The Ozone Story (OZ)

Revision guide

Clarity, confidence, and top grades.

What this storyline covers

- Electronegativity and bond polarity
- Intermolecular bonds and hydrogen bonding
- Reaction kinetics and the Boltzmann distribution
- Composition by volume and ppm
- Haloalkanes and nucleophilic substitution
- Radicals and chain reactions
- The ozone layer
- Radiation and the electromagnetic spectrum

Required practicals in this storyline: reaction kinetics, relative reactivity of the haloalkanes, the alkane–bromine reaction, and intermolecular-bond experiments.



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How to use this guide

The Ozone Story covers a lot of new ground: **intermolecular bonding**, **reaction kinetics**, **haloalkanes** and the two great mechanism types — **nucleophilic substitution** and **radical reactions**. These mechanisms and the kinetics ideas return in What's in a Medicine?, Polymers and Life and Colour by Design, so they are worth mastering here.

How it is assessed

OCR B is context-led, so OZ content can appear in **any** of the three written papers, in any context:

- **Paper 1** — Fundamentals of chemistry (110 marks)
- **Paper 2** — Scientific literacy, including the pre-release Advance Notice article (100 marks)
- **Paper 3** — Practical skills in chemistry (60 marks)

How to revise it

- Learn the **definitions in the teal boxes** word-for-word — they are marks you can guarantee.
- Work every **worked example** yourself before reading the solution.
- Practise the **mechanisms by hand** — full arrows for substitution, half arrows for radicals, with partial charges.
- Use the **spec checklist** on the last page to confirm you can do every point.

1 Electronegativity and bond polarity

Spec reference: OZ(a).

Key definition

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

- **Trends:** electronegativity **increases across a period** (more protons, similar shielding) and **decreases down a group** (the bonding pair is further from the nucleus, with more shielding). The most electronegative atoms are **F, O, N and Cl**.
- **Bond polarity:** if the two atoms differ in electronegativity, the bonding electrons are pulled towards the more electronegative atom, which becomes **δ−**, leaving the other **δ+**. A large difference gives an ionic bond; little or no difference gives a non-polar covalent bond.

Exam tip — molecular polarity

A molecule is only **polar overall** if it has polar bonds **and** they do not cancel by symmetry. CO_2 has polar bonds but is non-polar (linear, the dipoles cancel); H_2O is polar (bent, the dipoles do not cancel). Likewise CCl_4 is non-polar but $CHCl_3$ is polar.

2 Intermolecular bonds

Spec references: OZ(b), OZ(c), OZ(d).

Key definitions — three types, weakest to strongest

- **Instantaneous dipole–induced dipole (id–id) bonds** — present between **all** molecules. Random movement of electrons creates a temporary dipole, which induces a dipole in a neighbour. They get **stronger** with **more electrons** (larger M_r) and with **less branching** (more surface contact).
- **Permanent dipole–permanent dipole (pd–pd) bonds** — between **polar** molecules; the δ+ of one is attracted to the δ− of another.
- **Hydrogen bonds** — the strongest; form when H is bonded to **N, O or F** and is attracted to a **lone pair** on the N, O or F of another molecule.

Hydrogen bonding in water and ice OZ(c)

- Water molecules form an extensive hydrogen-bonded network, giving water an **unusually high boiling point**.
- In **ice**, hydrogen bonds hold the molecules in an **open, regular lattice**, so ice is **less dense** than liquid water and floats.

Boiling points OZ(d)

- The **more energy** needed to separate the molecules, the **higher** the boiling point. Only the intermolecular bonds break on boiling, not the covalent bonds.
- id–id bonds increase with M_r, which explains why **boiling points rise down the halogens** (F_2 to I_2) and along the alkanes, and why branched isomers boil lower.
- Hydrogen-bonded molecules boil **higher** than expected from their M_r alone.

3 Reaction kinetics

Spec references: OZ(e), OZ(f), OZ(g), OZ(h). Practical: reaction kinetics.

Key definition

The **activation enthalpy** is the minimum energy that colliding molecules must have in order to react.

- **Enthalpy profile:** a diagram of energy along the reaction. The reactants rise over an **activation-enthalpy barrier** to the products; ΔH is the difference between the product and reactant energies. A catalyst lowers the barrier.
- **Collision theory:** a reaction occurs only when particles collide with energy **greater than or equal to the activation enthalpy** and in the **correct orientation**.
- **Concentration or pressure:** increasing the concentration (or, for gases, the pressure) packs the particles closer, so collisions are **more frequent** and the rate increases.

The Boltzmann distribution OZ(f)

- The Boltzmann distribution shows the **spread of molecular energies** in a sample. Only molecules with energy **≥ the activation enthalpy** (the area to the right of E_a) can react.
- **Raising the temperature** shifts the curve to higher energies, so a **much greater proportion** of molecules exceed E_a — this is the main reason the rate rises sharply with temperature.
- **A catalyst lowers E_a**, so a greater proportion of molecules have enough energy to react.

Catalysis OZ(g), OZ(h)

- A **catalyst** provides an **alternative route of lower activation enthalpy**, speeding up the reaction without being used up.
- **Homogeneous catalysis** — the catalyst is in the **same phase** as the reactants. It works by forming an **intermediate**, which then reacts on to give the product and regenerate the catalyst. Chlorine radicals catalysing the breakdown of ozone are an example.

Exam tip — following a reaction

To measure a rate, follow a property that changes as the reaction proceeds — gas volume, loss of mass, or colour (colorimetry) — and plot it against time. The steeper the graph, the faster the rate.

4 Composition by volume

Spec reference: OZ(i).

- For a gas mixture, the **composition by volume** of a component = (volume of that gas ÷ total volume) × 100 for a **percentage**, or × 10^6 for **parts per million (ppm)**.
- At the same temperature and pressure, equal volumes of gases contain equal numbers of moles, so a volume fraction is also a mole fraction.

Worked example — percentage to ppm

Air contains 0.040% carbon dioxide by volume. Express this in parts per million.

`fraction = 0.040 / 100 = 4.0 × 10^-4`

`ppm = 4.0 × 10^-4 × 10^6 = 400 ppm`

5 Haloalkanes and nucleophilic substitution

Spec references: OZ(j), OZ(k), OZ(l), OZ(m), OZ(n).

Naming and properties OZ(j), OZ(k)

- **Haloalkanes** are named with **fluoro-, chloro-, bromo-, iodo-** prefixes and locants, e.g. 2-bromopropane, 1,2-dichloroethane. **Amines** are named from the alkyl group, e.g. ethylamine.
- Their **boiling points** depend on intermolecular bonds, rising with M_r (down F to I, and with chain length).

Nucleophilic substitution OZ(k), OZ(l)

Key definitions

- A **nucleophile** is an electron-pair donor (attracted to δ+ centres).
- **Substitution** is the replacement of one atom or group by another.

- The C–halogen bond is **polar** ($C^{\delta+}$–$X^{\delta-}$), so a nucleophile attacks the δ+ carbon.
- With **water or hydroxide ions** → an **alcohol**: R–X + OH^- → R–OH + X^-.

- With **ammonia** → an **amine**: R–X + $2NH_3$ → R–NH_2 + NH_4X.

The mechanism — one step (OZ(m))

For a hydroxide ion reacting with a haloalkane R–X:

- A **curly arrow** goes from the **lone pair** on the nucleophile (OH^-) to the **δ+ carbon**.
- At the same time, a second curly arrow goes from the **C–X bond** to the halogen, which leaves as **X^-**.
- The new bond forms as the old one breaks, in a **single step**; show the partial charges $C^{\delta+}$ and $X^{\delta-}$. (The SN1/SN2 labels are not required.)

Relative reactivity of the haloalkanes OZ(n)

- Reactivity could depend on **bond polarity** (C–F is the most polar) or on **bond enthalpy** (C–I is the weakest).
- Experiments on the rate of hydrolysis show **iodoalkanes react fastest** and **fluoroalkanes slowest**, so **bond enthalpy is the more important factor**: the weakest bond, C–I, breaks most easily. Reactivity increases F < Cl < Br < I.

6 Radicals and bond fission

Spec references: OZ(o), OZ(p). Practical: the alkane–bromine reaction.

Key definitions

- **Homolytic fission** — the bond breaks so that **each atom takes one** of the bonding electrons, forming two **radicals**. Shown with **half (single-barbed) curly arrows**.
- **Heterolytic fission** — the bond breaks so that **one atom takes both** electrons, forming a positive and a negative ion. Shown with a **full curly arrow**.
- A **radical** is a species with an **unpaired electron**; radicals are very reactive.

Radical chain reactions OZ(p)

The reaction of an alkane with a halogen in UV light proceeds by a radical chain with three stages (here CH_4 + Cl_2):

Stage	What happens
Initiation	Cl_2 → 2Cl• (UV light causes homolytic fission)
Propagation	Cl• + CH_4 → •CH_3 + HCl; •CH_3 + Cl_2 → CH_3Cl + Cl•
Termination	two radicals combine, e.g. Cl• + •CH_3 → CH_3Cl; or 2Cl• → Cl_2

- In **propagation**, a radical is used and a new one is made, so the chain **continues**; in **termination**, two radicals join and radicals are removed.
- Use **half curly arrows** (single-barbed) to show the movement of **single electrons** in radical mechanisms.

7 The ozone layer

Spec references: OZ(q), OZ(r).

Ozone in the atmosphere OZ(r)

- Ozone (O_3) is constantly **formed and destroyed** in the **stratosphere**, where its concentration stays roughly steady.
- **In the stratosphere** it acts as a **sunscreen**, absorbing high-energy **UV** that would otherwise reach the surface and harm living things (UV causes sunburn and skin cancer).
- **In the troposphere** (ground level) ozone is a **pollutant**, contributing to **photochemical smog** and respiratory problems.

Ozone depletion by haloalkanes OZ(q)

- **CFCs** are very **stable**, so they reach the stratosphere intact. There, UV causes **photodissociation** of a C–halogen bond, releasing **chlorine radicals** (Cl•).
- The radicals **catalyse** ozone destruction and are regenerated, so one radical destroys many ozone molecules: Cl• + O_3 → ClO• + O_2; ClO• + O_3 → Cl• + $2O_2$.
- The **ease of photodissociation** depends on **bond enthalpy**: the strong C–F bond is hard to break, while the weaker C–Cl, C–Br and C–I bonds break more readily, so the ease increases from **fluoroalkanes to iodoalkanes**.

8 Radiation and the electromagnetic spectrum

Spec references: OZ(s), OZ(t), OZ(u).

- The **Sun** emits mainly **ultraviolet, visible and infrared** radiation; the cooler **Earth** re-emits mainly **infrared**.
- **UV and visible** radiation can **promote electrons** to higher energy levels; high-energy UV carries enough energy to cause **bond breaking** (photodissociation).

$$\Delta E = h\nu$$

energy of a photon (J) = Planck constant (6.63×10^{-34} J s) × frequency (Hz)

$$c = \nu\lambda$$

speed of light (3.00×10^{8} m s^{-1}) = frequency (Hz) × wavelength (m)

Worked example — energy of UV radiation

Find the energy of one photon of ultraviolet radiation of wavelength 300 nm.

$\nu = c / \lambda = (3.00 \times 10^{8}) / (300 \times 10^{-9}) = 1.00 \times 10^{15}$ Hz

$\Delta E = h\nu = (6.63 \times 10^{-34}) \times (1.00 \times 10^{15}) = 6.63 \times 10^{-19}$ J

P Required practicals in this storyline

These PAG activities are most likely to be examined in Paper 3, but the techniques can appear in any paper.

Activity	What to be able to do
Reaction kinetics	follow a reaction by gas volume, mass loss or colour; plot a graph against time and describe how rate changes with concentration and temperature
Relative reactivity of haloalkanes	warm fluoro-, chloro-, bromo- and iodoalkanes with aqueous silver nitrate in ethanol; time the appearance of the silver-halide precipitate (iodo fastest)
Alkane and bromine	react an alkane with bromine in UV light and observe the orange colour fade (radical substitution)
Intermolecular bonds	experiments to illustrate the formation and effects of intermolecular bonds, including hydrogen bonding

Exam tip — drawing mechanisms

Use **full curly arrows** (a pair of electrons) for nucleophilic substitution and heterolytic fission, and **half curly arrows** (a single electron) for radical steps. Always mark the **partial charges** (δ+, δ−) on a polar bond.

Spec coverage checklist — can you do every point?

Every assessable learning outcome for The Ozone Story, with where it is covered in this guide. Tick each one once you can do it confidently.

OZ(a)	Electronegativity, its trends, and predicting bond and molecular polarity — §1
OZ(b)	id–id and permanent dipole–permanent dipole intermolecular bonds — §2
OZ(c)	Hydrogen bonding, including in water and ice — §2
OZ(d)	Relative boiling points in terms of intermolecular bonds — §2
OZ(e)	Activation enthalpy and enthalpy profiles — §3
OZ(f)	Effects of concentration, pressure, temperature and catalysts on rate; the Boltzmann distribution — §3
OZ(g)	Catalysts providing a route of lower activation enthalpy — §3
OZ(h)	Homogeneous catalysis and the formation of intermediates — §3
OZ(i)	Composition by volume calculations (percentage and ppm) — §4
OZ(j)	Recognising and naming haloalkanes and amines — §5
OZ(k)	Properties of haloalkanes; nucleophilic substitution with water, hydroxide and ammonia — §5
OZ(l)	The terms substitution and nucleophile — §5
OZ(m)	The one-step nucleophilic substitution mechanism with curly arrows and partial charges — §5
OZ(n)	Relative reactivity of haloalkanes depends mainly on bond enthalpy — §5
OZ(o)	Homolytic and heterolytic bond fission — §6
OZ(p)	Radicals and the radical chain mechanism (initiation, propagation, termination) — §6
OZ(q)	Ozone depletion by haloalkanes; photodissociation and bond enthalpy — §7
OZ(r)	Formation, destruction and effects of ozone in the stratosphere and troposphere — §7
OZ(s)	The principal radiations of the Earth and the Sun — §8
OZ(t)	UV and visible radiation promoting electrons and breaking bonds — §8
OZ(u)	Calculating frequency, wavelength and energy of radiation — §8