell of 8.

i) is it likely to be an ionic or covalent compound?

ii) Suggest a likely formula and name for this compound.

iii) Are the lists of properties above likely to be of any help in predicting the properties of the compound? Explain.

c) Sketch a Lewis Formula and structural formula for the compound.

d) Given the information that the compound is molecular rather than a lattice structure, predict (in general terms) its:

i) mp & bp. (high, low?)

ii) electrical conductivity.

iii) hardness & flexibility of the solid.