Unit 8 · Chemical Reaction

STUDY NOTES

Key terms

Chemical reaction: reactants → new products; bonds break and form; atoms rearranged, none made or lost.

Balanced equation: same atoms of each element on both sides.

Spectator ions: in the water before and after; left out of an **ionic equation**.

Precipitation reaction: two solutions form an insoluble solid, a **precipitate**.

Hydrolysis: a substance reacts with water; water splits, H to one part, OH to the other.

Catalyst: changes the rate without permanent chemical change.

Enzymes (biocatalysts): catalysts of living things; proteins.

Photochemical reaction: started or driven by light.

Electrolytic reaction: brought about by a current through a molten or dissolved electrolyte.

Oxidation: loss of electrons. **Reduction**: gain of electrons. **Redox**: both together.

Monomer: small molecule that joins into a chain. **Polymer**: macromolecule of many monomer units, covalently bonded. **Polymerization**: the joining reaction.

Degree of polymerization, n: repeating units in one chain.

Formulas

molar mass $= n \times$ mass of repeating unit	n degree of polymerization **Use:** polythene, $56{,}000 \div 28 = 2{,}000$
chain of n units $= n \times$ unit $- (n-1) \times 18$	$n - 1$ links, one water each **Use:** glycine: $50 \times 75 - 49 \times 18 = 2{,}868$

- amounts: numbers in an equation count moles; then $n = m/M$, $n = V/22.4$ L
- $2H_2O_2 \rightarrow 2H_2O + O_2$: 68 g → 36 g + 32 g (22.4 L at STP)
- 1.7 g H_2O_2 = 0.05 mol → 0.025 mol O_2 = 0.8 g, 0.56 L

Equations

- signs of a reaction:
  - new color
  - gas
  - solid from solutions
  - heat or light
  - new smell or taste
- the test: **a new substance?**
- (s), (l), (g), (aq); ↑ gas; ↓ precipitate; Δ heat; catalyst or light over the arrow; ⇌ reversible
- $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s)\downarrow + NaNO_3(aq)$; ionic: $Ag^+ + Cl^- \rightarrow AgCl$ (any silver salt, any chloride)
- **doesn't say**:
  - whether it happens (Cu + 2HCl balances, but no reaction)
  - how fast
  - how far
  - concentrations
  - how atoms rearrange
- formulas right first, then change only the numbers in front
- one reaction, several names: $2AgCl \rightarrow 2Ag + Cl_2$ is decomposition, photochemical, redox

Precipitation

Dissolve	Except
all nitrates	none
Na, K, ammonium salts	none
most chlorides, bromides, iodides	Ag, Pb(II)
most sulphates	Ba, Pb(II) (Ca slightly)

Don't dissolve	Except
most hydroxides	Na, K, ammonium (Ca slightly)
most carbonates	Na, K, ammonium

Mix	Precipitate
$AgNO_3 + NaCl$	AgCl, white curds
$BaCl_2 + Na_2SO_4$	$BaSO_4$, white, stays milky
$CuSO_4 + 2NaOH$	$Cu(OH)_2$, pale blue jelly
$Pb(NO_3)_2 + 2KI$	PbI_2, bright yellow
$FeCl_3 + 3NaOH$	$Fe(OH)_3$, reddish-brown
$Ca(OH)_2 + CO_2$	$CaCO_3$, white (milky)

- ionic: $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$; $Cu^{2+} + 2OH^- \rightarrow Cu(OH)_2$; $Pb^{2+} + 2I^- \rightarrow PbI_2$
- **tests**:
  - $AgNO_3$ (with dilute HNO_3) white: chloride
  - $BaCl_2$ white: sulphate
  - NaOH: blue Cu(II), dirty green Fe(II), reddish-brown Fe(III)
  - lime water milky: CO_2

- uses:
  - tests
  - insoluble salts ($BaSO_4$ for X-rays)
  - softening ($CaCl_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2NaCl$)
  - cleaning water
- 1.17 g NaCl = 0.02 mol → 2.87 g AgCl, uses 3.4 g $AgNO_3$

Hydrolysis

The solution takes the side of the stronger partner.

Salt from	Examples	Solution
strong acid + strong base	NaCl, KNO_3, Na_2SO_4	neutral, no hydrolysis
strong acid + weak base	NH_4Cl, $CuSO_4$, $FeCl_3$, alum	acidic
weak acid + strong base	Na_2CO_3, CH_3COONa, $NaHCO_3$	basic
weak acid + weak base	CH_3COONH_4	near neutral

- $NH_4Cl + H_2O \rightleftharpoons NH_4OH + HCl$: HCl fully ionized, NH_4OH mostly not → more H^+
- $CuSO_4 + 2H_2O \rightleftharpoons Cu(OH)_2 + H_2SO_4$; $FeCl_3 + 3H_2O \rightleftharpoons Fe(OH)_3 + 3HCl$
- $CH_3COONa + H_2O \rightleftharpoons CH_3COOH + NaOH$; $Na_2CO_3 + 2H_2O \rightleftharpoons 2NaOH + H_2CO_3$ → more OH^-
- $\rightleftharpoons$: only a small part reacts
- really ions: $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$; $CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$; molecular form accepted in exams
- wood ash (K_2CO_3): basic. Alum: $Al^{3+} + 3H_2O \rightleftharpoons Al(OH)_3 + 3H^+$, jelly traps mud; clear isn't yet safe
- **others**:
  - esters: $CH_3COOC_2H_5 + H_2O \rightleftharpoons CH_3COOH + C_2H_5OH$
  - fats + NaOH → soap, glycerol (**saponification**)
  - $C_{12}H_{22}O_{11} + H_2O \rightarrow$ glucose + fructose
  - $CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$
  - digestion
- not dissolving: sugar dissolved stays sugar

Catalytic

Reaction	Catalyst
$2KClO_3 \rightarrow 2KCl + 3O_2$	MnO_2
$2H_2O_2 \rightarrow 2H_2O + O_2$	MnO_2
$N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Haber)	Fe
$2SO_2 + O_2 \rightleftharpoons 2SO_3$ (contact)	V_2O_5
$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$	Pt
oil + H_2 → vanaspati ghee	Ni
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$	yeast enzymes
starch + water → maltose	amylase

Characteristics

1. not used up: same mass, composition (may crumble)
2. small amount enough
3. can't start a reaction that can't happen
4. same amount of product, only sooner
5. specific
6. best at a certain temperature (enzymes about 37 °C, destroyed by boiling)
7. **poisons** stop it (As on Pt; Pb on converters); **promoters** help (Mo, K_2O on Haber's Fe)

- positive catalyst; negative catalyst = inhibitor (H_3PO_4 in H_2O_2, antioxidants)
- 24.5 g $KClO_3$ + 2 g MnO_2 → 6.72 L O_2 at STP; 2 g MnO_2 left; without it the same 6.72 L, above about 400 °C
- catalytic converter: Pt, Pd, Rh

Photochemical

- light breaks a bond; often violet, UV; in the dark hardly any reaction
- $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ (light, chlorophyll)
- $2AgCl \rightarrow 2Ag + Cl_2$; $2AgBr \rightarrow 2Ag + Br_2$ (violet-gray silver; film)
- $H_2 + Cl_2 \rightarrow 2HCl$ (dark none, diffused steady, bright explodes); $CH_4 + Cl_2$
- $O_2 \rightarrow 2O$ (UV); $O + O_2 \rightarrow O_3$
- brown bottles: H_2O_2, $AgNO_3$ ($2AgNO_3 \rightarrow 2Ag + 2NO_2 + O_2$); fading; vitamin D
- practical: AgCl on paper, coin on it, sun 10–15 min: open part violet-gray, under coin white; shade stays white
- Daguerre 1838; Fox Talbot

Electrolytic

- electrical → chemical energy
- $2H_2O \rightarrow 2H_2 + O_2$ (with a little acid)
- $2NaCl$ (molten) $\rightarrow 2Na + Cl_2$
- $2NaCl + 2H_2O \rightarrow 2NaOH + H_2 + Cl_2$ (brine)
- $2Al_2O_3 \rightarrow 4Al + 3O_2$ (in molten cryolite)
- cathode: $Na^+ + e^- \rightarrow Na$; anode: $2Cl^- \rightarrow Cl_2 + 2e^-$

Oxidation and reduction

	Oxidation	Reduction
oxygen	added	removed
hydrogen	removed	added
electronegative element	added	removed
electropositive element	removed	added
electrons	lost	gained
electrolysis	anode	cathode
happens to the	reducing agent	oxidizing agent

- **OIL RIG**; “an ox”, “red cat”

- $Mg \rightarrow Mg^{2+} + 2e^-$; $Fe^{2+} \rightarrow Fe^{3+} + e^-$; $2Cl^- \rightarrow Cl_2 + 2e^-$
- $Cu^{2+} + 2e^- \rightarrow Cu$; $Fe^{3+} + e^- \rightarrow Fe^{2+}$; $Cl_2 + 2e^- \rightarrow 2Cl^-$
- $CuO + H_2 \rightarrow Cu + H_2O$: CuO reduced, oxidizing agent; H_2 oxidized, reducing agent
- $Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$: $Fe \rightarrow Fe^{2+} + 2e^-$; $Cu^{2+} + 2e^- \rightarrow Cu$; sulphate takes no part
- $H_2S + Cl_2 \rightarrow 2HCl + S$: H_2S oxidized, Cl_2 reduced; $ZnO + C \rightarrow Zn + CO$
- oxidizing agents:
  - O_2
  - H_2O_2
  - conc. HNO_3
  - Cl_2
  - $KMnO_4$
- reducing:
  - H_2
  - CO
  - Zn
  - C
  - H_2S
  - Na
- not redox: $Ag^+ + Cl^- \rightarrow AgCl$; $H^+ + OH^- \rightarrow H_2O$ (no electrons pass)
- rusting, respiration, rancidity (chips packed in nitrogen); $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
- photosynthesis: CO_2 reduced, H_2O oxidized

Polymers

Addition	Condensation
monomers with C=C	two reactive groups (–OH, –COOH, $–NH_2$)
nothing given off	small molecule at each link, usually water
unit = monomer's formula	unit has fewer atoms than monomers
grows quickly at its end	short chains join step by step
polythene, PVC, PP, PTFE, rubber	nylon, polyester, Bakelite, proteins, starch, cellulose

Monomer	Polymer
$CH_2=CH_2$	polythene
$CH_2=CH–CH_3$	polypropylene
$CH_2=CHCl$	PVC
$CF_2=CF_2$	PTFE
$CH_2=CH–C_6H_5$	polystyrene
$CH_2=CH–CN$	acrylic

- nylon-6,6: $H_2N(CH_2)_6NH_2 + HOOC(CH_2)_4COOH$; amide link –CO–NH–; $2n\ H_2O$
- PET: diol + diacid, ester link –CO–O–; Bakelite: phenol + methanal, network
- proteins: amino acids, peptide bond –CO–NH–; starch, cellulose: $n\ C_6H_{12}O_6 \rightarrow (C_6H_{10}O_5)_n + n\ H_2O$; DNA, RNA
- hydrolysis is condensation backward: $(C_6H_{10}O_5)_n + n\ H_2O \rightarrow n\ C_6H_{12}O_6$; polythene has no link to open
- **natural**: starch, cellulose, proteins, natural rubber (isoprene, C_5H_8), DNA
- **synthetic**: from oil, gas
- **semi-synthetic**: rayon, vulcanized rubber
- **vulcanization**: Goodyear 1839; sulphur links chains; elastic hot and cold; much sulphur: ebonite
- Staudinger: macromolecules, 1920; Nobel 1953

Thermoplastic	Thermosetting
softens again and again	sets once; chars when reheated
separate chains	cross-linked network
recyclable	not by melting
polythene, PVC, PP, PS, nylon, PET	Bakelite, melamine, epoxy

Uses:

- polythene bags, tanks, pipes
- PP buckets, ropes
- PVC pipes, wire coating
- PS thermocol
- PTFE non-stick
- acrylic sweaters
- nylon ropes, nets, bristles
- PET bottles, clothes
- Bakelite switches, handles
- vulcanized rubber tyres, chappals
- problem:
  - don't rot
  - microplastics
  - burning PVC gives HCl and dioxins
  - use less, reuse, recycle
  - polylactic acid

COMMON MISTAKES

✗ catalyst gives more product
✓ same amount, only sooner.

✗ catalyst written as a reactant
✓ over the arrow; not used up.

✗ oxidizing agent is oxidized
✓ it is **reduced**.

✗ balanced, so it happens
✓ Cu + 2HCl balances, no reaction.

✗ dissolving = hydrolysis
✓ water must react, new substances.

✗ salt always neutral
✓ strong/weak partners decide.

✗ 50 units give 50 waters
✓ 49 links, 49 waters.

✗ addition polymer gives off water
✓ nothing given off.