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Chemistry Class 10

Complete Notes

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Prepared by freebooks.pk — original student notes covering the PECTAA Board Chemistry Class 10 syllabus. Each chapter includes key concepts, definitions, formulas, diagrams, solved examples, short and long questions, MCQs, revision and exam tips.

Chapter 14: States of Matter and Phase Changes

Matter exists in four physical states -- gas, liquid, solid and plasma -- and the kinetic particle theory explains not only the behaviour of gases but also the properties of liquids and solids and how they change into one another. This chapter explains internal energy and the interconversion of physical states -- melting, boiling, condensation, sublimation and deposition -- and how heating and cooling curves represent these changes graphically.

The second half of the chapter applies kinetic particle theory to the gas laws -- Boyle's law, Charles' law and Avogadro's law -- and to diffusion, including why lighter gases diffuse faster than heavier ones and why the rate of diffusion of medicines inside the human body matters for how quickly a drug takes effect.

Learning Objectives

- Explain changes of state and internal energy in terms of kinetic particle theory (melting, boiling, freezing, condensation, sublimation and deposition)
- Distinguish between evaporation and boiling
- Interpret heating and cooling curves in terms of kinetic particle theory
- Explain Boyle's law, Charles' law and Avogadro's law using kinetic particle theory
- Explain the effect of external pressure on the rate of boiling and evaporation
- Explain diffusion of gases in terms of kinetic particle theory, and the effect of molecular mass and temperature on its rate
- Discuss real-life applications of sublimation, such as solid air fresheners and sublimation printing
- Explain the importance of diffusion rates of medicines in the human body

Key Concepts

14.1 Internal Energy and the Three States of Matter

According to kinetic particle theory, gases are composed of particles in continuous, random motion in all directions; the pressure a gas exerts comes from its particles colliding with the walls of the container, and its average kinetic energy is directly proportional to its absolute (kelvin) temperature. In a liquid, particles are close together and still move in all directions -- translational, rotational and vibrational -- but inter-particle forces give a liquid a fixed volume even though it has no fixed shape. In a solid, inter-particle forces are so strong that particles are locked into fixed positions and can only vibrate, which is why solids have both a fixed shape and a fixed volume.

The internal energy of a substance is the total energy it contains -- the kinetic energy of its particles plus the potential energy arising from the bonding between them. Supplying heat to a substance increases its internal energy, either by raising the kinetic energy (and hence the temperature) of its particles or by weakening the forces holding those particles together during a phase change.

14.2 Interconversion of Physical States: Melting, Boiling and Condensation

Melting: heating a solid increases the kinetic energy of its particles, making them vibrate faster, until at a specific temperature -- the melting point -- this vibration overcomes the cohesive forces holding the particles in place, and the solid collapses into a liquid. Once melting begins, further heat energy is used entirely to break the remaining forces of attraction, not to raise the temperature, so the temperature stays constant until all the solid has melted.

Boiling: molecules continuously escape from a liquid's surface at all temperatures, a process called evaporation. As a liquid is heated further, its molecules gain enough kinetic energy that bubbles of vapour form throughout the liquid; when the vapour pressure of the liquid becomes equal to the external (atmospheric) pressure, the liquid boils. The boiling point is the temperature at which this happens, and like melting, the temperature stays constant throughout

boiling because the heat supplied is used only to overcome the inter-particle forces of attraction.

Condensation: cooling a gas lowers the kinetic energy of its molecules, letting them come closer together under a significant force of attraction until, at a suitably lower temperature, they change into a liquid. This is condensation, and the temperature of the substance stays constant throughout the transition until all the gas has condensed.

14.3 Heating and Cooling Curves

A heating or cooling curve plots the internal energy (or heat supplied) of a substance against its temperature, and it makes the interconversion of physical states easy to visualise. On a heating curve, a solid's temperature rises steadily until it reaches its melting point, where the curve flattens into a plateau while the solid melts at constant temperature; once melting is complete, the temperature rises again until the liquid reaches its boiling point, where a second plateau appears while the liquid turns to gas at constant temperature; after that, the temperature of the gas rises again.

A cooling curve is simply the same graph read in the opposite direction: a gas cools until it reaches its condensation (liquefaction) point -- numerically the same temperature as the boiling point -- where the temperature stays constant while the gas condenses; further cooling brings the liquid to its freezing point -- numerically the same as the melting point -- where the temperature again stays constant while the liquid solidifies. For water specifically, the heating curve shows a plateau at 0 degC while ice melts and a second plateau at 100 degC while liquid water turns to steam.

14.4 Evaporation, Boiling and the Effect of External Pressure

Evaporation is a surface phenomenon that occurs slowly, at all temperatures below the boiling point, and produces a cooling effect because the escaping molecules carry away kinetic energy; it needs only a small amount of energy, supplied from within the liquid itself. Boiling, by contrast, is a bulk phase change that occurs throughout the liquid at one specific temperature (the boiling point) under a given external pressure, does not cause cooling, and requires a continuous external energy source.

Both evaporation and boiling are affected by external pressure. Decreasing the external pressure makes evaporation easier, because fewer escaping molecules are forced back into the liquid; it also lowers the boiling point, because the liquid's vapour pressure can then match the (lower) external pressure at a lower temperature. This is why water boils at about 100 degC in Karachi (sea level) but at only about 98 degC in Murree, where the atmospheric pressure is lower.

14.5 Sublimation and Deposition

Sublimation is the direct conversion of a solid into vapour without first passing through the liquid state -- for example, solid carbon dioxide (dry ice) turns directly into gaseous carbon dioxide at room temperature, and naphthalene balls used to repel insects slowly disappear the same way. As in evaporation, the energy needed for sublimation is absorbed by the substance from its surroundings, and it is enough to overcome the attractive forces between neighbouring particles so they can escape directly into the vapour phase.

Deposition is the reverse of sublimation: a gas changes directly into a solid without passing through the liquid state. The formation of frost on cold surfaces during winter mornings is a common everyday example of deposition.

14.6 Applications of Sublimation

Solid air fresheners rely on sublimation: a scented solid substance, when exposed to air or gently heated, gains enough energy to overcome the attractive forces holding its particles together and disperses sweet-smelling vapours throughout a room, masking unpleasant odours.

Sublimation printing uses the same principle to transfer a design permanently onto a material. A design is first printed onto special paper with sublimation inks; when this paper is pressed onto fabric (or a specially coated surface such as ceramic, wood or metal) under heat and pressure, the ink converts into vapour, enters the pores that the heat has opened up in the material, and then cools back into a solid form embedded within it -- which is why the print does not fade or wash off the way ordinary surface printing does.

14.7 Kinetic Theory and the Gas Laws

Boyle's law (pressure-volume relationship): according to kinetic theory, increasing the pressure on a fixed mass of gas at constant temperature pushes its molecules closer together, reducing its volume; halving the volume doubles the number of molecules per unit volume and therefore doubles the rate of collisions with the container walls, doubling the pressure. Robert Boyle verified this experimentally and formulated the law: the volume of a given mass of gas is inversely proportional to its pressure at constant temperature, written as V is proportional to 1/P.

Charles' law (temperature-volume relationship): raising the temperature of a gas increases the average speed and kinetic energy of its molecules, causing more frequent and harder collisions with the container walls. If the gas is free to expand so that its pressure stays constant, its volume must increase to accommodate this. Jacques Charles summarised this as: the volume of a given mass of gas varies directly with its absolute (kelvin) temperature at constant pressure, written as V is proportional to T.

Avogadro's law: the pressure a gas exerts depends on how often its particles collide with the container walls, which depends on both the number of particles present and their speed. If more gas is added to a container at constant temperature and pressure, the volume must increase to keep the collision rate -- and hence the pressure -- unchanged. Avogadro's law states that equal volumes of different gases, at the same temperature and pressure, contain an equal number of molecules, written as V is proportional to n.

14.8 Diffusion and Its Importance in Medicine

Diffusion is the spontaneous spreading and intermixing of gas particles from a region of higher concentration to one of lower concentration, caused by their constant random motion -- it is why the smell of a perfume opened in one corner of a room eventually spreads throughout it. Since all gases have the same average kinetic energy at a given temperature, a lighter gas (such as hydrogen) moves faster than a heavier one (such as oxygen) at the same temperature, so it diffuses faster; raising the temperature increases the kinetic energy and speed of all gas particles, further increasing the rate of diffusion.

Diffusion rate matters directly in medicine: when a medicine is taken orally, how quickly it diffuses from the stomach and intestine into the bloodstream determines how fast it is absorbed and how soon it starts acting. Once absorbed, the drug diffuses into different tissues and organs -- lipid-soluble drugs, for instance, diffuse more easily through cell membranes and so act faster -- and a higher rate of diffusion generally means a higher drug concentration reaching its target organ sooner, giving a more effective response.

Important Definitions

Define internal energy.

The total energy contained in a substance, made up of the kinetic energy of its particles plus the potential energy arising from bonding between them; supplying heat increases it.

What is the melting point of a solid?

The specific temperature at which the vibrational motion of a solid's particles becomes fast enough to overcome the cohesive forces holding them in place, so the solid turns into a liquid.

What is the boiling point of a liquid?

The temperature at which a liquid's vapour pressure becomes equal to the external (atmospheric) pressure, so the liquid boils and turns into a gas.

Define freezing point.

The temperature at which a liquid turns into a solid on cooling; it is numerically the same temperature as the substance's melting point.

Define evaporation.

The continuous escape of molecules from the surface of a liquid at all temperatures below its boiling point; it is a surface phenomenon that produces a cooling effect.

Define condensation.

The change of a gas into a liquid on cooling, as the kinetic energy of its molecules decreases and they are drawn together by increasing forces of attraction.

Define sublimation.

The direct conversion of a solid into vapour without first passing through the liquid state, e.g. dry ice or naphthalene balls.

Define deposition.

The direct conversion of a gas into a solid without passing through the liquid state, e.g. the formation of frost.

What is a heating curve?

A graph of internal energy (or heat supplied) against temperature that shows how a substance's temperature rises and then plateaus during each phase change as it is heated.

What is a cooling curve?

A graph of internal energy against temperature, read in the reverse direction of a heating curve, showing condensation and freezing plateaus as a substance is cooled.

State Boyle's law.

The volume of a given mass of a gas is inversely proportional to its pressure at constant temperature: V is proportional to 1/P.

State Charles' law.

The volume of a given mass of a gas varies directly with its absolute (kelvin) temperature at constant pressure: V is proportional to T.

State Avogadro's law.

Equal volumes of different gases, at the same temperature and pressure, contain an equal number of molecules: V is proportional to n.

Define diffusion.

The spontaneous spreading and intermixing of particles of a gas (or liquid) from a region of higher concentration to one of lower concentration, due to their random motion.

What is vapour pressure?

The pressure exerted by the vapour of a liquid; a liquid boils when its vapour pressure becomes equal to the external atmospheric pressure.

Why do solids have a fixed shape and volume, according to kinetic particle theory?

Because the inter-particle forces in a solid are strong enough to hold its particles in fixed positions, restricting them to vibrational motion only.

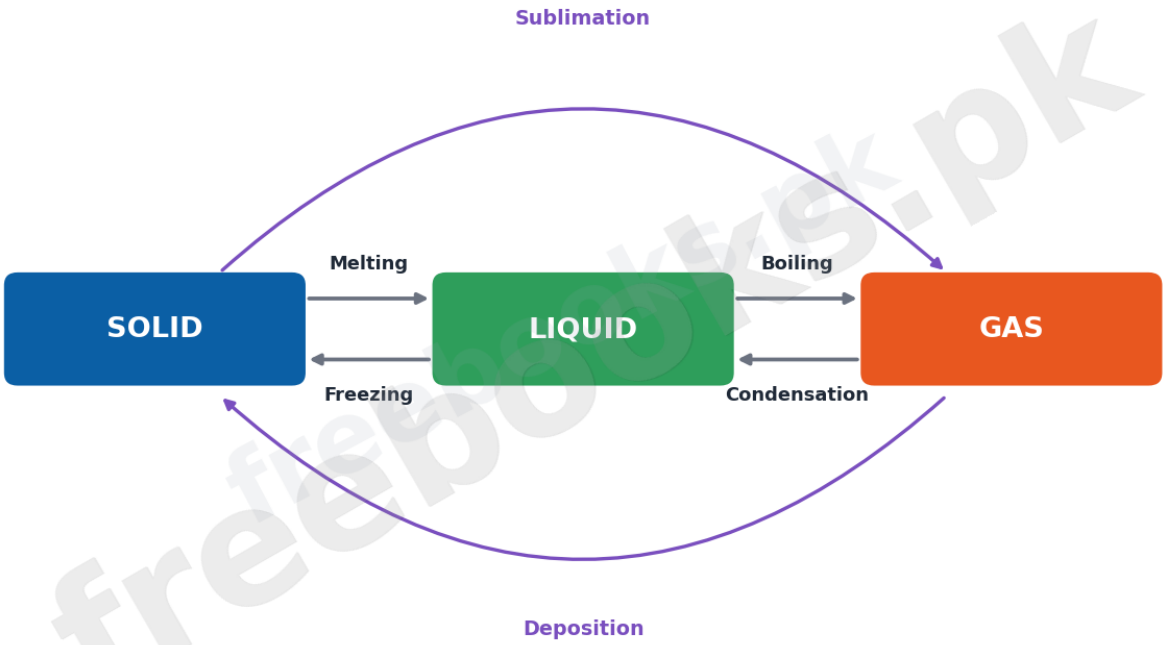
Key Formulas

Topic	Relation
Boyle's law (T, mass constant)	V is proportional to 1/P
Charles' law (P, mass constant)	V is proportional to T (T on the absolute/ kelvin scale)
Avogadro's law (T, P constant)	V is proportional to n (n = number of moles/ molecules)
Melting point = Freezing point	Same numerical temperature, for a given substance
Boiling point = Condensation (liquefaction) point	Same numerical temperature, for a given substance

Diagrams

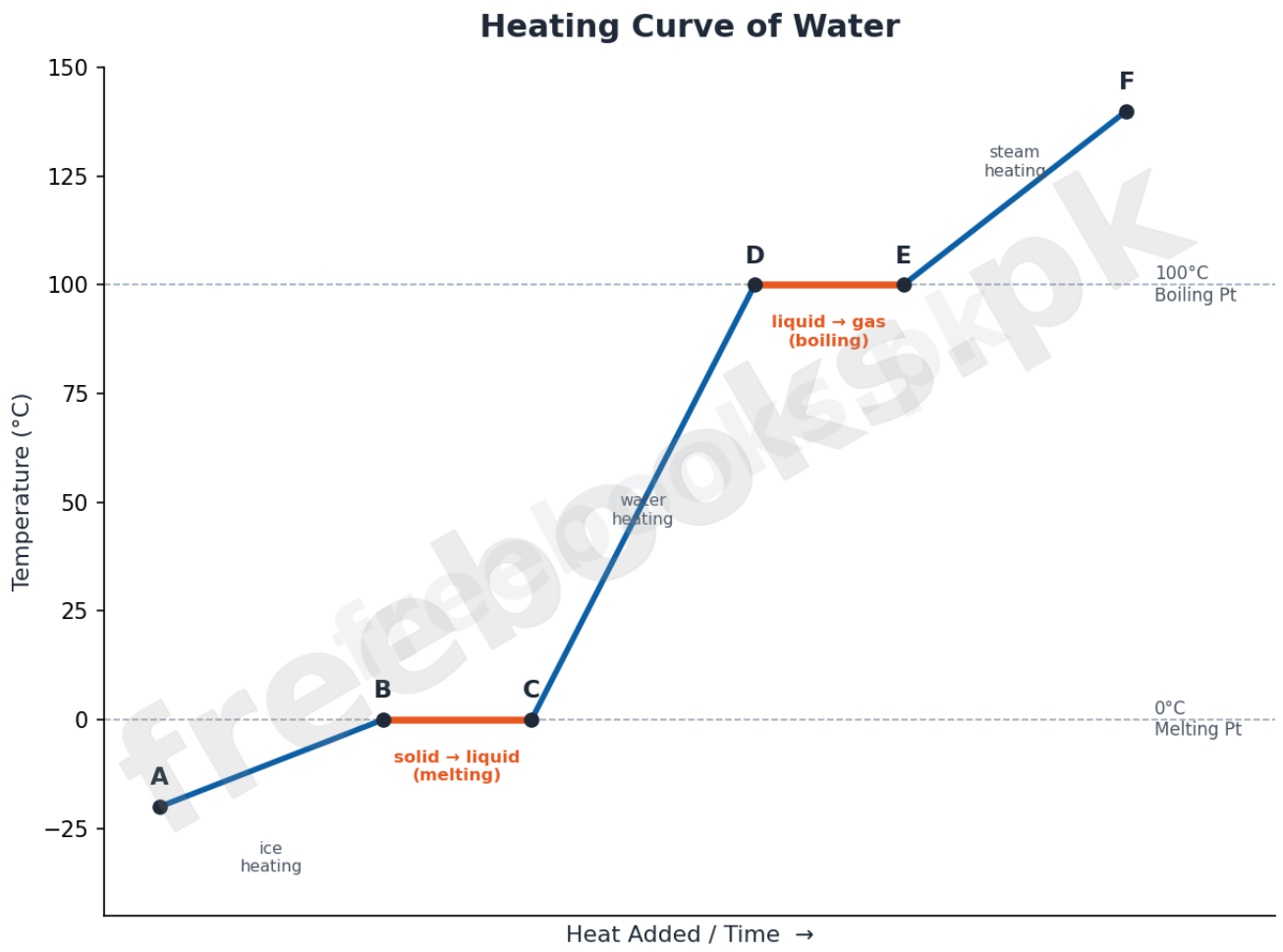
States of Matter and Their Interconversion: A flowchart showing solid, liquid and gas linked by the six named phase changes -- melting, freezing, boiling/ vaporisation, condensation, sublimation and deposition.

States of Matter and Their Interconversion

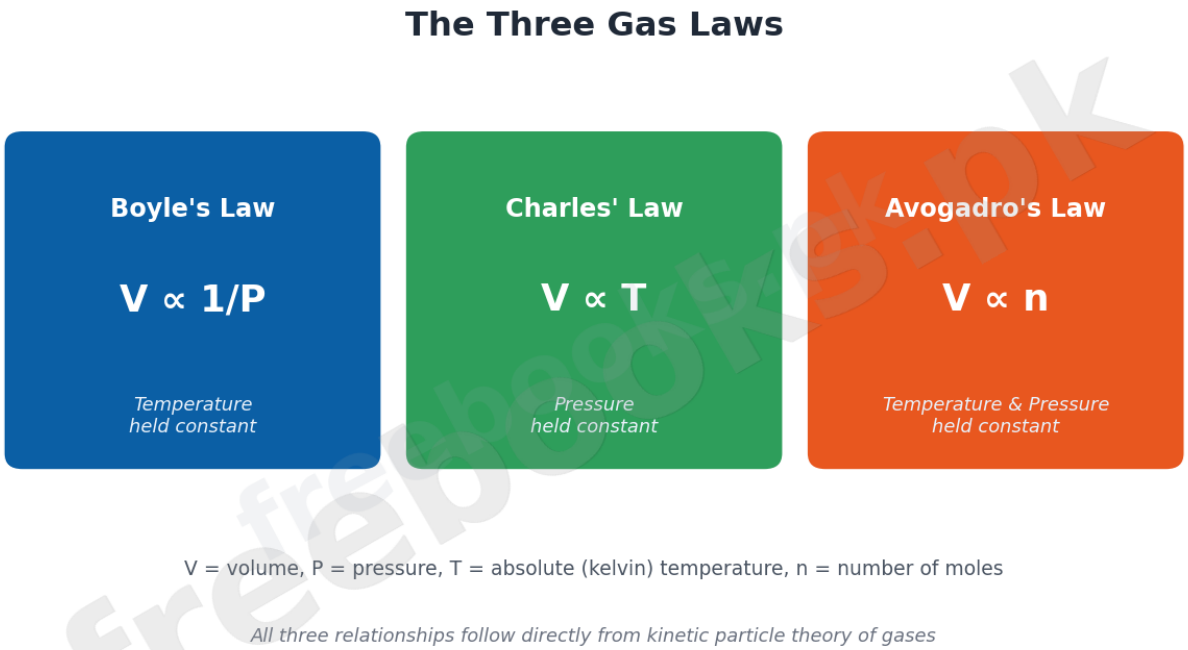


Temperature stays constant during every phase change shown above

Heating Curve of Water: A temperature-vs-heat-added graph showing the melting plateau at 0 degC and the boiling plateau at 100 degC, with points A-F matching the stages described in the text.



The Three Gas Laws: A side-by-side comparison of Boyle's law, Charles' law and Avogadro's law, showing the proportionality relationship and the variable held constant in each.



Short Questions & Answers

What is the internal energy of a substance?

It is the total energy a substance contains -- the kinetic energy of its particles plus the potential energy from bonding between them; heat increases it.

Why does the temperature of a substance remain constant during melting or boiling?

Because the heat supplied during a phase change is used entirely to break the forces of attraction between particles, not to raise their kinetic energy or temperature.

Differentiate between evaporation and boiling in one line each.

Evaporation is a slow surface process occurring at all temperatures and causing cooling; boiling is a bulk process occurring throughout the liquid at one fixed temperature and does not cause cooling.

Why does water boil at a lower temperature in Murree than in Karachi?

Because Murree is at a higher altitude where atmospheric pressure is lower, so the liquid's vapour pressure matches the external pressure at a lower temperature.

Give one example each of sublimation and deposition.

Sublimation: solid carbon dioxide (dry ice) turning directly into gas. Deposition: frost forming directly from water vapour in cold air.

Why does an evaporating liquid feel cool?

Because the escaping molecules carry away kinetic energy from the liquid's surface, lowering the average kinetic energy -- and hence the temperature -- of the liquid left behind.

According to Boyle's law, what happens to the volume of a gas when its pressure is doubled at constant temperature?

The volume is halved, since volume is inversely proportional to pressure at constant temperature.

State Charles' law.

The volume of a given mass of gas varies directly with its absolute temperature when the pressure is kept constant.

Why does hydrogen gas diffuse faster than oxygen gas at the same temperature?

Because all gases have the same average kinetic energy at a given temperature, and since hydrogen molecules are lighter than oxygen molecules, they must move faster, so hydrogen diffuses faster.

Why is a faster rate of diffusion important for orally-taken medicines?

Because it allows the drug to move more quickly from the stomach and intestine into the bloodstream, giving faster absorption and a quicker onset of action.

Long Questions & Answers

Explain, with reference to kinetic particle theory, how a solid substance is converted into a liquid and then into a gas, and describe how a heating curve represents this process.

What happens to the particles of a solid as it is heated towards its melting point?

Heating a solid increases the kinetic energy of its particles, making them vibrate more vigorously about their fixed positions. As heating continues, this vibrational

motion becomes fast enough that, at the melting point, it overcomes the cohesive forces holding the particles in their fixed arrangement, and the solid begins to collapse into a liquid.

What happens to the heat supplied once melting begins, and why does the temperature stay constant?

Once melting starts, any further heat supplied is used entirely to break the remaining forces of attraction between particles and convert the solid into liquid, rather than to increase kinetic energy. Because no energy is going into raising particle speed during this stage, the temperature of the substance remains constant until the solid has completely melted.

How does a liquid convert into a gas, and what defines its boiling point?

Heating a liquid increases the kinetic energy of its molecules, first increasing the rate of evaporation at the surface and then, as heating continues, causing bubbles of vapour to form throughout the liquid. When the vapour pressure inside these bubbles becomes equal to the external atmospheric pressure, the liquid boils; this temperature is called its boiling point, and it too stays constant while the liquid changes into gas.

How does a heating curve represent melting and boiling together?

A heating curve plots temperature against the heat supplied (or time), and shows the temperature rising steadily through the solid phase until it reaches a flat plateau at the melting point; after the plateau, the temperature rises again through the liquid phase until it reaches a second flat plateau at the boiling point, after which the temperature of the resulting gas rises once more. The two plateaus correspond exactly to the melting and boiling processes, where added heat changes the phase rather than the temperature.

State and explain Boyle's law, Charles' law and Avogadro's law using kinetic particle theory, and explain the factors that affect the rate of diffusion of a gas.

What does Boyle's law state, and how does kinetic theory explain it?

Boyle's law states that the volume of a given mass of gas is inversely proportional to its pressure at constant temperature. Kinetic theory explains this because reducing the volume forces gas molecules closer together, increasing the number of molecules per unit volume and hence the frequency of their collisions with the container walls, which raises the pressure proportionally.

What does Charles' law state, and how does kinetic theory explain it?

Charles' law states that the volume of a given mass of gas varies directly with its absolute temperature at constant pressure. Kinetic theory explains this because heating a gas increases the average speed and kinetic energy of its molecules, causing more frequent and forceful collisions with the container walls; to keep the pressure constant, the volume must expand to reduce the frequency of these collisions back to its original rate.

What does Avogadro's law state?

Avogadro's law states that equal volumes of different gases, measured at the same temperature and pressure, contain an equal number of molecules. This follows because pressure depends on the frequency of molecular collisions with the container walls, so at fixed temperature and pressure, the volume must scale directly with the number of gas particles present.

How do molecular mass and temperature affect the rate of diffusion of a gas?

At a given temperature, all gases share the same average kinetic energy, so a gas with a lower molecular mass must have faster-moving molecules and therefore diffuses more quickly than a heavier gas -- which is why ammonia diffuses faster than hydrogen chloride. Raising the temperature of any gas increases the kinetic energy and speed of its particles, which increases its rate of diffusion regardless of its molecular mass.

Multiple Choice Questions (MCQs)

According to kinetic particle theory, solids, liquids and gases mainly differ from one another in: (A) their chemical composition (B) the size of their particles (C) the movement of their particles (D) the colour of their particles

Correct answer: (C) the movement of their particles. Kinetic particle theory explains the three states of matter mainly through the differing freedom of movement of their particles -- vibrational only in solids, and increasingly free in liquids and gases.

Increasing the temperature of a liquid causes its rate of evaporation to: (A) decrease (B) increase (C) stay the same (D) first decrease, then increase

Correct answer: (B) increase. Higher temperature gives liquid molecules more kinetic energy, so more of them escape the surface, increasing the rate of evaporation.

Inter-particle forces of attraction are strongest in: (A) gases (B) liquids (C) solids (D) plasma

Correct answer: (C) solids. Solids have the strongest inter-particle forces, which is why their particles are locked into fixed positions and can only vibrate.

The direct change of a gas into a solid, without passing through the liquid state, is called: (A) sublimation (B) condensation (C) deposition (D) evaporation

Correct answer: (C) deposition. Deposition is the reverse of sublimation -- a gas converting directly into a solid, as in the formation of frost.

During a phase change such as melting or boiling, the temperature of a substance: (A) increases (B) decreases (C) remains constant (D) fluctuates randomly

Correct answer: (C) remains constant. Heat supplied during a phase change is used entirely to change the phase (breaking or forming inter-particle forces), so the temperature stays constant until the change is complete.

Which of these gases will diffuse fastest under similar conditions of temperature and pressure: SO_2, H_2S, CO_2, NO_2? (A) SO_2 (B) H_2S (C) CO_2 (D) NO_2

Correct answer: (B) H_2S. H_2S has the lowest molecular mass (34 g/mol) of the four, and lighter gas molecules move faster and diffuse more quickly at the same temperature.

Boyle's law relates the volume of a fixed mass of gas to its: (A) temperature (B) pressure (C) number of moles (D) density

Correct answer: (B) pressure. Boyle's law states that volume is inversely proportional to pressure at constant temperature.

Charles' law states that, at constant pressure, the volume of a gas is directly proportional to its: (A) pressure (B) absolute (kelvin) temperature (C) number of molecules (D) density

Correct answer: (B) absolute (kelvin) temperature. Charles' law relates volume directly to the gas's absolute temperature, provided pressure is held constant.

Avogadro's law states that equal volumes of different gases, at the same temperature and pressure, contain equal: (A) masses (B) densities (C) numbers of molecules (D) numbers of atoms only

Correct answer: (C) numbers of molecules. Avogadro's law is about the number of molecules (or particles), not their mass, density, or atom count specifically.

The boiling point of water is lower at a higher altitude (such as in Murree) mainly because: (A) the temperature there is naturally lower (B) the atmospheric pressure there is lower (C) the water is purer there (D) gravity is weaker there

Correct answer: (B) the atmospheric pressure there is lower. At higher altitude, atmospheric pressure is lower, so the liquid's vapour pressure can match it at a lower temperature, lowering the boiling point.

Quick Revision Summary

- Kinetic particle theory: solid particles only vibrate in fixed positions; liquid particles move in all three ways but stay close together; gas particles move freely and randomly.

- Melting point = temperature where a solid turns to liquid; Boiling point = temperature where a liquid's vapour pressure equals the external pressure.
- Temperature stays constant during any phase change (melting, boiling, freezing, condensation) -- the heat supplied changes the phase, not the temperature.
- Sublimation = solid to gas directly (e.g. dry ice); Deposition = gas to solid directly (e.g. frost) -- the reverse of sublimation.
- Evaporation occurs at the surface at all temperatures and causes cooling; boiling occurs throughout the liquid at one fixed temperature and needs external heat.
- Boyle's Law: V is proportional to 1/P (T constant); Charles' Law: V is proportional to T (P constant); Avogadro's Law: V is proportional to n (T, P constant).
- Lower external pressure lowers the boiling point (Murree vs Karachi) and makes evaporation easier.
- Lighter gas molecules diffuse faster than heavier ones at the same temperature (e.g. ammonia diffuses faster than hydrogen chloride).

Exam Tips

- Learn the exact definitions of melting, boiling, freezing, condensation, sublimation and deposition point by point -- these are common short-question topics.
- Practice sketching and labelling a heating/cooling curve for water with the correct plateau temperatures (0 degC and 100 degC).
- Remember: temperature always stays constant during a phase change -- this is a frequent conceptual MCQ trap.
- Memorise which variable is held constant in each gas law: Boyle's (temperature constant), Charles' (pressure constant), Avogadro's (temperature and pressure constant).
- For diffusion questions, always connect rate to molecular mass -- the lighter gas diffuses faster at the same temperature.
- Revise the real-life applications of sublimation (solid air fresheners, sublimation printing) since these often appear as descriptive questions.

Chapter 15: Stoichiometry

Stoichiometry is the branch of chemistry that uses the quantitative relationships between reactants and products in a balanced chemical equation to calculate reacting masses, gas volumes and solution concentrations. This chapter builds on the mole concept to introduce molar volume -- the fact that one mole of any gas occupies 24 dm3 at room temperature and pressure (RTP) -- and shows how to express and convert between the two common ways of stating the concentration of a solution, g/dm3 and mol/dm3, including how titration data can be used to calculate an unknown concentration.

The second half of the chapter uses percentage composition by mass to calculate a compound's empirical formula and, from its molar mass, its molecular formula. It then applies the mole ratios given by a balanced chemical equation to calculate reacting masses and gas volumes, to identify the limiting reactant in a reaction where reactants are not mixed in exact stoichiometric proportions, and to calculate percentage yield and percentage purity from experimental data.

Learning Objectives

- Use the molar gas volume (24 dm3 at RTP) in calculations involving gases
- Define concentration and use both g/dm3 and mol/dm3, converting between them
- Calculate the concentration of a solution in a titration from empirical data
- Calculate reacting masses, limiting reactants and gas volumes at RTP from a balanced chemical equation
- Calculate percentage composition by mass of a compound
- Calculate the empirical formula and molecular formula of a compound from appropriate data
- Calculate percentage yield of a reaction from actual and theoretical yield
- Calculate percentage purity of a sample from appropriate data

Key Concepts

15.1 Molar Volume and Room Temperature and Pressure (RTP)

The volume of a gas changes with pressure and temperature, so to compare volumes of different gases fairly, chemists use a fixed set of standard conditions called room temperature and pressure (RTP): 25 degC (298.15 K) and one atmosphere (760 torr). Under these conditions, one mole of ANY gas -- regardless of its identity, molecule size or mass -- occupies exactly 24 dm3. This is called the molar volume, and it follows directly from the fact that equal numbers of gas particles occupy equal volumes at the same temperature and pressure.

Because molar volume is fixed, it lets us convert directly between the volume of a gas at RTP and the number of moles it contains: number of moles of a gas = volume of the gas at RTP divided by the molar volume (24 dm3). This single relationship is the starting point for almost every gas calculation in this chapter, including finding the volume produced by a given mass of gas, or the mass corresponding to a measured volume.

15.2 Concentration of a Solution

Concentration is a measure of how much solute is dissolved in a given amount of solution. The amount of solute can be expressed either in grams or in moles, while the amount of solution is expressed as a volume, in dm3 or cm3 (with 1 dm3 = 1000 cm3, so a volume in cm3 is converted to dm3 by dividing by 1000).

Mass concentration is expressed in g/dm3: concentration = mass of solute in grams divided by volume of solution in dm3. Molar concentration, also called molarity, is expressed in mol/dm3: concentration = number of moles of solute divided by volume of solution in dm3. The two are related through the solute's molar mass, since moles = mass divided by molar mass.

15.3 Calculating Concentration from Titration Data

A titration determines the concentration of a solution of unknown concentration by reacting it, drop by drop, with a solution of known concentration until the reaction between them is exactly complete -- the end point. To calculate the unknown concentration from a titration, three pieces of information are needed:

the balanced chemical equation for the reaction, the volumes of both solutions used, and the concentration of the known solution.

The calculation proceeds in a fixed sequence: convert both volumes to dm3; calculate the number of moles of the known solution used (concentration times volume); use the mole ratio from the balanced equation to find the number of moles of the unknown solution that must have reacted; then divide that number of moles by the unknown solution's volume (in dm3) to get its concentration.

15.4 Percentage Composition by Mass

The percentage composition of a compound is the percentage, by mass, of each element present in it -- the number of grams of that element present in every 100 grams of the compound. It is calculated as: percentage of an element = (mass of the element in the compound divided by the formula mass of the compound) times 100.

Percentage composition can be worked out theoretically from a compound's formula, or experimentally by quantitative analysis -- decomposing a known mass of the compound and weighing the elements recovered. It is a useful tool for checking the purity of a compound and for calculating its empirical and molecular formulae.

15.5 Empirical Formula and Molecular Formula

An empirical formula shows the simplest whole-number ratio of atoms of each element present in a compound. All ionic compounds are represented by empirical formulae, since they do not exist as discrete molecules -- the formula NaCl, for example, simply shows the 1:1 ratio between sodium and chloride ions. Because an empirical formula only records a simplified ratio, different compounds can share the same one: acetylene (C2H2) and benzene (C6H6) both reduce to the empirical formula CH, and acetic acid (CH3COOH) and glucose (C6H12O6) both reduce to CH2O.

To calculate an empirical formula: find the percentage composition of the compound; convert each element's percentage into grams (treating it as grams per 100 g of compound); divide each mass by that element's atomic mass to get the number of moles; divide every mole value by the smallest one to get the

atomic ratio; and if that ratio is not already whole numbers, scale the whole ratio up by a small whole number until it is.

The molecular formula, by contrast, shows the actual number of atoms of each element present in one molecule -- for example H2O2 for hydrogen peroxide, rather than its empirical formula HO. It is calculated as molecular formula = n times the empirical formula, where n = molecular mass divided by empirical formula mass.

15.6 Calculations Based on a Balanced Chemical Equation

A complete, balanced chemical equation tells us the mole ratio -- and therefore the mass ratio -- between every reactant and product in a reaction. For example, CaCO3(s) + 2HCl(aq) -> CaCl2(aq) + H2O(l) + CO2(g) tells us that 1 mole (100 g) of calcium carbonate always reacts with 2 moles (73 g) of hydrochloric acid to produce 1 mole (111 g) of calcium chloride, 1 mole (18 g) of water and 1 mole (44 g) of carbon dioxide.

Using this fixed ratio, the mass of any product can be calculated from a given mass of any reactant (or vice versa) by proportion: work out how much product 1 gram of the reactant would give, then scale that up to the actual mass of reactant used. The same logic extends to gas volumes at RTP using the molar volume relationship from section 15.1.

15.7 Limiting Reactant

In real experiments, reactants are rarely mixed in the exact stoichiometric ratio given by the balanced equation. Often one reactant is deliberately supplied in excess, to make sure that another -- usually more expensive or more important -- reactant is used up completely. The reactant that is consumed first is called the limiting reactant, because it is the one that actually controls, or limits, how much product the reaction can form; the other reactant is left over (in excess) once the reaction stops.

A limiting reactant is identified in three steps: calculate the number of moles of each reactant supplied; calculate, using the balanced equation's mole ratio, how many moles of product each reactant would give if it reacted completely on its

own; and identify whichever reactant gives the SMALLER amount of product -- that one is the limiting reactant, since it runs out first.

15.8 Percentage Yield and Percentage Purity

The actual yield of a reaction is the quantity of product actually obtained when the reaction is carried out in the laboratory or industry. It is almost always less than the theoretical yield -- the amount calculated on paper by assuming every reactant reacts completely and exactly as the balanced equation describes -- because of side reactions, incomplete reactions, and losses during handling and purification. Percentage yield expresses how efficient a reaction actually was: percentage yield = (actual yield divided by theoretical yield) times 100.

Percentage purity measures how much of a sample is the substance you actually want, expressed as a percentage of the sample's total mass: percentage purity = (mass of the pure substance divided by total mass of the impure sample) times 100. This matters wherever a sample is not 100% pure -- for example, checking how much active drug is present in a pharmaceutical tablet, or how much gold is present in a sample of alloy.

Important Definitions

Define molar volume.
The volume occupied by one mole of any gas at room temperature and pressure (RTP); it equals 24 dm3 for every gas.

What are the standard conditions for RTP?
25 degC (298.15 K) and one atmosphere (760 torr) pressure.

Define concentration of a solution.
The amount of solute dissolved in a given volume of solution, expressed in g/dm3 (mass concentration) or mol/dm3 (molar concentration).

What is molarity?
The concentration of a solution expressed in moles of solute per dm3 of solution (mol/dm3); also called molar concentration.

Define titration.

A technique in which a solution of known concentration is added to a solution of unknown concentration until the reaction between them is just complete (the end point), allowing the unknown concentration to be calculated.

Define percentage composition by mass.

The percentage mass of each element present in a compound, found by dividing the mass of that element by the formula mass of the compound and multiplying by 100.

Define empirical formula.

The formula that shows the simplest whole-number ratio of atoms of each element present in a compound.

Define molecular formula.

The formula that shows the actual number of atoms of each element present in one molecule of a compound.

How is molecular formula related to empirical formula?

Molecular formula = n times the empirical formula, where n = molecular mass divided by empirical formula mass.

Define limiting reactant.

The reactant that is completely consumed first in a chemical reaction, and which therefore controls the amount of product formed.

Define theoretical yield.

The amount of product calculated assuming that all the reactants react completely according to the balanced chemical equation.

Define actual yield.

The quantity of product actually obtained when a chemical reaction is carried out in practice; always less than or equal to the theoretical yield.

Define percentage yield.

The actual yield of a reaction expressed as a percentage of its theoretical yield: (actual yield divided by theoretical yield) times 100.

Define percentage purity.

The mass of the pure substance in a sample expressed as a percentage of the total mass of the impure sample.

Why are ionic compounds written with empirical rather than molecular formulae?

Because ionic compounds do not exist as discrete molecules; their formula only shows the simplest ratio between the ions present, e.g. NaCl or CaCl2.

What does a balanced chemical equation tell you, in stoichiometric terms?

The mole ratio, and therefore the mass ratio, between the reactants and the products of the reaction.

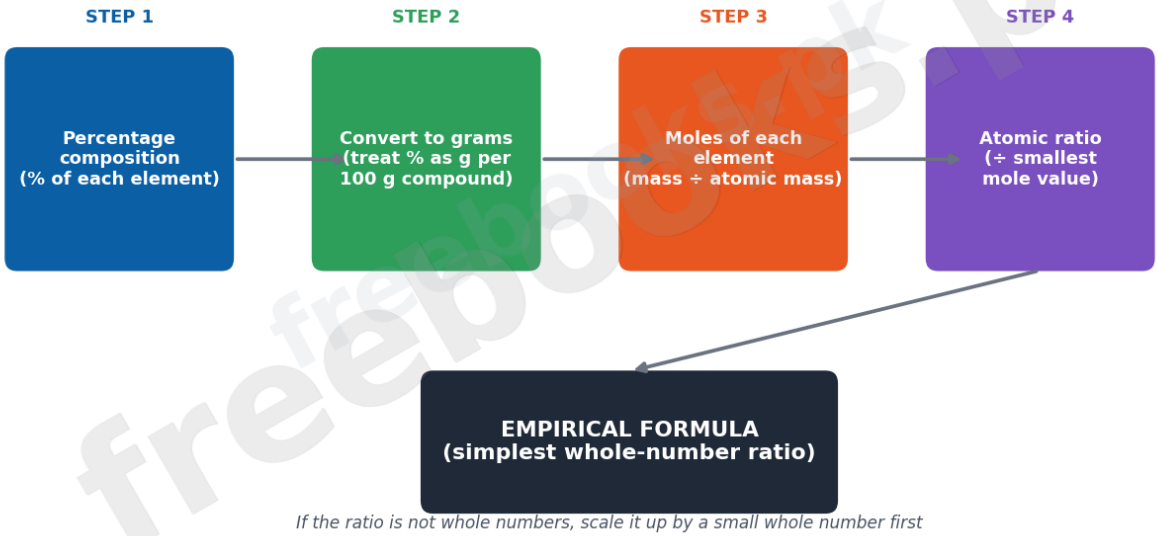
Key Formulas

Topic	Relation
No. of moles of a gas	Volume of gas at RTP / Molar volume (24 dm3)
Concentration (mass/volume)	Mass of solute (g) / Volume of solution (dm3)
Concentration (molar)	No. of moles of solute / Volume of solution (dm3)
Percentage composition of an element	(Mass of element / Formula mass of compound) x 100
Molecular formula	n x Empirical formula, where n = Molecular mass / Empirical formula mass
Percentage yield	(Actual yield / Theoretical yield) x 100
Percentage purity	(Mass of pure sample / Total mass of impure sample) x 100

Diagrams

Steps to Calculate an Empirical Formula: A flowchart showing the four steps from percentage composition to empirical formula: convert percentages to grams, find moles of each element, divide by the smallest mole value for the atomic ratio, and scale to the simplest whole-number formula.

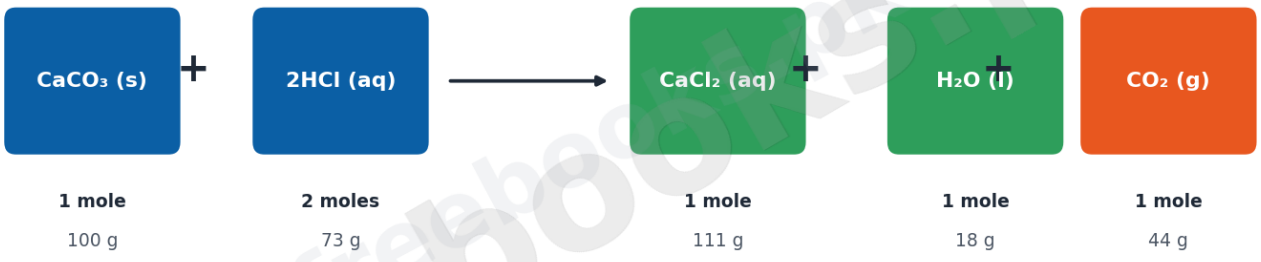
Steps to Calculate an Empirical Formula



If the ratio is not whole numbers, scale it up by a small whole number first

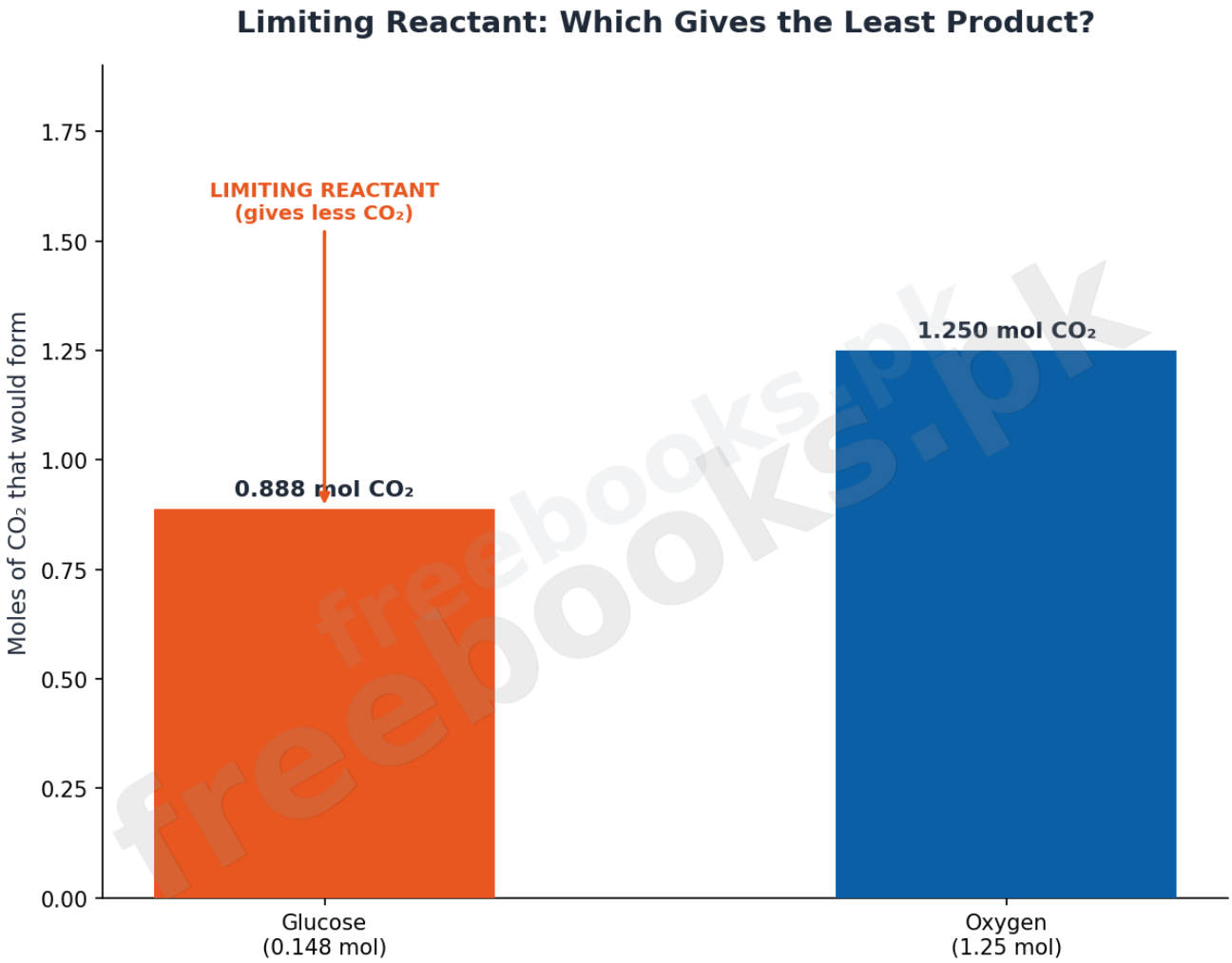
Reading a Balanced Equation in Moles and Masses: A labelled diagram of CaCO3 + 2HCl -> CaCl2 + H2O + CO2 showing the mole ratio and corresponding mass in grams for each species, illustrating how reacting masses are read directly from a balanced equation.

Reading a Balanced Equation in Moles and Masses



The coefficients (1, 2, 1, 1, 1) give the mole ratio; multiplying each by its molar mass gives the mass ratio -- 100 g of $CaCO_3$ always reacts with 73 g of HCl.

Limiting Reactant Comparison: A bar-chart comparison showing how much carbon dioxide two reactants (glucose and oxygen) would each give if fully consumed in a photosynthesis-reverse reaction, with the smaller bar identifying the limiting reactant.



$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ -- whichever reactant would form fewer moles of CO_2 is the limiting reactant

Short Questions & Answers

What is the molar volume of a gas at RTP?

The volume occupied by one mole of any gas at room temperature and pressure; it is 24 dm3 for every gas, regardless of its identity.

How is the concept of molar volume useful?

It lets us convert directly between the volume of a gas at RTP and the number of moles (or mass) of that gas, without needing to know its density.

How does molar volume relate to Avogadro's law?

Avogadro's law states that equal volumes of different gases at the same temperature and pressure contain equal numbers of molecules; molar volume follows directly from this, since one mole of any gas -- containing the same number of molecules -- must occupy the same volume at RTP.

Why may two different compounds show the same empirical formula?

Because an empirical formula shows only the simplest whole-number ratio of atoms, not the actual number of atoms in a molecule; compounds whose molecular formulae are simple multiples of each other, such as C2H2 and C6H6, reduce to the same ratio.

Why is percentage yield important?

It tells a chemist how efficient a reaction actually is in practice compared with the maximum possible (theoretical) yield, which matters for cost, resource use and industrial process design.

What is the concentration, in mol/dm3, of a solution containing 49 g of H2SO4 in one dm3 of solution?

Moles of H2SO4 = 49 / 98 = 0.5 mol; since the volume is exactly 1 dm3, the concentration is 0.5 mol/dm3.

How would you identify the limiting reactant in a reaction?

Calculate the number of moles of each reactant supplied, then calculate how many moles of product each would give according to the balanced equation; the reactant that gives the smaller amount of product is the limiting reactant.

Why is it important to know the purity of a compound used as a medicine?

Because the dose a patient receives depends on how much of the pure active drug the sample actually contains; an impure sample would deliver a weaker or unpredictable dose than intended.

How do you know whether a formula is empirical or molecular?

An empirical formula cannot be reduced to a simpler whole-number ratio, while a molecular formula shows the actual atom count and may be a whole-number

multiple of the empirical formula, found using n = molecular mass / empirical formula mass.

Why must a chemical equation be balanced before it is used in stoichiometric calculations?

Because the calculation depends entirely on the mole ratio between reactants and products shown by the equation's coefficients; an unbalanced equation gives the wrong ratio and therefore the wrong answer.

Long Questions & Answers

Explain, with reference to worked calculations, how the empirical formula and then the molecular formula of a compound are determined from its percentage composition by mass.

Why must percentage composition be converted into a mole ratio rather than used directly?

Percentage composition gives the ratio of masses of the elements present, but a chemical formula is a ratio of atoms (or moles), not masses; dividing each element's percentage (taken as grams per 100 g of compound) by its atomic mass converts the mass ratio into a mole ratio, which is what a formula actually represents.

How is the mole ratio converted into the empirical formula?

Each element's number of moles is divided by the smallest number of moles among the elements present, giving the simplest ratio relative to that element; if this ratio comes out as whole numbers, it is used directly as the subscripts in the empirical formula, and if not, the whole ratio is scaled up by a small whole number until it does.

Why can the empirical formula alone not identify a compound uniquely?

Because it only records a simplified ratio of atoms, so unrelated compounds whose molecular formulae are whole-number multiples of each other -- such as acetylene C2H2 and benzene C6H6 -- reduce to exactly the same empirical formula, CH.

How is the molecular formula calculated once the empirical formula is known?

The compound's molar mass is divided by its empirical formula mass to give n, the number of empirical formula units in one molecule; the molecular formula is then obtained by multiplying every subscript in the empirical formula by n.

Explain how a balanced chemical equation is used to identify the limiting reactant in a reaction, and how percentage yield is then calculated for the product obtained.

What information does a balanced chemical equation provide for these calculations?

It gives the exact mole ratio in which reactants combine and products form, shown by the coefficients in front of each formula; this ratio is the basis for converting between moles, masses and, for gases, volumes of any species in the reaction.

Why does a reaction usually have a limiting reactant?

Reactants are rarely mixed in the exact stoichiometric ratio given by the equation; often one reactant is deliberately supplied in excess so that a more expensive or important reactant is used up completely, leaving the excess reactant left over at the end.

What are the steps used to identify which reactant is limiting?

Convert the given mass of each reactant into moles; use the mole ratio from the balanced equation to calculate how many moles of product each reactant would produce if it reacted completely; the reactant that would give the smaller amount of product is the limiting reactant, since it runs out first and stops the reaction.

How is percentage yield calculated once the theoretical yield is known?

The theoretical yield -- the maximum product possible from the limiting reactant according to the equation -- is compared with the actual yield obtained experimentally, using percentage yield = (actual yield / theoretical yield) x 100; the percentage yield is always at or below 100% because side reactions,

incomplete reactions and losses during handling reduce the actual amount recovered.

Multiple Choice Questions (MCQs)

One mole of any gas at room temperature and pressure (RTP) occupies a volume of: (A) 11.2 dm3 (B) 22.4 dm3 (C) 24 dm3 (D) 32 dm3

Correct answer: (C) 24 dm3. At RTP (25 degC, 1 atm), molar volume is 24 dm3 for every gas, regardless of its identity or mass.

What is the concentration, in g/dm3, of a solution containing 1.8 g of HCl dissolved in 500 cm3 of solution? (A) 0.9 g/dm3 (B) 1.8 g/dm3 (C) 3.6 g/dm3 (D) 9.0 g/dm3

Correct answer: (C) 3.6 g/dm3. Volume = 500/1000 = 0.5 dm3; concentration = 1.8 divided by 0.5 = 3.6 g/dm3.

Which formula shows the actual number of atoms of each element present in one molecule of a compound? (A) Empirical formula (B) Molecular formula (C) Structural formula (D) Ionic formula

Correct answer: (B) Molecular formula. The molecular formula gives the true atom count in a molecule; the empirical formula only gives the simplest whole-number ratio.

Acetylene (C2H2) and benzene (C6H6) share the same: (A) molecular formula (B) molar mass (C) empirical formula (D) boiling point

Correct answer: (C) empirical formula. Both reduce to the simplest ratio CH, even though their molecular formulae and molar masses differ.

In a reaction where reactants are not mixed in exact stoichiometric proportions, the reactant consumed completely first is called the: (A) excess reactant (B) limiting reactant (C) catalytic reactant (D) theoretical reactant

Correct answer: (B) limiting reactant. The limiting reactant runs out first and therefore controls (limits) how much product can form.

If the actual yield of a reaction is 0.198 g and the theoretical yield is 0.220 g, the percentage yield is closest to: (A) 90% (B) 80% (C) 95% (D) 100%

Correct answer: (A) 90%. Percentage yield = (0.198 / 0.220) x 100, which is approximately 90%.

Percentage purity of a sample is calculated using: (A) actual yield / theoretical yield x 100 (B) mass of pure sample / total mass of sample x 100 (C) mass of element / formula mass x 100 (D) moles of solute / volume in dm3

Correct answer: (B) mass of pure sample / total mass of sample x 100. Percentage purity compares the mass of the pure substance present with the total mass of the impure sample.

A compound has an empirical formula CH2O and a molar mass of 180 g/mol. Its molecular formula is: (A) CH2O (B) C2H4O2 (C) C6H12O6 (D) C3H6O3

Correct answer: (C) C6H12O6. Empirical formula mass of CH2O = 30; n = 180/30 = 6, so the molecular formula is 6x(CH2O) = C6H12O6, which is glucose.

The unit mol/dm3 describes a solution's: (A) mass concentration (B) molar concentration (C) percentage purity (D) percentage yield

Correct answer: (B) molar concentration. mol/dm3 (moles of solute per dm3 of solution) is the unit of molar concentration, or molarity.

In a titration used to find an unknown concentration, which piece of information is NOT required? (A) the balanced equation for the reaction (B) the volumes of both solutions used (C) the concentration of the known solution (D) the colour of the solutions

Correct answer: (D) the colour of the solutions. The calculation needs the balanced equation, both volumes, and the known concentration -- the colour of the solutions plays no role in the stoichiometric calculation itself.

Quick Revision Summary

- Molar volume: 1 mole of any gas occupies 24 dm3 at RTP (25 degC, 1 atm) -- no. of moles = volume at RTP / 24.
- Concentration: g/dm3 = mass of solute / volume of solution in dm3; mol/dm3 (molarity) = moles of solute / volume of solution in dm3.
- Titration calculations need the balanced equation, both volumes, and one known concentration to find the other.

- Percentage composition = (mass of element / formula mass of compound) x 100.
- Empirical formula = simplest whole-number atom ratio; Molecular formula = n x empirical formula, n = molar mass / empirical formula mass.
- A balanced equation gives the mole ratio (and mass ratio) between reactants and products -- always balance first.
- Limiting reactant: found by comparing the amount of product each reactant would give -- the smaller amount identifies the limiting reactant.
- Percentage yield = (actual / theoretical) x 100; Percentage purity = (mass of pure sample / total mass of sample) x 100.

Exam Tips

- Always convert volumes from cm3 to dm3 (divide by 1000) before using them in a concentration or titration formula.
- When finding an empirical formula, always divide by the SMALLEST number of moles, not by any other value, to get the atomic ratio.
- Check that a chemical equation is balanced before using its coefficients for any mole or mass calculation.
- To find the limiting reactant, compare the amount of PRODUCT each reactant would give -- not just the number of moles of each reactant.
- Remember percentage yield and percentage purity are always 100% or less -- if your answer exceeds 100%, recheck your calculation.
- Practice converting cleanly between percentage composition, empirical formula and molecular formula -- this progression appears frequently as a multi-part numerical question.

Chapter 16: Electrochemistry

Electrochemistry studies the connection between chemical reactions and electricity. This chapter begins with oxidation numbers -- a bookkeeping tool for tracking how electrons are apparently distributed in a compound or ion -- and uses them to write formulas of ionic compounds and to identify oxidation, reduction and redox (oxidation-reduction) reactions in terms of oxygen, hydrogen, electrons and changes in oxidation number.

The second half of the chapter covers electrolysis, the process by which an electric current decomposes molten or dissolved ionic compounds at an anode and a cathode, with worked cases including brine, dilute and concentrated metal halide solutions, molten lead(II) chloride, dilute sulphuric acid and copper(II) sulphate. It then covers hydrogen-oxygen fuel cells, corrosion and its prevention, electroplating, and galvanic cells such as the Daniel cell, ending with how voltage data from galvanic cells is used to build the electrochemical (reactivity) series of metals.

Learning Objectives

- Define oxidation number and use the rules for assigning it to atoms in compounds and ions
- Derive the formula of an ionic compound from oxidation numbers or ionic charges
- Define oxidation and reduction in terms of oxygen, hydrogen, electrons and oxidation number changes
- Identify the oxidizing agent and reducing agent in a given redox reaction
- Define electrolysis and identify the anode, cathode, electrolyte and direction of electron flow in an electrolytic cell
- Predict the products formed at each electrode during electrolysis of common electrolytes (brine, dilute/concentrated metal halides, molten lead(II) chloride, dilute sulphuric acid, copper(II) sulphate)
- Describe how a hydrogen-oxygen fuel cell works and compare its advantages and disadvantages with petrol/diesel engines

- Define corrosion, explain the reactions involved in the rusting of iron, and describe methods used to prevent it
- Describe electroplating and its main objectives (decoration, protection, repair)
- Sketch a galvanic cell such as the Daniel cell and use voltage data to compare the reactivity of metals

Key Concepts

16.1 Oxidation Number

The oxidation number of an atom is an apparent charge assigned to it in a compound or ion, used to track electron distribution and identify oxidation-reduction reactions and oxidizing/reducing agents. It is found using a set of rules: an atom in its free (uncombined) element always has oxidation number zero; a monatomic ion's oxidation number equals the charge on that ion; group 1 elements are +1, group 2 are +2; the more electronegative atom in a binary compound is given the negative oxidation number (fluorine is always -1); hydrogen is +1 with more electronegative atoms and -1 with less electronegative atoms (as in metal hydrides); oxygen is usually -2.

Two further rules tie everything together: the oxidation numbers of all atoms in a neutral compound must add up to zero, and the oxidation numbers of all atoms in a polyatomic ion must add up to the charge on that ion. These two rules are what let us calculate an unknown oxidation number -- for example, in SO4(2-), since oxygen is -2, S + 4(-2) = -2 gives S = +6.

16.2 Writing Formulas of Ionic Compounds Using Oxidation Numbers and Ionic Charges

Once the oxidation numbers (or ionic charges) of the elements or polyatomic ions in a compound are known, its formula can be written so that the total positive and negative charges add up to zero. For calcium chloride, calcium (group 2) has oxidation number +2 and chlorine (group 17, combined with a less electronegative element) has -1, so two chloride ions are needed for every calcium ion, giving CaCl2.

The same method works for polyatomic ions: combine the cation and anion in whatever ratio makes the compound electrically neutral, writing a polyatomic ion's formula in brackets with a subscript when more than one is needed -- ammonium carbonate, from NH4(1+) and CO3(2-), becomes (NH4)2CO3. Common polyatomic ions include acetate, ammonium, carbonate, chromate, dichromate, hydroxide, nitrate, permanganate, phosphate and sulfate, among others.

16.3 Oxidation, Reduction and Redox Reactions

Oxidation and reduction are simultaneous, opposite processes described in three equivalent ways. In terms of oxygen and hydrogen: oxidation is the addition of oxygen or removal of hydrogen (as when iron rusts, or oxygen removes hydrogen from CH4); reduction is the addition of hydrogen or removal of oxygen (as when hydrogen reduces CuO to copper metal). In terms of electrons: oxidation is the loss of electrons (Cu -> Cu2+ + 2e-) and reduction is the gain of electrons (Fe3+ + e- -> Fe2+). In terms of oxidation number: oxidation is an increase in oxidation number, and reduction is a decrease.

A chemical reaction involving both oxidation and reduction together is called a redox reaction. The substance that is reduced is the oxidizing agent (it causes oxidation in the other species by accepting electrons), while the substance that is oxidized is the reducing agent. Acidified potassium permanganate is a strong oxidizing agent, visibly losing its dark purple colour as it oxidizes oxalic acid to carbon dioxide (Mn going from +7 to +2), and turning colourless potassium iodide solution yellow-brown as it oxidizes iodide ions to iodine.

16.4 Electrolysis: Basic Concepts

Electrolysis is the decomposition of a molten or dissolved ionic compound (an electrolyte) by passing an electric current through it, using two electrodes in an electrolytic cell. The anode is the positive electrode, where oxidation occurs and electrons enter the external circuit; the cathode is the negative electrode, where reduction occurs and electrons leave the external circuit. Positive ions in the electrolyte migrate to the cathode and are reduced there; negative ions migrate to the anode and are oxidized there.

Because electrolysis forces a non-spontaneous reaction to occur using electrical energy from a battery, the charges on the electrodes are the reverse of those in a galvanic cell (covered in section 16.8): in an electrolytic cell, the anode is positive and the cathode is negative, even though oxidation still always happens at the anode and reduction still always happens at the cathode in both types of cell.

16.5 Electrolysis of Aqueous Solutions and Molten Compounds

When brine (concentrated aqueous NaCl) is electrolyzed with inert electrodes, hydrogen gas forms at the cathode (H+ and water are reduced in preference to Na+) and chlorine gas forms at the anode, leaving sodium hydroxide solution behind. For dilute aqueous metal halides, which ion is discharged at the cathode depends on the metal's position in the electrochemical series: metals below hydrogen (like copper and silver) are deposited as metal, metals above hydrogen (like sodium and magnesium) are not, and hydrogen gas is evolved instead; at the anode of a dilute halide, oxygen is usually discharged in preference to the halide ion, because hydroxide ions are more concentrated. In concentrated metal halide solutions, however, the halide ion IS discharged at the anode because its higher concentration now favours it.

Molten lead(II) chloride (heated above 501 degC to free its ions) deposits liquid lead metal at the cathode and releases chlorine gas at the anode, with no water present to complicate the outcome. Electrolysis of dilute sulphuric acid with inert electrodes decomposes water itself: hydrogen gas forms at the cathode and oxygen gas forms at the anode (hydroxide ions are discharged in preference to sulphate ions, which resist oxidation), so the acid's concentration slowly increases as water is used up. Electrolysis of dilute copper(II) sulphate deposits copper metal at an inert cathode and releases oxygen at an inert anode -- but if copper electrodes are used instead, the copper anode itself dissolves into solution as Cu2+ while copper is still deposited at the cathode, so the blue colour of the solution and the electrode masses barely change; this principle underlies copper electroplating.

16.6 Hydrogen-Oxygen Fuel Cells

A fuel cell converts the chemical energy of a continuously supplied fuel directly into electrical energy. In a hydrogen-oxygen fuel cell, porous carbon electrodes coated with platinum catalyst sit in an aqueous potassium hydroxide electrolyte; at the anode, hydrogen is oxidized (combining with hydroxide ions to form water and release electrons), and at the cathode, oxygen is reduced (combining with water and electrons to form more hydroxide ions). The overall reaction is 2H2(g) + O2(g) -> 2H2O(l), with water as the only chemical product, and the cell keeps producing electricity as long as hydrogen and oxygen are supplied.

Compared with petrol or diesel engines, fuel cells produce zero carbon dioxide emissions, convert a much larger share of the fuel's chemical energy into useful electrical energy, and run more quietly; hydrogen can also be produced from renewable sources, making fuel cells more sustainable. Their disadvantages are that producing hydrogen by electrolysis is currently expensive, hydrogen is highly flammable and needs special storage and transport, and fuel cells and electric motors are currently less durable than conventional engines.

16.7 Corrosion and Its Prevention

Corrosion is the gradual chemical decay of a metal as it reacts with substances in its environment, coating its surface with oxides, sulphides or carbonates. Rusting of iron is the most familiar example: iron loses electrons to form Fe2+, oxygen gains those electrons in the presence of water to form hydroxide ions, and Fe2+ then reacts further with oxygen and water to form hydrated iron(III) oxide (rust). Because rust is porous, it lets air and moisture keep reaching fresh metal underneath, so an unprotected piece of iron will eventually corrode completely.

Corrosion is prevented mainly by keeping the metal surface out of contact with air and moisture: barrier methods include greasing, painting, galvanizing (dipping iron or steel in molten zinc, which also protects sacrificially if the coating is scratched) and electroplating with a more resistant metal. Sacrificial protection instead deliberately attaches a more reactive metal, such as magnesium or zinc, which corrodes in place of the metal it protects -- magnesium blocks are commonly used to protect ship hulls and buried steel pipelines.

16.8 Electroplating and Galvanic Cells

Electroplating deposits a thin layer of one metal onto another electrolytically, for decoration (coating cheap metals with gold or silver), protection (against corrosion or acid attack) or repair (rebuilding worn machine parts). The object to be plated is made the cathode, the metal being deposited is made the anode, and the electrolyte is usually a soluble salt of that metal (for example CuSO4 with a little sulphuric acid for copper plating, or potassium argentocyanide for silver plating); good current density, low temperature and a concentrated electrolyte all favour a good-quality deposit.

A galvanic (voltaic) cell does the reverse of electrolysis: a spontaneous redox reaction is used to generate electricity. In the Daniel cell, a zinc electrode sits in zinc sulphate solution and a copper electrode sits in copper sulphate solution, connected by a wire and kept apart by a porous partition that lets ions, but not the two solutions, pass through. Zinc is oxidized at the anode (Zn -> Zn2+ + 2e-) and copper ions are reduced at the cathode (Cu2+ + 2e- -> Cu); electrons travel through the external wire while ions cross the partition, and the cell produces a standard voltage of about 1.10 volts.

Comparing the voltage produced by galvanic cells built from different metal pairs reveals how strongly each metal tends to lose electrons -- its reactivity. A cell between magnesium and copper produces a higher voltage than one between iron and copper, showing magnesium is more reactive than iron. Ranking metals this way by their measured voltages (standard reduction potentials) builds the electrochemical series, with the most reactive, most easily oxidized metals placed highest.

Important Definitions

Define oxidation number.

An apparent charge assigned to an atom in a compound or ion, used to track electron distribution and identify oxidation-reduction reactions; it can be positive, negative or zero.

Define oxidation (in terms of electrons).

A process in which an atom, ion or molecule loses one or more electrons; also defined as gain of oxygen, loss of hydrogen, or an increase in oxidation number.

Define reduction (in terms of electrons).

A process in which an atom, ion or molecule gains one or more electrons; also defined as loss of oxygen, gain of hydrogen, or a decrease in oxidation number.

Define a redox reaction.

A chemical reaction in which oxidation and reduction occur simultaneously.

Define oxidizing agent.

A substance that is itself reduced while causing another substance to be oxidized (it accepts electrons from the other substance).

Define reducing agent.

A substance that is itself oxidized while causing another substance to be reduced (it donates electrons to the other substance).

Define electrolysis.

The decomposition of an ionic compound, in the molten state or in aqueous solution, by passing an electric current through it.

Define electrolyte.

A molten or dissolved ionic compound that conducts electricity and is decomposed during electrolysis.

Define anode.

The electrode at which oxidation occurs; positive in an electrolytic cell but negative in a galvanic cell.

Define cathode.

The electrode at which reduction occurs; negative in an electrolytic cell but positive in a galvanic cell.

Define a fuel cell.

A device that converts the chemical energy of a continuously supplied fuel (such as hydrogen and oxygen) directly into electrical energy, with water as the only product of a hydrogen-oxygen fuel cell.

Define corrosion.

The gradual chemical decay of a metal as it reacts with substances in its environment, such as oxygen and water, coating its surface with compounds like oxides.

Define galvanization.

A method of protecting iron or steel from rusting by coating it with a layer of zinc, usually by dipping it in molten zinc.

Define sacrificial protection.

A method of corrosion prevention in which a more reactive metal, such as magnesium or zinc, is deliberately attached to a less reactive metal so that it corrodes first, protecting the other metal.

Define electroplating.

A process in which a metal is deposited electrolytically onto another metal, for decoration, protection or repair.

Define the electrochemical series.

A list of metals (and some other substances) arranged in order of their standard reduction potentials, showing their relative tendency to lose or gain electrons; more reactive metals are placed higher.

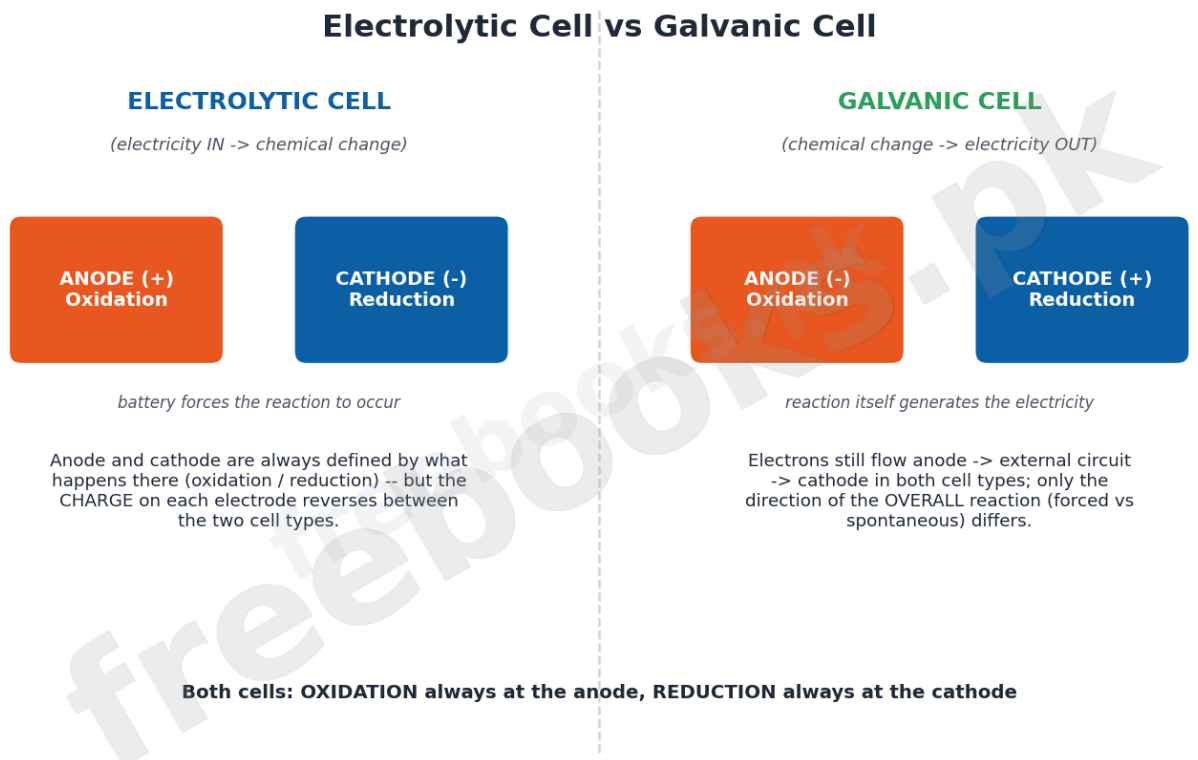
Key Formulas

Topic	Relation
Oxidation number of a free element	Always zero
Oxidation number of a monatomic ion	Equal to the charge on the ion
Sum of oxidation numbers in a neutral compound	Zero
Sum of oxidation numbers in a polyatomic ion	Equal to the charge on the ion
In an electrolytic cell	Anode = positive (oxidation); Cathode = negative (reduction)
In a galvanic cell	

	Anode = negative (oxidation); Cathode = positive (reduction)
Daniel cell overall reaction	Zn(s) + Cu2+(aq) -> Zn2+(aq) + Cu(s), E deg = +1.10 V
Hydrogen-oxygen fuel cell overall reaction	2H2(g) + O2(g) -> 2H2O(l)

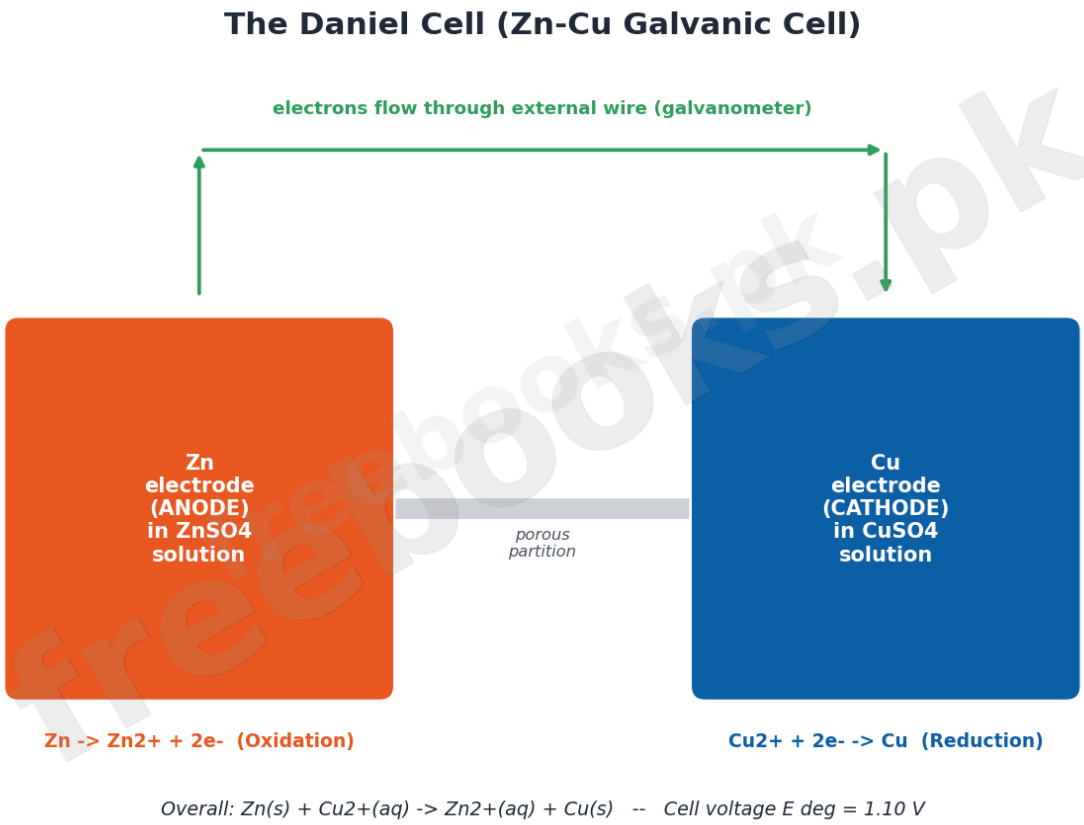
Diagrams

Electrolytic Cell vs Galvanic Cell: A side-by-side comparison showing that oxidation always occurs at the anode and reduction always at the cathode in both cell types, but the charge on each electrode reverses between an electrolytic cell (electricity forces the reaction) and a galvanic cell (the reaction produces electricity).

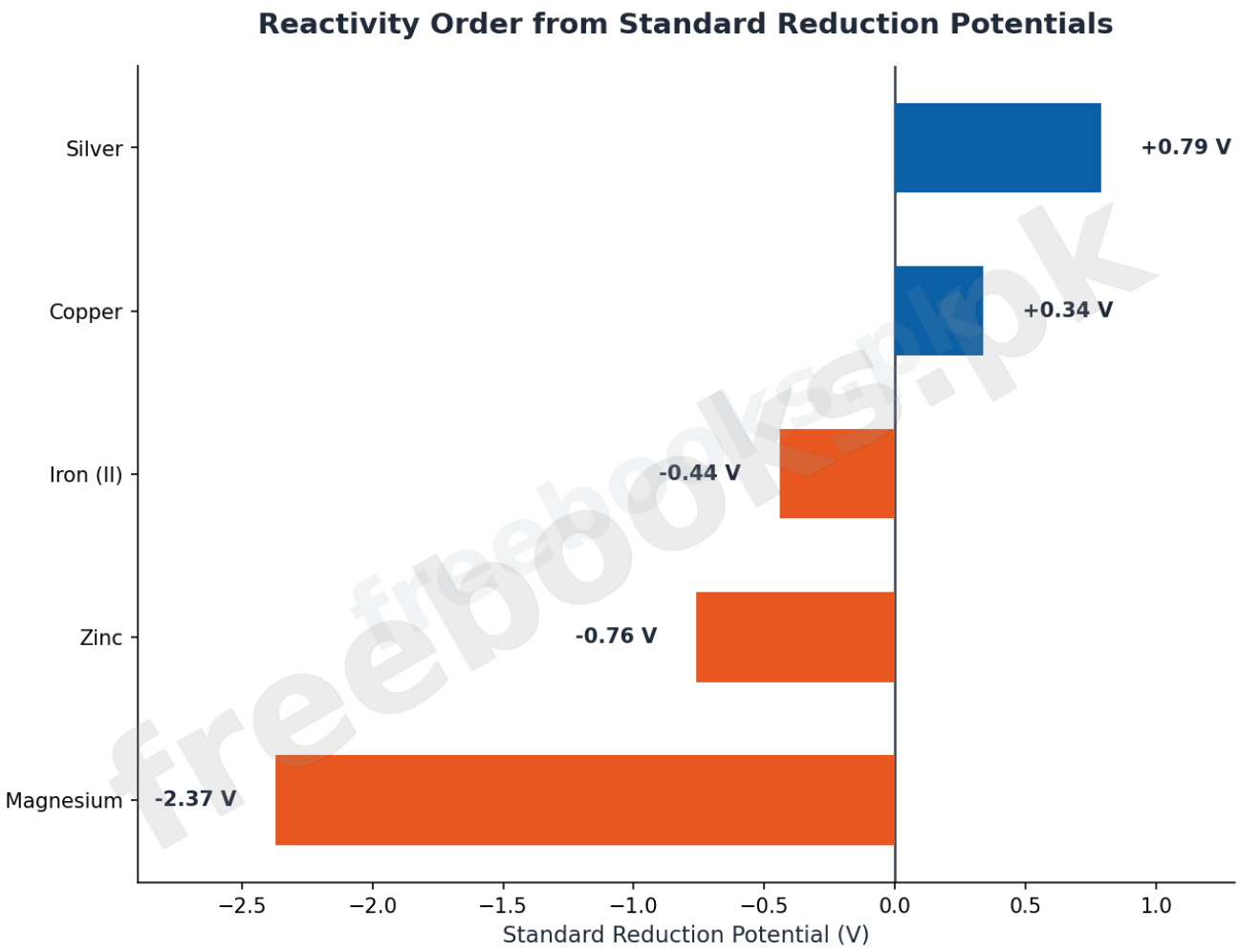


The Daniel Cell (Zn-Cu Galvanic Cell): A schematic of a Daniel cell showing the zinc anode in zinc sulphate solution and the copper cathode in copper sulphate solution, connected by an external wire and separated by a porous

partition, with the oxidation and reduction half-reactions and the overall cell voltage.



Reactivity Order from Standard Reduction Potentials: A bar chart comparing the standard reduction potentials of magnesium, zinc, iron(II), copper and silver, showing how a more negative potential corresponds to a more reactive metal and a higher position in the electrochemical series.



More negative potential = more reactive metal (loses electrons more easily) = higher in the electrochemical series

Short Questions & Answers

What happens when electricity is passed through an aqueous solution of NaCl?

The solution (brine) is electrolyzed: hydrogen gas forms at the cathode, chlorine gas forms at the anode, and sodium hydroxide solution is left behind.

What are the main objectives of electroplating?

Decoration (coating an inexpensive metal with a noble metal like gold or silver), protection (against corrosion or acid attack), and repair (rebuilding worn machine parts).

Mention one difference between an electrolytic cell and a galvanic cell.

In an electrolytic cell, electrical energy is supplied to force a non-spontaneous reaction (the anode is positive); in a galvanic cell, a spontaneous reaction generates electrical energy (the anode is negative).

Through which electrode do electrons leave an electrolytic cell?

Through the anode, which is connected to the positive terminal of the battery and is where electrons enter the external circuit.

How does an electrolyte conduct electricity?

By the movement of its freely moving positive and negative ions towards the cathode and anode respectively, where they are reduced or oxidized.

What will happen if a strip of copper metal is dipped in FeSO4 solution?

Nothing significant happens, because copper is below iron in the electrochemical series and is less reactive, so it cannot displace iron from its salt solution.

Why are fuel cells regarded as environment-friendly?

Because a hydrogen-oxygen fuel cell produces only water as a chemical product, with zero carbon dioxide emissions, unlike petrol or diesel engines.

Why does the blue colour of copper sulphate solution fade during electrolysis with inert electrodes?

Because copper ions are continuously removed from solution as they are reduced and deposited as copper metal at the cathode, lowering the concentration of Cu^{2+} in the solution.

Why are carbon (graphite) electrodes used for electrolyzing concentrated NaCl solution?

Because graphite is inert and does not react with the chlorine gas produced at the anode, unlike some metals would.

Why does corrosion become faster during the rainy season?

Because rusting needs both oxygen and water, and the increased moisture in the air during the rainy season speeds up the electrochemical reactions involved in rusting.

Long Questions & Answers

Explain, with reference to the electrolysis of aqueous sodium chloride and dilute sulphuric acid, how the products formed at each electrode are determined.

What ions are present in these two electrolytes, and why does that matter?

Brine contains Na+ and Cl- from sodium chloride plus H+ and OH- from water; dilute sulphuric acid contains H+ and SO4(2-) from the acid plus H+ and OH- from water. Because more than one type of ion approaches each electrode, there is a choice over which ion is actually discharged, and that choice determines the products.

Why is hydrogen gas, not sodium, produced at the cathode of brine?

Water molecules and hydrogen ions have a greater tendency to be reduced than sodium ions do, so H+ (or water) picks up electrons at the cathode to form hydrogen gas, leaving Na+ and the resulting OH- in solution, which is why the solution around the cathode becomes alkaline.

What happens at the anode in each case, and why does dilute sulphuric acid give oxygen rather than sulphate discharge?

At the anode of brine, chloride ions are oxidized to chlorine gas. At the anode of dilute sulphuric acid, hydroxide ions are oxidized to oxygen gas instead of sulphate ions, because sulphate ions are much harder to oxidize than hydroxide ions, even though both are present.

How does the overall outcome change between dilute and concentrated solutions, or with different electrode materials?

In a dilute halide solution, the anode gives oxygen because hydroxide ions dominate, but in a concentrated halide solution, the halide ion's much higher concentration means it is discharged instead, giving the halogen gas; using an active electrode (such as copper in copper sulphate electrolysis) instead of an

inert one also changes the anode outcome, since the electrode metal itself dissolves into solution rather than oxygen being produced.

Explain how a Daniel cell generates an electric current, and how measuring cell voltages between different metal pairs is used to build the electrochemical (reactivity) series.

What happens at the zinc and copper electrodes of a Daniel cell?

At the zinc electrode (the anode), each zinc atom loses two electrons and enters the solution as a Zn2+ ion -- an oxidation reaction. At the copper electrode (the cathode), Cu2+ ions from the solution gain those electrons and are deposited as copper metal -- a reduction reaction.

Why must the two half-cells be kept in separate compartments?

If the zinc metal were placed directly into the copper sulphate solution, the oxidation and reduction reactions would happen right at the zinc surface and the electron transfer would not pass through an external circuit, so no usable electric current could be generated; keeping the reactions physically apart forces the electrons to travel through a wire instead.

What is the role of the porous partition and the external wire?

The porous partition allows ions to move between the two half-cells to keep both solutions electrically neutral as the reaction proceeds, but stops the two solutions from mixing directly; the external wire (through a galvanometer) is the only path by which the electrons released at the zinc anode can reach the copper cathode, and this flow of electrons is the electric current the cell produces.

How does comparing cell voltages between different metal pairs establish the order of reactivity?

A galvanic cell's voltage measures the difference in how strongly its two metals tend to lose electrons; a higher voltage between a given pair means a bigger difference in reactivity. Since a magnesium-copper cell produces a higher voltage than an iron-copper cell, magnesium must be more reactive than iron, and by

measuring many such pairs, metals can be ranked from most to least reactive, giving the electrochemical series.

Multiple Choice Questions (MCQs)

The oxidation number of Mn in K2MnO4 is: (A) +7 (B) +5 (C) +6 (D) -6
Correct answer: (C) +6. K is +1 (x2 = +2), O is -2 (x4 = -8); for the neutral compound, +2 + Mn - 8 = 0, so Mn = +6.

In the reaction 4HBr + MnO2 -> MnBr2 + Br2 + 2H2O, which element is being reduced? (A) Br (B) Mn (C) H (D) Both Mn and H
Correct answer: (B) Mn. Manganese goes from +4 in MnO2 to +2 in MnBr2, a decrease in oxidation number, so manganese is reduced.

During electrolysis of dilute H2SO4 using platinum electrodes, which process takes place at the cathode? (A) Reduction (B) Neither oxidation nor reduction (C) Oxidation (D) First oxidation and then reduction
Correct answer: (A) Reduction. Hydrogen ions gain electrons at the cathode to form hydrogen gas, which is a reduction.

What product forms at the anode when an aqueous solution of CuSO4 is electrolysed using copper electrodes? (A) Cu (B) O2 (C) H2 (D) No gas product -- the copper anode dissolves into solution as Cu2+
Correct answer: (D) No gas product -- the copper anode dissolves into solution as Cu2+. With an active copper anode, copper metal atoms leave the electrode as Cu2+ ions instead of oxygen being produced, keeping the electrolyte concentration roughly constant.

Which of the following statements is NOT correct about a Zn-Cu galvanic (electrochemical) cell? (A) Anode is negatively charged (B) Reduction occurs at the anode (C) Cathode is positively charged (D) Reduction occurs at the cathode
Correct answer: (B) Reduction occurs at the anode. In a galvanic cell, oxidation -- not reduction -- occurs at the anode; reduction occurs at the cathode.

Which product is obtained at the anode when a concentrated solution of NaCl is electrolysed? (A) Cl2 (B) O2 (C) More O2 and less Cl2 (D) More Cl2 and less O2

Correct answer: (A) Cl2. In a concentrated chloride solution, the high concentration of Cl- means chloride ions are preferentially discharged at the anode, giving chlorine gas.

When a dilute aqueous solution of ZnCl2 is electrolysed, which product forms at the cathode? (A) H2 (B) Zn (C) O2 (D) Zn and O2

Correct answer: (A) H2. Zinc is above hydrogen in the electrochemical series, so hydrogen ions (or water) are preferentially reduced at the cathode instead of zinc ions.

What is produced at the cathode in a hydrogen-oxygen fuel cell? (A) H+ (B) O2- (C) H2O (D) OH-

Correct answer: (D) OH-. At the cathode, oxygen combines with water and electrons to form hydroxide ions: O2 + 2H2O + 4e- -> 4OH-.

Which of the following metals is highest (most reactive) in the electrochemical series? (A) Tin (B) Iron (C) Magnesium (D) Zinc

Correct answer: (C) Magnesium. Magnesium has the most negative standard reduction potential of the four, making it the most reactive and the one that loses electrons most easily.

Which corrosion-prevention method deliberately uses a more reactive metal to corrode in place of the metal being protected? (A) Galvanization (B) Sacrificial protection (C) Electroplating (D) Painting

Correct answer: (B) Sacrificial protection. Sacrificial protection attaches a more reactive metal, such as magnesium or zinc, which corrodes first and protects the less reactive metal underneath.

Quick Revision Summary

- Oxidation number rules: free element = 0; monatomic ion = its charge; neutral compound's oxidation numbers sum to 0; polyatomic ion's sum to its charge.
- Oxidation = loss of electrons / gain of oxygen / loss of hydrogen / increase in oxidation number. Reduction is the exact opposite of each.
- A redox reaction involves both oxidation and reduction together; the oxidizing agent is reduced, the reducing agent is oxidized.

- Electrolysis: anode = oxidation, cathode = reduction, in every cell -- but the CHARGE on each electrode is opposite in an electrolytic cell versus a galvanic cell.
- Dilute halide solution: H2 or O2 tends to form at the electrodes (unless the metal is below hydrogen); concentrated halide solution: the halogen forms at the anode.
- Hydrogen-oxygen fuel cell: 2H2 + O2 -> 2H2O, water is the only product, very efficient and clean but currently costly.
- Corrosion (rusting) needs both oxygen and water; prevented by barrier methods (paint, galvanizing, electroplating) or sacrificial protection (Mg/Zn).
- Daniel cell: Zn anode oxidized, Cu cathode reduced, E deg = 1.10 V; higher cell voltage between a metal pair = bigger difference in reactivity -- basis of the electrochemical series.

Exam Tips

- Practice assigning oxidation numbers using the neutral-compound-sums-to-zero and ion-sums-to-its-charge rules -- this is the most common calculation-style question.
- Remember: OXIDATION is always at the ANODE and REDUCTION is always at the CATHODE, in every cell type -- only the electrode's charge sign changes between electrolytic and galvanic cells.
- For electrolysis questions, always check whether the solution is dilute or concentrated, and whether the metal is above or below hydrogen in the electrochemical series, before predicting the cathode/anode product.
- Learn the Daniel cell's electrode reactions and overall cell voltage (1.10 V) as a model answer for any galvanic cell question.
- Connect corrosion prevention methods to their mechanism: barrier methods physically block air/water; sacrificial protection works because a more reactive metal is oxidized instead.
- When comparing reactivity of metals, remember: a MORE NEGATIVE standard reduction potential means a MORE reactive metal, higher in the electrochemical series.

Chapter 17: Reaction Kinetics

Reaction kinetics is the study of the rate at which chemical reactions proceed and of the factors that govern that rate. This chapter explains reactions at the molecular level using collision theory: particles must collide with enough energy and the right orientation for a reaction to occur, and only a small fraction of collisions -- effective collisions -- actually lead to products.

The chapter then examines the physical signs that let us follow a reaction's progress (change in mass, change in temperature, formation of a gas) and works through the factors that speed up or slow down a reaction -- concentration, pressure of gases, surface area of solids, temperature, and catalysts including biological enzymes -- explaining each one using collision theory. It closes by connecting these ideas to the food industry, where reaction rates determine ideal harvesting, storage and transportation times for produce.

Learning Objectives

- Describe collision theory in terms of number of particles per unit volume, frequency of collisions, kinetic energy of particles and activation energy
- State that a catalyst increases the rate of reaction by providing an alternate pathway with lower activation energy, and remains unchanged at the end of the reaction
- Describe the physical parameters that may be affected by the rate of reaction, including change in mass, change in temperature, and formation of a gas
- Interpret data, including graphs, for investigating the rate of a reaction
- Explain the effect on rate of reaction of changing concentration of a reactant, pressure of gases, surface area of solids, temperature, and presence of a catalyst (including enzymes), using collision theory
- Justify the importance of chemical kinetics in the food industry for determining ideal harvesting and transportation times for produce

Key Concepts

17.1 Collision Theory of Reaction Rate

A reaction takes place only when the participating particles (atoms, molecules or ions) collide with one another, but only a very small fraction of collisions actually lead to the formation of products -- these are called effective collisions. In the majority of collisions the reactant particles simply bounce back without any change. The rate of a reaction depends on the number of effective collisions occurring per second, which in turn depends on four factors.

The number of particles per unit volume: the higher the concentration of the reactants, the more particles are present and the more collisions occur between them. The frequency of collisions: a greater number of collisions per second increases the number of effective collisions -- at higher temperature the velocities of molecules increase, raising the frequency of collisions. The kinetic energy of the particles: as temperature increases, particles move faster and have more chances to collide with each other with greater force.

The fourth and most decisive factor is activation energy -- the minimum energy the colliding particles must possess to break the bonds present in the reactant molecules and start the reaction. At a given temperature, most molecules possess only the average energy; only the small fraction whose energy exceeds the activation energy can react on collision. When particles with enough energy collide, they briefly form a high-energy state (with a corresponding rise in the potential energy of the system) before falling to the more stable products, a process usually shown as a graph of potential energy against the path of the reaction.

17.2 Change in Mass during a Chemical Reaction

The total mass during a chemical reaction always remains the same, obeying the law of conservation of mass. However, in an open container where gases can escape or enter, a reaction may appear to change mass because a reactant or product is a gas: if a gas is evolved, an apparent decrease in mass is observed; if a gas is absorbed, an apparent increase in mass is observed.

For example, burning a ribbon of magnesium in an open crucible produces MgO whose mass is greater than the magnesium alone, because oxygen from the air has combined with it -- but if the same reaction were carried out in a closed container, the total mass would stay the same. Conversely, reacting marble chips with dilute hydrochloric acid in an open container gives an apparent decrease in mass because CO2 gas escapes into the atmosphere: CaCO3(s) + 2HCl(aq) -> CaCl2(aq) + H2O(l) + CO2(g). As a reaction proceeds, the concentration of reactants steadily decreases while the concentration of products increases, reaching its maximum once the reaction is complete -- a relationship usually shown on a concentration-time graph.

17.3 Change in Temperature during a Chemical Reaction

Chemical reactions are often accompanied by a change in temperature that reveals whether they are exothermic or endothermic. In an exothermic reaction, heat energy is released and absorbed by the surroundings, raising their temperature -- for example, quicklime reacting with water to form slaked lime releases a large amount of heat: CaO(s) + H2O(l) -> Ca(OH)2(s).

In an endothermic reaction, heat energy is absorbed from the surroundings, cooling them down -- for example, dissolving ammonium chloride or ammonium nitrate in water absorbs heat and cools the container. Increasing the temperature of a reaction also increases its rate: for many reactions, the rate roughly doubles with every 10 degC rise

in temperature, which is why cooking food at high temperature speeds up the reactions that break down its components.

17.4 Factors Affecting the Rates of Reactions

According to collision theory, any factor that changes the number of successful collisions per second will affect the rate of a reaction. Effect of concentration: the higher the concentration of reactants, the more particles per unit volume and the higher the chance of effective collisions, so the rate increases -- coal burns faster in pure oxygen than in air (21% oxygen), and limestone reacts with hydrochloric acid at a rate that depends on the acid's concentration. Reactants in the gas phase behave the same way with respect to pressure: doubling the pressure of chlorine gas (with hydrogen in excess) doubles the rate of the hydrogen-chlorine reaction, because pressure increases the concentration of gas particles.

Effect of surface area: reactions involving solids occur at their surfaces, so the larger the surface area exposed, the more particles can come into contact and the higher the rate -- finely divided aluminium reacts rapidly with cold aqueous sodium hydroxide, evolving hydrogen gas, while aluminium foil reacts only slowly with warm sodium hydroxide: 2Al(s) + 2NaOH(aq) + 6H2O(l) -> 2NaAl(OH)4(aq) + 3H2(g). Effect of temperature: raising the temperature increases the kinetic energy and hence the velocity of reacting particles, increasing the frequency of successful collisions -- the rate of many reactions roughly doubles for every 10 degC rise, which is why food cooks faster at higher temperature and iron oxidizes far faster when hot than at room temperature.

Effect of a catalyst: a catalyst alters the rate of a reaction without being consumed, by providing an alternative reaction pathway with a substantially lower activation energy -- when the activation energy is lowered, a much larger fraction of reactant particles has enough energy to reach the high-energy state, so the rate increases. Platinum metal, for example, catalyses the addition of hydrogen to ethene by adsorbing both molecules on its surface and weakening their bonds. Enzymes are biological catalysts -- proteins that bind specific reactant molecules at active sites, weaken particular bonds enough for the reaction to occur, then release the product and become free to bind another reactant molecule; their active sites are highly specific, so a given enzyme usually catalyses only one particular reaction.

17.5 Importance of Chemical Kinetics in Food Industry

Studying reaction rates and the factors that affect them plays an important role in the food industry. The rates of reactions involved in food ripening and food spoilage are studied for different fruits and vegetables, and this information helps minimize losses due to spoilage -- food scientists use the rates of enzymatic reactions, oxidation and microbial growth to determine the optimum conditions for harvesting, storage and transportation of food products.

Fruits and vegetables ripen because of enzymatic reactions that convert starches into sugars, soften tissues, and develop characteristic flavour and colour; by monitoring the rate of these reactions -- for example, the rate of ethene production during ripening -- farmers can predict when produce will reach peak quality and is ready for harvesting. Some naturally present enzymes also spoil food by changing its texture, flavour and nutritional value over time, so understanding the rates of these reactions lets producers plan how to slow spoilage -- for instance, using refrigeration to slow the rapid degradation of a fruit that is sensitive to high temperature during transport or storage, or understanding the kinetics of fat oxidation to help prevent the spoilage of butter.

Important Definitions

Define rate of reaction.
The speed at which a chemical reaction takes place, usually measured as the change in concentration of a reactant or product per unit time.

Define an effective collision.
A collision between reacting particles that possesses enough energy and proper orientation to result in the formation of products.

Define collision theory.
The theory that a reaction occurs only when reactant particles collide with sufficient energy (activation energy) and correct orientation, and that the rate of reaction depends on the frequency of such effective collisions.

Define activation energy.
The minimum energy that colliding particles must possess to break the bonds present in the reactant molecules and allow a reaction to occur.

Define an exothermic reaction.
A reaction in which heat energy is released, causing the temperature of the surroundings to increase.

Define an endothermic reaction.
A reaction in which heat energy is absorbed from the surroundings, causing their temperature to decrease.

Define a catalyst.
A substance that alters the rate of a reaction by providing an alternative pathway with a different activation energy, without itself being consumed during the reaction.

Define an enzyme.
A biological catalyst, usually a protein, that speeds up a specific chemical reaction in a living organism by binding the reactant at an active site.

Define collision frequency.
The number of collisions occurring between reactant particles per unit time; a higher collision frequency increases the number of effective collisions.

Define the law of conservation of mass (in a chemical reaction).
The principle that the total mass of the reactants equals the total mass of the products in a chemical reaction, so mass is neither created nor destroyed.

Define concentration (as it affects rate of reaction).
The number of particles of a reactant present per unit volume; a higher concentration increases the rate of a reaction by increasing the chance of effective collisions.

Define surface area (as a rate factor).
The exposed area of a solid reactant available for contact with other reactants; a larger surface area, as in a finely divided solid, increases the rate of reaction.

Define a biosensor.
A device that uses a biological component, such as an enzyme, to detect a specific substance -- for example, enzyme-based biosensors used to detect glucose in blood.

Define potential energy (in the context of a reaction pathway).
The stored energy of a chemical system that rises as colliding particles absorb activation energy to reach the high-energy state, then falls as stable products are formed.

Define kinetic energy (of reacting particles).
The energy a particle possesses due to its motion; it increases with temperature and determines how forcefully and how often particles collide.

Define food ripening (in terms of kinetics).
The set of enzymatic reactions in fruits and vegetables that convert starches into sugars, soften tissues and develop flavour and colour as the produce matures.

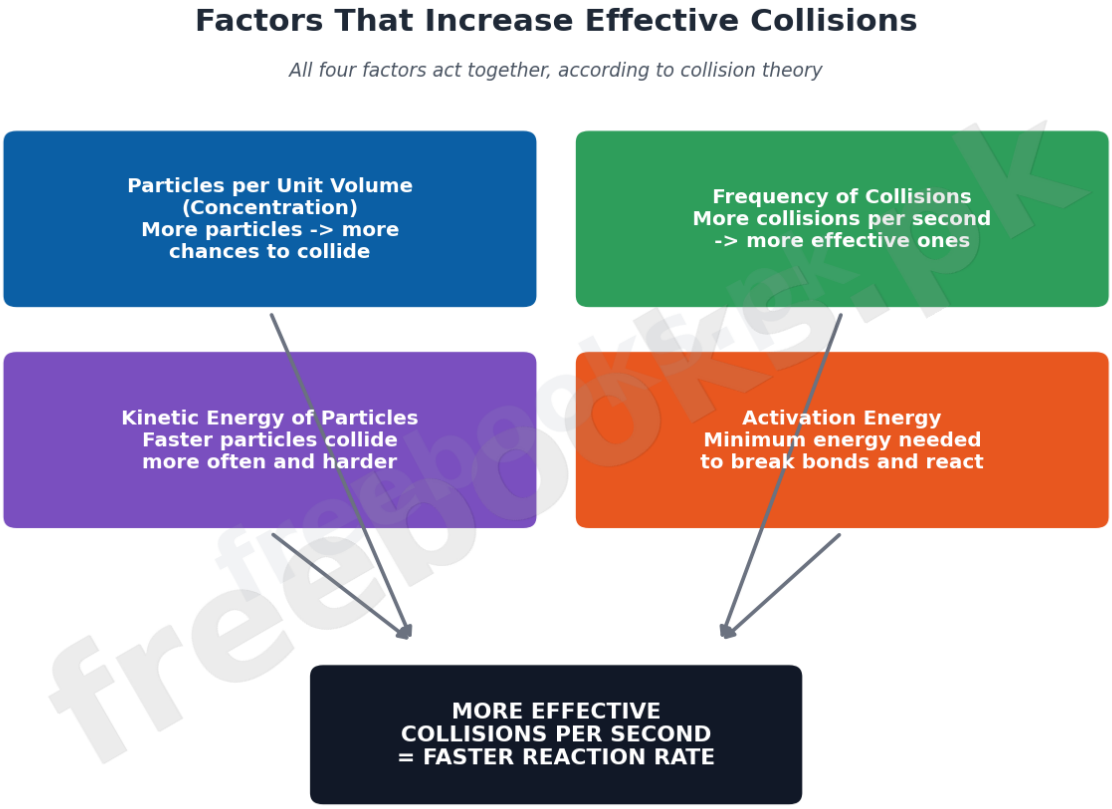
Key Facts & Relations

Topic	Relation
Effect of concentration on rate	Rate increases as concentration of reactants increases
Effect of temperature on rate	Rate roughly doubles for every 10 degC rise in temperature (many reactions)
Effect of pressure on rate (gases)	Rate increases as pressure of gaseous reactants increases
Effect of surface area on rate	Rate increases as surface area of a solid reactant increases
Effect of a catalyst on rate	Catalyst lowers activation energy; rate increases; catalyst is unchanged at the end
Mass-loss example reaction	CaCO3(s) + 2HCl(aq) -> CaCl2(aq) + H2O(l) + CO2(g)

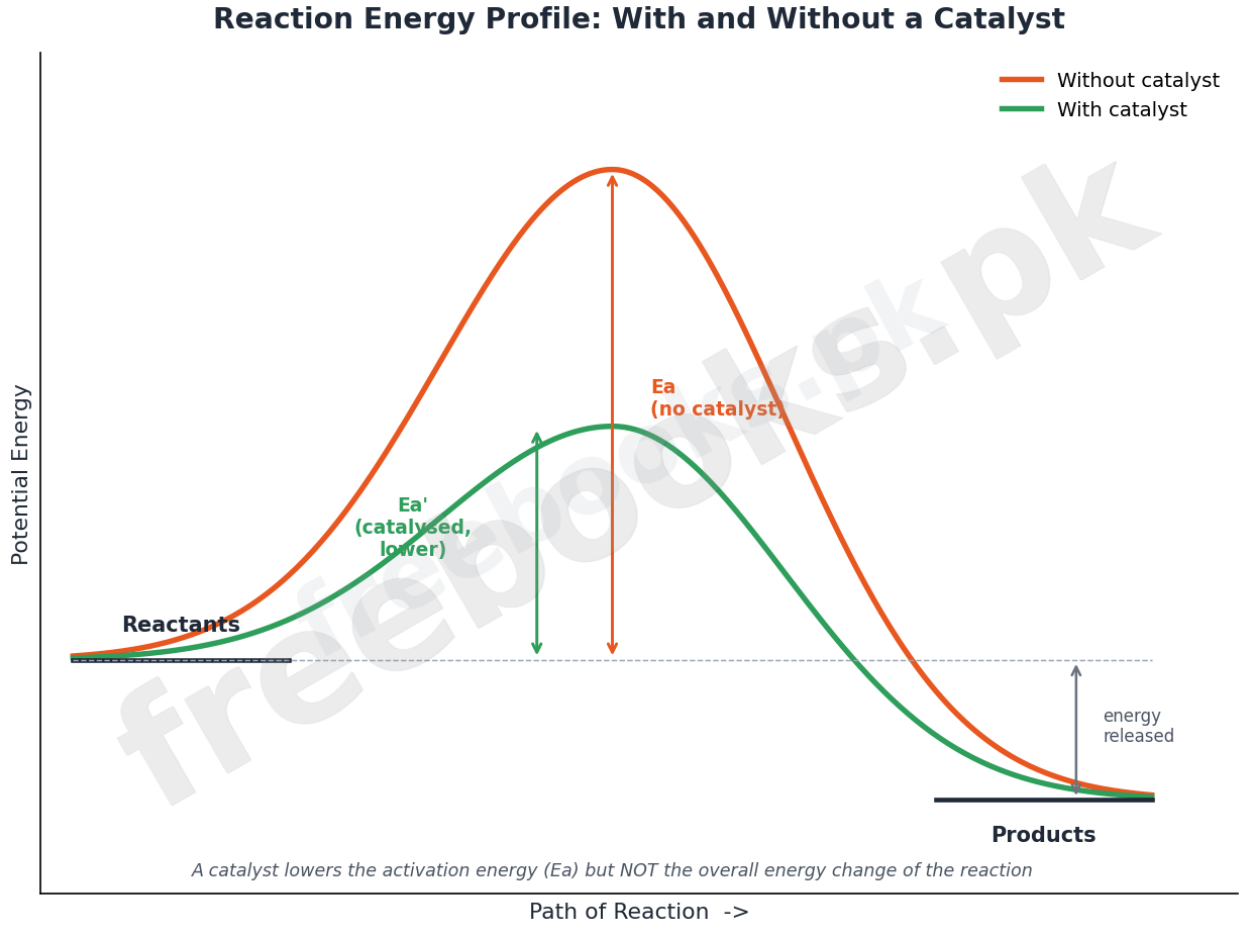
Mass-gain example reaction	2Mg(s) + O2(g) -> 2MgO(s)
Exothermic example reaction	CaO(s) + H2O(l) -> Ca(OH)2(s) (releases heat)

Diagrams

Factors Affecting Collision Theory: A summary diagram of the four factors that increase the number of effective collisions per second: particles per unit volume (concentration), frequency of collisions, kinetic energy of particles, and activation energy.

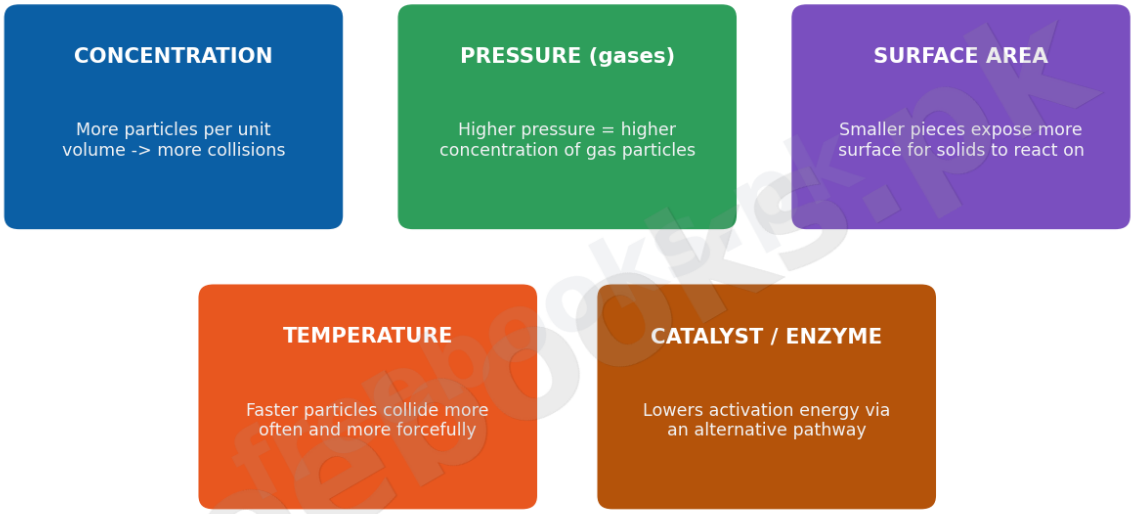


Reaction Energy Profile With and Without a Catalyst: A potential-energy-versus-reaction-path diagram comparing the uncatalysed and catalysed pathways for the same reaction, showing how a catalyst provides an alternative route with a lower activation energy while the overall energy change of the reaction stays the same.



Factors That Change the Rate of Reaction: A grid summarising how concentration, pressure, surface area, temperature and catalysts each increase the rate of reaction, with a short collision-theory reason given for each factor.

Five Factors That Increase the Rate of Reaction



Each factor increases the rate by raising the number of effective collisions per second

Short Questions & Answers

What is a successful (effective) collision?
A collision between reactant particles that has enough energy (equal to or greater than the activation energy) and the correct orientation to result in the formation of products.

How does an increase in temperature increase the rate of a reaction?
Higher temperature increases the kinetic energy and hence the velocity of particles, increasing both the frequency of collisions and the fraction of particles with energy above the activation energy, so more collisions become effective.

Why does the burning of sulphur proceed slower in air than in pure oxygen?
Air contains only about 21% oxygen, so the concentration of oxygen particles per unit volume is lower than in pure oxygen, giving fewer effective collisions per second and a slower rate.

Why is a catalyst preferably used in a finely divided (powdered) form?
A finely divided catalyst has a much larger surface area exposed to the reactants, allowing more reactant particles to be adsorbed and react at once, which increases the rate at which the catalyst can speed up the reaction.

Why is the rate of a reaction often very fast at the beginning of the reaction?
At the start, the concentration of reactants is at its highest, giving the greatest possible number of effective collisions per second; as reactants are used up, their concentration falls and the rate progressively slows down.

Magnesium does not react with air at room temperature but reacts very fast at high temperature, giving intense white light. Explain.

At room temperature, very few magnesium and oxygen particles collide with energy equal to or greater than the activation energy, so the reaction is negligible; at high temperature, particle kinetic energy rises sharply, greatly increasing the frequency and effectiveness of collisions, so the reaction proceeds rapidly and releases a large amount of light and heat.

What happens to the reactants after they climb the energy hill during a reaction?

Once reactant particles reach the top of the energy hill (the high-energy transition state), they descend to form the more stable products, releasing the excess potential energy that was gained during activation.

How does a catalyst lower the activation energy of a reaction?

A catalyst provides an alternative reaction pathway or mechanism, often by adsorbing reactant particles on its surface and weakening the bonds within them, so that a lower amount of energy is needed for the particles to reach the high-energy state and react.

Give two features of the catalytic action of an enzyme.

An enzyme binds its reactant molecule at a specific active site and lowers the activation energy needed for that particular reaction; it is highly specific, usually catalysing only one type of reaction, and is released unchanged once the product has formed.

How does chemical kinetics help determine the best time for fruit harvesting?

By studying the rate at which ripening reactions (such as ethene production) proceed in a fruit, scientists can predict when the fruit will reach its peak quality, allowing harvesting to be timed for the best flavour, texture and shelf life.

Long Questions & Answers

Describe the main points of the collision theory of reaction rate.

What must happen for reactant particles to react, according to collision theory?

Reactant particles (atoms, molecules or ions) must collide with each other; however, only a small fraction of these collisions are effective collisions that actually lead to the formation of products, since the particles must also possess enough energy and the correct orientation.

How does the number of particles per unit volume affect the rate?

The larger the number of reactant particles per unit volume -- that is, the higher the concentration -- the greater the possibility of particles meeting and colliding, so more effective collisions occur per second and the rate of reaction increases.

How does the frequency of collisions affect the rate?

A greater number of collisions occurring per second increases the number of effective collisions among them; at higher temperature, particle velocities increase, which raises the frequency of collisions and therefore the rate.

Why is activation energy central to whether a collision leads to a reaction?

Colliding particles react only if their combined energy is equal to or greater than the activation energy, the minimum energy needed to break bonds in the reactants; only a small fraction of molecules possess this much energy at a given temperature, which is why most collisions are unsuccessful even though particles are constantly colliding.

Discuss the factors affecting the rate of a chemical reaction, explaining each one using collision theory.

How does the concentration of reactants affect the rate of reaction?

Increasing the concentration of reactants raises the number of particles per unit volume, which increases the chance of particles meeting and colliding effectively; this is why coal burns faster in pure oxygen than in ordinary air, which contains only about 21% oxygen.

How does the surface area of a solid reactant affect the rate of reaction?

Reactions involving solids occur only at their exposed surfaces, so increasing the surface area -- for example, by using a powdered solid instead of a large lump -- exposes more particles to collision with the other reactant, increasing the frequency of effective collisions and the overall rate.

How does temperature affect the rate of reaction?

Raising the temperature increases the kinetic energy of the reacting particles, making them move faster; this increases both the frequency of collisions and the fraction of particles with energy equal to or above the activation energy, so the rate of reaction increases, often roughly doubling for every 10 degC rise.

How does a catalyst, including an enzyme, affect the rate of reaction?

A catalyst provides an alternative pathway for the reaction with a lower activation energy, so a much larger proportion of particles can react on collision, increasing the rate without the catalyst itself being used up; an enzyme is a biological catalyst that achieves the same effect by binding its specific reactant at an active site and weakening the bonds that must break.

Multiple Choice Questions (MCQs)

The number of collisions per unit volume of the reaction mixture is called: (A) Collision energy (B) Activation energy (C) Collision frequency (D) Collision force

Correct answer: (C) Collision frequency. Collision frequency is defined as the number of collisions occurring between reactant particles per unit time/volume.

If the reactant particles possess an energy higher than the activation energy, the reaction will be: (A) Slow (B) Fast (C) Not affected (D) Instantaneous

Correct answer: (B) Fast. Particles with energy above the activation energy can react readily on collision, so a greater fraction of high-energy particles gives a faster reaction.

Which of the following explains the increase in rate of reaction in the presence of a catalyst? (A) Catalyst provides extra energy to the reactant molecules (B) Catalyst provides an alternative pathway which lowers the activation energy (C) Catalyst increases the collision frequency directly (D) Catalyst decreases the collision frequency

Correct answer: (B) Catalyst provides an alternative pathway which lowers the activation energy. A catalyst works by opening an alternative reaction pathway with a lower activation energy, not by adding energy to the particles themselves.

Which of the following statements is correct? (A) Collisions with energy equal to or greater than the activation energy lead to reaction (B) Collision frequency is not related to the reaction rate (C) All collisions lead to a reaction (D) Collisions with energy less than the activation energy lead to the reaction

Correct answer: (A) Collisions with energy equal to or greater than the activation energy lead to reaction. Only collisions in which the particles have energy equal to or greater than the activation energy (and correct orientation) are effective and lead to a reaction.

When a reaction proceeds forward, how do the concentrations of reactants and products change? (A) Concentration of reactants increases and that of products decreases (B) Concentration of reactants decreases and that of products increases (C) Concentration of both reactants and products decreases (D) Concentration of both reactants and products increases

Correct answer: (B) Concentration of reactants decreases and that of products increases. As a reaction proceeds, reactants are consumed (their concentration falls) while products accumulate (their concentration rises), until the reaction is complete.

A ribbon of magnesium burnt in an open crucible shows an apparent: (A) Decrease in mass, because a gas escapes (B) Increase in mass, because it combines with oxygen from air (C) No change in mass (D) Decrease in mass, because magnesium evaporates

Correct answer: (B) Increase in mass, because it combines with oxygen from air. Magnesium combines with oxygen from the surrounding air to form MgO, so the solid product's mass is greater than the mass of magnesium alone.

Marble chips reacting with dilute hydrochloric acid in an open container show an apparent decrease in mass because: (A) Hydrochloric acid evaporates (B) Carbon dioxide gas escapes into the atmosphere (C) Marble dissolves completely (D) Water is absorbed from the air

Correct answer: (B) Carbon dioxide gas escapes into the atmosphere. CO_2 gas produced in the reaction escapes from the open container, so the measured mass of the remaining contents appears to decrease even though total mass is conserved.

Doubling the pressure of chlorine gas (with hydrogen present in excess) has what effect on the rate of the hydrogen-chlorine reaction? (A) No effect (B) Roughly doubles the rate (C) Halves the rate (D) Stops the reaction

Correct answer: (B) Roughly doubles the rate. For gaseous reactants, increasing pressure increases the concentration of particles per unit volume, so doubling the pressure of chlorine roughly doubles the reaction rate.

Why does finely divided aluminium react much faster with cold sodium hydroxide solution than aluminium foil does with warm sodium hydroxide? (A) Finely divided aluminium is a different element (B) Finely divided aluminium has a much larger exposed surface area (C) Powdered aluminium is at a higher temperature (D) Aluminium foil is more concentrated

Correct answer: (B) Finely divided aluminium has a much larger exposed surface area. Breaking aluminium into fine particles greatly increases its exposed surface area, allowing many more particles to be in contact with the sodium hydroxide solution at once.

Enzyme-based biosensors are commonly used to detect which substance in blood? (A) Oxygen (B) Glucose (C) Iron (D) Carbon dioxide

Correct answer: (B) Glucose. Enzyme-based biosensors are widely used to detect glucose levels in blood, an application of enzyme specificity and reaction-rate measurement.

Quick Revision Summary

- Rate of reaction depends on the number of effective collisions per second, which needs both enough energy (activation energy) and correct orientation.
- Higher concentration (particles per unit volume) and higher collision frequency both increase the number of effective collisions and therefore the rate.
- Activation energy is the minimum energy colliding particles need to react; only a small fraction of molecules possess this much energy at a given temperature.
- Total mass is always conserved in a reaction; apparent mass changes in open containers are usually caused by a gas escaping (apparent decrease) or being absorbed (apparent increase).
- Exothermic reactions release heat and raise the surrounding temperature; endothermic reactions absorb heat and lower it.

- Rate increases with: higher concentration, higher pressure of gases, larger surface area of solids, higher temperature (often roughly doubling per 10 degC), and the presence of a catalyst.
- A catalyst speeds up a reaction by lowering its activation energy through an alternative pathway, without being consumed; enzymes are specific biological catalysts.
- Chemical kinetics helps the food industry determine ideal harvesting, storage and transportation times by studying the rates of ripening, spoilage and oxidation reactions.

Exam Tips

- When asked to explain any rate-increasing factor, always connect it back to collision theory: does it increase the number of particles colliding, the frequency of collisions, or the fraction of particles with enough energy to react?
- Remember the four collision-theory factors together: particles per unit volume, frequency of collisions, kinetic energy of particles, and activation energy.
- For mass-change questions, first identify whether a gas is a reactant or product and whether the container is open or closed -- that alone tells you whether mass will appear to increase, decrease or stay the same.
- Learn one worked example for each rate factor (concentration: coal in air vs oxygen; surface area: aluminium foil vs powder; temperature: the 10 degC doubling rule; catalyst: platinum with hydrogen and ethene) as model answers.
- A catalyst changes the RATE of a reaction by lowering activation energy -- it never changes the overall energy released or absorbed by the reaction itself, and it is chemically unchanged at the end.
- For food-industry questions, connect the kinetics concept directly to a practical outcome: monitoring ripening rate to decide harvest time, or using refrigeration to slow spoilage reaction rates.

Chapter 18: Salts

Salts are ionic compounds formed when the positive ions from a base and the negative ions from an acid combine, most commonly in a neutralization reaction. This chapter explains why salts arrange themselves into ordered, repeating three-dimensional crystal lattices, using sodium chloride as the model example, and connects this ordered structure to two of the salts' most characteristic properties: very high melting points and the fact that they conduct electricity only when molten or dissolved in water, never as solids.

The chapter then covers the general solubility rules that predict whether a given salt will dissolve in water, before working through the practical laboratory methods used to prepare pure, soluble salts -- reacting a soluble acid with a soluble base (titration), and reacting a soluble acid with an excess of an insoluble base, metal or carbonate -- including the crystallization, filtration and drying steps needed to isolate pure crystals at the end.

Learning Objectives

- Explain that salts are ionic compounds formed due to electrostatic attraction between oppositely charged ions, with positive ions coming from bases and negative ions from acids
- Explain why salts are solids with high melting points at STP
- Describe that under normal conditions, ionic compounds are usually solids with lattice structures
- Explain why the molten and aqueous solutions of salts conduct electricity, by making reference to the idea of mobile ions
- Describe the general solubility rules for salts (sodium, nitrate, potassium and ammonium salts are soluble; chlorides are soluble except lead and silver; carbonates are insoluble except sodium, potassium and ammonium; hydroxides are insoluble except sodium, potassium, ammonium and calcium, which is partially soluble)
- Describe the preparation, separation and purification of soluble salts by reactions of an acid with an alkali (titration), an excess metal, an excess insoluble base, or an excess insoluble carbonate

Key Concepts

18.1 Arrangement of Ions in Salts

When an acid neutralizes a base or an alkali, a salt and water are formed -- for example, sodium hydroxide neutralizes hydrochloric acid to give sodium chloride and water: NaOH(aq) + HCl(aq) -> NaCl(aq) + H2O(l). A salt is a chemical combination of positive

and negative ions held together by the electrostatic force of attraction between them; the strength of this attraction depends on the magnitude of the charges on the ions and the distance between them.

These oppositely charged ions arrange themselves in a regular, repeating pattern to give a three-dimensional network called a crystal lattice, and this ordered structure is responsible for the properties shown by ionic compounds, which exist as crystalline solids under ordinary conditions of temperature and pressure. In sodium chloride, each sodium ion is surrounded by six chloride ions and each chloride ion is surrounded by six sodium ions, forming a face-centred cube in which the larger chloride ions sit at the corners and face-centres of the cube while the smaller sodium ions occupy its edges.

18.2 Melting Points of Ionic Compounds

Very strong electrostatic forces of attraction exist between the ions within a crystal lattice, so a significant amount of energy is needed to break these forces apart -- this is why the melting points of ionic compounds are generally very high. During melting, these attractive forces break down and the ions become free to move.

The melting point of a particular ionic compound depends on the charges present on its ions and their sizes: higher charges and smaller ion sizes lead to stronger electrostatic attractions between the ions, and therefore to higher melting points.

18.3 Conduction of Electricity by Ionic Compounds

Ionic compounds do not conduct electricity in the solid state, but they start conducting electricity in the molten state or when dissolved in water. In the solid state, ions are held tightly in place by strong forces of attraction and are not free to move, so they cannot carry a current.

When an ionic compound is heated to its melting point, its ions become free to move around and the compound starts conducting electricity; similarly, when an ionic compound dissolves in water, the forces of attraction between its ions break down and the ions become free to move independently through the solution. Because ionic compounds dissociate completely into ions when dissolved in water, they serve as strong electrolytes.

18.4 Soluble and Insoluble Salts

The solubility of a salt in water depends on several factors, including the nature of the salt and the temperature, but general rules can predict solubility for most common salts. All sodium, potassium and ammonium salts are soluble, as are all metallic nitrates; most chlorides and sulfates are also soluble, except for the chlorides of silver and lead, and the sulfates of barium, lead and calcium.

In contrast, all carbonates are insoluble in water except for the carbonates of sodium, potassium and ammonium. Among hydroxides, only sodium hydroxide, potassium

hydroxide and ammonium hydroxide are freely soluble, calcium hydroxide is only partially soluble, and all other hydroxides are insoluble in water.

18.5 Preparation of Soluble Salts

Soluble salts can be prepared by reacting a water-soluble acid with a water-soluble base (a method also called titration): the acid and base are chosen based on the salt required -- for example, potassium nitrate is prepared by reacting appropriate volumes of potassium hydroxide and nitric acid: KOH(aq) + HNO3(aq) -> KNO3(aq) + H2O(l). The resulting solution of salt and water is transferred to an evaporating dish and either evaporated to dryness (if the salt is heat-stable) or heated gently until a thin film of crystals forms on the surface, then cooled slowly so that pure crystals form, which are then filtered out and dried between the folds of filter paper.

Alternatively, a soluble acid can be reacted with an excess of an insoluble base, metal or carbonate -- also a form of neutralization (or, for a metal, a displacement reaction that also produces hydrogen gas). The insoluble reactant is always added in excess to ensure that all of the acid has reacted completely, then the mixture is filtered to remove the unreacted excess; the filtrate is evaporated to give a saturated solution, which is cooled to allow pure crystals to form, then filtered and dried. Examples include Cu(OH)2(s) + 2HCl(aq) -> CuCl2(aq) + 2H2O(l), Mg(s) + H2SO4(aq) -> MgSO4(aq) + H2(g), and CaCO3(s) + 2HCl(aq) -> CaCl2(aq) + CO2(g) + H2O(l).

In a titration-based preparation, an indicator such as phenolphthalein is often used to judge the exact point of neutralization during a first trial run, and the experiment is then repeated using the same measured volumes but without the indicator, so that the final salt solution is not contaminated by indicator dye before it is evaporated and crystallized.

Important Definitions

Define a salt.
An ionic compound formed by the electrostatic attraction between positive ions, usually from a base, and negative ions, usually from an acid, commonly produced in a neutralization reaction.

Define a neutralization reaction.
A reaction in which an acid reacts with a base or alkali to form a salt and water.

Define a crystal lattice.
A regular, repeating three-dimensional arrangement of positive and negative ions in an ionic solid, held together by electrostatic forces of attraction.

Define electrostatic force of attraction (in an ionic compound).
The force of attraction between oppositely charged ions, whose strength depends on the magnitude of the charges on the ions and the distance between them.

Define an electrolyte.

A substance that, in the molten state or dissolved in water, conducts electricity by allowing its ions to move freely; ionic compounds are strong electrolytes because they dissociate completely into ions in water.

Define solubility (of a salt).
The extent to which a salt dissolves in a given solvent, usually water, under specified conditions; it depends on the nature of the salt and the temperature.

Define titration (as a salt-preparation method).
A method of preparing a soluble salt by reacting measured volumes of a water-soluble acid and a water-soluble base together until they are exactly neutralized.

Define an insoluble base.
A base, such as certain metal oxides, carbonates or hydroxides, that does not dissolve appreciably in water and can be reacted with excess acid to prepare a soluble salt.

Define crystallization.
The process by which pure solid crystals of a salt form and separate out from a cooled, saturated solution.

Define a saturated solution.
A solution that contains the maximum amount of a dissolved solute possible at a given temperature, such that no more solute will dissolve into it.

Define filtration (in salt preparation).
The process of separating an insoluble solid, such as excess unreacted base or metal, or the crystals of a prepared salt, from a liquid by passing the mixture through a filter.

Define an indicator (in salt preparation).
A substance, such as phenolphthalein, that changes colour to show when a titration reaction between an acid and a base has reached the point of exact neutralization.

Define a face-centred cubic lattice.
A crystal lattice arrangement, as seen in sodium chloride, in which ions occupy the corners and the centres of each face of a cube, with other ions occupying the edges between them.

Define evaporation (in salt preparation).
The process of heating a salt solution to drive off water as vapour, concentrating the solution until crystals begin to form or the salt is left completely dry.

Define a strong electrolyte.
An electrolyte that dissociates completely into its constituent ions when dissolved in water, allowing it to conduct electricity efficiently; ionic compounds such as salts are strong electrolytes.

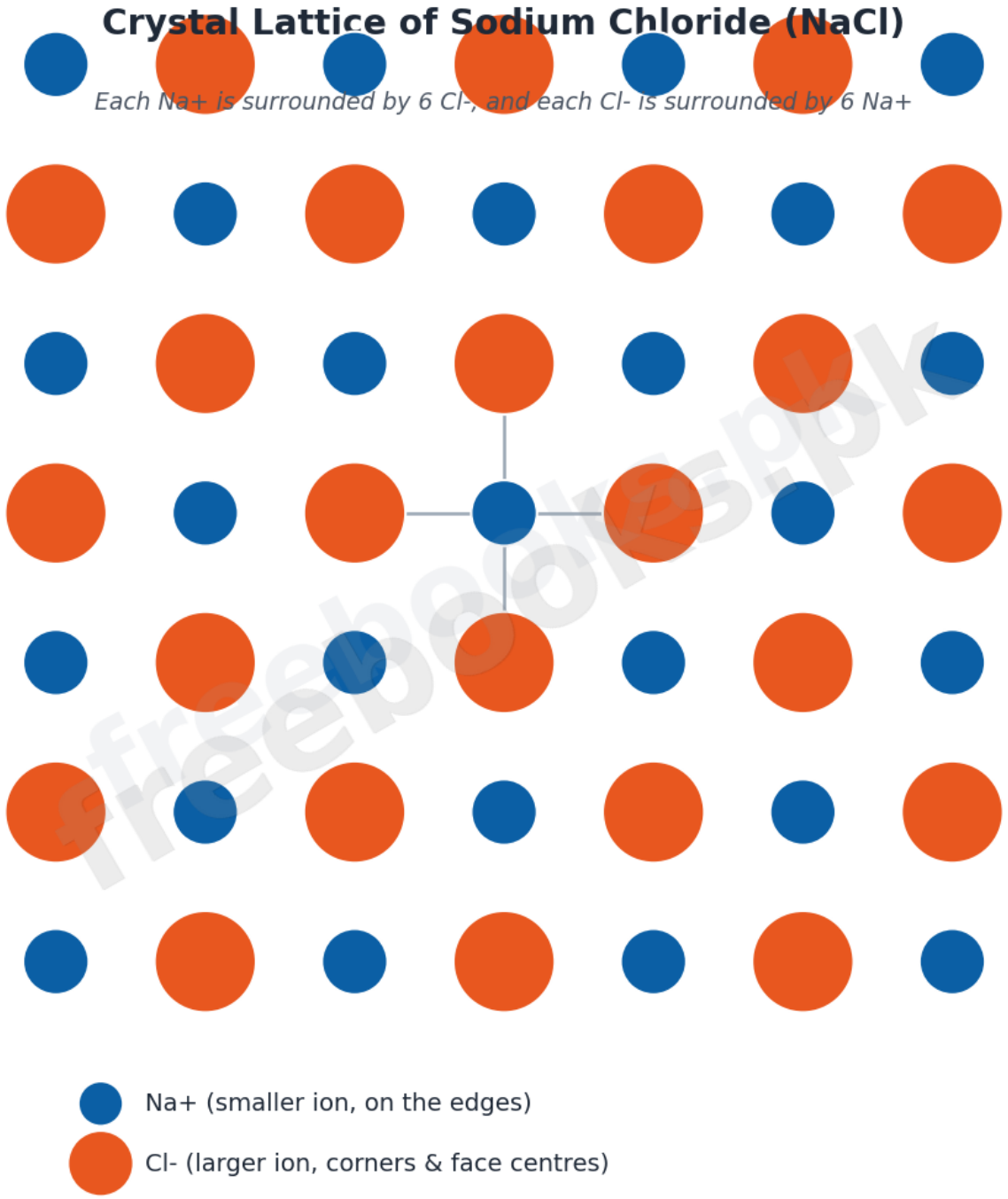
Define the general solubility rule for carbonates.
All carbonates are insoluble in water except the carbonates of sodium, potassium and ammonium.

Key Facts & Relations

Topic	Relation
Neutralization (general)	Acid + Base -> Salt + Water
Soluble salts (always)	Salts of sodium, potassium, ammonium; all nitrates
Chlorides	Soluble, except silver chloride and lead(II) chloride
Sulphates	Soluble, except barium, lead(II) and calcium sulphate
Carbonates	Insoluble, except sodium, potassium and ammonium carbonate
Hydroxides	Insoluble, except sodium, potassium, ammonium (soluble) and calcium (partially soluble)
Titration example	KOH(aq) + HNO3(aq) -> KNO3(aq) + H2O(l)
Acid + insoluble base/metal example	Mg(s) + H2SO4(aq) -> MgSO4(aq) + H2(g)

Diagrams

Crystal Lattice of Sodium Chloride: A schematic of the repeating, alternating arrangement of sodium and chloride ions in the NaCl crystal lattice, showing each ion surrounded by six oppositely charged neighbours.

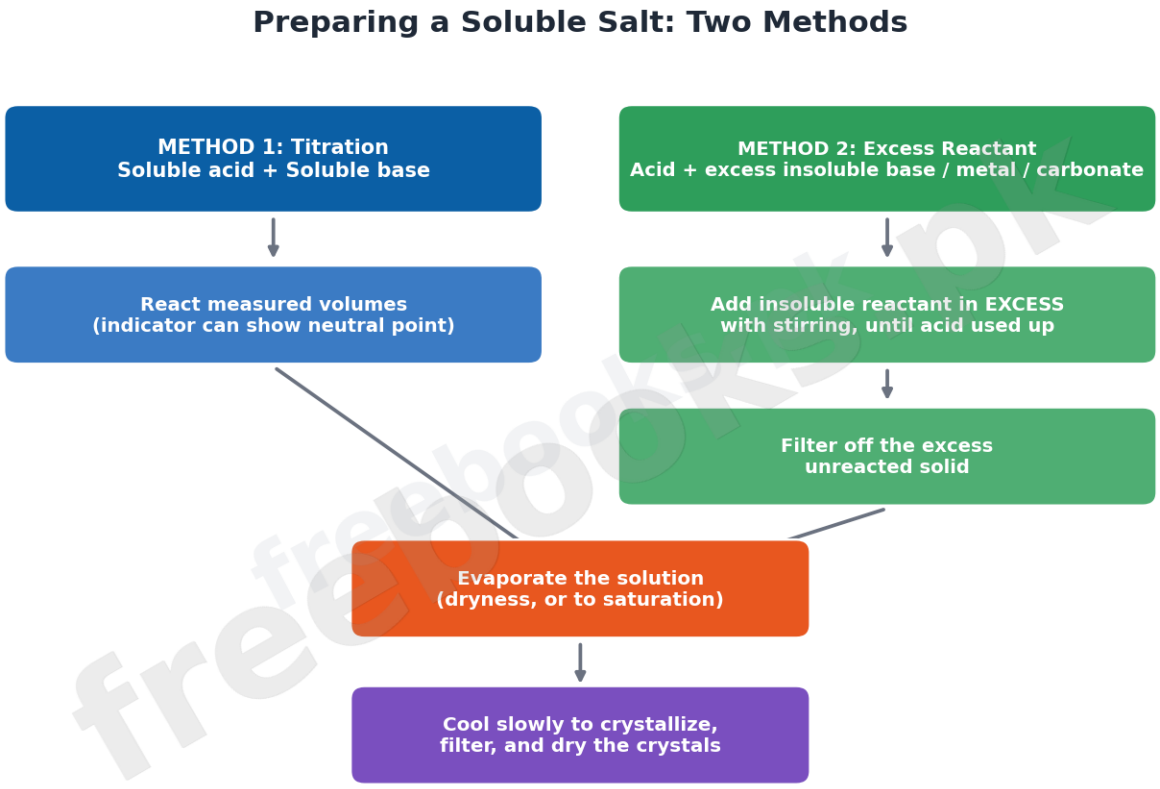


Solubility Rules for Common Salts: A summary chart of the general solubility rules covering nitrates, chlorides, sulphates, carbonates and hydroxides, with their soluble and insoluble exceptions.

Solubility Rules for Common Salts

Solubility also depends on temperature, but these general rules cover most common salts

Preparing a Soluble Salt: Two Methods: A flowchart comparing the titration method (soluble acid + soluble base) with the excess-reactant method (soluble acid + excess insoluble base, metal or carbonate), both ending in evaporation, cooling, filtration and drying to obtain pure crystals.



Both methods end the same way: pure salt crystals, filtered and dried

Short Questions & Answers

Which factors are responsible for the strength of electrostatic forces between ions?

The magnitude of the charges on the ions and the distance between them; higher charges and smaller ion sizes (shorter distances) give stronger electrostatic forces.

Is lead(II) chloride soluble in water?

No, lead(II) chloride is one of the two exceptions to the general rule that chlorides are soluble in water, the other being silver chloride.

Which lead salts are insoluble in water?

Lead(II) chloride, lead(II) sulphate and lead(II) carbonate are all insoluble in water, following the general solubility rules for chlorides, sulphates and carbonates respectively.

Name two insoluble carbonates.

Calcium carbonate and magnesium carbonate are both insoluble in water, since only sodium, potassium and ammonium carbonates are soluble.

What is a crystal lattice?

A regular, repeating three-dimensional arrangement of positive and negative ions in an ionic solid, held together by electrostatic forces of attraction between the ions.

Do you expect the melting point of KCl to be higher or lower than that of NaCl?

Lower, because the potassium ion is larger than the sodium ion, giving a greater distance between the oppositely charged ions and therefore a weaker electrostatic attraction and a lower melting point.

Which salts of barium and calcium are soluble in water?

Barium and calcium salts of chloride and nitrate are soluble, but their sulphates and carbonates are insoluble; calcium hydroxide is only partially soluble.

How is barium sulphate prepared in the laboratory?

By mixing solutions containing barium ions and sulphate ions, such as barium chloride and sodium sulphate or dilute sulphuric acid, since barium sulphate is insoluble and precipitates immediately out of solution.

Why don't ionic compounds conduct electricity in the solid state?

Because their ions are held tightly in fixed positions within the crystal lattice by strong electrostatic forces and are not free to move, so no charge can flow through the solid.

Why is an insoluble base or metal always added in excess when preparing a soluble salt this way?

To make sure that all of the acid present has fully reacted, so that the final filtrate contains only the pure salt and water, with no leftover acid to contaminate the crystals.

Long Questions & Answers

Explain the formation and structure of a sodium chloride crystal.

How is sodium chloride formed as a salt?

Sodium hydroxide (a base) reacts with hydrochloric acid in a neutralization reaction, producing sodium ions from the base and chloride ions from the acid, which then combine by electrostatic attraction to form solid sodium chloride and water: NaOH(aq) + HCl(aq) -> NaCl(aq) + H2O(l).

What holds the sodium and chloride ions together in the solid?

The oppositely charged sodium and chloride ions are held together by the electrostatic force of attraction between them; this attraction is strong enough that the ions arrange themselves into a fixed, ordered structure rather than remaining randomly mixed.

How are the ions arranged in the crystal lattice of sodium chloride?

The ions form a regular, repeating three-dimensional network called a crystal lattice, shaped as a face-centred cube; the larger chloride ions occupy the corners and the centres of each face of the cube, while the smaller sodium ions occupy the edges, with each sodium ion surrounded by six chloride ions and each chloride ion surrounded by six sodium ions.

How does this lattice structure explain sodium chloride's physical properties?

Because the electrostatic forces throughout the whole lattice are very strong, a large amount of energy is needed to break them apart, giving sodium chloride a high melting point; and because the ions are fixed in place in the solid lattice, solid sodium chloride cannot conduct electricity, only doing so once melted or dissolved and its ions are set free to move.

Explain the methods used to prepare soluble salts in the laboratory, using an example for each.

How is a soluble salt prepared by titration?

A measured volume of a water-soluble acid is reacted with a measured volume of a water-soluble base until the two exactly neutralize each other, often judged using an indicator such as phenolphthalein in a trial run; for example, potassium nitrate is prepared from potassium hydroxide and nitric acid: KOH(aq) + HNO3(aq) -> KNO3(aq) + H2O(l).

How is a soluble salt prepared using an excess insoluble base, metal or carbonate?

A soluble acid is reacted with an excess of an insoluble base, metal or carbonate, added gradually with stirring, until no more of the acid reacts; for example, magnesium sulphate is prepared from excess magnesium metal and dilute sulphuric acid: Mg(s) + H2SO4(aq) -> MgSO4(aq) + H2(g).

What steps are common to both methods after the reaction is complete?

Any excess unreacted base, metal or carbonate is removed by filtration, and the resulting solution (or filtrate) is evaporated, either to dryness or until a saturated solution forms, so that the salt is concentrated enough to begin crystallizing out as it cools.

Why are the final crystals filtered and dried carefully, and why might the solution be cooled slowly?

Cooling slowly allows large, well-formed, pure crystals to grow out of the saturated solution rather than a mass of small impure ones; filtering separates these crystals from the remaining liquid, and drying them between the folds of filter paper (or in an oven) removes surface moisture without dissolving or damaging the crystals.

Multiple Choice Questions (MCQs)

Which base is not soluble in water? (A) KOH (B) Mg(OH)2 (C) NaOH (D) Na2CO3

Correct answer: (B) Mg(OH)2. Magnesium hydroxide is insoluble in water; only sodium, potassium, ammonium hydroxides are soluble, and calcium hydroxide is only partially soluble.

The shape of the crystal lattice of NaCl is: (A) Cubic (B) Hexagonal (C) Rhombic (D) Trigonal

Correct answer: (A) Cubic. Sodium chloride crystallizes in a cubic (face-centred cubic) lattice structure.

Which salts are always soluble in water? (A) Chlorides (B) Sulphates (C) Nitrates (D) Carbonates

Correct answer: (C) Nitrates. All metallic nitrates are soluble in water without exception, unlike chlorides, sulphates and carbonates, which each have specific insoluble exceptions.

Which salt will be formed when marble chips react with dilute nitric acid? (A) Sodium nitrate (B) Calcium nitrate (C) Potassium nitrate (D) Magnesium nitrate

Correct answer: (B) Calcium nitrate. Marble is calcium carbonate; reacting it with nitric acid produces calcium nitrate, water and carbon dioxide gas.

Which of the following is a water-insoluble salt? (A) Calcium sulphate (B) Sodium sulphate (C) Potassium sulphate (D) Magnesium sulphate

Correct answer: (A) Calcium sulphate. Calcium sulphate is one of the exceptions to the general rule that sulphates are soluble in water.

A salt's melting point tends to be higher when its ions have: (A) Lower charges and larger sizes (B) Higher charges and smaller sizes (C) Higher charges and larger sizes (D) Lower charges and smaller sizes

Correct answer: (B) Higher charges and smaller sizes. Higher ionic charges and smaller ion sizes both increase the strength of electrostatic attraction in the lattice, raising the melting point.

Why does molten NaCl conduct electricity but solid NaCl does not? (A) Molten NaCl contains different ions than solid NaCl (B) In the molten state, ions are free to move and carry charge (C) Solid NaCl has no ions at all (D) Molten NaCl is not really NaCl

Correct answer: (B) In the molten state, ions are free to move and carry charge. Melting breaks down the fixed lattice structure and frees the ions to move, which is what allows a substance to conduct electricity.

In the preparation of a soluble salt using an insoluble base, why is the base added in excess? (A) To make the reaction go faster (B) To ensure all the acid has fully reacted (C) To change the colour of the solution (D) To increase the melting point of the salt

Correct answer: (B) To ensure all the acid has fully reacted. Adding the insoluble base in excess ensures that all of the acid is consumed, so the resulting solution and crystals are not contaminated with unreacted acid.

Which of the following pairs would react to prepare a soluble salt by titration? (A) Nitric acid and copper metal (B) Sulphuric acid and magnesium carbonate (C) Hydrochloric acid and sodium hydroxide solution (D) Nitric acid and calcium carbonate

Correct answer: (C) Hydrochloric acid and sodium hydroxide solution. Titration specifically means reacting a soluble acid with a soluble base/alkali; hydrochloric acid and sodium hydroxide solution are both water-soluble.

Which step in preparing a soluble salt from excess insoluble base removes the unreacted excess? (A) Evaporation (B) Crystallization (C) Filtration (D) Cooling

Correct answer: (C) Filtration. Filtration separates the insoluble unreacted excess base, metal or carbonate from the salt solution before it is evaporated and crystallized.

Quick Revision Summary

- A salt is an ionic compound formed by electrostatic attraction between positive ions from a base and negative ions from an acid, usually in a neutralization reaction.
- Ions arrange themselves into a regular, repeating crystal lattice; in NaCl this is a face-centred cube with each ion surrounded by six oppositely charged neighbours.
- Strong electrostatic forces throughout the lattice give ionic compounds high melting points; stronger attraction (higher charge, smaller ion size) means a higher melting point.
- Ionic compounds do not conduct electricity as solids (ions fixed in place) but do conduct when molten or dissolved in water (ions free to move); they are strong electrolytes.
- Solubility rules: Na/K/NH4 salts and all nitrates are always soluble; chlorides are soluble except AgCl and PbCl2; sulphates are soluble except BaSO4, PbSO4, CaSO4; carbonates are insoluble except Na2CO3, K2CO3, (NH4)2CO3; hydroxides are insoluble except NaOH, KOH, NH4OH (soluble) and Ca(OH)2 (partially soluble).
- Soluble salts are prepared by titration (soluble acid + soluble base) or by reacting a soluble acid with excess insoluble base, metal, or carbonate.
- After the reaction: filter to remove any excess insoluble reactant, evaporate the filtrate to concentrate it, cool to crystallize, filter again, then dry the crystals.
- An indicator such as phenolphthalein helps judge the neutralization point during titration; the reaction is often repeated without indicator so the final crystals are not contaminated.

Exam Tips

- Memorize the solubility rules as a short checklist: Na/K/NH4/nitrate = always soluble; Cl = soluble except Ag, Pb; SO4 = soluble except Ba, Pb, Ca; CO3 = insoluble except Na, K, NH4; OH = insoluble except Na, K, NH4 (soluble), Ca (partial).

- When asked why ionic melting points are high, always mention BOTH ideas: strong electrostatic forces throughout the lattice, AND the amount of energy needed to break them.
- When asked why solid salts don't conduct but molten/dissolved salts do, the key word to include every time is 'mobile' or 'free to move' ions.
- For salt-preparation questions, always name which method fits: soluble acid + soluble base = titration; soluble acid + excess insoluble base/metal/carbonate = the other method (filter off the excess afterward).
- Remember the standard sequence for salt preparation from excess insoluble reactant: react with excess -> filter -> evaporate -> cool/crystallize -> filter -> dry.
- Learn one full worked equation for each preparation method (KOH + HNO3 for titration; Mg + H2SO4 for excess metal) as model answers you can adapt to any similar salt.

Chapter 19: Nitrogen and Sulphur

This chapter covers two of the most important industrial chemicals -- ammonia, made by the Haber process, and sulphuric acid, made by the Contact process -- along with the sources, conditions and equations used in each. It then classifies oxides as acidic, basic, neutral or amphoteric based on how they behave with acids, bases and water, connecting this classification to whether an element is metallic or non-metallic in character.

The chapter then surveys the general chemical properties of metals -- their reactions with cold water, steam, dilute acids and oxygen -- and uses these reactions to build the reactivity series of metals. It closes by examining the environmental role of oxides of nitrogen (NOx), explaining how they contribute to photochemical smog (through peroxyacetyl nitrate, PAN) and to acid rain, both directly and through their catalytic role in oxidizing atmospheric sulphur dioxide.

Learning Objectives

- Recognize that atmospheric oxides of nitrogen (NO and NO2) can react with unburned hydrocarbons to form peroxyacetyl nitrate (PAN), a component of photochemical smog
- Describe the role of NO and NO2 in the formation of acid rain, both directly and through their catalytic role in the oxidation of atmospheric sulphur dioxide
- State the symbol equation for the production of ammonia in the Haber process, and the sources of nitrogen (air) and hydrogen (methane), along with the typical conditions (450 degC, about 20000 kPa/20 atm, iron catalyst)
- State the symbol equation for the conversion of sulphur dioxide to sulphur trioxide in the Contact process, and the sources of sulphur dioxide (burning sulphur or roasting sulphide ores) and oxygen (air), along with the typical conditions (450 degC, about 200 kPa/atm, vanadium(V) oxide catalyst)
- Describe amphoteric oxides as oxides that react with both acids and bases to produce a salt and water, and classify oxides as acidic (SO2, CO2), basic (CuO, CaO) or amphoteric (Al2O3, ZnO), relating this to metallic and non-metallic character
- Identify the general chemical properties of metals in their reactions with dilute acids, cold water, steam and oxygen, and arrange metals in order of reactivity given relevant information

Key Concepts

19.1 Ammonia (The Haber Process)

Ammonia is one of the most important chemicals produced globally, with about 80% of it used to make urea and other ammonium salts as fertilizers; it is also used in plastics,

pharmaceuticals and as a refrigerant. It is manufactured industrially by the Haber process: nitrogen and hydrogen gases, in a 1:3 ratio by volume, are heated to about 400-500 degC under about 200 atmospheres of pressure in the presence of an iron-based catalyst (Fe/Al2O3): N2(g) + 3H2(g) <=> 2NH3(g).

The equilibrium mixture contains about 35% ammonia by volume. This mixture is cooled by refrigeration until ammonia liquefies at -33.4 degC and is removed, while the unreacted nitrogen and hydrogen are recycled back into the reaction chamber. Nitrogen is obtained from the fractional distillation of liquefied air, since it boils off at -196 degC before oxygen does; hydrogen is obtained by heating methane in a limited supply of oxygen (giving mainly CO and H2), then reacting the carbon monoxide produced with steam to release more hydrogen: CH4(g) + H2O(g) -> CO(g) + 3H2(g), followed by CO(g) + H2O(g) -> CO2(g) + H2(g).

19.2 Sulphuric Acid (The Contact Process)

Sulphuric acid, sometimes called the 'king of chemicals', is used directly or indirectly in almost every manufacturing process, and is prepared industrially by the Contact process in four stages. First, sulphur dioxide is produced either by burning elemental sulphur in air, S(s) + O2(g) -> SO2(g), or by roasting the sulphide ore iron pyrite in excess air, 4FeS2(s) + 11O2(g) -> 2Fe2O3(s) + 8SO2(g); the gas is then purified (removing dust and arsenic compounds that would poison the catalyst) and dried using concentrated sulphuric acid.

Second, the clean, dry SO2 and O2 gases are passed over a vanadium(V) oxide catalyst at about 450 degC and 2-3 atmospheres in a contact chamber; although the reaction is reversible, about 98% of the SO2 is converted to SO3 under these conditions: 2SO2(g) + O2(g) -> 2SO3(g). Third, the SO3 gas is absorbed into 98% sulphuric acid (rather than water, to avoid a dangerous, hard-to-condense acid mist) to give oleum: SO3(g) + H2SO4(l) -> H2S2O7(l). Finally, the oleum is diluted with the appropriate amount of water to give sulphuric acid of the desired concentration: H2S2O7(l) + H2O(l) -> 2H2SO4(l).

19.3 Oxides

An oxide is a binary compound of an element with oxygen, in which oxygen usually shows an oxidation state of -2. Metal oxides are typically ionic and are commonly basic or amphoteric, while non-metal oxides are typically covalent and acidic; both form when the corresponding element is heated in air or oxygen. Basic oxides are formed by metals; when dissolved in water they produce hydroxides that turn red litmus blue, and they react with acids to give a salt and water -- for example Na2O(s) + H2O(l) -> 2NaOH(aq), and CaO(s) + 2HCl(aq) -> CaCl2(aq) + H2O(l).

Acidic oxides are formed by non-metals such as sulphur, carbon and nitrogen; they react with water to give acids that turn blue litmus red, and react with bases to give a salt and water -- for example SO2(g) + H2O(l) -> H2SO3(l) (sulphurous acid), and SO2(g) + 2NaOH(aq) -> Na2SO3 + H2O (sodium sulphite). Neutral oxides, such as

carbon monoxide, nitric oxide and nitrous oxide, produce neither an acid nor a base with water and have no effect on litmus paper.

Amphoteric oxides, usually formed by less electropositive metals such as zinc and aluminium, react as a base in the presence of an acid and as an acid in the presence of an alkali, giving a salt and water either way -- for example ZnO(s) + 2HCl(aq) -> ZnCl2(aq) + H2O(l) (acting as a base), and ZnO(s) + 2NaOH(aq) + H2O(l) -> Na2Zn(OH)4(aq) (sodium zincate, acting as an acid). Amphoteric oxides are insoluble in water and have no effect on litmus paper by themselves.

19.4 Metals

Nearly three-quarters of the elements in the periodic table are metals, most occurring in the earth's crust as oxides, hydroxides, carbonates or sulphides; metals tend to lose electrons to form cations and usually form ionic bonds. Reaction with cold water: group 1 and most group 2 metals react vigorously with cold water to give a hydroxide and hydrogen gas, for example 2Na(s) + 2H2O(l) -> 2NaOH(aq) + H2(g); magnesium reacts only slowly with cold water.

Reaction with steam: the more reactive the metal, the more readily it reacts with steam -- lithium, sodium, potassium and calcium react violently (and dangerously) with steam; beryllium and aluminium react with steam only at high temperature (about 700 degC) to give an oxide and hydrogen, for example Be(s) + H2O(g) -> BeO(s) + H2(g); magnesium, iron and zinc react moderately with steam to give their oxides and hydrogen.

Reaction with oxygen: metals react with oxygen to give metal oxides, with the ease of reaction and flame colour depending on the metal's reactivity -- sodium burns with a yellow flame to give both sodium oxide and sodium peroxide, while magnesium burns with an intense white flame, calcium with a white flame tinged red, strontium with a crimson flame and barium with a pale green flame, each giving its characteristic oxide. Reaction with dilute acids: the more reactive the metal, the more vigorous its reaction with dilute acids, giving a salt and hydrogen gas -- sodium and potassium react violently and dangerously, for example 2Na(s) + 2HCl(aq) -> 2NaCl(aq) + H2(g), while all group 2 metals react, generally more vigorously further down the group, for example Mg(s) + 2HCl(aq) -> MgCl2(aq) + H2(g).

19.5 Reactivity Series of Metals

Based on their reactions with water and acids, metals can be arranged in decreasing order of reactivity, called the reactivity series: potassium, sodium, lithium, barium, strontium, calcium, magnesium, aluminium, carbon, manganese, zinc, iron, hydrogen, copper, silver, gold (from most to least reactive; carbon and hydrogen are included as reference points even though they are non-metals). Calcium and the metals above it react with cold water to give a metal hydroxide and hydrogen; metals below calcium do not react with cold water but do react with steam to give a metal oxide and hydrogen.

Only metals above hydrogen in the series can liberate hydrogen gas when reacting with dilute acids, and the more reactive the metal, the more vigorous this reaction is; unreactive metals below hydrogen, such as copper, silver and gold, do not react with dilute acids at all. Similarly, more reactive metals react with oxygen more readily than less reactive ones. Because the metals at the top of the series are easily oxidized (they readily lose electrons), they act as powerful reducing agents, and this reducing ability decreases going down the series -- allowing a more reactive metal to displace a less reactive one from its salt solution, for example Zn(s) + CuSO4(aq) -> ZnSO4(aq) + Cu(s).

19.6 Role of Oxides of Nitrogen in Air Pollution

Primary pollutants such as oxides of nitrogen, sulphur and carbon, along with various hydrocarbons, are converted by reactions in the atmosphere into secondary pollutants, including ozone, peroxyacetyl nitrate (PAN) and sulphuric acid -- all of which are toxic and need to be controlled. Oxides of nitrogen (NOx, meaning NO and NO2) come from both natural sources (electrical discharges during lightning, which convert atmospheric nitrogen and oxygen into nitric oxide that is then rapidly oxidized to nitrogen dioxide) and human sources (combustion of fossil fuels in vehicles, industrial processes, power plants, and agricultural activities and fertilizers).

Ultraviolet radiation in sunlight drives a complex series of reactions between NOx and volatile organic compounds (VOCs, especially unburned hydrocarbons) to produce secondary pollutants such as ozone, aldehydes and peroxyacetyl nitrate (PAN) -- together forming photochemical smog. Oxides of nitrogen also contribute directly to acid rain: NO2 reacts with water vapour and other atmospheric chemicals to form nitric and nitrous acid vapours, 2NO2(g) + H2O(l) -> HNO3(g) + HNO2(g), which then mix with water vapour and fall as acid rain.

In addition to this direct role, NOx acts as a catalyst that speeds up the oxidation of another primary pollutant, sulphur dioxide, into sulphur trioxide, which then reacts with water vapour to form sulphuric acid -- another major component of acid rain: 2SO2(g) + O2(g) -[oxides of nitrogen]-> 2SO3(g), followed by SO3(g) + H2O(g) -> H2SO4(g). Acid rain, with a pH below 5.6, damages ecosystems, corrodes materials and can cause respiratory problems.

Important Definitions

Define the Haber process.
The industrial process for manufacturing ammonia by reacting nitrogen and hydrogen gas in a 1:3 ratio at about 400-500 degC and about 200 atmospheres pressure, using an iron-based catalyst: N2(g) + 3H2(g) <=> 2NH3(g).

Define the Contact process.

The industrial process for manufacturing sulphuric acid, in which sulphur dioxide is produced, purified, oxidized to sulphur trioxide over a vanadium(V) oxide catalyst, absorbed into concentrated sulphuric acid to form oleum, and then diluted with water.

Define oleum.
A concentrated, fuming form of sulphuric acid ($H_2S_2O_7$) formed when sulphur trioxide gas is absorbed into 98% sulphuric acid during the Contact process.

Define an oxide.
A binary compound of an element with oxygen, in which oxygen usually shows an oxidation state of -2.

Define a basic oxide.
An oxide, usually formed by a metal, that dissolves in water to form a hydroxide (turning red litmus blue) and reacts with an acid to form a salt and water.

Define an acidic oxide.
An oxide, usually formed by a non-metal, that reacts with water to form an acid (turning blue litmus red) and reacts with a base to form a salt and water.

Define a neutral oxide.
An oxide that produces neither an acid nor a base when in contact with water and has no effect on litmus paper, such as carbon monoxide, nitric oxide and nitrous oxide.

Define an amphoteric oxide.
An oxide that reacts with both acids and bases to produce a salt and water, behaving as a base towards an acid and as an acid towards an alkali; examples are zinc oxide and aluminium oxide.

Define the reactivity series of metals.
An arrangement of metals in decreasing order of reactivity, based on their reactions with cold water, steam, dilute acids and oxygen.

Define a reducing agent (in the context of metals).
A substance, such as a reactive metal, that is easily oxidized (loses electrons readily) and thereby causes another substance to be reduced.

Define a displacement reaction (of a metal).
A reaction in which a more reactive metal displaces a less reactive metal from a solution of its salt, as in $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$.

Define a primary pollutant.
A pollutant, such as oxides of nitrogen, sulphur or carbon, or unburned hydrocarbons, that is released directly into the atmosphere.

Define a secondary pollutant.
A pollutant, such as ozone, peroxyacetyl nitrate (PAN) or sulphuric acid, formed in the atmosphere by chemical reactions between primary pollutants.

Define peroxyacetyl nitrate (PAN).

A secondary air pollutant and major component of photochemical smog, formed when oxides of nitrogen react with unburned hydrocarbons in the presence of sunlight.

Define acid rain.

Rainfall with a pH below 5.6, made acidic mainly by nitric acid and sulphuric acid formed from atmospheric oxides of nitrogen and sulphur, which damages ecosystems, corrodes materials and can cause respiratory problems.

Define photochemical smog.

A type of air pollution formed when oxides of nitrogen and volatile organic compounds react in the presence of ultraviolet sunlight to produce secondary pollutants such as ozone, aldehydes and PAN.

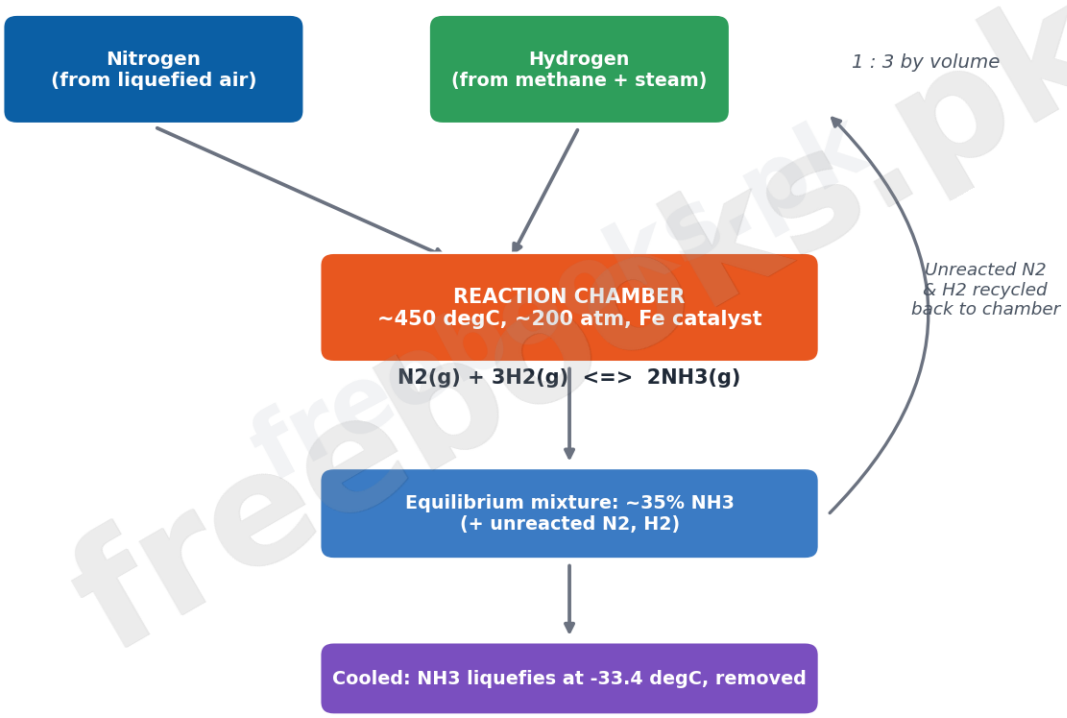
Key Facts & Relations

Topic	Relation
Haber process (ammonia)	N2(g) + 3H2(g) <=> 2NH3(g); ~450 degC, ~200 atm, Fe/Al2O3 catalyst
Contact process, key step (SO3 formation)	2SO2(g) + O2(g) -> 2SO3(g); 450 degC, 2-3 atm, V2O5 catalyst
Basic oxide + water example	Na2O(s) + H2O(l) -> 2NaOH(aq)
Acidic oxide + water example	SO2(g) + H2O(l) -> H2SO3(l) (sulphurous acid)
Amphoteric oxide + acid example	ZnO(s) + 2HCl(aq) -> ZnCl2(aq) + H2O(l)
Amphoteric oxide + alkali example	ZnO(s) + 2NaOH(aq) + H2O(l) -> Na2Zn(OH)4(aq)
Metal displacement example	Zn(s) + CuSO4(aq) -> ZnSO4(aq) + Cu(s)
Acid rain formation (from NO2)	2NO2(g) + H2O(l) -> HNO3(g) + HNO2(g)

Diagrams

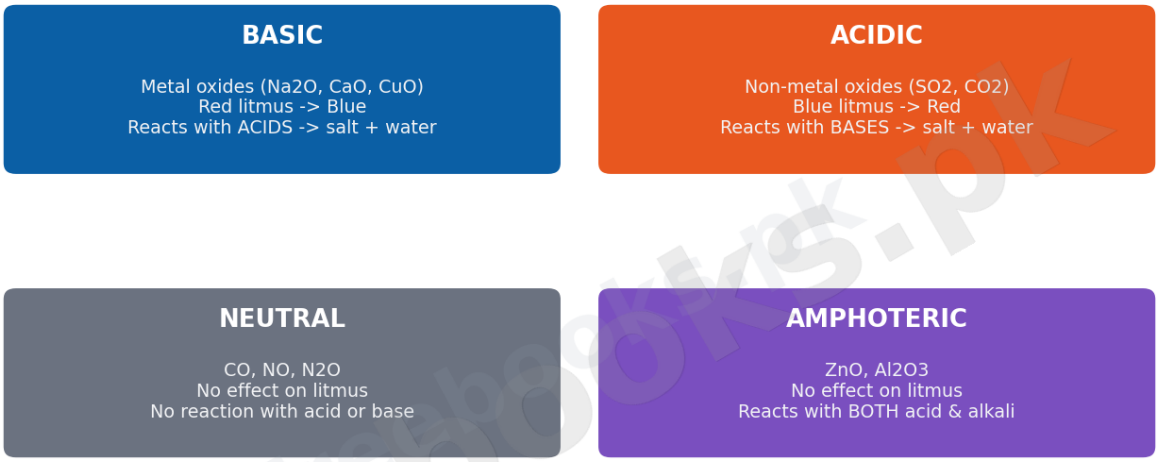
The Haber Process: A flow diagram of ammonia production: nitrogen (from liquefied air) and hydrogen (from methane) combined over an iron catalyst at high temperature and pressure, with unreacted gases recycled and ammonia liquefied and removed.

The Haber Process



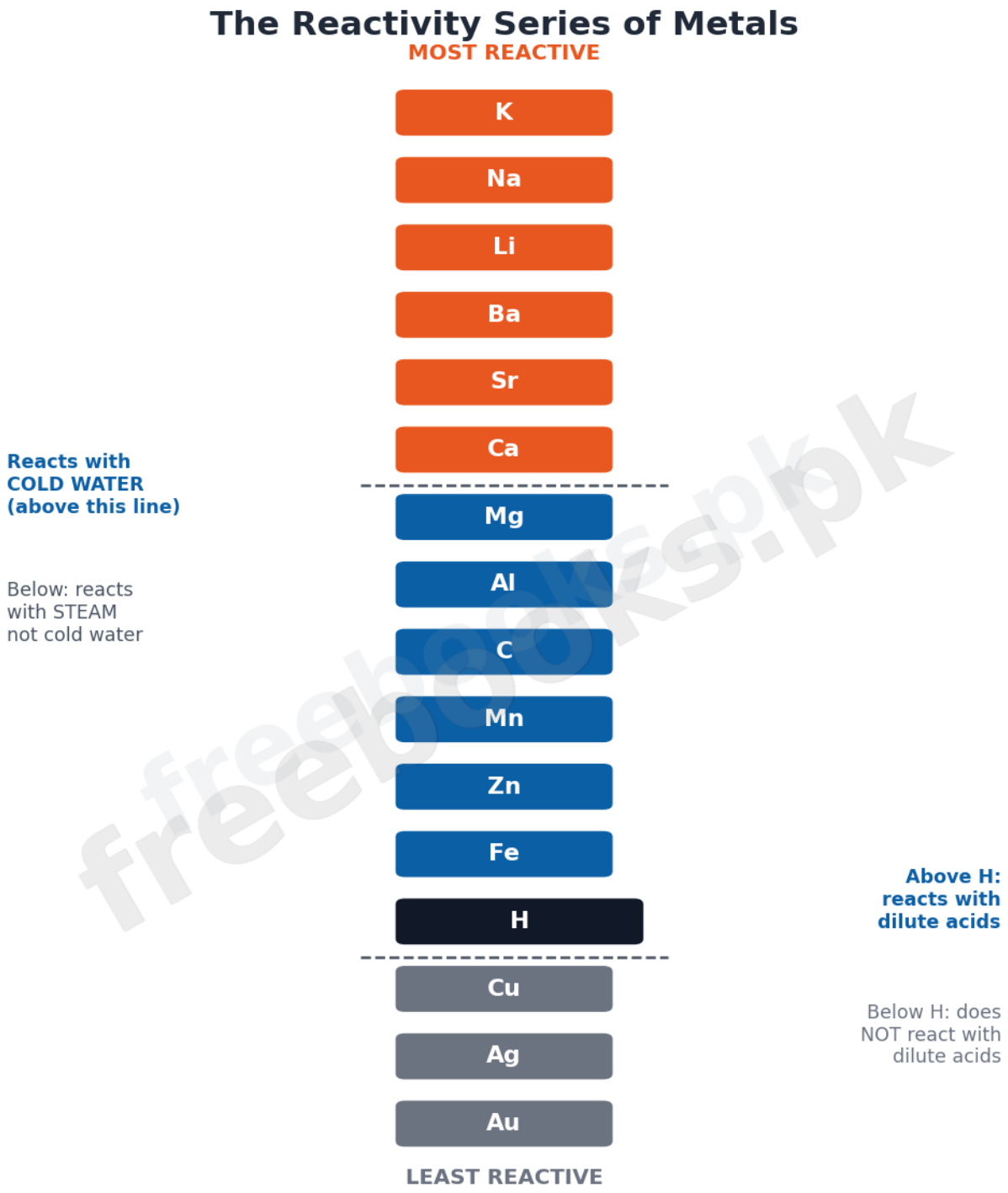
Classification of Oxides: A summary chart classifying oxides as acidic, basic, neutral or amphoteric, with examples of each and how they behave with acids, bases and water.

Classification of Oxides



Basic + Acidic oxides each react with ONE of acid/base; Amphoteric reacts with BOTH; Neutral reacts with NEITHER

The Reactivity Series of Metals: A ladder diagram of the reactivity series from potassium (most reactive) down to gold (least reactive), marking where metals react with cold water versus only steam, and where reaction with dilute acids stops (at hydrogen).



Short Questions & Answers

How is nitrogen obtained from air?

By fractional distillation of liquefied air: air is compressed, cooled and expanded repeatedly until it liquefies, then distilled; since nitrogen boils at a lower temperature (-196 degC) than oxygen, it evaporates first and is collected separately.

How is hydrogen produced from methane?

Methane is heated with a limited supply of oxygen (not enough to fully oxidize it), producing mainly hydrogen and carbon monoxide; the carbon monoxide is then reacted with steam to release additional hydrogen gas, along with carbon dioxide.

Which conditions are used to oxidize SO2 to SO3?

A temperature of about 450 degC, a pressure of about 2-3 atmospheres, and a vanadium(V) oxide (V2O5) catalyst, in the contact chamber of the Contact process.

Why is CO2 called an acidic oxide while CO is called a neutral oxide?

Carbon dioxide reacts with water to form carbonic acid, which turns blue litmus red, making it acidic; carbon monoxide does not react with water to form an acid or a base and has no effect on litmus, making it neutral.

How do magnesium and calcium differ in their reactions with cold water?

Calcium reacts readily with cold water to form calcium hydroxide and hydrogen gas, since it is above magnesium in the reactivity series; magnesium reacts only slowly with cold water, though it reacts more readily with steam.

How are the reactivities of metals determined?

By observing and comparing how vigorously different metals react with cold water, steam, dilute acids and oxygen; the more vigorous the reaction, the higher (more reactive) the metal is placed in the reactivity series.

Which secondary pollutants are produced by oxides of nitrogen?

Ozone, peroxyacetyl nitrate (PAN) and aldehydes are produced when oxides of nitrogen react with volatile organic compounds in sunlight; oxides of nitrogen also contribute to the formation of nitric acid and sulphuric acid in acid rain.

Which will react faster with dilute HCl, zinc or iron?

Zinc, because it is placed above iron in the reactivity series and is therefore more reactive, giving a more vigorous reaction with dilute hydrochloric acid.

Name one metal which will displace zinc from its salt solution.

Magnesium (or any metal above zinc in the reactivity series, such as aluminium or calcium) will displace zinc from a solution of its salt, since it is more reactive than zinc.

Why is SO3 absorbed into concentrated H2SO4 rather than directly into water?

Because the reaction of SO3 with water is highly exothermic and produces a fine, difficult-to-condense mist of sulphuric acid; absorbing SO3 into concentrated sulphuric acid instead forms oleum safely, which can then be diluted with water in a controlled way.

Long Questions & Answers

Explain the industrial production of ammonia by the Haber process.

Where do the raw materials, nitrogen and hydrogen, come from?

Nitrogen is obtained by fractional distillation of liquefied air, since it boils off at -196 degC before oxygen does; hydrogen is obtained by heating methane in a limited amount of oxygen to give hydrogen and carbon monoxide, with the carbon monoxide then reacted with steam to release further hydrogen.

What are the reaction conditions used in the Haber process, and why?

Nitrogen and hydrogen, in a 1:3 ratio by volume, are reacted at about 400-500 degC and about 200 atmospheres pressure in the presence of an iron-based catalyst; the high pressure and catalyst help achieve a reasonable rate and yield despite the reaction being reversible and not going to completion.

What happens to the equilibrium mixture leaving the reaction chamber?

The mixture, which contains only about 35% ammonia by volume, is cooled by refrigeration coils; ammonia gas liquefies at -33.4 degC and is removed from the mixture as a liquid, while the unreacted nitrogen and hydrogen gases remain gaseous and are separated out.

What happens to the unreacted nitrogen and hydrogen, and why does this matter economically?

The unreacted nitrogen and hydrogen gases are recycled back into the reaction chamber rather than being wasted, since the reaction does not convert all of the starting gases into ammonia in a single pass; recycling makes the overall process far more efficient and economical on an industrial scale.

Describe the classification of oxides as acidic, basic, neutral or amphoteric, using examples.

What is a basic oxide, and how does it behave?

A basic oxide is usually formed by a metal; it dissolves in water to give a hydroxide that turns red litmus blue, and reacts with an acid to give a salt and water -- for example, calcium oxide reacts with hydrochloric acid: CaO(s) + 2HCl(aq) -> CaCl2(aq) + H2O(l).

What is an acidic oxide, and how does it behave?

An acidic oxide is usually formed by a non-metal such as sulphur, carbon or nitrogen; it reacts with water to give an acid that turns blue litmus red, and reacts with a base to give a salt and water -- for example, sulphur dioxide reacts with water to give sulphurous acid: SO2(g) + H2O(l) -> H2SO3(l).

What is a neutral oxide, and how does it differ from acidic and basic oxides?

A neutral oxide, such as carbon monoxide, nitric oxide or nitrous oxide, produces neither an acid nor a base on contact with water and has no effect on litmus paper at all, unlike acidic oxides (which turn litmus red) or basic oxides (which turn litmus blue).

What is an amphoteric oxide, and how does it behave differently from the other types?

An amphoteric oxide, such as zinc oxide or aluminium oxide, can behave as both an acid and a base depending on what it reacts with: it acts as a base when reacted with an acid ($ZnO(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$) and as an acid when reacted with an alkali ($ZnO(s) + 2NaOH(aq) + H_2O(l) \rightarrow Na_2Zn(OH)_4(aq)$), unlike acidic or basic oxides, which react in only one of these two ways.

Multiple Choice Questions (MCQs)

The reason for maintaining a higher temperature for the production of ammonia is: (A) Activation energy of the reaction is very high (B) Activation energy of the reaction is very low (C) Nitrogen and hydrogen are both gases (D) At low temperature, nitrogen and hydrogen change into liquids
Correct answer: (A) Activation energy of the reaction is very high. A higher temperature is needed to give the reacting particles enough energy to overcome the reaction's high activation energy and react at a reasonable rate.

The Contact process is sensitive to impurities present in SO_2 and O_2 because the impurities: (A) Affect the capability of the catalyst (B) Affect the purity of H_2SO_4 only (C) Do not let SO_2 react with oxygen at all (D) Decrease the rate of reaction appreciably but do not affect the catalyst
Correct answer: (A) Affect the capability of the catalyst. Impurities such as arsenic compounds poison (deactivate) the vanadium(V) oxide catalyst, which is why the gases are carefully purified before entering the contact chamber.

Which of the following oxides is neutral in character? (A) Al_2O_3 (B) SO_2 (C) CO_2 (D) NO
Correct answer: (D) NO. Nitric oxide (NO) is a neutral oxide -- it has no effect on litmus and forms neither an acid nor a base with water, unlike SO_2 and CO_2 (acidic) or Al_2O_3 (amphoteric).

Sodium is considered more reactive than magnesium because: (A) It is more electropositive than magnesium (B) It reacts with water slowly (C) It is present in the second group (D) It is less metallic
Correct answer: (A) It is more electropositive than magnesium. Sodium is more electropositive than magnesium, meaning it loses its outer electron more readily, making it more reactive and placing it higher in the reactivity series.

Secondary pollutants present in the atmosphere include: (A) Oxides of nitrogen (B) Oxides of sulphur (C) Ozone and PAN (D) Oxides of carbon

Correct answer: (C) Ozone and PAN. Ozone and peroxyacetyl nitrate (PAN) are secondary pollutants, formed in the atmosphere from primary pollutants; oxides of nitrogen, sulphur and carbon are themselves primary pollutants.

SO3 is absorbed in H2SO4 rather than H2O during the production of sulphuric acid because: (A) SO3 does not react with H2O at all (B) Reaction of SO3 with H2O is highly exothermic, producing a mist of H2SO4 that is difficult to condense (C) It gives a better yield of H2SO4 for economic reasons (D) Reaction of SO3 with H2O can cause an explosion

Correct answer: (B) Reaction of SO3 with H2O is highly exothermic, producing a mist of H2SO4 that is difficult to condense. SO3 reacting directly with water releases a large amount of heat and forms a fine acid mist that is difficult to condense safely, so it is absorbed into concentrated H2SO4 to form oleum instead.

Oxides formed when oxygen reacts with metals are generally: (A) Acidic (B) Basic (or amphoteric for less electropositive metals) (C) Always neutral (D) Always amphoteric

Correct answer: (B) Basic (or amphoteric for less electropositive metals). Metal oxides are typically basic, though less electropositive metals such as zinc and aluminium form amphoteric oxides instead.

Major components of acid rain are: (A) H2SO4 and HNO3 (B) H2SO3 and HNO2 (C) H2SO4 and HCl (D) Acetic acid and HNO3

Correct answer: (A) H2SO4 and HNO3. Acid rain's main acidic components are sulphuric acid (from oxidized SO2) and nitric acid (from oxidized NO2), both formed from atmospheric pollutants.

Which metal reacts with steam only at a high temperature of about 700 degC? (A) Sodium (B) Potassium (C) Aluminium (D) Calcium

Correct answer: (C) Aluminium. Aluminium (along with beryllium) reacts with steam only at high temperature, unlike the far more reactive sodium, potassium and calcium, which react readily or violently.

Which of the following metals will NOT react with dilute hydrochloric acid to produce hydrogen gas? (A) Zinc (B) Magnesium (C) Copper (D) Iron

Correct answer: (C) Copper. Copper lies below hydrogen in the reactivity series, so it cannot displace hydrogen from a dilute acid and does not react with dilute HCl.

Quick Revision Summary

- Haber process: N2 + 3H2 <=> 2NH3, at ~450 degC, ~200 atm, iron catalyst; nitrogen from liquefied air, hydrogen from methane; unreacted gases recycled, ammonia liquefied out at -33.4 degC.
- Contact process: SO2 is made, purified, oxidized to SO3 (V2O5 catalyst, ~450 degC, 2-3 atm), absorbed into H2SO4 to form oleum, then diluted with water to give H2SO4.

- Oxides: basic (mostly metal oxides, react with acids), acidic (mostly non-metal oxides, react with bases), neutral (no reaction with litmus, e.g. CO, NO), amphoteric (react with BOTH acids and bases, e.g. ZnO, Al2O3).
- Metals react with cold water, steam, dilute acids and oxygen with a vigour that depends on their reactivity; more reactive metals react more violently and with milder conditions.
- Reactivity series (most to least reactive): K, Na, Li, Ba, Sr, Ca, Mg, Al, C, Mn, Zn, Fe, H, Cu, Ag, Au -- only metals above H liberate H2 from dilute acids.
- A more reactive metal displaces a less reactive metal from its salt solution; the top of the reactivity series contains the strongest reducing agents.
- NOx contributes to photochemical smog (via PAN, formed with unburned hydrocarbons in sunlight) and to acid rain, both directly (forming HNO3/HNO2) and by catalysing the oxidation of SO2 to SO3, which becomes H2SO4.
- Acid rain (pH below 5.6) damages ecosystems, corrodes materials, and can cause respiratory problems.

Exam Tips

- For the Haber and Contact processes, always be ready to state all three together: the equation, the source of each raw material, and the exact conditions (temperature, pressure, catalyst) -- exam questions often ask for all three.
- When classifying an oxide, check what it does to litmus AND how it behaves with an acid or base -- amphoteric oxides are the ones that react with BOTH an acid and an alkali; neutral oxides react with neither.
- Learn the reactivity series in order (K, Na, Li, Ba, Sr, Ca, Mg, Al, C, Mn, Zn, Fe, H, Cu, Ag, Au) as a single memorized sequence -- most questions about metal reactivity can be answered directly from its order.
- Remember the position of hydrogen in the reactivity series as the dividing line: metals above it react with dilute acids to release H2; metals below it do not react with dilute acids at all.
- For acid rain questions, name BOTH acids involved (nitric acid from NOx directly, and sulphuric acid from NOx catalysing SO2 oxidation) rather than only one.
- Connect flame colours to specific metals as a quick recall aid: Mg = intense white, Ca = white with red tinge, Sr = crimson, Ba = pale green -- useful for both descriptive and MCQ-style questions.

Chapter 20: Water

Water is essential to all life on earth, and this chapter starts with the practical chemistry of water itself: the sensitive anhydrous copper(II) sulphate test for its presence, and how boiling point and melting point are used to check its purity. It then contrasts distilled water (pure, ion-free, used in laboratories and pharmaceuticals) with tap water (containing dissolved minerals, chlorine and fluoride, and able to conduct electricity), and surveys the useful and harmful substances found in water from natural sources, from dissolved oxygen to heavy metals, microplastics, nitrates and phosphates.

The chapter then covers how domestic water supplies are treated -- sedimentation, filtration, chlorination and activated-carbon odour removal -- and the negative effects of water pollution on health and ecosystems, along with common water-borne diseases, ways to prevent them, and the specific challenge of water scarcity facing Pakistan. It closes with plant nutrition: the micro- and macro-nutrients plants need, the qualities of a good fertilizer, and the three main classes of NPK (nitrogenous, phosphatic and potassium) fertilizers used in agriculture.

Learning Objectives

- Investigate the chemical test for the presence of water using anhydrous copper(II) sulphate
- Explain how to test the purity of water using its melting point and boiling point
- Distinguish between distilled water and tap water and their applications in practical chemistry
- State that water from natural sources may contain both useful substances (such as dissolved oxygen) and harmful substances (such as heavy metals, plastics, sewage, harmful microbes, nitrates and phosphates)
- Explain the treatment of domestic water supply, including sedimentation and filtration to remove solids, use of carbon to remove tastes and odours, and chlorination to kill microbes
- Describe various water-borne diseases and the steps that can be taken to avoid them, and identify the negative effects of water pollutants on life and ways to avoid them
- Explain water scarcity as an important issue facing Pakistan and the ways in which it can be resolved
- State that urea, ammonium salts and nitrates are used as fertilizers, and explain the use of NPK fertilizers to supply nitrogen, phosphorus and potassium for improved plant growth

Key Concepts

20.1 Testing for Water and Checking Its Purity

Identifying the presence of water is important for determining the purity of substances and for the food and pharmaceutical industries. Hydrated copper(II) sulphate (CuSO4.5H2O) is blue, but on heating it loses its water of crystallization to become white anhydrous copper(II) sulphate; a drop of water added to the white anhydrous solid turns it blue again: CuSO4 + 5H2O <=> CuSO4.5H2O. This is a very sensitive test that can detect even a small amount of water.

Pure water boils at exactly 100 degC and freezes (melts) at exactly 0 degC under standard conditions; the presence of impurities changes both these physical constants -- raising the boiling point slightly and lowering the melting/freezing point. So a sample's purity can be checked by measuring its boiling point at STP (100 degC confirms purity) or by cooling it, freezing it, and recording the temperature at which the ice begins to melt (0 degC confirms purity; a lower melting point suggests impurities). Both constants are specific to standard pressure and will shift at high altitude or lower pressure.

20.2 Distilled Water versus Tap Water

Tap water is supplied to homes and offices from rivers, lakes, ponds or underground sources; it typically contains dissolved minerals such as calcium and magnesium salts (depending on its source), along with chlorine and fluoride added during treatment. Because it contains free ions from these dissolved minerals, tap water conducts electricity, and its pH typically ranges from 6.5 to 8.5 depending on its source.

Distilled water is produced by distillation: heating water to produce steam, then condensing that steam back into liquid, which removes dissolved minerals, microorganisms and other contaminants, leaving only pure water molecules. Its purity makes it ideal for laboratories, medical procedures and the pharmaceutical industry, ensuring accurate measurements, safe sterilization and reduced corrosion. Distilled water has a pH of 7 and, lacking dissolved ions, is a poor conductor of electricity; it is safe to drink but lacks the minerals the body normally obtains from water.

20.3 Substances Present in Water from Natural Sources

Water from rivers, lakes and aquifers contains substances that may be useful or harmful. Dissolved oxygen enters water by diffusion from the atmosphere and from photosynthesis by aquatic plants and algae; it is essential for aquatic organisms to breathe, and the health of an ecosystem depends directly on how much dissolved oxygen its water contains.

Harmful substances include microbes (bacteria, viruses and parasites entering through human and animal waste, landfills, agricultural runoff and industrial wastewater, causing diseases such as dysentery, typhoid, hepatitis and cholera); heavy metals such

as lead, mercury, cadmium and chromium (entering through industrial wastewater, mining and the use of fertilizers and pesticides, damaging the liver and kidneys, causing neurological problems, and in the case of arsenic and cadmium, increasing cancer risk); and microplastics (entering through wastewater and rainwater carrying plastic debris, found even in some human organs, and able to disturb the immune and reproductive systems).

Nitrates and phosphates enter natural water both naturally (weathering of rocks) and from human sources (fertilizers, detergents, industrial wastewater); while essential nutrients in small amounts, excess nitrogen and phosphorus trigger eutrophication -- excessive growth of algae and aquatic plants that, as it decays, lowers the water's dissolved oxygen level, harming aquatic life and disrupting the whole ecosystem.

20.4 Treatment of Domestic Water Supply

Natural water contains dissolved impurities, suspended impurities and microorganisms, which are removed by a combination of sedimentation, filtration, chlorination and other methods. Sedimentation removes larger insoluble impurities (soil, plant matter, sand): water is pumped into sedimentation tanks and left to stand for a few hours, allowing suspended particles to settle to the bottom by gravity while cleaner water is drawn off the top.

Filtration removes smaller suspended particles not caught by sedimentation, by trickling water through layers of sand and gravel that trap the particles. Chlorination sterilizes the water by adding a small amount of liquid chlorine, which kills harmful bacteria and other microbes. Finally, water is often passed through powdered activated carbon (charcoal) to remove tastes and odours by absorbing a wide range of organic compounds, and odours can also be reduced by aeration -- exposing the water to air.

20.5 Water Pollution, Water-Borne Diseases and Water Scarcity in Pakistan

Water pollution affects human health, ecosystems, aquatic organisms and industries; pollutants can disrupt aquatic ecosystems through eutrophication and habitat destruction, and can lower crop yields and contaminate food. Its negative effects can be controlled by treating sewage and industrial wastewater before discharge, reusing and recycling plastics, never pouring chemical cleaners, fats, oils or grease down drains, minimizing pesticide and fertilizer use, raising public awareness through campaigns, and enforcing water-pollution laws strictly.

The World Health Organization estimates that 80% of the world's sickness and disease is caused by polluted water and poor sanitation, with about 500 million people affected by water-borne diseases every year, including cholera, typhoid, malaria, trachoma (a leading cause of blindness, especially in children in developing countries) and viral hepatitis. These diseases can largely be prevented by drinking clean water that has been purified and boiled, and by practising good hygiene and using proper sanitation facilities.

Pakistan lies in a semi-arid region with low annual rainfall -- northern Pakistan (including Punjab) typically receives 250-600 mm per year, mostly during the monsoon, while southern Pakistan receives less than 200 mm per year. Combined with a growing population, flood irrigation, climate change, depleting aquifers and poor water management, this has created a severe water scarcity crisis; the situation can be addressed by building reservoirs and storage facilities to collect monsoon rainwater, adopting more efficient crop irrigation techniques, taking measures against climate change impacts, and managing water resources more effectively.

20.6 Plant Nutrients and Fertilizers

Plants need nutrients from the soil for healthy growth, classified as micro-nutrients (trace elements needed in tiny amounts, such as boron, copper, iron, manganese, zinc, molybdenum and chlorine, typically 6-200 grams per acre -- too much can be poisonous) and macro-nutrients (needed in larger amounts, such as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen, typically 5-200 kg per acre).

Fertilizers are substances added to soil to make up deficiencies of essential elements, especially nitrogen, phosphorus and potassium (NPK). A good fertilizer must supply its nutrient elements in a water-soluble, readily available form; be stable in soil and storage (not absorbing moisture or hardening); be inexpensive; not harm plants; and not alter soil pH. Fertilizers are classified as nitrogenous, phosphatic or potassium fertilizers, according to which of these three main nutrients they supply.

Nitrogenous fertilizers (such as ammonium sulphate, ammonium nitrate and urea) supply nitrogen, needed early in plant growth for stem and leaf development, as the main constituent of proteins, and for green colour and yield; urea is the most concentrated solid nitrogen fertilizer (about 46% nitrogen) and the most widely used in Pakistan, while ammonium nitrate, though hygroscopic, is unsuitable for paddy rice because flooded-field bacteria decompose it to nitrogen gas. Phosphatic fertilizers (such as superphosphate and diammonium phosphate) supply phosphorus, which stimulates early growth, accelerates seed and fruit formation, and increases disease resistance. Potassium fertilizers (such as potassium chloride, potassium sulphate and potassium nitrate) supply potassium, needed for starch and sugar formation, healthy root development, disease resistance and the ripening of seeds and fruit -- especially valuable for tobacco, coffee, potato and corn.

Important Definitions

Define the water test using copper(II) sulphate.
A sensitive chemical test in which a drop of water turns white anhydrous copper(II) sulphate blue, as it re-forms hydrated CuSO4.5H2O: CuSO4 + 5H2O <=> CuSO4.5H2O.

Define pure water (in terms of physical constants).

Water that boils at exactly 100 degC and freezes/melts at exactly 0 degC under standard conditions of temperature and pressure, with no dissolved impurities to shift these values.

Define distilled water.
Water purified by distillation (boiling to steam, then condensing), which removes dissolved minerals, microorganisms and contaminants, leaving pure water with a pH of 7 and no ability to conduct electricity.

Define tap water.
Water supplied to homes and offices from rivers, lakes, ponds or underground sources, typically containing dissolved minerals, chlorine and fluoride, with a pH of 6.5 to 8.5 and able to conduct electricity due to dissolved ions.

Define dissolved oxygen (in natural water).
Oxygen present in water from atmospheric diffusion and aquatic photosynthesis, used by aquatic organisms to breathe; its level directly affects the health of the ecosystem.

Define eutrophication.
A process in which excess nitrogen and phosphorus nutrients cause excessive growth of algae and aquatic plants in a water body, which lowers dissolved oxygen levels as the overgrowth decays, harming aquatic life.

Define sedimentation (in water treatment).
A water-treatment process in which water is left to stand in tanks so that larger suspended particles settle to the bottom under gravity, leaving cleaner water at the top.

Define filtration (in water treatment).
A water-treatment process in which water is passed through layers of sand and gravel to trap and remove smaller suspended particles not removed by sedimentation.

Define chlorination.
The addition of a small amount of liquid chlorine to water to kill harmful bacteria and other microbes, sterilizing it for safe use.

Define a water-borne disease.
A disease, such as cholera, typhoid or hepatitis, caused by consuming water contaminated with harmful microbes or pollutants.

Define water scarcity.
A shortage of adequate freshwater resources to meet a region's demand, caused in Pakistan's case by low rainfall, population growth, flood irrigation, climate change and poor water management.

Define a micro-nutrient (for plants).
An element, such as boron, copper, iron, manganese, zinc, molybdenum or chlorine, needed by plants only in very small amounts, with excess amounts potentially toxic.

Define a macro-nutrient (for plants).

An element, such as nitrogen, phosphorus, potassium, calcium, magnesium or sulphur, needed by plants in relatively large amounts for healthy growth.

Define a fertilizer.

A substance added to soil to make up deficiencies of essential elements, especially nitrogen, phosphorus and potassium, needed for healthy plant growth.

Define an NPK fertilizer.

A fertilizer, or a classification of fertilizers, that supplies nitrogen (N), phosphorus (P) and/or potassium (K), the three main nutrient elements plants need in the largest amounts.

Define a nitrogenous fertilizer.

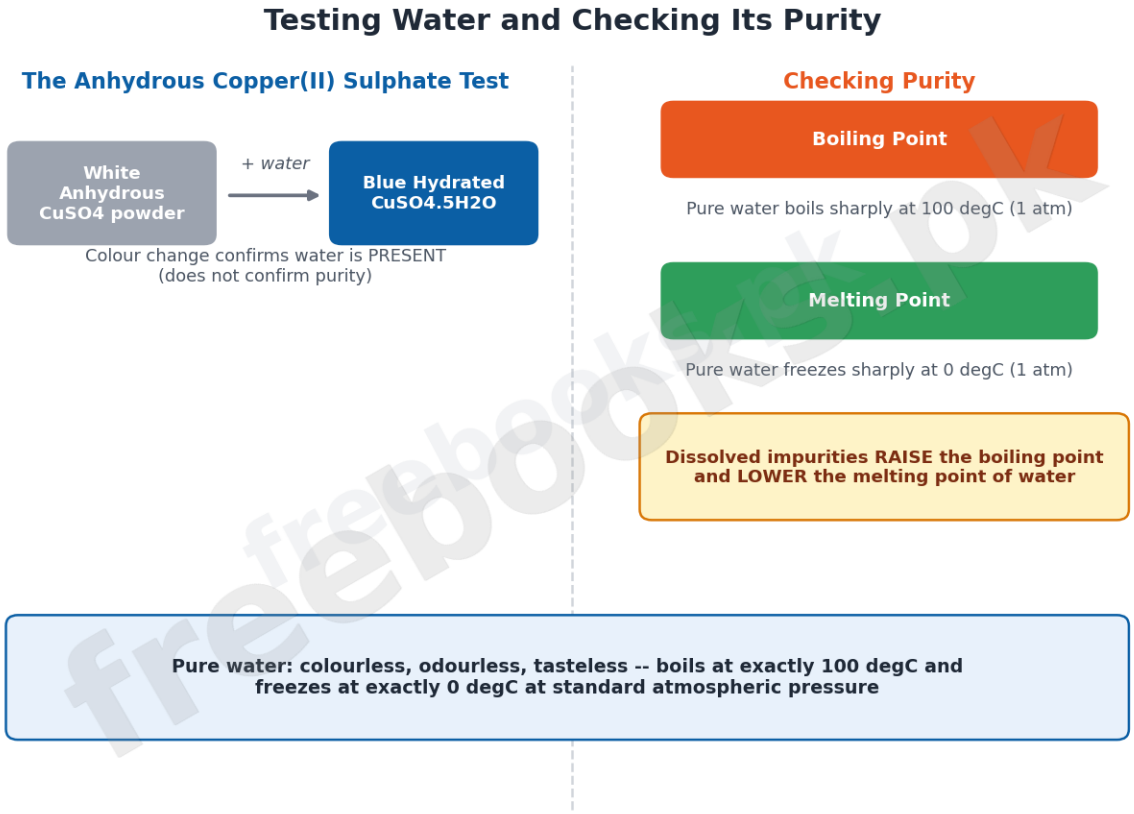
A fertilizer, such as urea or ammonium nitrate, that supplies nitrogen to plants for stem and leaf development, protein formation and improved yield.

Key Facts & Relations

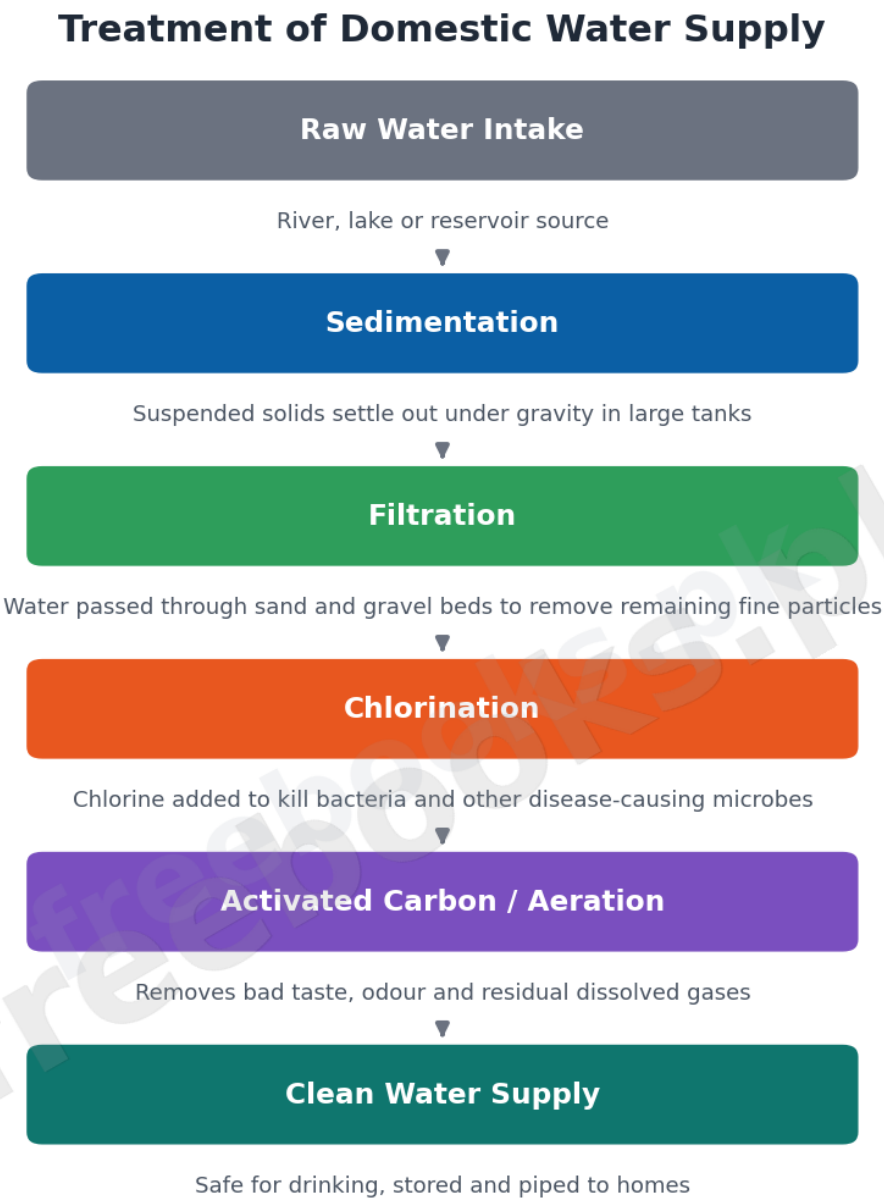
Topic	Relation
Water test reaction	CuSO4 (white) + 5H2O <=> CuSO4.5H2O (blue)
Pure water boiling point (STP)	100 degC (impurities raise it slightly)
Pure water melting/freezing point (STP)	0 degC (impurities lower it)
Distilled water pH	7 (neutral; poor conductor, no dissolved ions)
Tap water pH range	6.5 - 8.5 (conducts electricity; contains dissolved minerals)
Urea nitrogen content	About 46% nitrogen; most concentrated solid N fertilizer
Superphosphate formula	Ca(H2PO4)2
Diammonium phosphate formula	(NH4)2HPO4

Diagrams

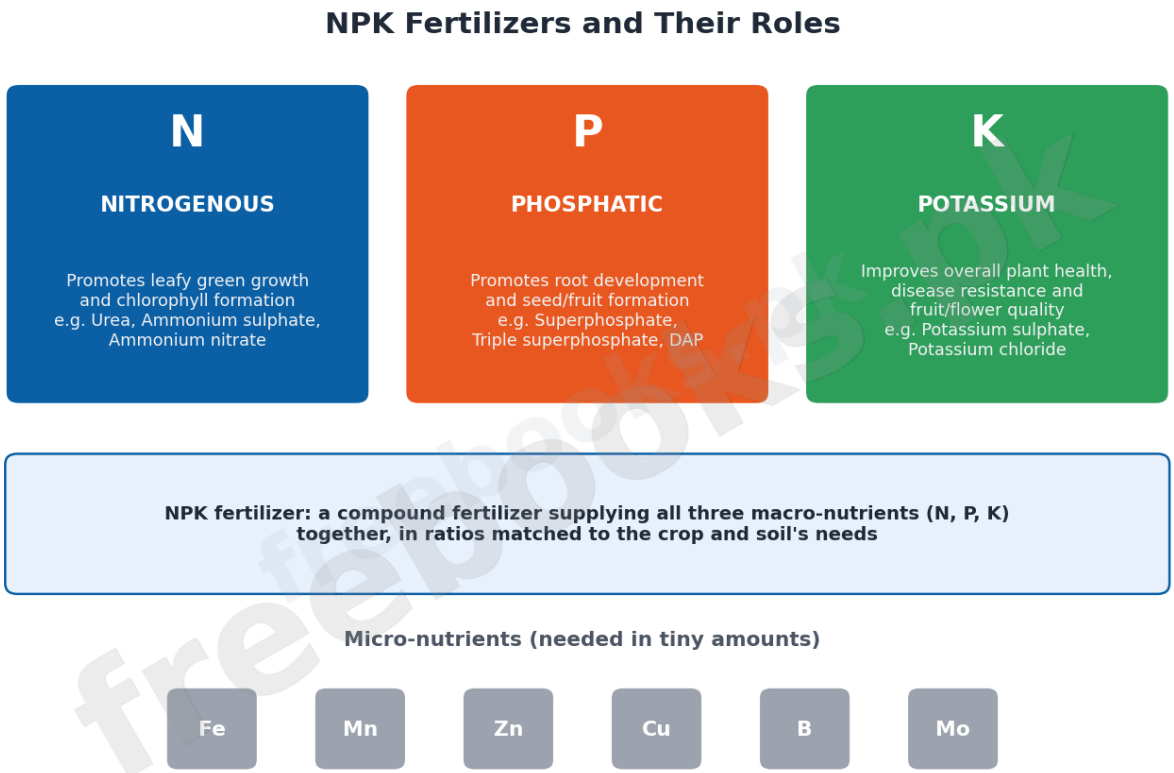
Testing Water and Checking Its Purity: A diagram of the anhydrous copper(II) sulphate colour-change test for water (white to blue), alongside the boiling-point and melting-point checks used to confirm a water sample's purity.



Domestic Water Treatment Process: A flow diagram of domestic water treatment: raw water through sedimentation, filtration, chlorination and activated-carbon odour removal to produce clean, safe water.



NPK Fertilizers and Their Roles: A summary chart of the three main fertilizer types -- nitrogenous, phosphatic and potassium -- showing the nutrient each supplies, its role in plant growth, and common examples.



Short Questions & Answers

Name two methods to check the purity of water.

Measuring its boiling point (pure water boils at exactly 100 degC) and measuring its melting/freezing point (pure water freezes at exactly 0 degC); impurities raise the boiling point and lower the melting point.

What is the main difference between tap water and distilled water?

Tap water contains dissolved minerals, chlorine and fluoride and conducts electricity due to free ions, while distilled water has been purified by distillation to remove all dissolved substances, has a neutral pH of 7, and does not conduct electricity.

How is water distilled in the laboratory?

By heating the water sample to boiling so that it turns to steam, then cooling and condensing that steam back into liquid water in a separate container, leaving dissolved minerals and other impurities behind.

Name one useful and one harmful substance present in natural water.

Dissolved oxygen is useful, since aquatic organisms need it to survive; heavy metals such as lead or mercury are harmful, since they can damage organs and cause neurological problems or cancer.

How would you remove harmful bacteria and other microbes present in water?

By chlorination -- adding a small amount of liquid chlorine to the water, which kills the harmful bacteria and other microbes present.

What is the difference between sedimentation and filtration?

Sedimentation removes larger suspended particles by letting them settle to the bottom of a tank under gravity, while filtration removes smaller suspended particles by passing water through layers of sand and gravel that trap them.

Name any three water-borne diseases.

Cholera, typhoid and hepatitis are common water-borne diseases (other accepted examples include dysentery, malaria and trachoma).

Why are fertilizers containing nitrogen added to the soil?

Because nitrogen is essential for the early development of a plant's stem and leaves, is a main constituent of proteins, gives leaves their green colour, and improves the yield and quality of the crop.

What is trachoma?

A water-borne eye disease that is a leading cause of blindness, particularly prevalent among babies and children in developing countries with poor water quality and sanitation.

Why is urea regarded as a good nitrogenous fertilizer?

Because it contains about 46% nitrogen, making it the most concentrated solid nitrogen fertilizer available, and it is relatively cheap and widely used, which is why it is the most common nitrogen fertilizer used in Pakistan.

Long Questions & Answers

Describe how a domestic water supply can be made fit for drinking.

How are larger suspended impurities first removed from natural water?

Water pumped from a natural source is left to stand in sedimentation tanks for a few hours, during which larger insoluble particles such as soil, sand and plant matter settle to the bottom under gravity, and the cleaner water at the top is drawn off for the next stage.

How are smaller suspended particles removed?

The water is passed through filtration beds of sand and gravel, which trap the finer suspended particles that sedimentation alone could not remove, producing visually clear water.

How are harmful microbes killed?

A small, carefully controlled amount of liquid chlorine is added to the filtered water; chlorine kills harmful bacteria, viruses and other microbes, sterilizing the water so it is safe to drink.

How are unwanted tastes and odours removed?

The water is passed through powdered activated carbon (charcoal), which absorbs a wide range of organic compounds responsible for taste and odour; aeration (exposing the water to air) can also help remove odours before the water is distributed for domestic use.

Explain the three main classes of NPK fertilizers and the role each plays in plant growth.

What role does nitrogen play, and which fertilizers supply it?

Nitrogen is needed early in a plant's growth for stem and leaf development, is a key constituent of proteins, gives leaves their green colour and improves yield and quality; nitrogenous fertilizers that supply it include urea (about 46% nitrogen, the most concentrated solid form) and ammonium nitrate (unsuitable for paddy rice, since flooded-field bacteria decompose it to nitrogen gas).

What role does phosphorus play, and which fertilizers supply it?

Phosphorus stimulates early plant growth and accelerates seed and fruit formation in later growth stages, while also increasing disease resistance; phosphatic fertilizers that supply it include superphosphate, $Ca(H_2PO_4)_2$, and diammonium phosphate, $(NH_4)_2HPO_4$, both of which are water-soluble.

What role does potassium play, and which fertilizers supply it?

Potassium is needed for forming starch, sugar and fibrous plant material, increases disease resistance, supports healthy root development, and helps ripen seeds, fruit and cereals; potassium fertilizers that supply it include potassium chloride, potassium sulphate and potassium nitrate, and are especially valuable for crops like tobacco, coffee, potato and corn.

What must be true of any compound for it to be used as a good fertilizer, regardless of which nutrient it supplies?

It must supply its nutrient in a water-soluble form that plants can readily absorb, be stable in both soil and storage (not absorbing moisture or hardening over time), be inexpensive to manufacture, not harm the plants it is applied to, and not significantly alter the pH of the soil.

Multiple Choice Questions (MCQs)

The pH of distilled water is: (A) 6.5 (B) 8.5 (C) 7 (D) 7.5
Correct answer: (C) 7. Distilled water is neutral, with a pH of exactly 7, since it contains no dissolved ions or minerals to shift it acidic or alkaline.

The unpleasant odours in water can be removed by: (A) Adding chlorine (B) Treating it with activated charcoal (C) Sedimentation (D) Filtration

Correct answer: (B) Treating it with activated charcoal. Activated charcoal (powdered activated carbon) absorbs the organic compounds responsible for tastes and odours in water; chlorine, sedimentation and filtration serve other purposes.

A major source of harmful microbes in natural water is: (A) Human and animal wastes (B) Fertilizers used for crops (C) Industrial waste-water only (D) Microbes in rocks

Correct answer: (A) Human and animal wastes. Human and animal wastes, along with sewage and agricultural runoff, are major sources of the bacteria, viruses and parasites that contaminate natural water.

Which gases dissolve in natural water from the atmosphere through diffusion? (A) O2 and CO2 (B) N2 and CO2 (C) O2 and N2 (D) O2, N2 and CO2

Correct answer: (D) O2, N2 and CO2. Oxygen, nitrogen and carbon dioxide from the atmosphere all dissolve into natural water through diffusion, though oxygen is the most important for aquatic life.

The fertilizer that is harmful to paddy rice is: (A) Superphosphate (B) Ammonium nitrate (C) Urea (D) Potassium sulphate

Correct answer: (B) Ammonium nitrate. Ammonium nitrate is unsuitable for paddy rice because the microbial bacteria present in flooded fields decompose it into nitrogen gas, wasting the nutrient.

Fertilizers that increase disease resistance and promote healthy root development are mainly: (A) Nitrogenous fertilizers (B) Phosphatic fertilizers (C) Potassium fertilizers (D) Magnesium fertilizers

Correct answer: (C) Potassium fertilizers. Potassium fertilizers strengthen plants by supporting healthy root development and increasing resistance to disease, in addition to helping ripen fruit and seeds.

Water that boils exactly at 100 degC and freezes exactly at 0 degC under standard conditions is: (A) Definitely tap water (B) Definitely distilled water (C) Pure water (D) Water containing dissolved salts

Correct answer: (C) Pure water. These exact boiling and freezing points at STP indicate pure water with no dissolved impurities, regardless of its original source.

Excess nitrates and phosphates in natural water mainly cause: (A) Increased dissolved oxygen (B) Eutrophication and reduced dissolved oxygen (C) Higher water pH permanently (D) Immediate loss of all aquatic life

Correct answer: (B) Eutrophication and reduced dissolved oxygen. Excess nitrates and phosphates trigger eutrophication -- excessive algal growth that, as it decays, lowers dissolved oxygen levels and harms aquatic ecosystems.

Quick Revision Summary

- The CuSO4 water test: white anhydrous CuSO4 turns blue on contact with water (forming CuSO4.5H2O) -- a very sensitive test.
- Pure water: boils at 100 degC, freezes at 0 degC (STP); impurities raise the boiling point and lower the freezing point.
- Tap water: contains dissolved minerals, chlorine, fluoride; conducts electricity; pH 6.5-8.5. Distilled water: pure, pH 7, does not conduct electricity.
- Natural water contains useful substances (dissolved oxygen) and harmful ones (microbes, heavy metals, microplastics, excess nitrates/phosphates causing eutrophication).
- Domestic water treatment: sedimentation (large particles) -> filtration (smaller particles) -> chlorination (kills microbes) -> activated carbon/aeration (removes taste/odour).
- Water-borne diseases (cholera, typhoid, hepatitis, trachoma) cause about 80% of world sickness (WHO estimate); prevented by clean water, boiling, hygiene, sanitation.
- Pakistan faces severe water scarcity (semi-arid climate, low rainfall, population growth, poor management); addressed by reservoirs, better irrigation, and improved water management.
- NPK fertilizers: Nitrogenous (urea, ammonium nitrate) for stems/leaves/protein; Phosphatic (superphosphate, diammonium phosphate) for early growth/seed formation; Potassium (potassium chloride/sulphate/nitrate) for roots/disease resistance/ripening.

Exam Tips

- For the CuSO4 water test, always state the colour change direction correctly: white (anhydrous) to blue (hydrated) confirms water is present -- the reverse (blue to white) happens on heating, removing water.
- Remember both purity tests together: boiling point rises above 100 degC with impurities; melting/freezing point falls below 0 degC with impurities -- opposite directions.
- For tap-vs-distilled questions, connect conductivity directly to ions: tap water conducts because it has dissolved ions, distilled water doesn't conduct because it has none.
- Learn the domestic water treatment sequence in order: sedimentation -> filtration -> chlorination -> carbon/aeration for odour -- exam questions often ask for the correct order.
- For fertilizer questions, always match nutrient to its main plant function: N = leaves/stems/protein, P = early growth/seeds/fruit, K = roots/disease resistance/ripening.
- For water-scarcity-in-Pakistan questions, mention BOTH the natural cause (low/semi-arid rainfall) and the human causes (population growth, poor water management, flood irrigation) for a complete answer.

Chapter 21: Organic Chemistry

Organic chemistry is the branch of chemistry that studies compounds of carbon and hydrogen (hydrocarbons) and their derivatives. Organic compounds are covalently bonded structures built mainly from carbon, almost always combined with hydrogen, and often with oxygen, nitrogen, sulphur or halogens as well. Because carbon can form four strong covalent bonds and link with itself in chains, branches and rings, millions of organic compounds exist -- far more than all known inorganic compounds combined -- so chemists classify them into families to make their properties predictable and easy to study.

This chapter introduces the basic vocabulary used throughout organic chemistry: how compounds are classified by the shape of their carbon skeleton (open chain or closed ring), how structural formulae represent the exact arrangement of atoms in a molecule, what a homologous series is and why members of one behave so similarly, how structural isomerism allows the same molecular formula to represent more than one real compound, what a functional group is and how it fixes a compound's chemical behaviour, and finally how the IUPAC system builds a systematic name for any organic compound from its carbon-chain length and functional group.

Learning Objectives

- Classify organic molecules as straight-chained, branched or cyclic.
- Explain that a structural formula unambiguously describes how atoms in a molecule are arranged.
- Interpret general formulae of alkanes, alkenes, alkynes, alcohols and carboxylic acids.
- Define structural isomers and identify isomer pairs such as the two forms of C4H10 and C4H8.
- Identify the functional group of alcohols, aldehydes, ketones, phenols, carboxylic acids, amines, esters and amides.
- Describe the general characteristics shared by every homologous series.
- Distinguish saturated compounds (all single carbon-carbon bonds) from unsaturated compounds (one or more multiple bonds).
- Name and draw structural formulae of unbranched alkanes, alkenes, alcohols, carboxylic acids and esters using IUPAC rules.

Key Concepts

21.1 Classification of Organic Compounds

Organic compounds are broadly divided into two classes based on the shape of their carbon skeleton: open chain (acyclic) compounds, in which the carbon atoms form a chain with two free ends, and closed chain (cyclic) compounds, in which the carbon atoms (or carbon plus other atoms) form a closed ring.

Open chain compounds may be straight chain (non-branched), such as butane CH3-CH2-CH2-CH3, but-1-ene, and butan-1-ol, or branched chain, such as 2-methylpropane and 2,2-dimethylpropane, where a side chain of carbon atoms hangs off the main chain. Open chain compounds together with certain cyclic compounds are also called aliphatic compounds.

Closed chain (cyclic) compounds contain one or more rings of atoms. If the ring is made of carbon atoms only, the compound is carbocyclic; if the ring also contains other atoms such as oxygen or nitrogen, it is heterocyclic. Carbocyclic compounds are further divided into alicyclic compounds (such as cyclopropane, cyclobutane, cyclohexane and cyclohexene, which resemble aliphatic compounds and follow the general formula CnH2n for the saturated ones) and aromatic compounds, the simplest of which contain a benzene ring of six carbon atoms with three alternating double and single bonds, often drawn as a circle inside a hexagon.

21.2 Structural Formula

A structural formula shows the arrangement of atoms and bonds within a molecule clearly enough to identify its structure without ambiguity. Because writing out every single bond is repetitive, chemists commonly use two shorthand styles.

The displayed formula (or full structural formula) shows every atom and every bond as a separate line, giving the most detailed picture of a molecule's structure. The condensed structural formula still shows bonds between the main-chain atoms as lines or as juxtaposed symbols, but omits the individual carbon-to-hydrogen bonds -- for example, ethane is written CH3-CH3 instead of drawing each C-H bond separately, and ethanoic acid's -COOH group is written showing only the C=O and C-OH connections.

21.3 Homologous Series

Organic compounds are grouped into families called homologous series, where every member shares a similar structure and similar chemical behaviour. A homologous series is defined by several shared characteristics: every member fits a single general formula (alkanes CnH2n+2, alkenes CnH2n, alkynes CnH2n-2, alcohols CnH2n+1OH, carboxylic acids CnH2n+1COOH);

successive members differ from the next by exactly one CH2 unit, which adds 14 to the relative molecular mass each time; every member carries the same functional group, which gives the whole family near-identical chemical properties; and physical properties such as melting point, boiling point, density and solubility change in a smooth, predictable trend as molecular mass increases. Members of a series can also usually be prepared by similar general methods.

21.4 Isomerism

Two or more compounds that share the same molecular formula but have different structural formulae -- and therefore different physical and chemical properties -- are called structural isomers, and the phenomenon is called structural isomerism. Methane, ethane and propane exist in only one structural form each, so they show no isomerism, but butane (C4H10) is the simplest hydrocarbon with isomers: it can be arranged as the straight chain CH3-CH2-CH2-CH3 (butane) or as the branched CH3-CH(CH3)-CH3 (2-methylpropane), two real compounds with different physical properties despite sharing the same molecular formula.

The number of possible isomers grows very rapidly as chain length increases: pentane (five carbons) already has three isomers, while a thirty-carbon alkane has over four billion possible isomers. Isomerism is not limited to alkanes -- unsaturated compounds show it too. Butene (C4H8) has two structural isomers depending on where the double bond sits: but-1-ene (CH3-CH2-CH=CH2) and but-2-ene (CH3-CH=CH-CH3).

21.5 Functional Groups

A functional group is an atom or group of atoms that determines the characteristic chemical properties of an organic compound; members of a homologous series behave alike because they all carry the same functional group. The hydroxyl group (-OH) defines alcohols such as methanol (CH3-OH) and ethanol (CH3-CH2-OH); when -OH is attached directly to a benzene ring instead of a chain, the compound is a phenol rather than an alcohol.

The aldehyde group (-CHO) defines aldehydes such as methanal (formaldehyde) and ethanal (acetaldehyde); the ketone group (>C=O attached to two carbon chains) defines ketones such as propanone (acetone) and butanone. The carboxyl group (-COOH) defines carboxylic acids; the amino group (-NH2) defines amines such as methylamine and ethylamine; the amide group (-CONH2) defines acid amides; and the ester group (-COO-) defines esters such as methyl ethanoate and ethyl ethanoate.

21.6 Naming Organic Compounds (IUPAC Nomenclature)

Early chemists used simple common (trivial) names for organic compounds, but as millions of compounds became known, the International Union of Pure and Applied Chemistry (IUPAC) introduced a systematic naming method. Every IUPAC name has three parts: a root that tells the number of carbon atoms in the longest continuous chain (Meth- =1, Eth- =2, Prop- =3, But- =4, Pent- =5, Hex- =6, Hept- =7, Oct- =8, Non- =9, Dec- =10), a suffix added after the root that tells the class of compound, and a prefix before the root that names any group attached to the main chain.

Alkanes (saturated hydrocarbons, all single bonds) take the suffix -ane: methane, ethane, propane, butane, pentane and so on, following the general formula CnH2n+2. An alkyl group (R-) forms when an alkane loses one hydrogen atom. Alkenes (containing at least one C=C double bond) take the suffix -ene, with the position of the double bond numbered from the end nearest to it -- for example but-1-ene and but-2-ene. Alcohols (general formula ROH) replace the alkane's final 'e' with '-ol' and number the chain so the carbon bearing -OH gets the lowest possible number, giving names such as propan-1-ol, propan-2-ol, butan-1-ol and butan-2-ol. Carboxylic acids replace the alkane's final 'e' with '-oic acid', giving methanoic acid (formic acid), ethanoic acid (acetic acid), propanoic acid and butanoic acid. Esters (general formula RCOOR', made by reacting an alcohol with a carboxylic acid using an acid catalyst) are named as 'alkyl alkanoate', for example ethyl propanoate from propanoic acid and ethanol.

Important Definitions

Organic compound

A chemical compound made mainly of carbon atoms covalently bonded to each other and usually to hydrogen, and often also to oxygen, nitrogen, sulphur or halogens.

Hydrocarbon

An organic compound containing only carbon and hydrogen atoms.

Acyclic (open chain) compound

An organic compound whose carbon atoms form a chain with two open ends, which may be straight or branched.

Cyclic (closed chain) compound

An organic compound whose atoms form one or more closed rings.

Alicyclic compound

A carbocyclic compound with a ring of three or more carbon atoms that resembles aliphatic (open chain) compounds in its properties.

Aromatic compound

A cyclic compound containing a benzene ring or similar ring with alternating double and single bonds.

Structural formula

A formula that shows the arrangement of atoms and bonds within a molecule clearly enough to describe its structure without ambiguity.

Displayed formula

A structural formula that draws every atom and every bond in a molecule as a separate line.

Condensed structural formula

A structural formula that omits the individual carbon-to-hydrogen bonds, showing atoms grouped together for brevity.

Homologous series

A family of organic compounds with the same functional group and general formula, each member differing from the next by a CH_2 unit.

Structural isomerism

The existence of two or more compounds with the same molecular formula but different structural formulae and different properties.

Functional group

An atom or group of atoms in an organic molecule that determines its characteristic chemical properties.

Saturated compound

A compound in which all carbon-carbon bonds are single bonds.

Unsaturated compound

A compound containing one or more carbon-carbon double or triple bonds.

Alkyl group

The group (R-) formed when an alkane molecule loses one hydrogen atom.

IUPAC nomenclature

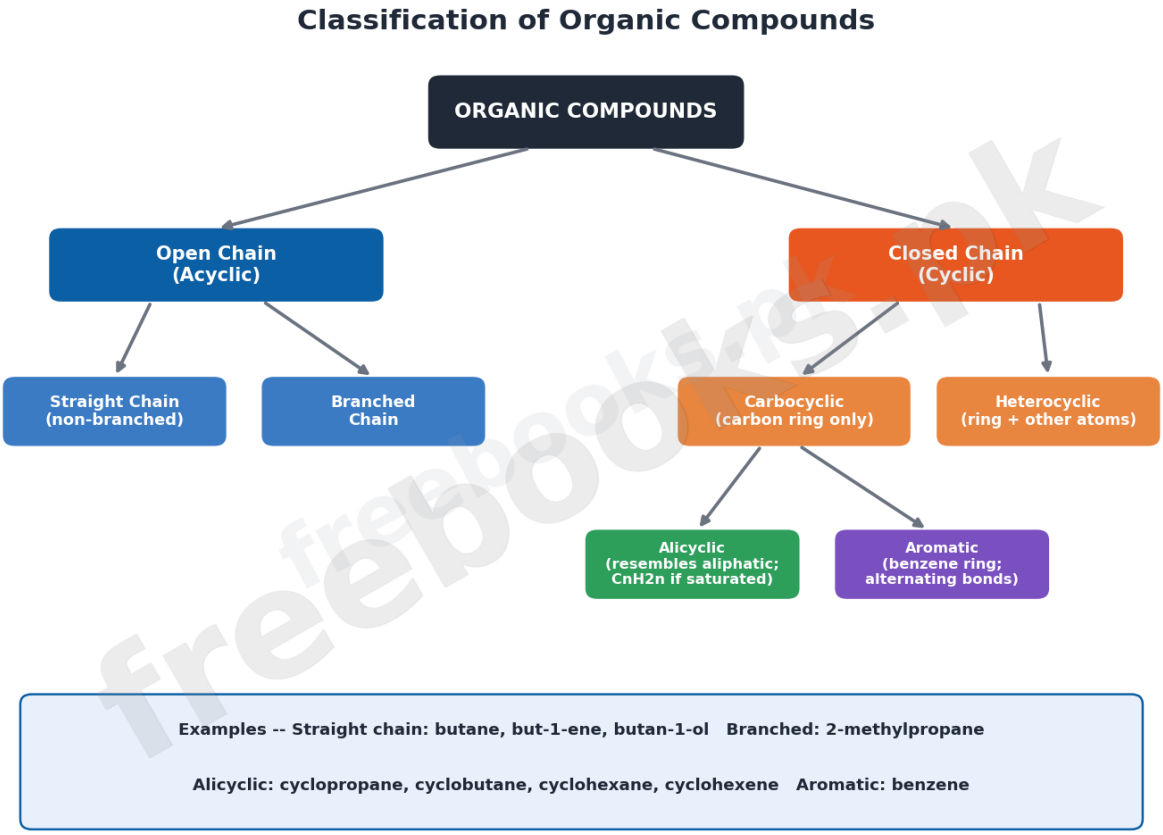
The International Union of Pure and Applied Chemistry's systematic method for naming organic compounds using a root, suffix and prefix.

Key Facts & Relations

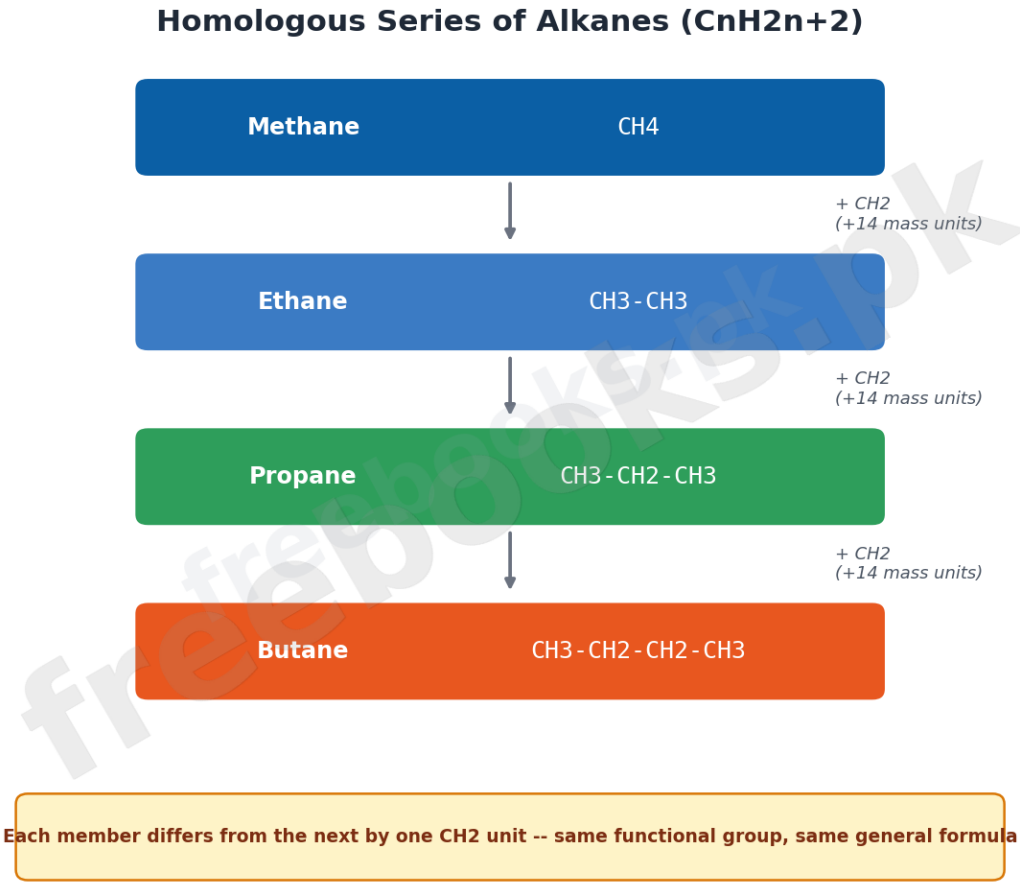
Topic	Relation
Alkanes (saturated hydrocarbons)	General formula CnH2n+2; suffix -ane
Alkenes	General formula CnH2n; suffix -ene
Alkynes	General formula CnH2n-2; suffix -yne
Alcohols	General formula CnH2n+1OH; suffix -ol
Carboxylic acids	General formula CnH2n+1COOH; suffix -oic acid
Esters	General formula RCOOR' (alkyl alkanoate)
Successive homologues	Differ by one CH2 unit = 14 units in relative molecular mass
Alicyclic saturated hydrocarbons	General formula CnH2n (ring compounds)

Diagrams

Classification of Organic Compounds: A classification tree showing organic compounds dividing into open chain (straight and branched) and closed chain (carbocyclic: alicyclic and aromatic; and heterocyclic) compounds.



Homologous Series of Alkanes: The first four alkanes -- methane, ethane, propane and butane -- shown with their condensed formulae, each differing from the next by one CH2 unit, illustrating the CnH2n+2 general formula.



Functional Groups and Their Families: A summary chart of the main functional groups -- hydroxyl, aldehyde, ketone, carboxyl, amino, amide and ester -- with the homologous series each one defines.

Short Questions & Answers

What is the difference between saturated and unsaturated hydrocarbons?

A saturated hydrocarbon has only single bonds between its carbon atoms (as in alkanes), while an unsaturated hydrocarbon has at least one carbon-carbon double or triple bond (as in alkenes and alkynes).

Write down the structural formula of Butan-2-ol.

CH3-CH(OH)-CH2-CH3, where the hydroxyl group is attached to the second carbon of the four-carbon chain.

Why is ethylamine (CH3-CH2-NH2) called an organic compound?

It is called organic because it is a covalent compound built on a carbon-hydrogen chain (an ethyl group) with an amino functional group attached, fitting the definition of a compound of carbon and hydrogen and their derivatives.

Write down the formula of the ester called ethyl methanoate.

HCOOCH2CH3 -- formed from methanoic acid (HCOOH) and ethanol (CH3CH2OH).

Define structural isomerism.

Structural isomerism is the phenomenon in which two or more compounds share the same molecular formula but have different structural formulae, and therefore different physical and chemical properties.

Give the IUPAC name to CH3-CH2-CH2-CH3.

Butane -- a four-carbon saturated hydrocarbon (root 'but-' plus suffix '-ane').

What is common in the carboxyl group, amide functional group and ester functional group?

All three contain a carbon atom double-bonded to oxygen (a carbonyl, C=O) as part of the functional group, differing only in what else is attached: -OH for carboxyl, -NH2 for amide, and -O-R for ester.

What is the difference between cyclohexane and benzene?

Cyclohexane is a saturated alicyclic ring (CnH2n) with only single bonds between its six carbon atoms, while benzene is an aromatic ring with three alternating double and single bonds among its six carbon atoms.

Give two examples of branched chain compounds.

2-methylpropane and 2,2-dimethylpropane are both branched chain (branched acyclic) compounds, each having a side chain of carbon atoms attached to the main chain.

Why does butane show isomerism but propane does not?

Butane has four carbon atoms, which is enough to arrange the chain in more than one valid way (straight chain or branched) while still satisfying every carbon's four bonds; propane's three carbons can only be arranged in a single valid straight-chain structure, so no isomer exists.

Long Questions & Answers

What is an organic compound, and how are organic compounds classified based on the type of carbon chain present in them?

What is an organic compound?

An organic compound is a chemical compound made mainly of carbon atoms covalently bonded to each other and to other elements, most commonly hydrogen, and often also oxygen, nitrogen, sulphur or halogens. A few simple carbon compounds such as oxides, carbonates and hydrogen carbonates are, for historical reasons, still classed as inorganic. Organic chemistry is the branch of chemistry that studies hydrocarbons and their derivatives.

What are open chain (acyclic) compounds?

Open chain compounds contain a chain of carbon atoms with two free ends, which may be a straight (non-branched) chain, as in butane, but-1-ene and butan-1-ol, or a branched chain with a side chain of carbon atoms, as in 2-methylpropane and 2,2-dimethylpropane. Open chain compounds, along with certain cyclic compounds, are also called aliphatic compounds.

What are closed chain (cyclic) compounds?

Closed chain compounds contain one or more rings of atoms. A ring made of carbon atoms only is called carbocyclic; a ring that also contains other atoms such as oxygen or nitrogen is called heterocyclic. Carbocyclic compounds are further divided into alicyclic compounds, which resemble aliphatic compounds and follow the general formula CnH2n when saturated (such as cyclopropane, cyclobutane and cyclohexane), and aromatic compounds.

What are aromatic compounds?

Aromatic compounds are cyclic compounds whose simplest members contain a single benzene ring: six carbon atoms joined by three alternating double and single bonds, often drawn as a circle inside a hexagon. Other cyclic compounds with alternating double bonds are also grouped as aromatic.

Explain the characteristics of a homologous series, and describe how structural isomerism arises among organic compounds.

What general formula and functional group do members of a homologous series share?

Every member of a homologous series fits a single general formula -- for example CnH2n+2 for alkanes or CnH2n+1OH for alcohols -- and carries the same functional group throughout the family, which is why the chemical properties of every member are almost identical.

How do successive members of a homologous series differ, and how do their physical properties change?

Successive members differ from the next by exactly one CH2 unit, adding 14 to the relative molecular mass each time. As molecular mass increases through the series, physical properties such as melting point, boiling point, density and solubility change in a smooth, regular trend, and every member can usually be prepared by similar general methods.

What is structural isomerism, and how does butane demonstrate it?

Structural isomerism is the existence of two or more compounds with the same molecular formula but different structural formulae and different properties. Butane (C4H10) is the simplest example: it can be arranged as the straight chain CH3-CH2-CH2-CH3 (butane) or as the branched CH3-CH(CH3)-CH3 (2-methylpropane), two distinct real compounds with different physical properties.

How does isomerism appear in unsaturated compounds such as butene?

Structural isomerism is not limited to saturated hydrocarbons -- butene (C4H8) has two isomers depending on where its double bond sits: but-1-ene (CH3-CH2-CH=CH2) and but-2-ene (CH3-CH=CH-CH3). As chain length increases, the number of possible isomers grows very rapidly -- pentane already has three, and a thirty-carbon alkane has over four billion.

Multiple Choice Questions (MCQs)

Choose the correct IUPAC name for the compound CH2=CH-CH2-CH3. (A) But-3-ene (B) But-1-ene (C) But-2-ene (D) Butene

Correct answer: (B) But-1-ene. The double bond starts at the first carbon of the four-carbon chain, so it is named but-1-ene, numbering from the end nearest the double bond.

Select a branched chain compound. (A) CH2=CH-CH2-CH3 (B) CH2=C(CH3)-CH-CH3 (C) CH3-CH=CH-CH3 (D) CH3-CH=CH-CH2-CH3

Correct answer: (B) CH2=C(CH3)-CH-CH3. Only the second option has a CH3 side group attached to the main chain, making it a branched compound; the other three are straight chains.

Which is the displayed formula of ethanol? (A) C2H5OH (B) CH3-CH2-OH (C) A full diagram showing every C-H, C-C and O-H bond as separate lines (D) H-C(H)-C(H)-O-H with brackets omitted

Correct answer: (C) A full diagram showing every C-H, C-C and O-H bond as separate lines. The displayed (full structural) formula shows every atom and every bond individually as separate lines, unlike the condensed formula CH3-CH2-OH which omits the C-H bonds.

Identify the aldehydic functional group among the following. (A) -COOH (B) -OH (C) a carbonyl attached to two carbon groups (ketone) (D) -CHO (a carbonyl bonded to one H)

Correct answer: (D) -CHO (a carbonyl bonded to one H). The aldehyde functional group is -CHO: a carbon double-bonded to oxygen and single-bonded to one hydrogen atom, distinguishing it from the ketone's C=O flanked by two carbon groups.

Select the general formula of the alkyne family. (A) CnH2n+1 (B) CnH2n (C) CnH2n-2 (D) CnH2n-1

Correct answer: (C) CnH2n-2. Alkynes contain a carbon-carbon triple bond and follow the general formula CnH2n-2, two hydrogens fewer than the corresponding alkene.

How many structural isomers are there for a saturated hydrocarbon having five carbon atoms? (A) 2 (B) 3 (C) 4 (D) 5

Correct answer: (B) 3. Pentane (C5H12) has exactly three structural isomers: pentane (straight chain), 2-methylbutane and 2,2-dimethylpropane.

Which ester among the following would be called ethyl propanoate? (A) CH3-CO-OCH3 (B) CH3-CH2-CO-OCH3 (C) CH3-CO-OC2H5 (D) CH3-CH2-CO-OC2H5

Correct answer: (D) CH3-CH2-CO-OC2H5. Ethyl propanoate comes from propanoic acid (CH3-CH2-COOH, three carbons) and ethanol (C2H5OH), giving CH3-CH2-CO-OC2H5.

Which functional group is present in alkenes? (A) No functional group (B) A carbon-carbon triple bond (C) A carbon-carbon double bond (D) A carbon-carbon single bond

Correct answer: (C) A carbon-carbon double bond. Alkenes are defined by having at least one carbon-carbon double bond as their functional group, which is why they undergo addition reactions that alkanes cannot.

Quick Revision Summary

- Organic compounds are covalent compounds built mainly from carbon, almost always with hydrogen, and often oxygen, nitrogen, sulphur or halogens.

- Compounds split into open chain (straight or branched) and closed chain (carbocyclic: alicyclic or aromatic; heterocyclic).
- A displayed formula shows every bond; a condensed structural formula omits C-H bonds for brevity.
- A homologous series shares one general formula and one functional group; successive members differ by CH2 (14 mass units).
- Structural isomers share a molecular formula but differ in structural formula and properties -- butane's simplest example is C4H10.
- Functional groups: -OH (alcohols), -CHO (aldehydes), C=O (ketones), -COOH (carboxylic acids), -NH2 (amines), -CONH2 (amides), -COO- (esters).
- IUPAC names have a root (chain length: Meth-, Eth-, Prop-, But-, Pent- ... Dec-), a suffix (class: -ane, -ene, -ol, -oic acid) and a prefix (substituents).
- General formulae: alkanes CnH2n+2, alkenes CnH2n, alkynes CnH2n-2, alcohols CnH2n+1OH, carboxylic acids CnH2n+1COOH.

Exam Tips

- When classifying a compound, first check for a ring (cyclic) versus an open chain (acyclic) -- then check straight versus branched, or alicyclic versus aromatic.
- Remember displayed = every bond shown; condensed = C-H bonds hidden, only the main chain and functional groups shown.
- To count isomers or name a compound, always find the LONGEST continuous carbon chain first, even if it isn't drawn in a straight line.
- Memorise the suffix pattern: -ane (saturated), -ene (one C=C), -yne (one C-triple-bond-C), -ol (alcohol), -oic acid (carboxylic acid).
- For alkenes and alcohols, always number the chain from the end that gives the double bond or -OH group the LOWEST possible number.
- Match functional groups to families by their oxygen/nitrogen pattern: one O (=O only) is ketone/aldehyde; two O's is carboxylic acid or ester; N with two H's is amine; N next to C=O is amide.

Chapter 22: Hydrocarbons

Hydrocarbons are organic compounds made only of carbon and hydrogen, and this chapter focuses on the unsaturated ones -- alkenes with a carbon-carbon double bond and alkynes with a carbon-carbon triple bond -- alongside alkanes' role as the starting material from which alkenes are made industrially. Because alkenes and alkynes contain reactive multiple bonds, they undergo addition reactions that saturated alkanes cannot, which is also how chemists test whether a hydrocarbon is saturated or unsaturated.

The chapter then turns to where hydrocarbons come from and how they are made useful: coal, petroleum and natural gas are the three major fossil-fuel sources of organic compounds, and crude petroleum -- a complex mixture of hundreds of hydrocarbons -- is separated by fractional distillation into fractions such as refinery gas, gasoline, naphtha, kerosene, diesel, lubricating oil and bitumen, each with its own boiling range, chain length and everyday use.

Learning Objectives

- State that alkenes contain a carbon-carbon double bond and are unsaturated hydrocarbons.
- Describe the cracking of large alkane molecules into smaller alkanes and alkenes, and explain why cracking is carried out.
- Describe the bromine water and KMnO4 tests used to distinguish saturated from unsaturated hydrocarbons.
- Describe the addition reactions of alkenes with bromine, hydrogen (with a nickel catalyst) and steam (with an acid catalyst).
- Describe, using symbol equations, the preparation of alkenes by elimination reactions from halogenoalkanes and alcohols.
- Identify alkynes as hydrocarbons containing a carbon-carbon triple bond, and describe the uses of ethyne as a welding fuel and fruit-ripening agent.
- Describe the fractional distillation of petroleum and name the main fractions and their uses.
- Describe how chain length, volatility, boiling point and viscosity change from the bottom to the top of the fractionating column.

Key Concepts

22.1 Alkenes

Alkenes are unsaturated hydrocarbons containing one or more carbon-carbon double bonds; they are also called olefins and follow the general formula CnH2n. Because of their reactive double bond, alkenes are widely used to make plastics, fuels and many other commercially important chemicals.

Alkenes are prepared in three main ways. Dehydration of alcohols removes a water molecule using a dehydrating agent such as concentrated sulphuric acid at about 180 degC, converting ethanol (CH3-CH2-OH) to ethene (CH2=CH2). Dehydrohalogenation of alkyl halides removes a molecule of hydrogen halide (HX) using potassium hydroxide dissolved in ethanol, converting chloroethane to ethene; both of these are elimination reactions, in which a small molecule is removed from a saturated compound to give an unsaturated one. Alkenes are also produced by cracking of alkanes -- heating high molecular mass alkanes at high temperature, without oxygen, in the presence of a zeolite catalyst, breaking them into smaller alkanes and alkenes. Cracking matters commercially because it produces smaller alkanes useful as fuel and alkenes such as ethene and propene that are valuable starting materials for many products; for example, kerosene oil or diesel oil can be cracked to give petrol, alkenes and hydrogen gas.

22.2 Important Reactions of Alkenes

Alkenes are very reactive because of their carbon-carbon double bond, and they mainly undergo addition reactions, in which two or more reactants combine to form a single new product. Addition of hydrogen (catalytic hydrogenation) uses a nickel catalyst at about 150 degC and 2 atm pressure to convert an alkene into the corresponding alkane, for example ethene plus hydrogen gives ethane. Addition of halogens adds bromine across the double bond in a non-polar solvent such as CCl4 to give an alkyl dihalide, for example ethene plus bromine gives 1,2-dibromoethane.

Oxidation with cold, dilute, alkaline potassium permanganate (KMnO4) converts an alkene into a diol, for example ethene gives ethane-1,2-diol (glycol). Both the bromine test and the KMnO4 test are used to distinguish saturated from unsaturated compounds: the reddish-brown colour of bromine, the purple colour of KMnO4, and the violet colour of iodine are all rapidly discharged (decolourised) by an alkene, but not by an alkane, because alkanes lack a reactive double bond. Addition of hydrogen halides (hydrohalogenation) adds HBr or similar acids across the double bond, for example ethene plus hydrogen bromide gives bromoethane. Addition of water (hydration) in the presence of sulphuric acid at about 300 degC adds water across the double bond, for example but-1-ene plus water gives butan-2-ol.

22.3 Alkynes

Alkynes are unsaturated hydrocarbons containing at least one carbon-carbon triple bond (-C-triple bond-C-), represented by the general formula CnH2n-2. Like alkenes, alkynes are named from the longest continuous chain containing the triple bond, with examples including ethyne (CH-triple bond-CH), propyne, but-1-yne and but-2-yne.

The simplest alkyne, ethyne (commonly called acetylene), is widely used in welding and cutting because it releases a large amount of heat when burned in oxygen, producing carbon dioxide, water and an extremely hot oxyacetylene flame that speeds up cutting and welding. Acetylene gas is also used to artificially ripen green fruit: when solid calcium carbide reacts with moisture in the air it produces acetylene gas, which accelerates ripening and induces a colour change -- though the use of calcium carbide for this purpose is prohibited in many countries because of health risks such as dizziness, vomiting and skin ulcers.

22.4 Sources of Organic Compounds

Coal, petroleum and natural gas -- the three major fossil fuels -- are the principal sources of organic compounds. Natural gas and petroleum are the chief sources of aliphatic (chain) hydrocarbons, while coal is the major source of aromatic hydrocarbons. Natural gas is a mixture of hydrocarbon gases with methane (CH4) as its largest component.

Petroleum and natural gas are usually found together, trapped between layers of non-porous rock underground; drilling releases the gas along with some volatile liquids, after which the liquid petroleum is pumped out. Liquid petroleum is a complex mixture of mainly aliphatic hydrocarbons -- boiling it up to 400 degC can yield at least 500 different compounds. Beyond fuels, petroleum products supply alkenes used to make plastics, and aromatic compounds such as benzene (produced from n-hexane) which is used to make perfumes, drugs, dyes and photographic developers.

22.5 Refining of Petroleum

Crude petroleum is a mixture of many hydrocarbons that does not burn easily, so it must be separated into useful fractions by refining, which is carried out by fractional distillation at about 400 degC. Crude oil is first neutralised by washing with an acidic or basic solution, then heated in a furnace above 400 degC; the resulting gases and vapours rise through a tall fractionating column fitted with shelves and bubble caps. Refinery gases escape at the very top; as the vapour rises, fractions with higher boiling points condense to liquids lower down in the column, while fractions with lower boiling points rise further before condensing, and each condensed fraction is drained off from its own shelf into storage tanks and later redistilled for better separation.

The main fractions, from lowest to highest boiling range, are refinery gases (below 0 degC, 1-4 carbons, used as stove fuel), gasoline/petrol (0-65 degC, 5-6 carbons, car fuel), naphtha (65-170 degC, 6-10 carbons, chemical feedstock), kerosene (170-250 degC, 10-14 carbons, jet fuel), diesel oil (250-340 degC, 14-19 carbons, fuel for cars/buses/trucks), lubricating oil and fuel oil (340-500 degC, 19 carbons and above, lubricants/ship and power-plant fuel) and bitumen (above 500 degC, above 35 carbons, road construction and waterproofing). As chain length decreases up the column, molecular mass and intermolecular forces fall, so the fractions near the top have higher volatility, lower boiling points and lower viscosity, while fractions near the bottom have longer chains, lower volatility, higher boiling points and higher viscosity.

Important Definitions

Alkene

An unsaturated hydrocarbon containing one or more carbon-carbon double bonds; general formula CnH2n; also called an olefin.

Alkyne

An unsaturated hydrocarbon containing at least one carbon-carbon triple bond; general formula CnH2n-2.

Dehydration

Removal of a water molecule from a compound, as when concentrated sulphuric acid converts an alcohol into an alkene.

Dehydrohalogenation

Removal of a molecule of hydrogen halide (HX) from an alkyl halide, typically using KOH dissolved in ethanol, to form an alkene.

Elimination reaction

A reaction in which a small molecule is removed from a saturated compound to produce an unsaturated compound.

Cracking

The process of converting high molecular mass alkanes into smaller alkanes and alkenes by heating at high temperature, without oxygen, using a catalyst such as zeolite.

Addition reaction

A reaction in which two or more reactants combine to form a single new product, typical of compounds containing a double or triple bond.

Catalytic hydrogenation

The addition of hydrogen to an alkene in the presence of a nickel catalyst to form the corresponding alkane.

Hydrohalogenation

The addition of a hydrogen halide (such as HBr) across the double bond of an alkene.

Hydration reaction

The addition of water across the double bond of an alkene in the presence of an acid catalyst such as sulphuric acid.

Fossil fuel

A fuel such as coal, petroleum or natural gas formed from the remains of ancient organisms, and a major source of organic compounds.

Petroleum

A complex, naturally occurring mixture of mainly aliphatic hydrocarbons found trapped underground.

Natural gas

A naturally occurring mixture of hydrocarbon gases, mainly methane, often found together with petroleum.

Fractional distillation (of petroleum)

The process of separating crude petroleum into fractions of differing boiling range by heating and condensing vapours in a fractionating column.

Volatility

A measure of how readily a liquid evaporates into vapour; higher for shorter-chain hydrocarbons.

Viscosity

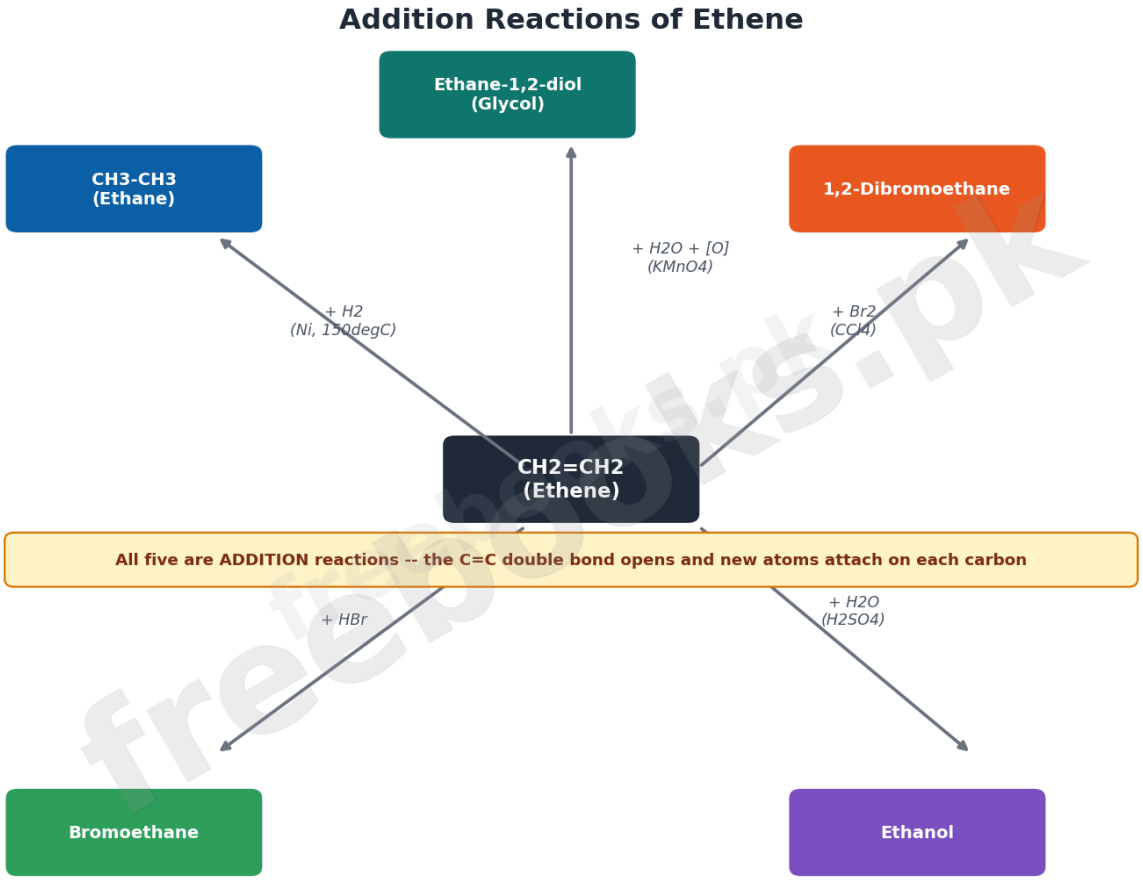
> A measure of a liquid's resistance to flow; higher for longer-chain, higher molecular mass hydrocarbons.

Key Facts & Relations

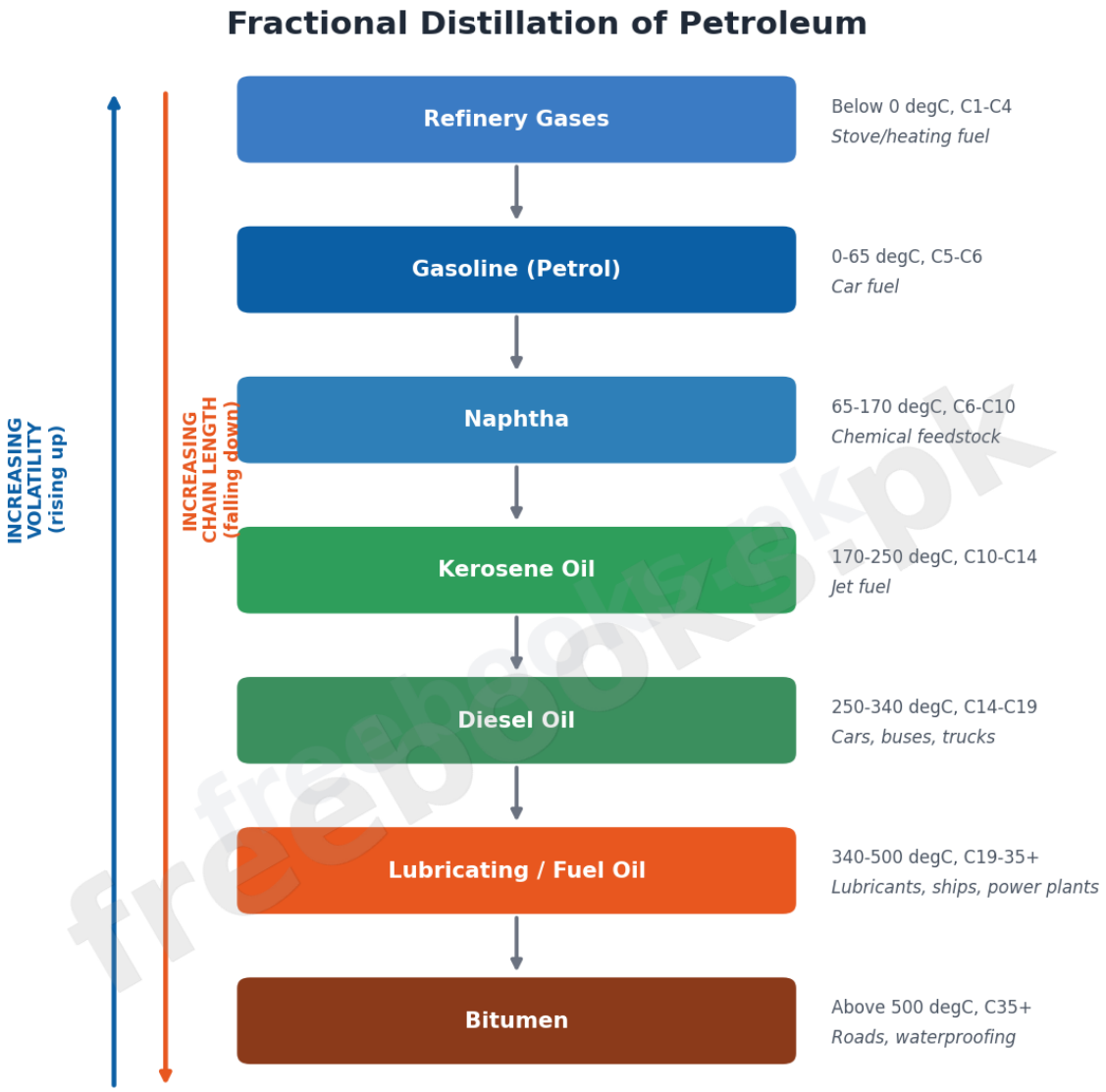
Topic	Relation
Alkenes	General formula CnH2n
Alkynes	General formula CnH2n-2
Catalytic hydrogenation	CH2=CH2 + H2 --Ni, 150 degC, 2 atm--> CH3-CH3
Halogen addition	CH2=CH2 + Br2 --CCl4--> 1,2-dibromoethane
KMnO4 oxidation (unsaturation test)	CH2=CH2 + H2O + [O] --KMnO4--> ethane-1,2-diol (glycol)
Hydrogen halide addition	CH2=CH2 + HBr --> bromoethane
Hydration (steam addition)	But-1-ene + H2O --H2SO4, ~300 degC--> Butan-2-ol
Combustion of ethyne (oxyacetylene)	2 CH-triple bond-CH + 5 O2 --> 4 CO2 + 2 H2O + heat

Diagrams

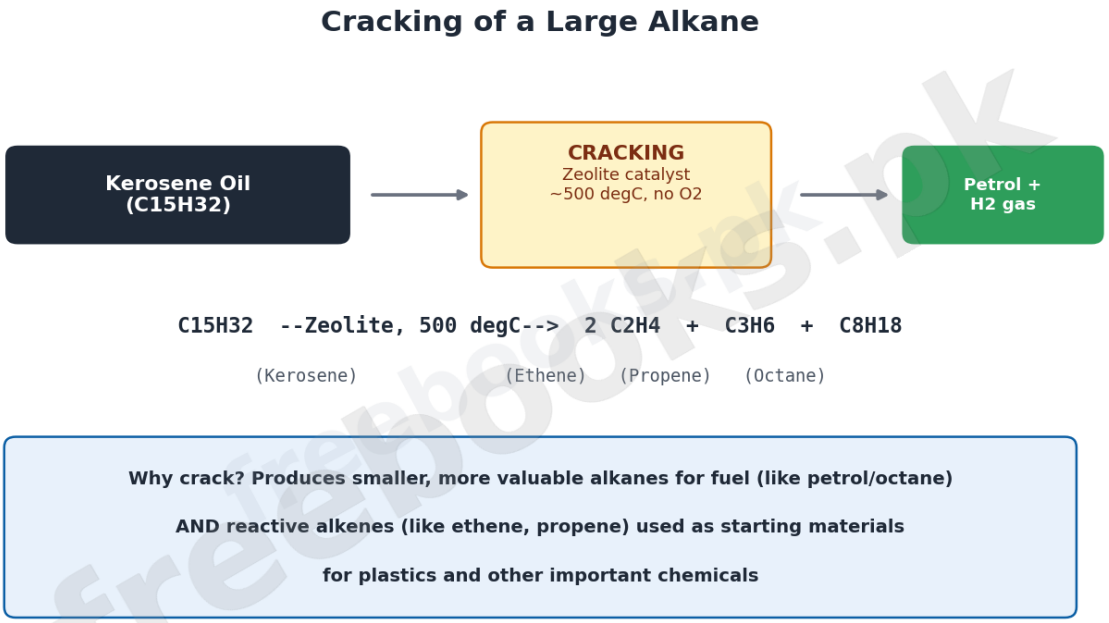
Addition Reactions of Ethene: A hub-and-spoke diagram showing ethene reacting with hydrogen (Ni catalyst), bromine, hydrogen bromide, and water/KMnO4 to give five different addition products.



The Fractionating Column of Petroleum: A labelled diagram of the petroleum fractionating column, showing the fractions from refinery gases at the top down to bitumen at the bottom, with their boiling ranges and the trend in chain length, volatility and viscosity.



Cracking of a Large Alkane: A flow diagram showing a high molecular mass alkane (such as kerosene, C15H32) being cracked at high temperature with a zeolite catalyst into smaller alkanes and alkenes, including the symbol equation.



Short Questions & Answers

Give two examples of addition reactions.

The addition of hydrogen to ethene (with a nickel catalyst) to give ethane, and the addition of bromine to ethene (in CCl4) to give 1,2-dibromoethane, are both addition reactions.

Give the names of the compounds obtained from coal tar and petroleum.

Coal tar is a major source of aromatic hydrocarbons such as benzene and its derivatives, while petroleum is the chief source of aliphatic hydrocarbons such as alkanes, alkenes and their derivatives used to make fuels and plastics.

How is ethene oxidised by a cold aqueous solution of potassium permanganate?

Cold, dilute, alkaline KMnO4 adds an oxygen atom and a water molecule across ethene's double bond to give ethane-1,2-diol (glycol); the purple colour of the KMnO4 is discharged as the reaction proceeds, which is why this reaction is also used to test for unsaturation.

Differentiate between elimination and addition reactions.

An elimination reaction removes a small molecule (such as water or a hydrogen halide) from a saturated compound to produce an unsaturated one, while an addition reaction combines two

or more reactants across a double or triple bond of an unsaturated compound to give a single saturated product -- the two are essentially opposite processes.

Name the starting materials used to generate an oxyacetylene flame.

Ethyne (acetylene) gas and oxygen gas are burned together to generate the very hot oxyacetylene flame used for welding and cutting metal.

How can an alkene be identified?

An alkene can be identified because it rapidly decolourises reddish-brown bromine water and purple potassium permanganate solution (and violet iodine solution) through addition/ oxidation reactions across its double bond, whereas a saturated alkane does not react with these reagents under the same mild conditions.

What is the difference between the terms dehydration and dehydrohalogenation?

Dehydration removes a molecule of water from an alcohol (using concentrated H_2SO_4) to form an alkene, while dehydrohalogenation removes a molecule of hydrogen halide (HX) from an alkyl halide (using KOH in ethanol) to form an alkene -- both are elimination reactions but remove different small molecules.

Why is the oxyacetylene flame so hot?

Burning ethyne in oxygen releases a very large amount of heat energy because of the high energy stored in its carbon-carbon triple bond and the efficient, complete combustion with pure oxygen rather than air, producing a flame hot enough to cut and weld metal.

Do you expect ethyne to decolourise a cold solution of $KMnO_4$?

Yes -- ethyne contains a carbon-carbon triple bond, an even more reactive unsaturated linkage than the double bond in alkenes, so it also reacts with and decolourises cold dilute $KMnO_4$ solution through oxidation.

How do chlorine and hydrogen chloride add to ethene?

Chlorine (Cl_2) adds across the double bond to give 1,2-dichloroethane, while hydrogen chloride (HCl) adds across the double bond to give chloroethane -- both are simple addition reactions typical of alkenes.

Long Questions & Answers

Describe the fractional distillation of petroleum, and explain how the properties of the fractions change from the bottom to the top of the column.

How is crude petroleum prepared and heated before distillation?

The crude oil is first neutralised by washing with an acidic or basic solution as needed, then heated in an electric furnace to above 400 degC so that it turns into a mixture of hot gases and vapours ready to enter the fractionating column.

How does the fractionating column separate the vapours into fractions?

The hot vapours rise through a tall column fitted with shelves covered by bubble caps. Refinery gases, which have the lowest boiling points, pass straight to the top and escape as gas; heavier fractions with higher boiling points condense back to liquid lower down, while lighter fractions rise further before condensing, and each condensed liquid is drained from its shelf into a separate storage tank, later redistilled for better purity.

What are the main fractions obtained and their uses?

From lowest to highest boiling range: refinery gases (fuel for stoves), gasoline/petrol (car fuel), naphtha (chemical feedstock), kerosene (jet fuel), diesel oil (fuel for cars, buses, trucks), lubricating oil and fuel oil (lubricants, waxes, ship and power-plant fuel), and bitumen (roads and waterproofing).

How do the physical properties of the fractions change from bottom to top?

As chain length decreases going up the column, molecular mass and the strength of intermolecular forces fall, so fractions near the top (like refinery gases) have higher volatility, lower boiling points and lower viscosity, while fractions near the bottom (like bitumen) have longer chains, higher boiling points and higher viscosity.

Describe two methods of preparation of ethene and its important addition reactions.

How is ethene prepared by dehydration of an alcohol?

Ethanol is heated with concentrated sulphuric acid as a dehydrating agent at about 180 degC, removing a water molecule to form ethene: CH3-CH2-OH gives CH2=CH2 + H2O.

How is ethene prepared by dehydrohalogenation of an alkyl halide?

Chloroethane is heated with potassium hydroxide dissolved in ethanol at about 180 degC; a molecule of HCl is eliminated to form ethene: CH3-CH2Cl + KOH gives CH2=CH2 + KCl + H2O -- this is an elimination reaction.

How does ethene react with hydrogen and with bromine?

With hydrogen and a nickel catalyst at about 150 degC and 2 atm, ethene undergoes catalytic hydrogenation to give ethane. With bromine in a non-polar solvent such as CCl4, ethene undergoes halogen addition to give 1,2-dibromoethane, discharging bromine's reddish-brown colour.

How does ethene react with KMnO4, hydrogen bromide and steam?

Cold dilute alkaline KMnO4 oxidises ethene to ethane-1,2-diol (glycol), discharging the purple colour -- a key test for unsaturation. Hydrogen bromide adds to give bromoethane. Steam, with a sulphuric acid catalyst at about 300 degC, adds across the double bond in a hydration reaction to give an alcohol.

Multiple Choice Questions (MCQs)

Which of the following compounds is expected to give an addition reaction? (A) CH3-CH3 (B) CH2=CH2 (C) CH4 (D) CH3-CH2-CH3

Correct answer: (B) CH2=CH2. Only CH2=CH2 (ethene) has a carbon-carbon double bond, which is needed for addition reactions; the other three are saturated alkanes.

Which of the following is not used as a fuel? (A) LPG (B) CNG (C) Diesel (D) Asphalt

Correct answer: (D) Asphalt. Asphalt (bitumen) is a thick, high-boiling petroleum fraction used for roads and waterproofing, not as a fuel; LPG, CNG and diesel are all common fuels.

Indicate the type of the following reaction: CH4 + 2O2 -> CO2 + 2H2O. (A) Substitution (B) Oxidation (C) Reduction (D) Addition

Correct answer: (B) Oxidation. Methane reacting with oxygen to form carbon dioxide and water is combustion, a form of oxidation.

Which species acts as a reducing agent in the reaction between ethene and KMnO4? (A) H2O (B) CH2=CH2 (ethene) (C) KMnO4 (D) NaOH

Correct answer: (B) CH2=CH2 (ethene). Ethene is oxidised (loses electrons/gains oxygen) by KMnO4, so ethene acts as the reducing agent while KMnO4 itself is the oxidising agent.

What product forms when propene reacts with a bromine molecule? (A) 1,2-Dibromopropane (B) 1,1-Dibromopropane (C) 2,3-Dibromopropane (D) 1,3-Dibromopropane

Correct answer: (A) 1,2-Dibromopropane. Bromine adds across propene's double bond (between carbons 1 and 2), giving 1,2-dibromopropane.

Which petroleum fraction is used to generate electricity in power plants? (A) Bitumen (B) Lubricating oil (C) Kerosene oil (D) Fuel oil

Correct answer: (D) Fuel oil. Fuel oil is burned in ships and power plants to generate energy/electricity, distinct from lubricating oil (used as a lubricant) and bitumen (used for roads).

In the reaction CH3-CH2-Br + KOH --ethanol--> CH2=CH2 + KBr + H2O, which molecule is eliminated? (A) Br2 (B) H2 (C) HBr (D) H2O

Correct answer: (C) HBr. A molecule of hydrogen bromide (HBr, released here as KBr + implied H) is eliminated from the alkyl halide during this dehydrohalogenation, forming the double bond of ethene.

Fractional distillation of petroleum is based on: (A) Viscosity (B) Boiling point range (C) Flammability (D) Melting point range

Correct answer: (B) Boiling point range. Fractional distillation separates the hydrocarbons in petroleum according to their different boiling point ranges, condensing each fraction at a different height in the column.

Quick Revision Summary

- Alkenes (CnH2n) have a C=C double bond; alkynes (CnH2n-2) have a C-triple bond-C; both are unsaturated and undergo addition reactions.
- Alkenes are made by dehydration of alcohols (conc. H2SO4), dehydrohalogenation of alkyl halides (KOH/ethanol), or cracking of large alkanes (heat, no O2, zeolite catalyst).
- Key alkene addition reactions: + H2 (Ni) -> alkane; + Br2 -> dibromide; + HX -> haloalkane; + H2O (H2SO4) -> alcohol; + [O]/KMnO4 -> diol (glycol).
- Bromine water, KMnO4 and iodine are all decolourised by alkenes (and alkynes) but not by alkanes -- the standard test for unsaturation.
- Ethyne (acetylene) burns with oxygen in a very hot oxyacetylene flame, used for welding/cutting and (via calcium carbide) fruit ripening.
- Coal, petroleum and natural gas are the three major fossil-fuel sources of organic compounds; natural gas is mostly methane.
- Petroleum is refined by fractional distillation (~400 degC) into refinery gas, gasoline, naphtha, kerosene, diesel, lubricating/fuel oil and bitumen.

- Going up the fractionating column, chain length falls while volatility rises and boiling point/viscosity fall; going down, the reverse trend holds.

Exam Tips

- To spot an addition reaction, look for a double or triple bond disappearing as new atoms attach on either side of it.
- Remember the unsaturation test as a colour-fade: bromine water (orange/brown to colourless), KMnO4 (purple to colourless) both fade only with alkenes/alkynes.
- Keep dehydration (removes H2O, needs H2SO4) and dehydrohalogenation (removes HX, needs KOH/ethanol) straight by what small molecule leaves.
- For petroleum fractions, remember the pattern: shorter chain = lower boiling point = higher up the column = more volatile and less viscous.
- Cracking always produces at least one smaller alkane AND at least one alkene from a larger alkane -- check both are present in an equation.
- Link ethyne's uses to its triple bond: huge combustion heat drives welding; its reactivity (via calcium carbide) drives fruit ripening.

Chapter 23: Monohydroxy Alkanes or Alcohols

Monohydroxy alkanes, or alcohols, are an important class of organic compounds carrying a single -OH group. This chapter focuses on ethyl alcohol (ethanol), which is manufactured on a large scale by two very different routes -- fermentation of glucose using yeast, a biological process, and catalytic hydration of ethene, an industrial chemical process -- and compares their conditions, costs and starting materials.

The chapter also covers how alcohols burn to release energy, why they are considered as an alternative fuel to petrol and diesel with real advantages and disadvantages, and the many roles ethanol plays beyond the fuel tank: as a solvent, disinfectant and preservative in the pharmaceutical industry, as a volatile, deodorising ingredient in cosmetics, and as an everyday antiseptic and solvent in ordinary households.

Learning Objectives

- Describe the manufacture of ethanol by fermentation of aqueous glucose using yeast, and by catalytic hydration of ethene.
- Compare the advantages and disadvantages of fermentation and hydration as methods of ethanol production.
- Describe the combustion of alcohols and write balanced equations for their complete combustion.
- Discuss the advantages and disadvantages of using alcohols as fuels compared with fossil fuels.
- Explain the role of ethanol in the pharmaceutical and cosmetic industries.
- Discuss the impact of alcohols on daily life, including their use as solvents and disinfectants.

Key Concepts

23.1 Manufacture of Ethyl Alcohol (CH3-CH2-OH)

Ethanol is manufactured by fermentation of glucose using yeast. Fermentation is a reaction in which a substance breaks down into simpler substances using enzymes present in yeast, and is also how yogurt and bread are made. Glucose is converted to ethanol by yeast at around 35 degC in a neutral or acidic solution, under anaerobic conditions (absence of air): C6H12O6 --Yeast, 35

degC--> 2 C2H5OH + 2 CO2. The temperature must stay near 35 degC -- lower temperatures slow the reaction, while higher temperatures inactivate the enzyme. Oxygen is excluded because it would oxidise the ethanol to ethanoic acid, and yeast itself becomes inactive once ethanol concentration exceeds about 15%, since ethanol is toxic to yeast at high concentration.

Ethanol is also manufactured by hydration of ethene, an addition reaction in which water adds across ethene's double bond. A mixture of ethene and steam is passed over hot phosphoric acid (H3PO4) as catalyst at about 300 degC and 60 atm pressure: CH2=CH2 + H2O --H3PO4, 300 degC, 60 atm--> CH3-CH2-OH. The gaseous ethanol produced is then condensed to liquid. Compared with fermentation, hydration runs at high temperature and pressure using a non-renewable crude-oil-derived starting material, but reacts quickly and gives relatively pure, though expensive, alcohol; fermentation runs at atmospheric pressure and around 35 degC using a renewable starting material such as cane sugar, reacts slowly (often taking days), and gives only about 15% alcohol that needs energy-intensive distillation to concentrate, but the resulting ethanol is cheap.

23.2 Combustion of Alcohols

Alcohols are flammable and burn completely in excess air (because of their hydrocarbon chain) to produce carbon dioxide and water, releasing a large amount of heat. For example: 2CH3OH + 3O2 -> 2CO2 + 4H2O, deltaH = -726 kJ/mol (methanol); C2H5OH + 3O2 -> 2CO2 + 3H2O, deltaH = -1367 kJ/mol (ethanol); 2C3H7OH + 9O2 -> 6CO2 + 8H2O, deltaH = -2017 kJ/mol (propanol); 2C4H9OH + 12O2 -> 8CO2 + 10H2O, deltaH = -2676 kJ/mol (butanol).

During combustion, the weaker C-H bonds in the alcohol's -CH2- groups break, and the stronger C=O and O-H bonds of CO2 and H2O form in their place. Because each additional -CH2- unit in the homologous series adds more C-H bonds to break and more C=O/O-H bonds to form, the amount of heat evolved increases steadily from methanol through ethanol, propanol and butanol.

23.3 Applications of Alcohols as Fuels

The first four aliphatic alcohols -- methanol, ethanol, propanol and butanol -- have properties suitable for use as fuel in internal combustion engines, instead of petrol or diesel. Advantages of alcohol fuels include: they come from renewable sources; their combustion produces no oxides of sulphur, making them more environmentally friendly than fossil fuels; and they have higher fuel efficiency than petrol or diesel. Because bioalcohols are made from plant material that absorbed CO2 during photosynthesis, and burning them releases that same CO2 back, the overall process is considered carbon-neutral -- it does not add extra CO2 to the atmosphere.

Disadvantages include: alcohols carry less energy per unit volume than gasoline, so more fuel volume is needed to travel the same distance; alcohols can increase wear and tear on engine components; and land used to grow crops for alcohol production competes with land needed to grow food crops.

23.4 Role of Ethanol in Industries

In the pharmaceutical industry, ethyl alcohol is a very common ingredient thanks to its bactericidal activity: it is used as a disinfectant in hand sanitiser and methylated spirit, and as a solvent and preservative in many pharmaceutical preparations, including vaccines. Ethanol and isopropanol are also active ingredients in some oral and topical drug products, where they help solubilise other drugs. Ethanol as a fuel additionally reduces greenhouse gas emissions by 44-52% compared with petrol, and also cuts down on other pollutants such as CO, NOx and particulate matter.

In the cosmetic industry, ethanol's high volatility (fast evaporation), deodorising and anti-inflammatory properties, and refreshing, antimicrobial character make it an important ingredient in hair styling products, foundation creams, perfumes, deodorants and aftershave lotions.

23.5 Impact of Alcohols on Daily Life

Ethyl alcohol is a staple of the household first-aid kit in the form of methylated spirit, used as an antiseptic, for dressing wounds, and as an antidote for snake bites. In many parts of the world, ethanol also serves as a high-efficiency vehicle fuel. As a solvent, ethanol is widely used in perfumes and is relatively safe for dissolving many organic compounds that are insoluble in water. At the same time, ethanol as a drink can cause hangovers, alcohol poisoning, accidents and risky behaviour, and long-term alcohol use is linked to more than 200 different diseases.

Important Definitions

> **Fermentation**
>
> A reaction in which a substance (such as glucose) breaks down into simpler substances using enzymes present in a living catalyst such as yeast.

> **Ethanol (ethyl alcohol)**
>
> CH3-CH2-OH, the most important member of the alcohol homologous series, manufactured by fermentation or by hydration of ethene.

Enzyme

A biological catalyst, such as the one present in yeast, that speeds up a specific reaction like fermentation.

Anaerobic conditions

Conditions in which oxygen (air) is absent; required for the fermentation of glucose to ethanol.

Hydration of ethene

An addition reaction in which water adds across the double bond of ethene, using a phosphoric acid catalyst at high temperature and pressure, to give ethanol.

Combustion

The burning of a fuel such as an alcohol in oxygen/air to produce carbon dioxide, water and heat energy.

Methylated spirit

Ethanol used as a household antiseptic and first-aid product, and for dressing wounds.

Disinfectant

A substance, such as ethanol in hand sanitiser, that kills or inhibits harmful microbes on surfaces or skin.

Antiseptic

A substance, such as methylated spirit, applied to living tissue to prevent infection.

Solvent

A substance, such as ethanol, that dissolves other substances (solutes) to form a solution; ethanol dissolves many organic compounds insoluble in water.

Renewable source

A starting material, such as cane sugar used in fermentation, that can be replenished naturally and is not depleted by use.

Non-renewable source

A starting material, such as crude oil used to make ethene for hydration, that exists in a limited supply and is not naturally replenished on a human timescale.

Carbon-neutral process

A process, such as burning bioalcohol fuel, in which the CO2 released equals the CO2 absorbed during the production of the fuel, so atmospheric CO2 does not increase.

Biofuel (bioalcohol)

A fuel, such as ethanol, produced from plant material via fermentation, used as an alternative to fossil fuels.

Key Facts & Relations

Topic	Relation
Fermentation of glucose	C6H12O6 --Yeast, ~35 degC, anaerobic--> 2 C2H5OH + 2 CO2
Hydration of ethene	CH2=CH2 + H2O --H3PO4, ~300 degC, ~60 atm--> CH3-CH2-OH
Combustion of methanol	2 CH3OH + 3 O2 -> 2 CO2 + 4 H2O, deltaH = -726 kJ/mol
Combustion of ethanol	C2H5OH + 3 O2 -> 2 CO2 + 3 H2O, deltaH = -1367 kJ/mol
Combustion of propanol	2 C3H7OH + 9 O2 -> 6 CO2 + 8 H2O, deltaH = -2017 kJ/mol
Combustion of butanol	2 C4H9OH + 12 O2 -> 8 CO2 + 10 H2O, deltaH = -2676 kJ/mol
Yeast tolerance limit	Fermentation stops once ethanol concentration exceeds about 15% (toxic to yeast)
Ethanol as fuel (vs petrol)	Reduces greenhouse gas emissions by about 44-52%; also cuts CO, NOx and particulate matter

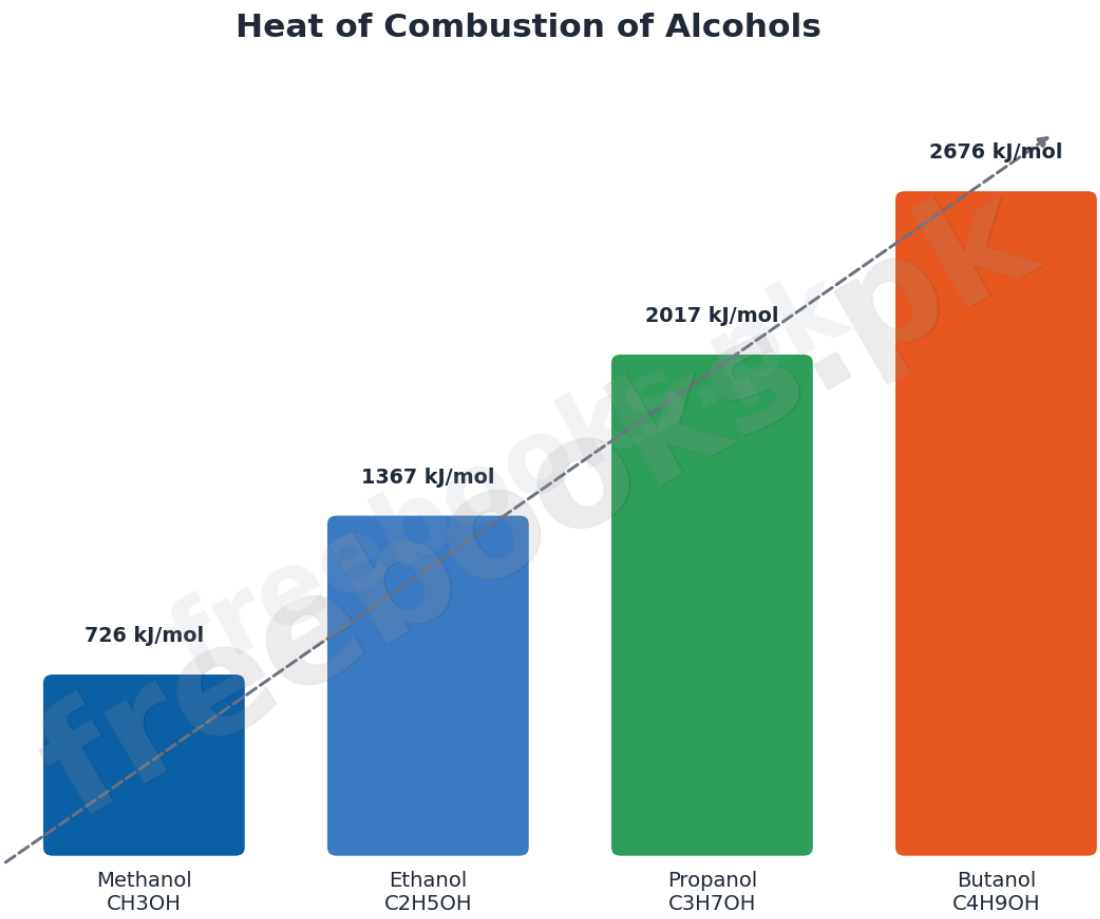
Diagrams

Fermentation vs Hydration of Ethene: A side-by-side comparison diagram of the two methods of manufacturing ethanol -- fermentation of glucose and catalytic hydration of ethene -- showing conditions, starting materials, rate and purity for each.

Two Methods of Manufacturing Ethanol

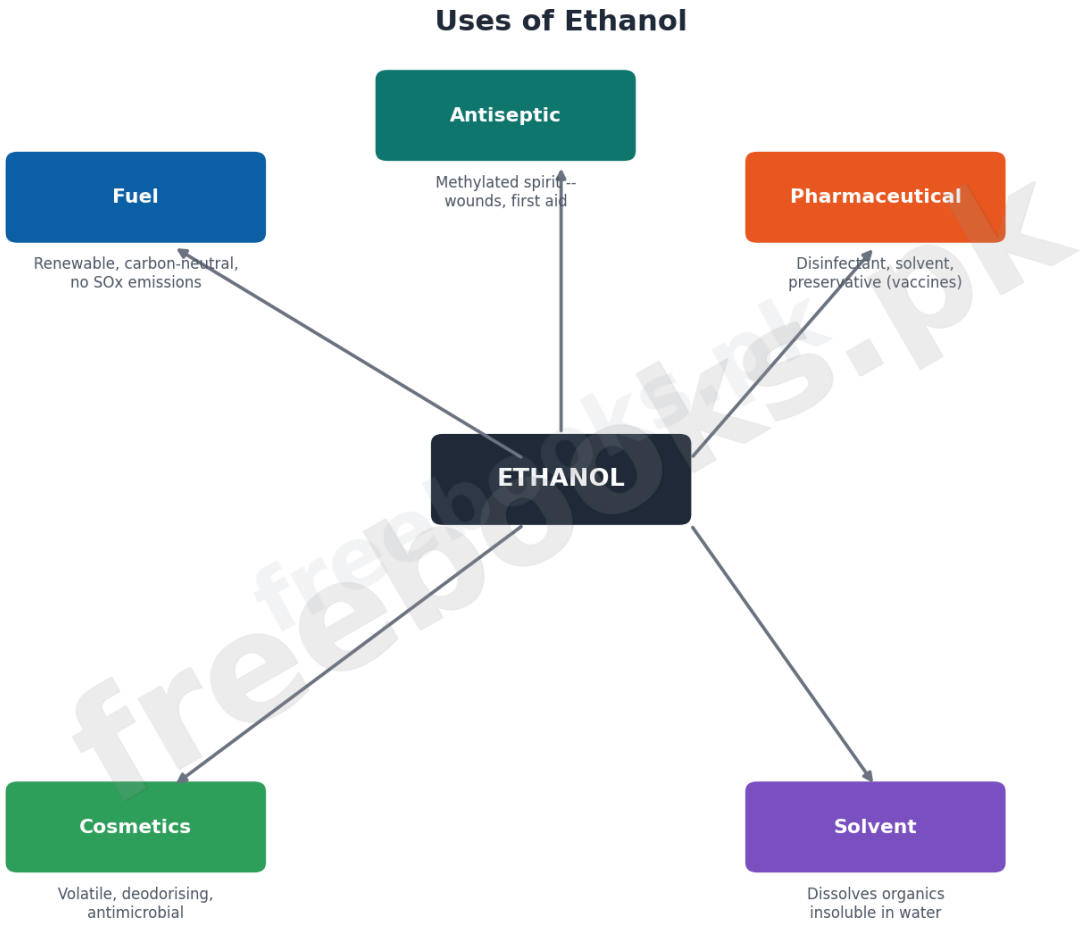
	FERMENTATION of Glucose	HYDRATION of Ethene
Conditions	~35 degC, atmospheric pressure, yeast enzyme, anaerobic	~300 degC, ~60 atm, H3PO4 catalyst
Source material	Renewable (e.g. cane sugar)	Non-renewable (crude oil)
Reaction rate	Slow (may take days)	Fast
Product purity	~15% alcohol -- needs distillation	Relatively pure directly
Cost	Cheap	Expensive

Heat of Combustion of Alcohols: A bar-style diagram showing the increasing heat of combustion from methanol to ethanol to propanol to butanol as the hydrocarbon chain lengthens.



Heat evolved increases as the hydrocarbon chain (and -CH2- units) get longer

Uses of Ethanol: A hub-and-spoke chart showing ethanol's major uses -- as a fuel, in pharmaceuticals, in cosmetics, as a solvent, and as an antiseptic/disinfectant.



Short Questions & Answers

Give two advantages of burning alcohols over burning fossil fuels.

Burning alcohols does not produce oxides of sulphur (unlike many fossil fuels), making them more environmentally friendly, and alcohols come from renewable sources rather than the non-renewable crude oil that fossil fuels are refined from.

Which properties of ethyl alcohol make it useful for the cosmetic industry?

Ethanol's high volatility (it evaporates quickly), its deodorising and anti-inflammatory properties, and its refreshing, antimicrobial character make it useful in hair styling products, foundation creams, perfumes, deodorants and aftershave lotions.

How is ethyl alcohol important for the pharmaceutical industry?

Ethanol's bactericidal activity makes it a common disinfectant (in hand sanitiser and methylated spirit) and it is also used as a solvent and preservative in many pharmaceutical preparations, including vaccines, and as an active ingredient that helps solubilise other drugs.

Give any two disadvantages of the fermentation reaction.

Fermentation is slow and may take days to complete, and it produces only about 15% alcohol, which then needs energy-intensive distillation to concentrate it into more usable, purer ethanol.

Write the conditions involved in the hydration of ethene.

Ethene and steam are passed over hot phosphoric acid (H3PO4) catalyst at about 300 degC and about 60 atm pressure to produce ethanol.

How is ethanol obtained as a by-product in the sugar industry?

Cane sugar (or its by-product molasses) provides the glucose/sugars that yeast ferments anaerobically at around 35 degC into ethanol and carbon dioxide, making ethanol a natural by-product of sugar production.

Why do we get relatively impure alcohol from the fermentation process?

Fermentation produces a dilute mixture of only about 15% ethanol in water along with other by-products, because yeast becomes inactive once the ethanol concentration rises too high, so the product must be distilled further to obtain purer, more concentrated alcohol.

How do the properties of ethyl alcohol help us use it as a fuel?

Ethanol is flammable and burns completely to release a large amount of heat, it is renewable and carbon-neutral as a bioalcohol, and it produces no sulphur oxides on combustion, all of which make it a practical, cleaner alternative fuel for internal combustion engines.

Why is oxygen excluded when the fermentation reaction is carried out?

Oxygen must be excluded because, in its presence, the ethanol produced would be further oxidised into ethanoic acid instead of accumulating as the desired product.

Why does butanol evolve a higher amount of heat than propanol when burnt in oxygen?

Butanol has one more -CH2- unit than propanol, so more C-H bonds are broken and more C=O and O-H bonds are formed during its combustion, releasing correspondingly more heat energy.

Long Questions & Answers

Give a comparison of the fermentation reaction and catalytic hydration of ethene for the preparation of ethanol.

How do the reaction conditions of the two methods differ?

Hydration of ethene is carried out at high temperature (~300 degC) and high pressure (~60 atm) using a phosphoric acid catalyst, while fermentation is carried out at a much gentler ~35 degC and atmospheric pressure using yeast's natural enzymes.

How do the starting materials differ?

Hydration uses ethene derived from crude oil, a non-renewable source, while fermentation uses glucose from sources such as cane sugar, a renewable source that can be regrown.

How do the reaction rate and product purity compare?

Hydration reacts quickly and produces relatively pure ethanol directly, while fermentation is slow (often taking days) and produces only about 15% alcohol that needs further distillation, which itself requires additional energy, to reach a usable concentration.

How does the cost of the ethanol produced compare?

Ethanol from hydration is relatively expensive because of the energy-intensive high-temperature, high-pressure process and non-renewable feedstock, whereas ethanol from fermentation is cheap, since it uses inexpensive renewable raw materials and mild reaction conditions, despite needing extra distillation.

Describe the applications of ethanol in the pharmaceutical and cosmetic industries, and its role in daily life.

What roles does ethanol play in the pharmaceutical industry?

Ethanol's bactericidal activity makes it a widely used disinfectant, for example in hand sanitiser and methylated spirit, and it also serves as a solvent and preservative in pharmaceutical preparations including vaccines, and as an active ingredient that helps solubilise other drugs in oral and topical products.

What roles does ethanol play in the cosmetic industry?

Because ethanol is highly volatile (evaporates quickly) and has deodorising, anti-inflammatory, refreshing and antimicrobial properties, it is a key ingredient in hair styling products, foundation creams, perfumes, deodorants and aftershave lotions.

How does ethanol feature in everyday household and first-aid use?

Ethanol, in the form of methylated spirit, is a staple of the household first-aid kit, used as an antiseptic, for dressing wounds, and as an antidote for snake bites; it is also a widely used, relatively safe solvent in perfumes for dissolving organic compounds that do not dissolve in water.

What risks are associated with ethanol's daily-life role as a drink?

Ethanol consumed as an alcoholic drink can cause hangovers, alcohol poisoning, accidents and risky behaviour, and long-term use of alcohol is linked to more than 200 different diseases, showing that the same compound useful in medicine and industry carries real health risks when consumed.

Multiple Choice Questions (MCQs)

Which conditions are considered best for the fermentation of glucose? (A) 35 degC, fresh yeast, absence of oxygen (B) 45 degC, yeast (C) 45 degC, absence of oxygen (D) 35 degC, fresh yeast

Correct answer: (A) 35 degC, fresh yeast, absence of oxygen. Fermentation needs a temperature of about 35 degC (not too low or the enzyme becomes inactive at higher temperatures), fresh active yeast, and anaerobic (oxygen-free) conditions to prevent the ethanol being further oxidised.

Which catalyst other than H3PO4 can also be used for hydration of alkenes? (A) NaOH (B) H2SO4 (C) CH3COOH (D) Ni

Correct answer: (B) H2SO4. Concentrated sulphuric acid (H2SO4) can also act as an acid catalyst for the hydration (addition of water) of alkenes, just like phosphoric acid.

Which alcohol has the maximum heat of combustion? (A) CH3CH2CH2OH (propanol) (B) CH3CH2OH (ethanol) (C) CH3OH (methanol) (D) CH3CH2CH2CH2OH (butanol)

Correct answer: (D) CH3CH2CH2CH2OH (butanol). Heat of combustion increases with chain length in the alcohol homologous series, so butanol, having the longest chain of the four listed, releases the most heat.

The most environmentally friendly fuel among the following is: (A) Coal (B) Kerosene oil (C) Ethanol (D) Wood

Correct answer: (C) Ethanol. Ethanol is a renewable, carbon-neutral bioalcohol that produces no sulphur oxides on combustion, making it more environmentally friendly than fossil fuels like coal and kerosene, or wood.

Which property or properties of ethanol make it suitable for use in the cosmetic industry? (A) Easily flammable (B) Highly volatile and deodorising (C) Antipyretic (D) Sedative

Correct answer: (B) Highly volatile and deodorising. Ethanol's high volatility (fast evaporation) and deodorising property make it valuable in cosmetics such as perfumes, deodorants and aftershave lotions.

What is the correct IUPAC name for CH3-CH(OH)-CH2-CH(CH3)-CH3? (A) 2-Methylpentan-4-ol (B) 4-Methylpentan-2-ol (C) Hexan-2-ol (D) Hexan-4-ol

Correct answer: (B) 4-Methylpentan-2-ol. The longest chain has five carbons (pentane) with -OH on carbon 2 and a methyl branch on carbon 4, numbered to give the principal -OH group the lowest locant, giving 4-methylpentan-2-ol.

Which property of ethanol makes it suitable for cleaning wounds? (A) Good solvent (B) Volatility (C) Antiseptic (D) Deodorizing

Correct answer: (C) Antiseptic. Ethanol's antiseptic (bactericidal) property is what allows it, as methylated spirit, to clean and disinfect wounds and prevent infection.

Which alcohol is added to petrol to improve combustion and also serves as a feedstock to prepare vinegar and other organic compounds? (A) Propanol (B) Propan-2-ol (C) Ethanol (D) Methanol

Correct answer: (C) Ethanol. Ethanol is commonly blended into petrol to improve combustion and is also the starting material used to manufacture vinegar (ethanoic acid) and many other organic compounds.

Quick Revision Summary

- Ethanol is made by fermentation of glucose (yeast, ~35 degC, anaerobic) or by hydration of ethene (H3PO4, ~300 degC, ~60 atm).
- Fermentation: renewable source, slow, cheap, gives ~15% impure alcohol needing distillation. Hydration: non-renewable source, fast, expensive, gives relatively pure alcohol directly.

- Alcohols combust completely in air to CO2 + H2O + heat; heat evolved rises from methanol to butanol as chain length (and C-H bonds broken) increases.
- Alcohol fuel advantages: renewable, no SOx emissions, higher efficiency, carbon-neutral. Disadvantages: less energy per volume, engine wear, competes with food-crop land.
- Ethanol in pharmaceuticals: disinfectant (hand sanitiser, methylated spirit), solvent and preservative (including in vaccines).
- Ethanol in cosmetics: volatile, deodorising, anti-inflammatory, antimicrobial -- used in hair products, creams, perfumes, deodorants, aftershave.
- Daily life: methylated spirit as first-aid antiseptic/wound dressing/snakebite antidote; ethanol as vehicle fuel and perfume solvent.
- Ethanol as a drink carries real risks -- hangover, poisoning, accidents, and long-term links to 200+ diseases.

Exam Tips

- Remember fermentation conditions with '35-yeast-no air': ~35 degC, yeast enzyme, anaerobic -- all three must hold for good yield.
- Contrast the two ethanol methods on FOUR axes: conditions (mild vs harsh), source (renewable vs non-renewable), rate/purity, and cost.
- For combustion equations, always balance CO2 and H2O against the number of carbons and hydrogens in the alcohol first, then balance oxygen last.
- Heat of combustion trend: more carbons = more bonds broken/formed = more heat released, going up the alcohol homologous series.
- Keep 'renewable' and 'non-renewable' tied to their sources: fermentation/crops = renewable; hydration/crude oil = non-renewable.
- Group ethanol's real-world roles into three buckets to remember them fast: medicine (disinfectant/solvent), cosmetics (volatile/deodorising), and fuel (renewable/carbon-neutral).

Chapter 24: Carboxylic Acids

Carboxylic acids, or organic acids, are a class of organic compounds containing a carboxyl group (-COOH) attached to an alkyl group or hydrogen. Compared with mineral acids like HCl or H2SO4, they are generally weak acids because they do not release protons easily, yet they occur widely in living organisms and can also be synthesised industrially. This chapter focuses on ethanoic acid (acetic acid), the most familiar member of the family, covering how it is manufactured, how it reacts as an acid, and how it combines with alcohols to form esters.

The chapter also surveys the huge range of everyday and industrial roles carboxylic acids and esters play -- as solvents, flavouring and fragrance agents, raw materials for synthetic fibres and plastics, food preservatives, and ingredients in medicines and cosmetics -- showing how a single functional group underpins products found in almost every kitchen, pharmacy and factory.

Learning Objectives

- Describe the reactions of carboxylic acids with metals, bases and carbonates, including the names and formulae of the salts produced.
- Describe the formation of ethanoic acid by the oxidation of ethanol with acidified aqueous potassium manganate (VII), and by bacterial oxidation during vinegar production.
- Describe the reaction of a carboxylic acid with an alcohol using an acid catalyst to form an ester (esterification).
- Describe the industrial applications of carboxylic acids and esters, including their use as solvents, flavours, fragrances and plastics.
- Explain the role of carboxylic acids and esters in daily life, including their use in food preservation, cosmetics and pharmaceuticals.

Key Concepts

24.1 Preparation of Acetic Acid or Ethanoic Acid

Ethanol is oxidised by acidified potassium manganate (VII) (KMnO4), first to ethanal, which then undergoes further oxidation under the same reaction conditions to give ethanoic acid. Hot acidified KMnO4 acts as a very efficient oxidising agent, and as it oxidises ethanol to ethanoic acid, its own purple colour changes to colourless -- a visible sign that oxidation has occurred.

Ethanoic acid is also produced industrially by oxidative (bacterial) fermentation. Alcoholic foodstuffs such as grain, malt, rice or potato mash are converted to vinegar when acetic acid bacteria oxidise the alcohol they contain, provided a sufficient and continuous supply of oxygen is available. In this process the liquid is held in a tank fitted with a continuous oxygen supply and is stirred continuously as oxygen bubbles through it; using this method, vinegar containing about 15% ethanoic acid can be produced in as little as 24 hours.

24.2 Reactions of Carboxylic Acids as Acids

Carboxylic acids are much weaker acids than mineral acids, but some react, rather slowly, with more reactive metals to give a salt and hydrogen gas. Dilute ethanoic acid reacts with magnesium metal to give magnesium ethanoate and hydrogen gas: 2CH3COOH + Mg -> (CH3COO)2Mg + H2. Reactions of carboxylic acids with bases such as metal hydroxides are simple neutralisation reactions: ethanoic acid reacts with sodium hydroxide to give sodium ethanoate and water: CH3COOH + NaOH -> CH3COONa + H2O.

When solid sodium carbonate is mixed with an aqueous solution of ethanoic acid, effervescence takes place as CO2 gas is evolved and sodium ethanoate forms in solution: 2CH3COOH + Na2CO3 -> 2CH3COONa + CO2 + H2O. The same reaction proceeds more slowly with marble chips (calcium carbonate): 2CH3COOH + CaCO3 -> (CH3COO)2Ca + CO2 + H2O.

24.3 Reaction of Carboxylic Acids with Alcohols (Esterification)

Carboxylic acids form esters when heated with an excess of alcohol in the presence of concentrated H2SO4 as a catalyst; this reaction is called esterification. In general, a carboxylic acid plus an alcohol, under acid catalysis and heat, yields an ester plus water -- for example, ethanoic acid reacting with ethanol gives ethyl ethanoate and water. Esters are named from the alcohol (the '-yl' part) and the acid (the '-oate' part) that formed them, and this single reaction type is the source of nearly every ester used in industry and food.

24.4 Industrial Applications of Carboxylic Acids and Esters

As solvents, acetic acid dissolves many compounds such as oils, sulphur, iodine and water, and industry uses it as a solvent for resins, paints and lacquers; pure acetic acid, known as glacial acetic acid, is a corrosive, colourless solid that is completely miscible with water. Esters are also widely used as solvents: ethyl acetate is used to extract caffeine from coffee and is found in nail-polish and paint remover, while other volatile esters serve as solvents for coatings, paints, varnishes, plastics, resins and lacquers.

As flavouring agents, substances that add taste or mask the unpleasant taste of drugs (especially for children), organic acids such as tartaric, citric and malic acid are commonly used as flavour enhancers, and are largely responsible for the sour taste of foods and beverages, especially soft drinks; esters, which have pleasant odours and flavours, are added to food products to improve their smell or taste. As raw materials for synthetic fibres and plastics, esters play a key role in making polymers -- polyester, an important polymer, is made by reacting diols with dicarboxylic acids, and esters are also important in manufacturing soaps and detergents. Acetic acid is used to make cellulose acetate plastic; palmitic and stearic acids go into soaps, cosmetics, pharmaceuticals, candles and protective coatings; oleic acid is used in soaps and detergents; and acrylic acid is the starting reagent for long-chain polymers called acrylates.

24.5 Carboxylic Acids and Esters in Daily Life

Food preservatives are chemical compounds added to foodstuffs to prevent or retard the growth of microorganisms -- examples include benzoic acid, acetic acid, propionic acid, and the methyl and ethyl esters of 4-hydroxybenzoic acid. These preservatives help maintain food quality and extend shelf life in products such as jams, juices, milk and other drinks, and acetic acid is very widely used as a preservative in pickles.

Carboxylic acids and compounds derived from them are commonly used as medicines, such as aspirin and ibuprofen, where added carboxylic acid groups can improve drug delivery, absorption and overall performance. Citric acid esters are primarily used as plasticisers across many industries, and polymethyl methacrylate -- known as Plexiglass -- is used as a substitute for glass. Carboxylic acids also occur naturally in many household fragrant items: ascorbic acid in vitamin C, citric acid in lemons, acetic acid in vinegar, and malic acid in apples, grapes and carrots. Esters, meanwhile, are important components of many fruits, giving them their pleasant, characteristic flavours -- for example, methyl butyrate smells of apple, ethyl butyrate of pineapple, n-amyl acetate of pears and bananas, n-octyl acetate of orange, and methyl salicylate of apricot.

Important Definitions

> **Carboxylic acid**
>
> An organic compound containing a carboxyl group (-COOH) attached to an alkyl group or hydrogen; generally a weak acid compared with mineral acids.

> **Carboxyl group**

The functional group -COOH that defines carboxylic acids, combining a carbonyl (C=O) and a hydroxyl (-OH) on the same carbon.

Ethanoic acid (acetic acid)

CH3COOH, the most familiar carboxylic acid, prepared by oxidation of ethanol or by bacterial fermentation, and the acid present in vinegar.

Oxidation (of ethanol)

The chemical change in which ethanol is converted, via ethanal, into ethanoic acid using an oxidising agent such as acidified potassium manganate (VII).

Oxidative (bacterial) fermentation

A process in which acetic acid bacteria oxidise alcohol in foodstuffs, using a continuous oxygen supply, to produce vinegar.

Esterification

The reaction of a carboxylic acid with an alcohol, in the presence of an acid catalyst such as concentrated H2SO4 and heat, to form an ester and water.

Ester

An organic compound formed from a carboxylic acid and an alcohol, generally having a pleasant odour, and named from its parent alcohol and acid.

Glacial acetic acid

Pure (water-free) acetic acid, a corrosive, colourless solid that is completely miscible with water.

Neutralisation reaction

The reaction of an acid with a base to form a salt and water, such as ethanoic acid reacting with sodium hydroxide.

Flavouring agent

A substance, such as an organic acid or ester, added to food or medicine to give or enhance taste or to mask an unpleasant taste.

Food preservative

A chemical compound, such as benzoic or acetic acid, added to food to prevent or slow the growth of microorganisms and extend shelf life.

Plasticiser

A substance, such as a citric acid ester, added to polymers to make them more flexible and workable.

Polyester

A polymer formed by reacting a diol with a dicarboxylic acid, widely used as a synthetic fibre and in plastics.

Solvent

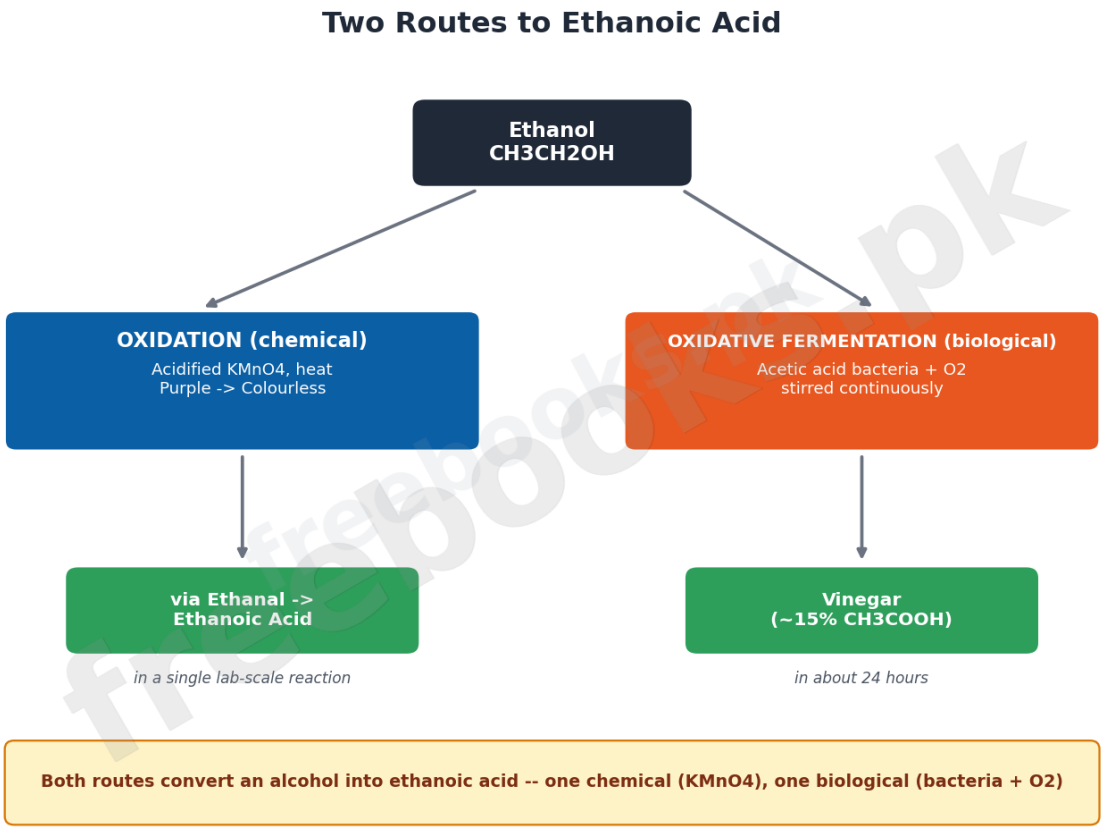
A substance, such as acetic acid or ethyl acetate, that dissolves other compounds to form a solution, used industrially in paints, resins and lacquers.

Key Facts & Relations

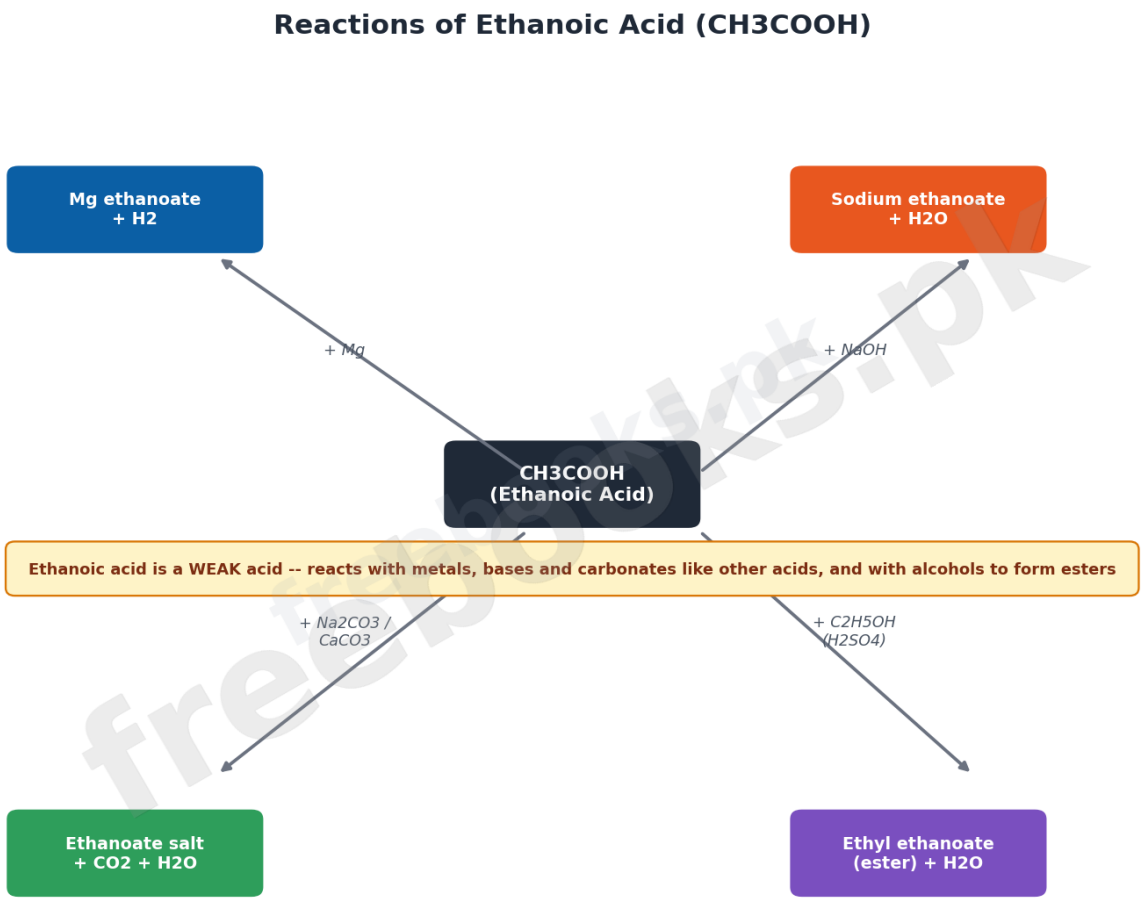
Topic	Relation
Oxidation of ethanol to ethanoic acid	CH3CH2OH --acidified KMnO4, heat--> (CH3CHO) --further oxidation--> CH3COOH; purple colour turns colourless
Reaction with a metal	2CH3COOH + Mg -> (CH3COO)2Mg + H2 (magnesium ethanoate + hydrogen gas)
Reaction with a base	CH3COOH + NaOH -> CH3COONa + H2O (sodium ethanoate + water)
Reaction with sodium carbonate	2CH3COOH + Na2CO3 -> 2CH3COONa + CO2 + H2O
Reaction with calcium carbonate (marble)	2CH3COOH + CaCO3 -> (CH3COO)2Ca + CO2 + H2O (slower reaction)
Esterification (general)	Carboxylic acid + Alcohol --conc. H2SO4, heat--> Ester + H2O
Vinegar by fermentation	Alcoholic foodstuff + O2 --acetic acid bacteria, ~24 hours--> ~15% ethanoic acid (vinegar)
Acids in household items	Vitamin C: ascorbic acid; lemons: citric acid; vinegar: acetic acid; apples/grapes/carrots: malic acid

Diagrams

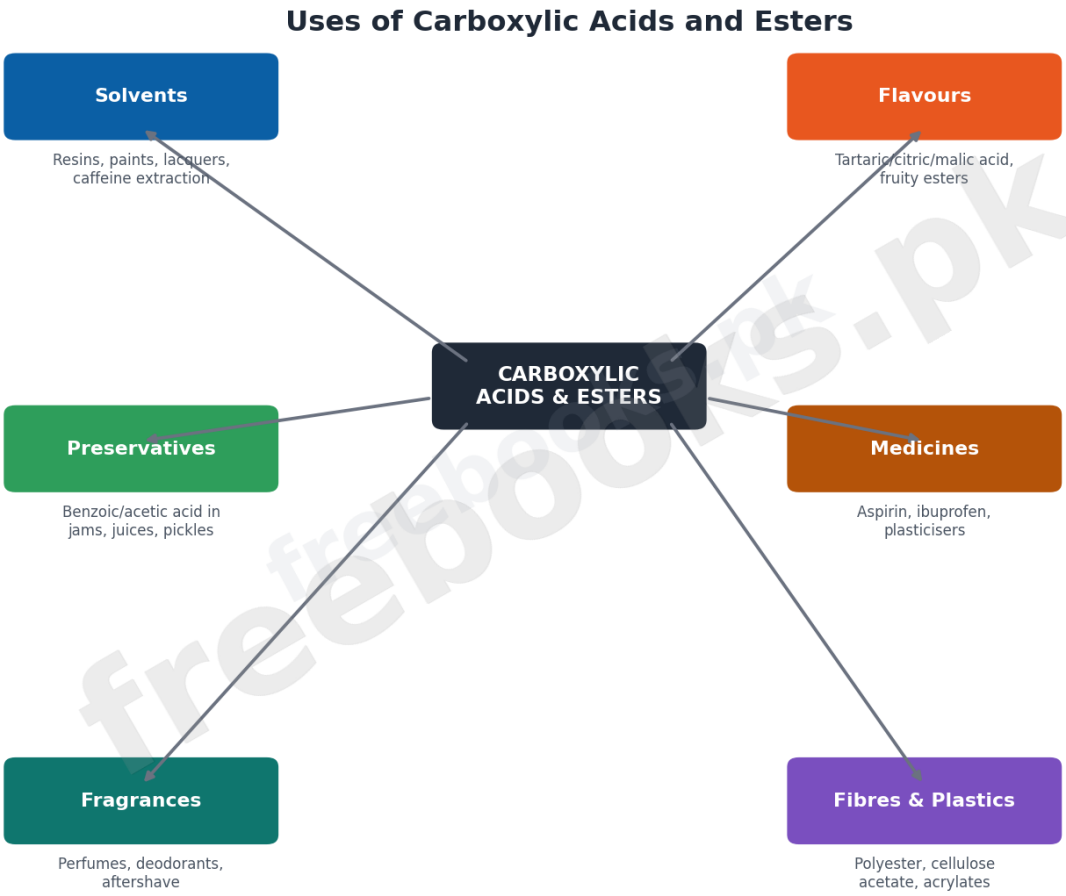
Two Routes to Ethanoic Acid: A comparison diagram showing the two methods of preparing ethanoic acid -- oxidation of ethanol with acidified KMnO4, and oxidative bacterial fermentation to make vinegar.



Reactions of Ethanoic Acid as an Acid: A hub-and-spoke diagram showing ethanoic acid reacting with a metal, a base, a carbonate, and an alcohol (esterification), with the product of each reaction.



Uses of Carboxylic Acids and Esters: A hub-and-spoke chart showing the major industrial and daily-life uses of carboxylic acids and esters -- as solvents, flavours/fragrances, synthetic fibres/plastics, preservatives, and medicines.



Short Questions & Answers

Can methanol be oxidised with KMnO4 just like ethanol?

Yes -- methanol, like ethanol, can be oxidised by acidified KMnO4, first to methanal and then further to methanoic acid, following the same overall oxidation pattern as ethanol to ethanoic acid.

What is the difference between a fermentation reaction and an ordinary chemical reaction?

A fermentation reaction is a biological process carried out by living organisms such as yeast or bacteria using their own enzymes under mild conditions (e.g. ~35 degC for yeast, or bacterial oxidation for vinegar), whereas an ordinary chemical reaction, like oxidation with KMnO4, is carried out directly with chemical reagents and does not require a living organism.

Is ethanoic acid a weak acid?

Yes -- ethanoic acid is a weak acid because it does not ionise completely in water and does not release protons as readily as mineral acids such as HCl or H2SO4.

How will calcium carbonate react with ethanoic acid?

Calcium carbonate reacts with ethanoic acid, though slowly, to give calcium ethanoate, carbon dioxide gas and water: 2CH3COOH + CaCO3 -> (CH3COO)2Ca + CO2 + H2O.

What is an esterification reaction?

Esterification is the reaction of a carboxylic acid with an alcohol, heated together in the presence of an acid catalyst such as concentrated H2SO4, to produce an ester and water.

Name an oxidising agent used to oxidise alcohols.

Acidified potassium manganate (VII) (KMnO4) is a common oxidising agent used to oxidise alcohols such as ethanol into ethanoic acid, changing colour from purple to colourless in the process.

Why is sufficient oxygen provided during fermentation to prepare acetic acid from ethanol?

A continuous supply of oxygen is needed because acetic acid bacteria require oxygen to oxidise the alcohol in the foodstuff into acetic acid; without enough oxygen the bacterial oxidation reaction cannot proceed efficiently, and vinegar will not form.

Give a practical example in which an acid or an ester is used as a flavouring agent.

Citric acid is used as a flavour enhancer in soft drinks, and methyl butyrate, an ester, is added to food products to give them an apple-like flavour.

Which carboxylic acids are very often used as flavour enhancers?

Tartaric acid, citric acid and malic acid are commonly used as flavour enhancers, largely responsible for the sour taste of many foods and beverages, especially soft drinks.

Which property of acetic acid makes it suitable to act as a preservative in pickles?

Acetic acid's ability to prevent or retard the growth of microorganisms makes it suitable as a preservative -- by lowering the pH and creating an environment unfavourable to microbial growth, it helps pickles resist spoilage and extends their shelf life.

Long Questions & Answers

How is ethanoic acid prepared, and how does it react as an acid with metals, bases and carbonates?

How is ethanoic acid prepared by oxidation of ethanol?

Ethanol is oxidised by hot acidified potassium manganate (VII), first to ethanal and then further to ethanoic acid; the purple colour of the KMnO4 reagent turns colourless as the oxidation proceeds, giving a clear visual sign that the reaction has occurred.

How is ethanoic acid prepared by oxidative fermentation (vinegar production)?

Alcoholic foodstuffs such as grain, malt, rice or potato mash are placed in a tank with a continuous, stirred supply of oxygen, where acetic acid bacteria oxidise the alcohol present into ethanoic acid; using this method, vinegar containing about 15% ethanoic acid can be produced in as little as 24 hours.

How does ethanoic acid react with metals and bases?

With a reactive metal such as magnesium, dilute ethanoic acid reacts slowly to give a salt and hydrogen gas: 2CH3COOH + Mg -> (CH3COO)2Mg + H2; with a base such as sodium hydroxide, it undergoes a simple neutralisation reaction to give a salt and water: CH3COOH + NaOH -> CH3COONa + H2O.

How does ethanoic acid react with carbonates?

Ethanoic acid reacts with sodium carbonate with effervescence, evolving CO2 gas and forming sodium ethanoate in solution: 2CH3COOH + Na2CO3 -> 2CH3COONa + CO2 + H2O; the same type of reaction occurs more slowly with calcium carbonate (marble chips) to give calcium ethanoate, CO2 and water.

Describe the industrial applications of carboxylic acids and esters, and their role in daily life.

How are carboxylic acids and esters used as solvents?

Acetic acid dissolves oils, sulphur, iodine and water and is used industrially as a solvent for resins, paints and lacquers, while esters such as ethyl acetate are used to extract caffeine from coffee and serve as solvents in nail-polish remover, coatings, varnishes, plastics and resins.

How are carboxylic acids and esters used as flavouring and fragrance agents?

Organic acids such as tartaric, citric and malic acid act as flavour enhancers and give foods and soft drinks their sour taste, while esters have naturally pleasant odours and are added to food

products to improve their smell or flavour, and also occur naturally in fruit to give them their characteristic aromas.

How are esters used in synthetic fibres and plastics?

Polyester, an important synthetic polymer used as a fibre and in plastics, is made by reacting a diol with a dicarboxylic acid; acetic acid is also used to make cellulose acetate plastic, and acids such as palmitic, stearic, oleic and acrylic acid are widely used to manufacture soaps, detergents and long-chain acrylate polymers.

How are carboxylic acids and esters used in daily life, including preservation and medicine?

Food preservatives such as benzoic acid and acetic acid are added to jams, juices, milk and pickles to prevent microbial growth and extend shelf life; carboxylic acid derivatives such as aspirin and ibuprofen are used as medicines, citric acid esters serve as plasticisers, and naturally occurring acids like ascorbic, citric and malic acid are found in everyday items such as vitamin C, lemons and fruit.

Multiple Choice Questions (MCQs)

Identify the ester functional group: (A) -COOR (B) -COOH (C) >C=O (D) -CH2-OH

Correct answer: (A) -COOR. The ester functional group is -COOR, where R is the alkyl group derived from the alcohol that reacted with the carboxylic acid; -COOH is the carboxylic acid group itself, not an ester.

During the oxidation of ethanol by acidified KMnO4, which element is reduced? (A) K (B) O (C) Mn (D) H

Correct answer: (C) Mn. Manganese in KMnO4 is reduced from the +7 oxidation state (in MnO4-) to a lower oxidation state as it accepts electrons while oxidising ethanol, which is why the purple colour of the reagent disappears.

Fermentation of foodstuff in the presence of acetic acid bacteria needs a sufficient supply of oxygen. What is the role of oxygen in this process? (A) It enhances the reactivity of bacteria (B) It oxidizes ethanol which is formed during the reaction (C) It inhibits the destruction of bacteria (D) It inhibits the oxidation of acetic acid

Correct answer: (B) It oxidizes ethanol which is formed during the reaction. Oxygen is needed because acetic acid bacteria use it to oxidise the ethanol present in the alcoholic foodstuff into ethanoic acid (vinegar) -- without enough oxygen, this oxidation cannot proceed.

Which organic acid is used as a component of food? (A) Formic acid (B) Oxalic acid (C) Propanoic acid (D) Acetic acid

Correct answer: (D) Acetic acid. Acetic acid, present in vinegar, is a common food component and preservative, widely used in pickles and other food products, unlike formic, oxalic or propanoic acid which are not typical food ingredients.

Which of the following acids is present in apples? (A) Citric acid (B) Tartaric acid (C) Acetic acid (D) Malic acid

Correct answer: (D) Malic acid. Malic acid is the carboxylic acid naturally present in apples, grapes and carrots, giving them part of their characteristic tart flavour.

Which polymer is made by reacting a diol and a dicarboxylic acid? (A) Polyethene (B) Polyester (C) Polystyrene (D) Polyamide

Correct answer: (B) Polyester. Polyester is the important synthetic polymer formed by reacting a diol with a dicarboxylic acid, and is widely used as a synthetic fibre and in plastics.

Which compound is used as a synthetic fiber? (A) Methyl acetate (B) Polyester (C) Resin (D) n-Amyl acetate

Correct answer: (B) Polyester. Polyester, formed from a diol and a dicarboxylic acid, is the ester-derived polymer used as a synthetic fibre in textiles, unlike the other listed esters, which are small-molecule flavouring/solvent esters.

Pure, water-free acetic acid is also known by which name? (A) Vinegar (B) Glacial acetic acid (C) Formic acid (D) Acetic anhydride

Correct answer: (B) Glacial acetic acid. Pure acetic acid, free of water, is called glacial acetic acid -- a corrosive, colourless solid that is completely miscible with water.

Quick Revision Summary

- Ethanoic acid is prepared by oxidation of ethanol with acidified $KMnO_4$ (via ethanal) or by oxidative bacterial fermentation of alcoholic foodstuffs (vinegar, ~15% in ~24 hours).
- As a weak acid, ethanoic acid reacts slowly with reactive metals (salt + H_2), neutralises bases (salt + H_2O), and effervesces with carbonates (salt + CO_2 + H_2O).
- Esterification: carboxylic acid + alcohol, with conc. H_2SO_4 catalyst and heat, gives an ester + water.

- Glacial acetic acid = pure, water-free acetic acid; a corrosive colourless solid, miscible with water.
- Carboxylic acids and esters as solvents: acetic acid (resins, paints, lacquers); esters like ethyl acetate (caffeine extraction, nail-polish remover).
- As flavouring agents: tartaric/citric/malic acid enhance sourness; esters (e.g. methyl butyrate = apple, ethyl butyrate = pineapple) give fruity flavours.
- Esters make polyester (diol + dicarboxylic acid) for synthetic fibres and plastics; acids like palmitic, stearic, oleic and acrylic acid go into soaps, detergents and polymers.
- Daily life: acids/esters preserve food (jams, juices, pickles), feature in medicines (aspirin, ibuprofen), plasticisers, and occur naturally in vitamin C, lemons, vinegar and fruit.

Exam Tips

- Remember the two ethanoic acid routes as 'chemical vs biological': KMnO4 oxidation (chemical) vs bacterial fermentation (biological, needs O2).
- For reactions with metals/bases/carbonates, always predict the products first (salt + H2 / salt + H2O / salt + CO2 + H2O) before balancing.
- Esterification recipe: acid + alcohol + conc. H2SO4 + heat -> ester + water -- name the ester from its alcohol ('-yl') and acid ('-oate') parts.
- Sort carboxylic acid/ester uses into three buckets: solvents, flavours/fragrances, and fibres/plastics -- then a fourth for daily life: preservatives and medicines.
- Link each named acid to its source for quick recall: citric = lemons, malic = apples, ascorbic = vitamin C, acetic = vinegar.
- 'Glacial' acetic acid just means pure, water-free acetic acid -- don't confuse it with a different compound.

Chapter 25: Biochemistry

Biochemistry is the study of the chemical substances that play a vital role in the processes taking place in living organisms. Carbohydrates, lipids (fats) and proteins are the three classes of food that not only provide energy to the human body but are also responsible for building its structures; lipids provide, on average, about twice as much energy as the same mass of carbohydrates or proteins. Proteins are present in all living organisms, forming skin, hair, muscle, blood and almost every organ, and playing central roles throughout life's processes.

This chapter surveys the main biomolecules -- carbohydrates, proteins, lipids, vitamins and nucleic acids -- their sources, structures and the daily intake a young adult needs, and closes with the many practical applications of biochemistry in modern medicine and genetics, from ordinary blood tests to genetic engineering, gene therapy and cloning.

Learning Objectives

- Explain the importance and basics of nutrition and healthy eating.
- Recognise the main biomolecules -- carbohydrates, proteins, lipids and nucleic acids -- their sources, and the required daily intake for young adults.
- Identify carbohydrates as a source of energy, and describe proteins as natural polyamides formed from amino acid monomers.
- Explain the sources, uses and structure of proteins, lipids and carbohydrates, and describe the importance of nucleic acids.
- Explain vitamins, their sources and their importance to health.
- Identify applications of biochemistry in testing (blood tests, pregnancy tests, cancer screening, parental genetic testing), genetic engineering, gene therapy and cloning.

Key Concepts

25.1 Nutrition and Healthy Eating

Nutrition is the study of the nutrients present in food and how they maintain a healthy body; nutrients are the components of food needed regularly to maintain health and prevent disease. Carbohydrates are the main source of energy and help the body use protein and fat efficiently -- a healthy adult needs about 225 to 325 grams per day on a standard 2000-calorie diet. Lipids act as major energy reserves and provide insulation and protection for vital organs, with a daily intake of

roughly 44 to 78 grams. Proteins also supply energy and are needed to build new cells and repair injured ones, with an adult needing about 60 grams per day. Vitamins and minerals help growth, reproduction, and the operation and maintenance of the body, and a diet rich in fruits, vegetables and grains provides most of what is needed daily.

Basic methods of healthy eating include consuming a wide range of nutrient-rich foods (fruits, vegetables, whole grains, lean proteins, healthy fats), eating less while staying hydrated, reducing intake of saturated fats, sugar and sodium, and avoiding processed and poor-quality foods. A healthy, balanced diet prevents diseases such as heart disease, diabetes, some cancers and osteoporosis, fuels healthy growth and development and helps maintain a healthy weight, and positively impacts brain function and the immune system.

25.2 Carbohydrates

Carbohydrates are the most abundant naturally occurring compounds on Earth, containing carbon, hydrogen and oxygen; because some taste sweet, they are commonly called 'sugars', and besides hydroxyl groups they also contain aldehyde or ketonic functional groups. They are classified into three groups based on their properties: monosaccharides, oligosaccharides and polysaccharides. Glucose, the most abundant carbohydrate (also called grape sugar or dextrose), occurs in grapes, honey and plant sap, and is the main energy source for animals, present in their blood and urine; fructose, found in sweet fruit juices and honey, shares glucose's molecular formula $C_6H_{12}O_6$.

Sucrose, lactose and maltose all share the molecular formula $C_{12}H_{22}O_{11}$: sucrose comes from sugar cane and sugar beets, maltose is found in bread and other cereals, and lactose is present in milk. Starch and cellulose are important polymeric carbohydrates sharing the formula $(C_6H_{10}O_5)_n$ -- starch occurs in potatoes, rice and grains, while cellulose comes from plant materials like wood and cotton; glycogen serves the same energy-storage function in animals that starch serves in plants.

25.3 Proteins

Proteins are very large molecules containing carbon, hydrogen, oxygen, nitrogen and sulphur atoms, and the human body contains thousands of different types performing a huge range of functions: fibrous proteins form muscles, hair, nails, skin and connective tissue; hormones such as insulin (which controls blood sugar) and enzymes (biological catalysts that speed up the body's reactions) are also proteins; and haemoglobin, which carries oxygen through the bloodstream, is a protein too. Despite this variety, every protein is built by linking together amino acids, each carrying a carboxyl group (-COOH) and an amino group ($-NH_2$) -- the simplest amino acid is glycine.

Proteins form when water is eliminated between two amino acid molecules, joining them through a peptide linkage to form a peptide; this can react further with more amino acids to build a long polypeptide chain, which then twists and folds into a three-dimensional structure. Heat, a change in pH, or oxidising and reducing agents can cause complex changes in a protein's structure called denaturation -- frying or boiling an egg, which denatures egg albumin in the egg white, is a familiar example. Children need large amounts of protein for growth, while adults need it to replace what the body's normal biochemical reactions use up each day.

25.4 Lipids

Most lipids are built from simpler building blocks called fatty acids -- long-chain carboxylic acids with 12 to 28 carbon atoms. Examples include lauric acid (from coconut oil), stearic acid (from animal fats), palmitic acid (from palm oil) and oleic acid (from olive oil, and unsaturated because of its C=C double bond). Fatty acids react with the alcohol glycerol to form triesters called fats -- for example, stearic acid and glycerol form tristearin; a triester of glycerol is also called a triglyceride.

Animal fats are located particularly in adipose tissue cells, while vegetable oils occur in the seeds and roots of plants; lipids mainly serve as an energy-rich reserve in animals. Soap, known since at least 600 BC, is chemically a mixture of sodium salts of long-chain fatty acids, produced by the hydrolysis of animal fat with alkali.

25.5 Vitamins and Nucleic Acids

Vitamins are organic substances that do not themselves provide energy or build cells the way carbohydrates, lipids and proteins do, but are necessary to maintain normal health and growth, functioning as catalysts for the body's biological processes; scientists have identified 13 vitamins the human body needs. Vitamin A (milk, egg, fish, liver) prevents night blindness and dry skin; vitamin D (butter, fish liver oils, and made by skin in sunlight) supports teeth and bone development, and its deficiency causes rickets; vitamin C or ascorbic acid (citrus fruits, green pepper, tomatoes) prevents scurvy; and vitamins B1 and B2 (red meat, nuts, leafy vegetables) prevent fatigue/depression and inflammation of the lips/eyes respectively.

Carbohydrates, proteins, fats and water together make up about 99% of most living organisms; the remaining 1% includes the two nucleic acids, DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), which are responsible for the existence, development and reproduction of all life. DNA molecules are much larger than RNA (molecular mass up to 660 Da versus about 340 Da for RNA, with DNA stretching up to 12 cm) and are mostly found in the cell nucleus, while RNA is smaller and mostly found outside it. DNA's function is to store genetic information and pass it to RNA at the proper time, while RNA reads, decodes and uses that information to make proteins.

25.6 Applications of Biochemistry

Blood tests let doctors identify conditions such as infections, diabetes, anaemia and organ failure by checking electrolytes, fats, proteins, glucose and enzymes, giving important information on how well the kidneys, liver and other organs are working. A pregnancy test checks urine or blood for HCG, a hormone produced when a woman becomes pregnant; quantitative blood tests can measure exact HCG levels and how far a pregnancy has progressed. The Galleri test is a specific blood test that uses DNA sequencing to detect characteristic patterns for early cancer screening, while parental genetic testing, performed on a blood or saliva sample, tells people whether they carry genetic changes they could pass on to their children.

Genetic engineering changes an organism's genome -- from altering a single DNA base to deleting or inserting whole regions of DNA -- to enhance an organism's capabilities beyond normal, such as engineering plants to resist disease or pollution. Gene therapy fixes a faulty gene or replaces it with a healthy one to cure a disease or help the body fight it better, and may in future help treat diseases such as diabetes, AIDS, cancer and haemophilia. Cloning creates an exact genetic replica -- a clone -- of a cell, tissue or whole organism, sharing the same genetic characteristics as the original.

Important Definitions

Biochemistry

The study of the chemical substances and processes that occur within living organisms.

Nutrition

The study of the nutrients present in food and how they maintain a healthy body.

Nutrient

A component of food needed regularly by the body to maintain health and prevent disease, such as carbohydrates, lipids, proteins, vitamins and minerals.

Carbohydrate

An organic compound of carbon, hydrogen and oxygen, often sweet-tasting, containing hydroxyl groups plus an aldehyde or ketone group; the body's main energy source.

Amino acid

The building-block molecule of proteins, carrying both a carboxyl group (-COOH) and an amino group (-NH2); the simplest is glycine.

Peptide bond (linkage)

The bond formed between two amino acids when a water molecule is eliminated, joining them into a peptide.

Polypeptide

A long chain formed by linking many amino acids together through peptide bonds, which folds into a protein's three-dimensional structure.

Denaturation

A complex structural change in a protein caused by heat, a change in pH, or an oxidising/reducing agent -- for example, the change egg albumin undergoes on frying or boiling.

Fatty acid

A long-chain carboxylic acid, typically with 12 to 28 carbon atoms, that serves as the building block of most lipids.

Triglyceride (fat)

A triester formed when three fatty acid molecules react with one glycerol molecule.

Vitamin

An organic substance that does not itself provide energy or build cells but is necessary for normal health, growth and body function, acting as a catalyst for biological processes.

Nucleic acid

A large biomolecule, such as DNA or RNA, responsible for storing and using genetic information for the existence, development and reproduction of life.

Genetic engineering

A method of changing an organism's genome, from altering a single DNA base to inserting or deleting whole regions of DNA.

Cloning

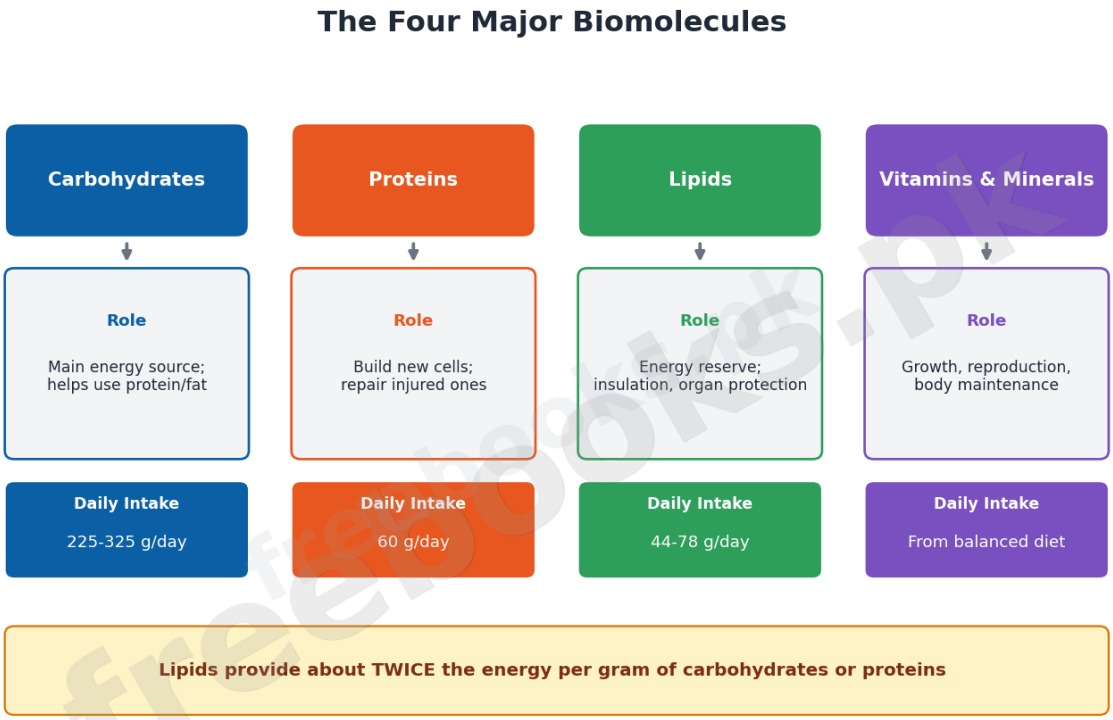
> The set of methods used to create an exact genetic replica -- a clone -- of a cell, tissue or whole organism.

Key Facts & Relations

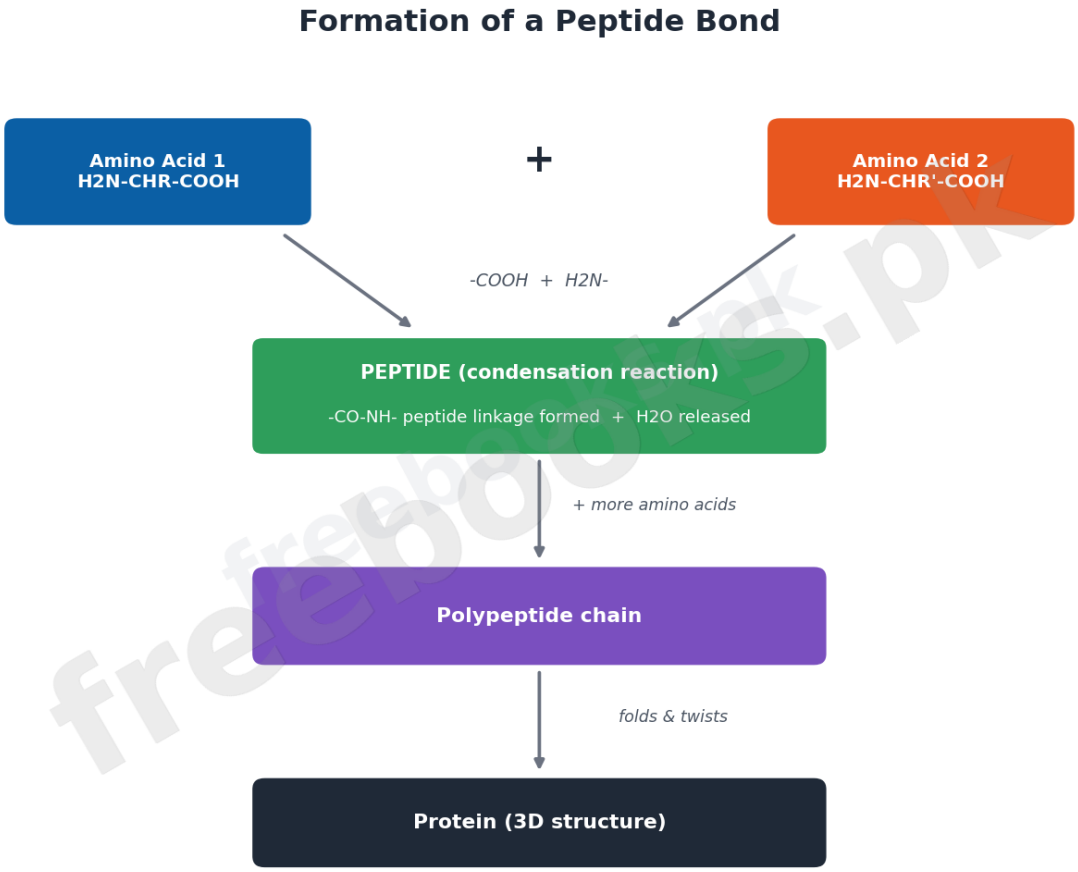
Topic	Relation
Glucose and fructose	Same molecular formula: C6H12O6 (glucose = grape sugar/dextrose; fructose = fruit sugar)
Sucrose, lactose, maltose	Same molecular formula: C12H22O11 (sucrose = cane/beet sugar; lactose = milk sugar; maltose = malt sugar)
Starch and cellulose	Common formula: (C6H10O5)n -- polymeric carbohydrates
Daily carbohydrate intake (adult)	About 225-325 g/day (2000-calorie diet)
Daily lipid intake (adult)	About 44-78 g/day
Daily protein intake (adult)	About 60 g/day
Amino acid general structure	Carboxyl group (-COOH) + amino group (-NH2) on the same molecule, e.g. glycine: CH2(NH2)-COOH
DNA vs RNA	DNA: molecular mass up to 660 Da, up to 12 cm stretched, mostly in nucleus. RNA: molecular mass about 340 Da, mostly outside nucleus

Diagrams

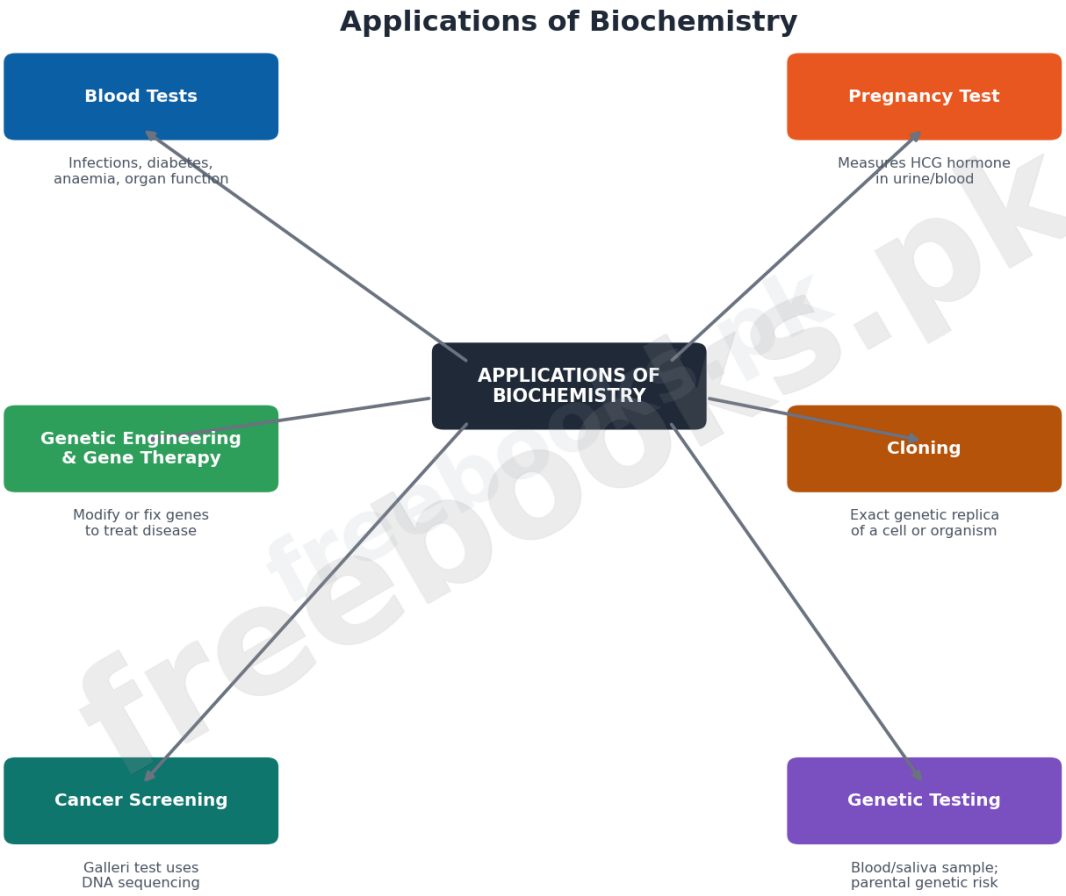
The Four Major Biomolecules: A comparison chart of carbohydrates, proteins, lipids and vitamins/minerals -- their main role and daily recommended intake for an adult.



Formation of a Peptide Bond: A diagram showing two amino acid molecules joining, with the elimination of water, to form a peptide bond, and the resulting polypeptide chain folding into a protein.



Applications of Biochemistry: A hub-and-spoke chart showing the major applications of biochemistry in testing and genetics -- blood tests, pregnancy tests, cancer screening, genetic testing, genetic engineering/gene therapy, and cloning.



Short Questions & Answers

Which two functions are performed by proteins?

Proteins supply energy to the body and are needed to build new cells and repair injured ones; many proteins also act as hormones (e.g. insulin) or enzymes that speed up biochemical reactions.

Is milk a fat, a protein, or both?

Milk contains both -- it supplies lactose (a carbohydrate) along with proteins and fats; specifically, lactose (a sugar) and butterfat (a lipid) are both present in milk, along with milk proteins.

What is a balanced diet?

A balanced diet is one that includes a wide range of nutrient-rich foods -- fruits, vegetables, whole grains, lean proteins and healthy fats -- in the right proportions, while limiting saturated fats, sugar, sodium and processed foods, to supply all the nutrients the body needs.

Name any three nutrients.

Three nutrients needed by the body are carbohydrates, proteins and lipids (fats); vitamins and minerals are also essential nutrients.

Name any two sources of starch.

Potatoes and rice are two common sources of starch; grains are another important source.

Are all carbohydrates equally beneficial for our health?

No -- simple sugars like glucose, fructose and sucrose provide quick energy but offer little else nutritionally and can be consumed in excess, while complex carbohydrates like starch and cellulose (fibre) support steadier energy release and digestive health, so not all carbohydrates play the same beneficial role.

What are hormones made of?

Hormones such as insulin are proteins, built from chains of amino acids linked by peptide bonds, just like other functional proteins in the body.

What is denaturation of a protein?

Denaturation is a complex structural change a protein undergoes when subjected to heat, a change in pH, or an oxidising/reducing agent, altering its natural three-dimensional shape -- as seen when egg albumin denatures on frying or boiling an egg.

What is the role of lipids in our body?

Lipids act as a major energy reserve for the body (providing about twice the energy of the same mass of carbohydrate or protein) and also provide insulation and protection for vital organs.

Which vitamin is present in lemon?

Vitamin C (ascorbic acid) is present in lemons and other citrus fruits, along with green pepper and tomatoes; its deficiency causes scurvy.

Long Questions & Answers

Describe the classification, structure and daily requirement of carbohydrates, proteins and lipids.

How are carbohydrates classified and what are their common sources?

Carbohydrates are classified into monosaccharides (like glucose and fructose, $C_6H_{12}O_6$), oligosaccharides (like sucrose, lactose and maltose, $C_{12}H_{22}O_{11}$), and polysaccharides (like starch and cellulose, $(C_6H_{10}O_5)_n$); they are the body's main energy source, and an adult needs about 225-325 g per day.

How are proteins built, and what is a peptide bond?

Proteins are built by linking amino acids -- each carrying a carboxyl group and an amino group -- through peptide bonds formed by eliminating water between two amino acid molecules; repeating this process builds a long polypeptide chain that folds into a protein's three-dimensional structure, and an adult needs about 60 g of protein per day.

What are lipids made of, and how much does the body need daily?

Lipids are mostly built from fatty acids, long-chain carboxylic acids that react with glycerol to form triglycerides (fats); lipids serve as a major, energy-dense reserve and provide insulation and organ protection, and an adult needs roughly 44-78 g per day.

Why do these three biomolecules have different daily requirements?

The differing daily requirements reflect each biomolecule's energy density and role -- lipids are needed in the smallest amount because they are the most energy-dense (about twice that of carbohydrate or protein per gram), carbohydrates are needed in the largest amount as the body's primary, readily used energy source, and protein sits in between, since its main job is building and repairing tissue rather than fuelling the body.

What are DNA, RNA and vitamins, and what are the applications of biochemistry in medicine and genetics?

What are DNA and RNA, and how do they differ?

DNA and RNA are nucleic acids that are chemically similar but play different roles: DNA is much larger (molecular mass up to 660 Da, up to 12 cm when stretched) and stores genetic information mostly in the cell nucleus, while RNA is smaller (about 340 Da), is mostly found outside the nucleus, and reads, decodes and uses DNA's information to make proteins.

What are vitamins and what happens when the body lacks them?

Vitamins are organic substances that do not provide energy directly but act as catalysts for the body's biological processes, maintaining normal health and growth; deficiencies cause specific diseases, such as night blindness from lack of vitamin A, rickets from lack of vitamin D, and scurvy from lack of vitamin C.

How are blood tests and pregnancy tests used in medicine?

Blood tests check electrolytes, fats, proteins, glucose and enzymes to identify conditions like infections, diabetes, anaemia and organ failure, while a pregnancy test measures the hormone HCG in urine or blood to confirm pregnancy and track how far it has progressed.

How are genetic engineering, gene therapy and cloning applied?

Genetic engineering changes an organism's genome (even a single DNA base) to enhance its capabilities, such as making plants disease-resistant; gene therapy fixes or replaces a faulty gene to treat diseases like diabetes or cancer; and cloning creates an exact genetic replica of a cell, tissue or organism, all showing how biochemistry now extends into medicine and genetics.

Multiple Choice Questions (MCQs)

Functional groups present in fructose are: (A) Hydroxyl and aldehyde (B) Hydroxyl and Ketone (C) Hydroxyl and ester (D) Hydroxyl and amide

Correct answer: (B) Hydroxyl and Ketone. Fructose is a ketohexose, meaning it carries hydroxyl groups plus a ketone functional group, unlike glucose, which is an aldohexose carrying hydroxyl groups plus an aldehyde group.

Which functional group is present in a fat? (A) Carboxyl group (B) Ester group (C) Carbonyl group (D) Hydroxyl group

Correct answer: (B) Ester group. Fats (triglycerides) are esters formed when fatty acids react with glycerol, so the ester functional group is what characterises them.

Which function is not performed by proteins in our body? (A) They serve as chemical messengers. (B) They serve as storage of energy-rich fuel. (C) They store genetic information. (D) They serve as catalysts for biochemical reactions.

Correct answer: (C) They store genetic information.. Storing genetic information is the role of nucleic acids (DNA and RNA), not proteins -- proteins do act as chemical messengers

(hormones), catalysts (enzymes), and can supply energy, but they do not store genetic information.

Which functional groups react to produce a peptide linkage in proteins? (A) Carboxyl group and hydroxyl group (B) Carboxyl group and amino group (C) Hydroxyl group and amino group (D) Ester group and amino group

Correct answer: (B) Carboxyl group and amino group. A peptide linkage forms when the carboxyl group (-COOH) of one amino acid reacts with the amino group (-NH2) of another, eliminating a water molecule.

The test performed to detect cancer in early stages is: (A) Genetic test (B) Urine test (C) Galleri test (D) Electrolyte test

Correct answer: (C) Galleri test. The Galleri test is a specific blood test that uses DNA sequencing to detect characteristic patterns associated with cancer at an early stage.

Fatigue and depression are caused by deficiency of: (A) Vitamin A (B) Vitamin C (C) Vitamin D (D) Vitamin B1

Correct answer: (D) Vitamin B1. A deficiency of vitamin B1 leads to fatigue and depression, while lack of vitamin B2 causes inflammation of the lips and dryness/burning of the eyes.

Which of the following is an unsaturated fatty acid? (A) Lauric acid (B) Stearic acid (C) Palmitic acid (D) Oleic acid

Correct answer: (D) Oleic acid. Oleic acid contains a C=C double bond in its chain (from olive oil), making it unsaturated, unlike lauric, stearic and palmitic acids, which are saturated fatty acids.

Which molecule is mostly found in the nucleus of the cell and stores genetic information? (A) RNA (B) DNA (C) Glycogen (D) A polypeptide

Correct answer: (B) DNA. DNA, which is much larger than RNA and mostly located in the cell nucleus, is the molecule that stores genetic information and passes it to RNA at the proper time.

Quick Revision Summary

- Nutrition: carbohydrates (~225-325 g/day, main energy), lipids (~44-78 g/day, energy reserve/insulation), proteins (~60 g/day, build/repair), plus vitamins and minerals.

- Carbohydrates: monosaccharides (glucose/fructose, $C_6H_{12}O_6$), oligosaccharides (sucrose/lactose/maltose, $C_{12}H_{22}O_{11}$), polysaccharides (starch/cellulose, $(C_6H_{10}O_5)_n$; glycogen in animals).
- Proteins are built from 20 amino acids linked by peptide bonds (water eliminated between -COOH and $-NH_2$ groups) into polypeptide chains that fold into 3D shapes; heat/pH/oxidising agents cause denaturation.
- Lipids are built from fatty acids (long-chain carboxylic acids) that react with glycerol to form triglycerides (fats); they store about twice the energy of carbs/proteins per gram.
- Vitamins act as catalysts for body processes, not energy sources -- deficiencies cause specific diseases (A: night blindness, D: rickets, C: scurvy, B1: fatigue).
- DNA (large, in nucleus, stores information) and RNA (smaller, outside nucleus, reads/uses information to make proteins) are the two nucleic acids.
- Applications of biochemistry: blood tests, pregnancy tests (HCG), Galleri cancer screening, parental genetic testing, genetic engineering, gene therapy, cloning.

Exam Tips

- Remember daily intake order by amount: carbohydrates (most, 225-325 g) > proteins (60 g) > lipids (least by mass, 44-78 g, but most energy-dense per gram).
- Group carbohydrates by size: mono- (simplest sugars) -> oligo- (double sugars, $C_{12}H_{22}O_{11}$) -> poly- (starch/cellulose/glycogen).
- Peptide bond formation = condensation reaction: -COOH + $-NH_2$ -> peptide bond + H_2O -- always eliminates water.
- Link each vitamin to its deficiency disease as a pair: A-night blindness, D-rickets, C-scurvy, B1-fatigue/depression, B2-lip/eye inflammation.
- DNA vs RNA -- remember 'DNA is the Director' (stores info, in the nucleus) while 'RNA is the Runner' (carries/uses info, outside the nucleus).
- Group biochemistry applications into two buckets: diagnostic testing (blood, pregnancy, cancer, genetic tests) and genetic intervention (engineering, gene therapy, cloning).

Chapter 26: Polymers

Polymers, or macromolecules, are extremely large molecules formed by linking together a very large number of simple molecular units called monomers, in a process called polymerisation. Carbohydrates, proteins and nucleic acids are everyday natural polymers, while plastics, synthetic fibres and rubber are man-made ones -- and one of the most significant changes across the modern world has been the gradual replacement of metals, wood and cotton with synthetic polymers, prized for their high strength, flexibility, and resistance to heat and chemicals.

This chapter covers the two main routes to building a polymer -- addition and condensation polymerisation -- how to deduce a polymer's repeat unit from its monomers and vice versa, what plastics are and why they are so widely used, the importance of synthetic fibres in the textile industry, and the serious environmental problems caused by plastic waste, from landfill and ocean accumulation to the toxic gases released when it is burned.

Learning Objectives

- Define polymers as large molecules built up from many smaller molecules called monomers, and describe the differences between addition and condensation polymerisation.
- Identify the repeating units and/or linkages in addition polymers and in condensation polymers, and deduce the structure or repeating unit of a condensation polymer from its monomers and vice versa (polyamides from a dicarboxylic acid and a diamine; polyesters from a dicarboxylic acid and a diol).
- State that plastics are made from polymers, and describe how the properties of plastics have implications for their disposal.
- Describe the environmental challenges caused by plastics, including disposal in landfill sites, accumulation in oceans, and the formation of toxic gases from burning.
- Describe the structure of nylon (a polyamide) and PET (a polyester), and state that PET can be converted back into monomers and repolymerised.
- Outline the importance of polymers in the textile industry.

Key Concepts

26.1 Types of Polymers: Addition and Condensation

Addition polymers form when monomer molecules containing a double bond join together through covalent bonds to give one very large molecule, with the C=C double bond breaking to let monomers link up. For example, a large number of ethene molecules add together to give polyethene (polythene). No molecule is eliminated and no by-product forms during addition polymerisation, which usually happens at high pressure with a catalyst present.

Condensation polymers form when two different molecules, each carrying two different functional groups, react together with the elimination of a small molecule such as H2O, HCl or NH3, usually in the presence of an acid or base. For example, ethane diol reacts with a dicarboxylic acid (terephthalic acid) to give Polyethylene Terephthalate (PET) -- the carboxyl group of the acid reacts with the hydroxyl group of the diol to form an ester linkage. Because the functional groups sit at both ends of the resulting molecule, polymerisation continues at both ends to build a very large molecule. A polyamide forms similarly when a dicarboxylic acid reacts with a diamine: each -COOH group reacts with an -NH2 group to form an amide linkage, losing a water molecule each time.

26.2 Deducing Monomer and Polymer Structures

To find the repeating unit of an addition polymer from its structure, remove the brackets, the extended bonds on each side, and the subscript n, then change the single bond back to a double bond -- for example, [CH2-CH2]n becomes CH2=CH2 (ethene), the monomer of polyethene.

For a condensation polymer such as a polyester, remove the brackets, extended bonds and subscript n, then break the bond within the linkage (the ester C-O bond, or the amide CO-NH bond for a polyamide); add -OH to each end of the dicarboxylic acid fragment, and add -H to each end of the diol (for a polyester) or diamine (for a polyamide) fragment. This recovers the two original monomers -- the dicarboxylic acid and the diol or diamine -- that combined to form the polymer's repeat unit.

26.3 Plastics

Polymerising monomers like ethylene, propylene and styrene gives polyethylene (PE), polypropylene (PP) and polystyrene (PS) respectively -- these are a few examples of plastics. Plastics are used to make carry-home food containers, soft-drink and water bottles, shopping bags, kitchenware, buckets, tables, chairs, food wrappers, cups and plates. Being lightweight, flexible and durable, and easily moulded into almost any shape, plastics have found their way into nearly

every sphere of daily life, and since the early 20th century, millions of tonnes of plastic have been produced every year.

26.4 Importance of Polymers in the Textile Industry

Polymers used in the textile industry are called synthetic fibres -- examples include nylon, polyester, rayon and acrylic. Synthetic fibres are cheaper than natural fibres like cotton and silk, stronger and more durable, do not shrink, resist wrinkling, are lightweight and quick-drying, and resist moths and insects. Polyester and nylon together account for about 69% of all material used in the global clothing industry -- polyester is prized for its strength and resistance to shrinking and is common in sportswear and hosiery, while acrylic is lightweight, soft, and provides warmth.

26.5 Adverse Effects of Plastics

Unlike most other materials, plastics do not biodegrade -- discarded plastic articles can take up to 1000 years to break down, leading to a huge build-up of plastic in the environment. Plastic pollution is now found almost everywhere, on land, in the air, and in every kind of water body from rivers and lakes to seas and oceans, and it has reached an alarming level, causing serious health problems. Discarded plastics are disposed of by burning, dumping in landfill, or being thrown into drains, from where they often end up in rivers and oceans; burning discarded plastic is especially hazardous, since it releases dangerous toxic gases into the air.

Important Definitions

Polymer (macromolecule)

An extremely large molecule formed by linking together many simple molecular units called monomers.

Monomer

A small, simple molecular unit that links together with many others to form a polymer.

Polymerisation

The process by which a polymer is formed from its monomers.

Addition polymer

A polymer formed when monomers containing a double bond join together by covalent bonds, with no molecule eliminated and no by-product formed, e.g. polyethene.

Condensation polymer

A polymer formed when two different monomers, each with two functional groups, react together with the elimination of a small molecule such as H2O, HCl or NH3, e.g. polyester or polyamide.

Repeat unit

The smallest structural unit that, repeated many times, makes up the full polymer chain.

Ester linkage

The -CO-O- linkage formed between a carboxyl group and a hydroxyl group during the formation of a polyester such as PET.

Amide linkage

The -CO-NH- linkage formed between a carboxyl group and an amino group during the formation of a polyamide such as nylon.

Plastic

A synthetic material made from polymers such as polyethylene, polypropylene or polystyrene, valued for being lightweight, flexible, durable and easily moulded.

Synthetic fibre

A man-made polymer, such as nylon, polyester, rayon or acrylic, used in the textile industry.

Biodegradation

The natural breakdown of a material by living organisms; most plastics do not biodegrade and can persist for up to 1000 years.

PET (polyethylene terephthalate)

A common polyester, formed from ethane diol and terephthalic acid, that can be chemically recycled back into its monomers and repolymerised.

Nylon

A polyamide synthetic fibre formed from a dicarboxylic acid and a diamine, widely used in the textile industry.

Chemical recycling

> Breaking a polymer such as PET back down into its monomer units, for example by heating it in the absence of oxygen, so it can be repolymerised.

Key Facts & Relations

Topic	Relation
Addition polymerisation (polyethene)	n CH2=CH2 --high pressure, catalyst--> [-CH2-CH2-]n (no by-product)
Condensation polymerisation (PET, polyester)	Dicarboxylic acid + Diol --acid/base catalyst--> Polyester (ester linkage) + n H2O
Condensation polymerisation (polyamide)	Dicarboxylic acid + Diamine --acid/base catalyst--> Polyamide (amide linkage) + n H2O
Deducing addition monomer	[CH2-CH2]n -> remove brackets/n, single->double bond -> CH2=CH2
Deducing condensation monomers	Break ester/amide linkage; add -OH to acid fragment ends, -H to diol/diamine fragment ends
Addition polymer molecular mass	= sum of the molecular masses of all monomers used (no mass lost)
Plastic degradation time	Discarded plastic can take up to 1000 years to break down (non-biodegradable)
Textile share of polyester + nylon	About 69% of all material used in the global clothing industry

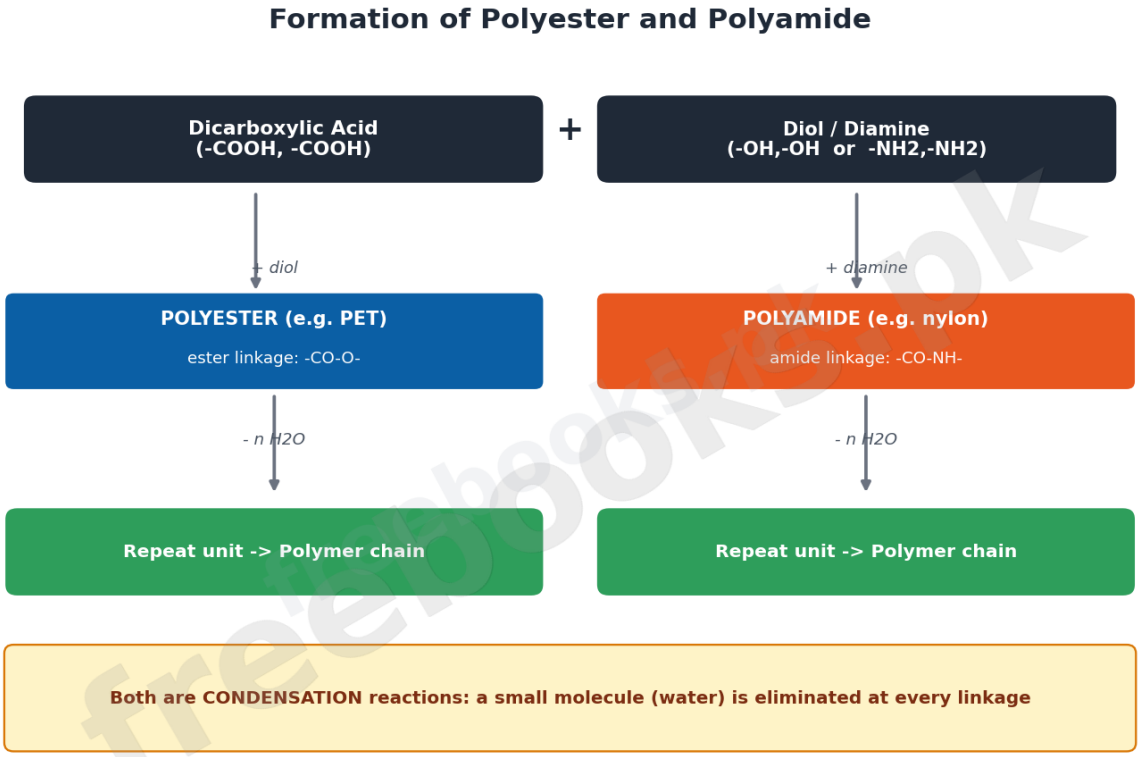
Diagrams

Addition vs Condensation Polymerisation: A comparison diagram of the two main types of polymerisation, showing monomer requirements, by-products, and example polymers for each.

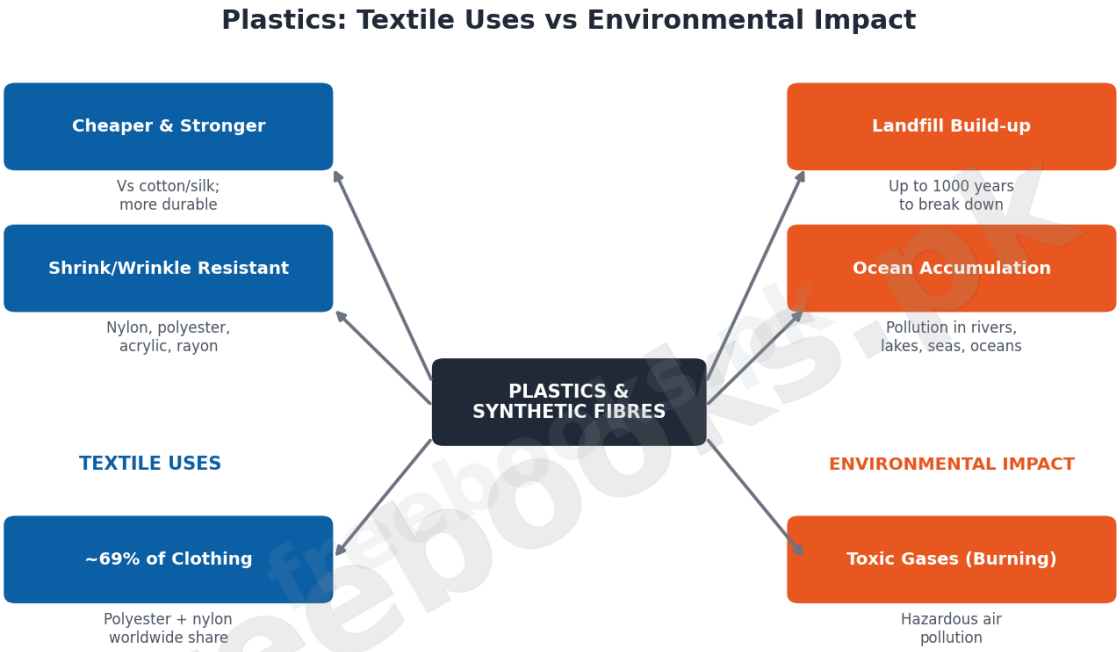
Addition vs Condensation Polymerisation

	ADDITION POLYMERISATION	CONDENSATION POLYMERISATION
Monomers	One monomer, has a C=C double bond	Two monomers, each with two functional groups
By-product	None -- addition only	Small molecule lost (H_2O, HCl or NH_3)
Polymer mass	= sum of all monomer masses	NOT equal to sum of monomer masses
Linkage	Single bonds only along the backbone	Specific linkage: ester or amide
Examples	Polyethene, polystyrene, PVC	Polyester, nylon, bakelite

Formation of Polyester and Polyamide: A diagram showing a dicarboxylic acid reacting with a diol to form a polyester (ester linkage), and with a diamine to form a polyamide (amide linkage), releasing water in each case.



Uses and Environmental Impact of Plastics: A hub-and-spoke chart showing the textile-industry uses of synthetic fibres alongside the environmental problems caused by plastic waste -- landfill, ocean accumulation, and toxic gases from burning.



Short Questions & Answers

Give an example of a commercial product formed using polyethene.

Shopping bags, water bottles, buckets and food-wrapper films are all common commercial products made from polyethene (polythene).

Write three properties of synthetic polymers.

Synthetic polymers are generally lightweight, flexible, and resistant to heat and chemicals -- properties that make them useful across a huge range of applications.

How is an ester linkage between two monomers formed?

An ester linkage forms when the carboxyl group (-COOH) of a dicarboxylic acid reacts with the hydroxyl group (-OH) of a diol, joining them through a -CO-O- linkage and releasing a water molecule.

How does condensation polymerisation occur?

Condensation polymerisation occurs when two different monomers, each carrying two functional groups, react repeatedly at both ends of the growing chain, eliminating a small molecule such as water at each linkage, to build up a long polymer chain.

What do you understand by the term 'repeating unit'?

A repeating unit is the smallest structural fragment of a polymer that, when repeated n times and joined end to end, reproduces the full polymer chain.

Give two examples each of addition polymers and condensation polymers.

Addition polymers: polyethene and polystyrene (also polyvinyl chloride/PVC). Condensation polymers: polyester and nylon (also bakelite).

How are polymers useful to us?

Polymers are useful because of their high strength, flexibility, and resistance to heat and chemicals, which make them suitable for products ranging from packaging and containers to textiles, and they have widely replaced heavier or more limited materials like metal, wood and cotton.

How are synthetic fibres different from natural fibres?

Synthetic fibres are generally cheaper, stronger, more durable, resistant to shrinking and wrinkling, lightweight, quick-drying, and moth/insect resistant compared with natural fibres such as cotton and silk.

Are natural polymers hazardous for the environment? Explain why.

No -- unlike synthetic plastics, natural polymers such as starch, cellulose and proteins are biodegradable and break down naturally through the action of living organisms, so they do not accumulate as long-term pollution the way synthetic plastics do.

Why is it dangerous to burn discarded plastic articles?

Burning discarded plastic releases dangerous, toxic gases into the air, creating hazardous environmental and health conditions for people and wildlife nearby.

Long Questions & Answers

Describe the two main types of polymerisation and how condensation polymers like PET and nylon are formed.

What is addition polymerisation and how does polyethene form?

In addition polymerisation, monomers containing a double bond (like ethene) join together through covalent bonds as the double bond breaks, with no molecule eliminated and no by-product formed; a very large number of ethene molecules combine this way, usually at high pressure with a catalyst, to give polyethene.

What is condensation polymerisation and how is PET formed?

In condensation polymerisation, two different monomers, each with two functional groups, react with the elimination of a small molecule such as water; PET forms when ethane diol reacts with terephthalic acid (a dicarboxylic acid), with the acid's carboxyl group reacting with the diol's hydroxyl group to form an ester linkage, and this repeats at both ends of the growing chain.

How is a polyamide such as nylon formed?

A polyamide forms when a dicarboxylic acid reacts with a diamine: each -COOH group of the acid reacts with an -NH2 group of the diamine to form an amide linkage, with a water molecule lost at each linkage, and the resulting repeat unit is built up into the full polymer chain.

How can the repeating unit or monomer be deduced from a given polymer structure?

For an addition polymer, remove the brackets, extended bonds and subscript n from the repeat unit and change the single bond back to a double bond to recover the monomer; for a condensation polymer, break the ester or amide linkage and add -OH to each end of the acid fragment and -H to each end of the diol or diamine fragment to recover the original monomers.

What are plastics, why are they important in the textile industry, and what environmental problems do they cause?

What are plastics and why are they so widely used?

Plastics are polymers such as polyethylene, polypropylene and polystyrene that are lightweight, flexible, durable, and easily moulded into almost any shape, which is why they are used for food containers, bottles, bags, kitchenware, furniture and countless other everyday products.

Why are synthetic fibres important in the textile industry?

Synthetic fibres such as nylon, polyester, rayon and acrylic are cheaper, stronger, more durable, shrink- and wrinkle-resistant, lightweight, quick-drying and insect-resistant compared with natural

fibres, and polyester and nylon alone account for about 69% of all material used in clothing worldwide.

What environmental problems does plastic disposal cause?

Because plastics do not biodegrade and can persist for up to 1000 years, discarded plastic accumulates in landfill sites and in oceans, rivers, lakes and seas, causing widespread pollution on land, in water and in the air, and leading to serious health and ecological problems.

Why is burning plastic dangerous, and can any plastics be recycled?

Burning discarded plastic releases dangerous toxic gases into the air, making it a hazardous disposal method; however, some plastics such as PET can be chemically recycled by heating them in the absence of oxygen to break them back down into their monomers, which can then be repolymerised into new material.

Multiple Choice Questions (MCQs)

Which of the following polymers is a synthetic polymer? (A) Starch (B) Cellulose (C) Animal fat (D) Polyester

Correct answer: (D) Polyester. Polyester is a man-made (synthetic) condensation polymer, whereas starch, cellulose and animal fat are all naturally occurring polymers/biomolecules.

Which polymer has an amide linkage? (A) Polyester (B) Polyamide (C) Polyethene (D) Polystyrene

Correct answer: (B) Polyamide. A polyamide, such as nylon, is defined by its amide (-CO-NH-) linkage, formed between a dicarboxylic acid and a diamine.

Identify an ester linkage: (A) R-C(=O)-O-R (B) R-C(=O)-R (C) R-C(=O)-NH-R (D) R-C-NH-R

Correct answer: (A) R-C(=O)-O-R. An ester linkage has the form R-C(=O)-O-R, with a carbonyl carbon bonded to an oxygen that connects to a second R group -- distinct from the amide linkage, R-C(=O)-NH-R.

A polymer has the repeat unit [-CH2-CH(OCOCH3)-]n. What is the structure of its monomer? (A) CH2=CH2 (B) CH2=CH2-CH3 (C) CH2=CH-OCOCH3 (D) CH2=CH-CO-O-CH3

Correct answer: (C) CH2=CH-OCOCH3. Removing the brackets/subscript n and converting the single C-C bond back to a double bond gives CH2=CH-OCOCH3 as the monomer (vinyl acetate).

Which of the following polymers can be recycled? (A) PET (B) Polystyrene (C) PVC (D) Epoxy

Correct answer: (A) PET. PET is a condensation polymer that can be chemically broken back down into its monomers (by heating in the absence of oxygen) and repolymerised, making it recyclable in this way.

Which of the following polymers is biodegradable? (A) Polyamide (B) Polyester (C) Starch (D) PET

Correct answer: (C) Starch. Starch is a naturally occurring polysaccharide and is biodegradable, unlike the synthetic polymers polyamide, polyester and PET, which persist in the environment for very long periods.

Which of the following polymers is obtained by condensation polymerisation? (A) Polyvinyl chloride (B) Polystyrene (C) Polyamide (D) Polyethene

Correct answer: (C) Polyamide. Polyamide (such as nylon) is a condensation polymer, formed with the elimination of water between a dicarboxylic acid and a diamine, unlike polyvinyl chloride, polystyrene and polyethene, which are all addition polymers.

In addition polymerisation, the molecular mass of the polymer can be found by: (A) Subtracting the mass of water lost (B) Adding the molecular masses of all monomers used (C) Dividing the monomer mass by n (D) It cannot be calculated at all

Correct answer: (B) Adding the molecular masses of all monomers used. Because addition polymerisation eliminates no molecule and forms no by-product, the polymer's molecular mass equals the sum of the molecular masses of all the monomer units used to build it.

Quick Revision Summary

- Polymers are large molecules (macromolecules) built from repeating monomer units through polymerisation; natural examples include carbohydrates, proteins and nucleic acids, man-made examples include plastics and synthetic fibres.
- Addition polymerisation: single monomer with a double bond, no by-product, polymer mass = sum of monomer masses (e.g. polyethene, polystyrene, PVC).

- Condensation polymerisation: two different monomers with two functional groups each, eliminates a small molecule (H2O/HCl/NH3), forms ester or amide linkages (e.g. polyester/PET, nylon, bakelite).
- To deduce a monomer: addition polymer -> remove brackets/n, restore double bond; condensation polymer -> break the linkage, add -OH to the acid fragment and -H to the diol/diamine fragment.
- Plastics (PE, PP, PS etc.) are lightweight, flexible, durable and mouldable, used in containers, bags, kitchenware and furniture.
- Synthetic fibres (nylon, polyester, rayon, acrylic) are cheaper, stronger, shrink/wrinkle-resistant, and light; polyester + nylon = ~69% of world clothing material.
- Plastics are non-biodegradable (up to 1000 years to break down) -- major problems: landfill accumulation, ocean pollution, and toxic gases released when burned. PET can be chemically recycled back to monomers.

Exam Tips

- Tell addition vs condensation apart fast: addition = ONE monomer + double bond + NO by-product; condensation = TWO monomers + two functional groups EACH + small molecule eliminated.
- To deduce an addition monomer: strip brackets/n, turn the single bond back into a double bond -- that's it.
- To deduce condensation monomers: find the linkage (ester = -CO-O-, amide = -CO-NH-), break it, then add -OH to the acid side and -H to the diol/diamine side.
- Remember polyester and nylon by their linkage: polyester = ester linkage (acid + diol); nylon/polyamide = amide linkage (acid + diamine).
- Three-part environmental problem to remember: landfill (takes up space), oceans (marine pollution), burning (toxic gases) -- plastics fail all three because they don't biodegrade.
- PET is the one 'exception' worth remembering: unlike most plastics, it can be chemically recycled back into its monomers by heating without oxygen.