PiXL Gateway: Masterclass - Chemistry

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Checklist of skills and basic knowledge

Amount of Substance	
	I can define relative atomic mass (Ar) and relative molecular mass (Mr)
	I can carry out calculations using the Avogadro constant
	I can carry out calculations using mass of substance, Mr and amount in moles
	I can carry out calculations using concentration, volume and amount of substance in a solution
	I can use the ideal gas equation pV = nRT in calculations
	I can calculate empirical formula from data giving composition by mass or percentage mass
	I can calculate molecular formula from the empirical formula and relative molecular mass
	I can calculate percentage yield and atom economy from given data
	I can calculate the concentration of a solution from mean titre results
	I can calculate the uncertainty in a burette
Bonding	
	I can describe ionic bonding
	I can predict the charge on a simple ion using the position of the element in the periodic table
	I can construct formulas for ionic compounds
	I can describe the difference between a single covalent bond and a co-ordinate (dative covalent) bond
	I can represent a covalent bond using a line and a co-ordinate bond using an arrow
	I can describe metallic bonding
	I can describe and explain the properties of: diamond, graphite, iodine, magnesium and sodium chloride as examples of one of these 4 crystal structures: ionic, metallic, macromolecular, molecular
	I can relate the melting point and conductivity of materials to the type of structure and bonding present
	I can draw diagrams to represent structures involving specified numbers of particles
	I can define electronegativity
	I can use partial charges to show that a bond is polar

Chemical Equilibria	
	I can define the term activation energy
	I can explain why most collisions do not lead to a reaction
	I can draw and explain Maxwell-Boltzmann distribution curves for different temperatures
	I can define the term: rate of reaction
	I can use the Maxwell-Boltzmann distribution curve to explain why a small increase in temperature can lead to a large increase in rate
	I can explain how a change in concentration or a change in pressure influences the rate of a reaction (collision frequency)
	I can define the term catalyst and explain how they work (activation energy; alternative pathway)
	I can use a Maxwell-Boltzmann distribution to help explain how a catalyst increases the rate of a reaction involving a gas
	I can explain what is happening in a reversible reaction at equilibrium
	I can use Le Chatelier's principle to predict qualitatively the effect of changes in temperature, pressure and concentration on the position of equilibrium
	I can explain why, for a reversible reaction used in an industrial process, a compromise temperature and pressure may be used

Amount of Substance

a. Avogadro Constant

The **relative atomic mass (A_r)** is the weighted average of the masses of its isotopes relative to 1/12 of the mass of a carbon-12 atom. The relative atomic masses can be found in the periodic table.

The **relative molecular mass (M_r)** is the sum of the relative atomic masses of the atoms in the numbers shown in the formula.

In a balanced chemical equation, the sum of the relative formula masses of the **reactants equals** the **sum** of the relative formula masses of the **products**.

For example: $2Mg + O_2 \rightarrow 2MgO$

$(2x24) + (2x16) \rightarrow 2 \times (24+16)$

$80 \rightarrow 80$

Chemical amounts are measured in **moles**. The symbol for the unit mole is **mol**.

The mass of **one mole** of a substance **in grams** is numerically **equal** to its **relative formula mass**. **One mole of a substance contains the same number of the stated particles, atoms, molecules or ions as one mole of any other substance.**

The **number** of atoms, molecules or ions in a mole of a given substance is the **Avogadro constant**. The value of the Avogadro constant is **6.02×10^{23} per mole**.

For example, 1 mole of H_2O has a mass of 18g and contains : 6.02×10^{23} water molecules, 6.02×10^{23} oxygen atoms and 1.204×10^{24} hydrogen atoms (2 x Avogadro).

For simple calculation questions, you need to be able to recall, use and rearrange the following equation:

$$\text{Number of moles} = \frac{\text{mass (g)}}{A_r} \text{ or } \frac{\text{mass (g)}}{M_r}$$

Going Deeper

Can you calculate the number of magnesium and chloride ions in 50g of magnesium chloride?

b. Ideal Gas Equation

An **ideal gas** is one in which the **molecules are far enough apart so that intermolecular forces can be neglected**. At high pressures, such forces cause significant departure from the Ideal Gas Equation, and more complicated equations have been devised to treat such cases.

The Ideal Gas Equation, however, gives useful results for most gases at pressures less than 100 atmospheres.

$$pV = nRT$$

where:

p = the **pressure** in **pascals**, **Pa** or **newtons per square metre**, **Nm^{-2}**

V = the **volume** in **cubic metres**, **m^3** (not cm^3)

n = the **number of moles**

R = the **gas constant**, 8.31441 $JK^{-1}mol^{-1}$

T = the **temperature** in **kelvin**, **K**. Add 273 to the temperature in degrees Celsius

Going Deeper

The density of ethane is 1.264 gdm^{-3} at 20 ^0C and 101325 Pa. Can you calculate the relative formula mass of ethane?

c. Empirical and Molecular Formula

The **empirical formula** tells you the **simplest ratio** of the various atoms present in a substance. For example, the empirical formula of ethane (which has a molecular formula of C_2H_6) would be CH_3.

The **molecular formula** gives the **total number of atoms of each element** present in a molecule of the substance. If the empirical formula and relative molecular mass is known, the molecular formula can be calculated.

For example, the empirical formula of ribose is CH_2O. The molar mass of this compound was determined to be 150g/mol. What is the molecular formula of ribose?

Step 1: Determine the molar mass of the empirical formula → 12 + (2 x 1) + 16 = 30$gmol^{-1}$

Step 2: Divide the given molar mass by your answer from step 1 → 150$gmol^{-1}$ / 30$gmol^{-1}$ = 5

Step 3: Multiply your empirical formula by your answer from step 2 → $C_{1x5}H_{2x5}O_{1x5}$ = **$C_5H_{10}O_5$**

Going Deeper

A hydrated salt is analysed and has the following percentage composition by mass:
Cr, 19.51%; Cl, 39.96%; H,4.51%; O, 36.02%
Calculate the formula of the compound showing clearly the water of crystallisation.

d. Percentage Yield and Atom Economy

The **yield** of a reaction is the actual mass of product obtained. The **percentage yield** can be calculated: $\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$

Reactions rarely produce 100% yield. Reasons for this could be the reaction is reversible, or side reactions are occurring or there are errors in experimental procedures.

Atom economy is a measure of the **amount** of **starting materials** that end up as **useful products**. It is important for **sustainable development** and for **economic reasons** to use reactions with **high atom economy**. The percentage atom economy is calculated using the following equation:

$$\frac{\text{Relative formula mass of desired product from equation}}{\text{Sum of relative formula mass of all reactants from equation}} \times 100$$

Going Deeper

Ethanol can be produced by fermenting sugar:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Calculate the atom economy for the reaction. Can you suggest a more effective method for ethanol production?

e. Calculating Concentration and Uncertainty

The **concentration** of a **solution** is the amount of **solute per volume of solution**. Chemists measure concentration in moles per cubic decimetre **(mol/dm^3)**.

Concentration (mol/dm^3) = amount (mol) ÷ volume (dm^3)

If the volumes of two solutions that react completely are known and the concentrations of one solution is known, the concentration of the other solution can be calculated.

Uncertainty is an **estimate** attached to a measurement which characterises the **range of values** within which the true value lies e.g. 44.0 ± 0.4

For a burette:

- Graduated in division every 0.1 cm^3
- Maximum error is half a division i.e. $\pm$ 0.05 cm^3
- Burettes are read twice, so the overall maximum error is 2 x 0.05 = $\pm$ **0.1 cm^3**

Going Deeper

A student prepares a solution of sodium sulfate, Na_2SO_4, by adding 6.25 x 10^{-2} $moldm^{-3}$ sulfuric acid, H_2SO_4, from a burette to 25.0 cm^3 of 0.124$moldm^{-3}$ NaOH in a conical flask.

$$2NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

Calculate the minimum volume of the acid that the student would need to completely react with the NaOH present.

Bonding

a. Ionic

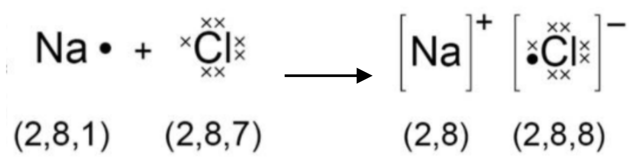
Ionic bonds form between **metals and non-metals**. Ionic bonding involves the **transfer of electrons** in the **outer** shells.

Metals **lose** electrons to become **positively** charged ions.

Non-metals **gain** electrons to become **negatively** charged ions.

Positive Ions		Negative Ions	
Hydrogen	H^+	Fluoride	F^-
Lithium	Li^+	Chloride	Cl^-
Sodium	Na^+	Bromide	Br^-
Potassium	K^+	Iodide	I^-
Magnesium	Mg^{2+}	Oxide	O^{2-}
Calcium	Ca^{2+}	Hydroxide	OH^-
Aluminium	Al^{3+}	Nitrate	NO_3^-
Silver	Ag^+	Sulphate	SO_4^{2-}
Copper	Cu^{2+}	Phosphate	PO_4^{3-}
Ammonium	NH_4^+	Carbonate	CO_3^{2-}
Iron	Fe^{2+} & Fe^{3+}		
These have all *lost* electrons. They're all metals apart from H^+ and NH_4^+		These have all *gained* electrons. They're all non-metals.	

The **electrostatic attraction** between the oppositely charged ions is called **ionic bonding**. The electron transfer during the formation of an ionic compound can be represented by a **dot and cross diagram**:

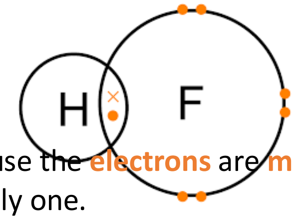


Going Deeper

Explain why magnesium oxide has a higher melting point than sodium chloride.

b. Covalent

Covalent bonds form between **non-metals**. Covalent bonding is a **shared pair of electrons** in the **outer** shells. Therefore a single bond is one shared pair of electrons, a double bond is two shared pairs of electrons etc.



Covalent bonding happens because the **electrons** are **more stable when attracted to two nuclei** than when attracted to only one.

Covalent bonds should **not** be regarded as **shared electron pairs in a fixed position**; the electrons are in a **state of constant motion** and are best regarded more as **charge clouds**.

A **dative covalent bond** (or **coordinate bond**) is a **pair of electrons shared between two** atoms, **one of which provides both electrons** to the bond.

A dative covalent bond is represented by a short arrow from the electron providing both electrons to the electron providing neither.

Going Deeper

Name the type of bond formed between N and Al in H_3NAlCl_3 and explain how this bond is formed.

c. Metallic

A **metallic bond** is an **attraction** between **cations** and a **sea of electrons**.

Metallic bonds are formed when **atoms lose electrons** and the resulting **electrons** are **attracted** to **all** the **resulting cations**. Metallic bonding happens because the **electrons** are **attracted** to **more than one nucleus** and hence **more stable**. The **electrons** are **delocalised** – they are not attached to any particular atom, but are free to move between the atoms.

Going Deeper

Explain why aluminium has a higher melting point than sodium.

d. Properties of Substances

Ionic:

- The **attraction** between opposite ions is **very strong**. **A lot** of kinetic **energy** is **required** to overcome them and the **melting point** and **boiling point** of ionic compounds is **very high**.
- Since ions are held strongly in place by the other ions, they **cannot move or slip over each other** easily and are therefore **hard and brittle**.
- Ionic compounds **contain charged ions** so they are able to move towards charged electrodes and will **therefore conduct electricity**. In the **solid state** the ions are **not free to move** as they are tightly held in place. They **do not conduct** electricity. In the **liquid state**, the ions are **free to move** and so can move towards their respective electrodes. Ionic compounds **can conduct** electricity in the liquid state.

Metallic:

- Metallic bonding is **relatively strong** so the **melting and boiling points** of metals are **relatively high**. **Smaller ions**, and those with a **high charge, attract** the **electrons more strongly** and so have **higher melting points** than larger ions with a low charge.
- **Delocalised electrons** are **free to move** throughout the crystal in a certain direction when a potential difference is applied. Metals therefore **conduct electricity** in the solid state. The delocalised electron system is still present in the liquid state, so metals can also conduct electricity well in the liquid state.
- Metal cations can be moved around and there will still be delocalised electrons available to hold the cations together. The **metal cations** can therefore **slip over each** other fairly **easily**. As a result, metals tend to be **soft**, **malleable** and **ductile**.

Molecular covalent:

- Melting and boiling points are generally **low**, since **intermolecular forces are weak**. Intermolecular forces also decrease rapidly with increasing distance, so there is often **little difference in the melting and boiling points.**
- There are **no ions** and **no delocalised electrons**, so there is **little electrical conductivity** in either solid or liquid state.
- The intermolecular forces are weak and generally non-directional, so most molecular covalent substances are **soft**, **crumbly** and **not very strong**.

Giant covalent – diamond and silicon dioxide:

- Generally **very high melting and boiling points**, since strong covalent bonds must be broken before any atoms can be separated.
- There are **no ions or delocalised electrons**, so there is **little electrical conductivity** in either solid or liquid state.
- Giant covalent substances are **hard, strong and brittle**.

Giant covalent – graphite:

- Due to the **delocalised electrons**, graphite is a **very good conductor** of electricity.
- Graphite has a **much lower density** than diamond due to the relatively large distances in between the planes.
- Much **softer** than diamond since the different **planes can slip over each other** fairly easily. This results in the widespread use of graphite in pencils and as an industrial lubricant.

Going Deeper

In terms of structure and bonding, explain why the boiling point of bromine is different from that of magnesium.

e. Bond Polarity

Electronegativity is the **relative ability** of an atom to **attract electrons** in a **covalent bond**.

Electronegativity **increases across a period** as the **nuclear charge** on the atoms **increases** but the **shielding stays the same**, so the **electrons** are **more strongly attracted** to the atom. Electronegativity **decreases down a group** as the **number of shells increases**, so **shielding increases** and the **electrons** are **less strongly attracted** to the atom. Electronegativity is a very useful in predicting whether the bonding between two atoms will be ionic, covalent or metallic.

If both atoms have a **similar electronegativity**, they **both attract** the electrons **with similar power** so **electrons** will **remain midway between** the two. The bond will therefore be **covalent** - the electrons are shared between the two atoms.

If **one atom** is significantly **more electronegative** than the other, it **attracts** the **electrons more strongly** than the other and the electrons are on average **closer to one atom** than the other. The electrons are **still shared**, but **one atom** has a **slight deficit** of electrons and a **slight positive charge** and the **other a slight surplus** of electrons and a **slight negative charge**. The bond is said to be **polar covalent**.

If the **difference in electronegativity** between the two atoms **is large**, the sharing of electrons is so uneven that the more electronegative atom will attract the electrons far more strongly. The **electrons** are **not shared** at all but an **electron** has essentially been **transferred** from one atom to the other. The more **electropositive** atom is **positively charged** and the more **electronegative** atom is **negatively charged**. The bonding is **ionic**.

If **both** atoms are **electropositive**, neither has a great ability to attract electrons and the **electrons** do not remain localised in the bond. They **become free to move**, both **atoms gain a positive charge** and the bonding is **metallic**.

Going Deeper

Explain how permanent dipole-dipole forces arise between hydrogen chloride molecules.

Chemical Equilibria

a. Simple Collision Theory

If a chemical reaction is to take place between two particles, they must first collide. **The number of collisions between particles per unit time in a system is known as the collision frequency** of the system.

The collision frequency of a given system **can be altered** by **changing** the **concentration** of the reactants, the **total pressure**, the **temperature** or the **size of the reacting particles**.

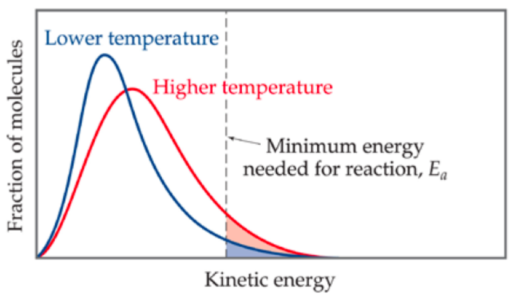
The **minimum energy** the colliding particles need in order to react is known as the **activation energy.** If the collision energy of the colliding particles is **less than the activation energy, the collision will be unsuccessful**. If the collision energy is **equal to or greater than the activation energy, the collision will be successful and a reaction will take place**.

Going Deeper

Draw a reaction profile diagram for an exothermic reaction that shows two reactions, one with a lower activation energy.

b. Factors Effecting Rate of Reaction

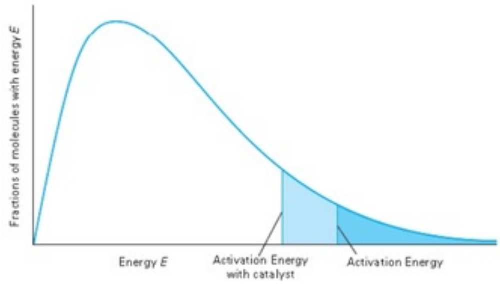
An increase in **temperature** will increase the number of colliding particles with an energy equal to or greater than the activation energy.



An increase in **concentration** causes the rate of reaction to increase by increasing the collision frequency because the number of particles per unit volume increases so the collision frequency increases.

An increase in **pressure** causes the rate of reaction to increase by increasing the collision frequency because the number of particles per unit volume increases so the collision frequency increases. The pressure of a system is generally increased by reducing its volume.

Catalysts provide an **alternative reaction pathway**, usually by introducing an extra step into the reaction, **which has a lower activation energy** than the uncatalysed reaction. A catalyst is a substance which changes the rate of a chemical reaction without itself being chemically altered at the end of the reaction.



Going Deeper

Describe two experimental methods for measuring the rate of a chemical reaction.

c. Dynamic Equilibrium

Dynamic = the reaction has not stopped; it is simply moving in both directions at the same rate.

Equilibrium = the amount of reactants and products in the system is staying the same.

In **reversible reactions**, the **rate of** the **forward reaction decreases** and the **rate of** the **reverse reaction increases**. **Eventually**, the reaction will reach a stage where **both forward and backward reactions are proceeding at the same rate**. At this stage, a **dynamic equilibrium** has been reached.

A closed system is one from which reactants and products cannot escape. In closed systems the **forward and reverse reactions continue until dynamic equilibrium is reached**. All reactions in a closed system are therefore reversible.

An open system is one from which reactants and products can escape. In an open system, the **products are removed** as soon as they are formed, so the **reverse reaction is not able** to take place. Such reactions **never reach equilibrium**, but proceed until all the reactions have been converted into products.

Going Deeper

When nitrogen and hydrogen react to form ammonia, the reaction can reach a dynamic equilibrium. Explain what is meant by dynamic equilibrium, with reference to the reaction described.

d. Le Chatelier's Principle

If a constraint is imposed on a system at equilibrium, then the system will respond in such a way as to counteract the effect of that constraint.

If the conditions are changed after equilibrium has been established, the system may no longer be at equilibrium and may move in one direction or another to re-establish equilibrium. The direction in which the system will move to re-establish equilibrium can be predicted by Le Chatelier's principle.

Increase in concentration of reactants	shifts the equilibrium in the direction of →	forward direction
Increase in concentration of products	shifts the equilibrium in the direction of →	backward direction

Le Chatelier's principle predicts that if the **pressure** of the system is **increased**, the system will move towards the side which has **fewer gas moles**. If the **pressure** of the system is **decreased**, the system will move towards the side which has **more gas moles**.

Le Chatelier's principle predicts that an **increase in temperature** will **favour the endothermic reaction**, and that a **decrease in temperature** will **favour the exothermic reaction**.

The addition of a **catalyst** will have **no effect on the position of equilibrium**. It will increase the rate of the forward and reverse reactions, but by the same amount. The position of equilibrium will therefore be unchanged. As the position of equilibrium is unchanged, it follows that adding a catalyst has no effect on the equilibrium constant.

Going Deeper

Many industrial ammonia plants operate at a compromise temperature of about 800 K. State and explain, using Le Chatelier's principle, one advantage, other than cost, of using a temperature lower than 800 K.

PiXL Independence: Thinking Hard Model

Name of Topic: ____

Name: ____

Class: ____

Take a section of the text and do the following:

1) Prioritise: Underline the three most important sentences here. Rank 1-3, briefly explain number 1. Cross out the least important sentence.
2) Reduce: Reduce the key information into 12 words.
3) Transform: Transform this information into 4 pictures or images (no words allowed).
4) Categorise: Sort this information into three categories. Highlight and think of a suitable title for each category.

5) Extend: Write down three questions you'd like to ask an expert in this subject.

PiXL Independence: Quizzing

Name of Topic: ____

Name: ____

Class: ____

Read the text and come up with 20 questions to ask someone about the text.

	Question	Answer
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