Unit 9 · Chemistry of Non-Metals

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Inorganic Chemistry (Units 9–11 together): 20 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: SO_2 through acidified H_2S (SO_2 is reduced to sulphur); short: HCl from NaCl and conc. H_2SO_4, why HI can't be made so, HCl gas against hydrochloric acid, finding the HCl bottle with NH_3; long: classify CO, Na_2O, Al_2O_3, SO_2, Fe_3O_4, H_2O_2, two equations for an amphoteric oxide, why CO is harmful, a use of O_2; OR the contact process from iron pyrites in four equations, H_2SO_4 as precipitant and dehydrating agent, a fertilizer from it, why it oxidizes
- **MCQ (1 mark)**
  - tritium and its β particle; neutrons in protium; heavy water's formula and use; nascent hydrogen with $KMnO_4$
  - amphoteric, acidic, neutral, mixed oxide; a peroxide; O_2 in air (21%); antidote for CO poisoning
  - ozone's layer, test, discovery (1985, Antarctica), Freon-11 (CCl_3F), Montreal Protocol
  - N_2's triple bond; Fe^{2+} brown ring; Mg with very dilute HNO_3; Zn and very dilute HNO_3 (NH_4NO_3); passive iron; P_4 + HNO_3 (H_3PO_4); aqua regia
- **Short and long (5 and 8 marks)**: atomic vs nascent hydrogen; isotopes; hydrogen as a fuel; types of oxides with equations; H_2O_2's uses; ozone (making, structure, tests, depletion's mechanism, effects, control); ammonia's reactions; HNO_3 with Zn, Cu, Fe, S, C; the ring test; halogens' preparation and reactions (water, alkali, ammonia, bleaching); haloacids; carbon's allotropes, fullerene; CO; phosphine; H_2S (Kipp's apparatus, as a reagent); SO_2; H_2SO_4

Key terms

Atomic hydrogen: free H atoms from H_2 in an electric arc (tungsten); recombine at a metal at ~4000 °C (welding torch).

Nascent hydrogen [H]: hydrogen that reacts as it is formed (Zn + dil. acid), a stronger reducer than H_2.

Isotopes: same Z, different neutrons: protium ^1H (0 n), deuterium ^2H (1 n), tritium ^3H (2 n, radioactive, β, 12.3 y).

Heavy water: D_2O (M = 20), by long electrolysis of water; moderator, coolant, tracer.

Allotropy: one element in forms with different physical but the same chemical properties (O_2, O_3; diamond, graphite).

Oxide types: acidic (CO_2, SO_2, P_2O_5); basic (Na_2O, CaO); neutral (CO, NO, N_2O, H_2O); amphoteric (ZnO, Al_2O_3, PbO); peroxide (O_2^{2-}, O at −1: Na_2O_2, BaO_2, H_2O_2); superoxide (KO_2); mixed (Fe_3O_4 = $FeO{\cdot}Fe_2O_3$, Pb_3O_4).

Active nitrogen: N atoms from an electric discharge through N_2 at low pressure; yellow glow, very reactive.

Oxyacids of nitrogen: $H_2N_2O_2$ hyponitrous (+1), HNO_2 nitrous (+3), HNO_3 nitric (+5), HNO_4 pernitric (+5).

Passivity: conc. HNO_3 leaves iron with a thin oxide film, so it stops reacting.

Aqua regia: 3 conc. HCl : 1 conc. HNO_3; dissolves gold.

ODS: ozone-depleting substances, mainly CFCs (Freons: CCl_3F, CCl_2F_2).

Kipp's apparatus: gives H_2S on demand from FeS and dil. H_2SO_4.

Hydrogen and oxygen

- atomic H reduces: $CuO + 2H \rightarrow Cu + H_2O$; nascent [H] decolorizes acidified $KMnO_4$ (pink → colorless) and turns $K_2Cr_2O_7$ green
- **fuel**: 143 kJ per g (petrol ~50); only water. Fuel cell: anode $2H_2 \rightarrow 4H^+ + 4e^-$, cathode $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$. Against it: storage, cost, platinum, leaks burn
- **amphoteric**: $ZnO + 2\,HCl \longrightarrow ZnCl_2 + H_2O$, $ZnO + 2\,NaOH \longrightarrow Na_2ZnO_2 + H_2O$; $Al_2O_3 + 6\,HCl \longrightarrow 2\,AlCl_3 + 3\,H_2O$, $Al_2O_3 + 2\,NaOH \longrightarrow 2\,NaAlO_2 + H_2O$
- **mixed**: $Fe_3O_4 + 8\,HCl \longrightarrow FeCl_2 + 2\,FeCl_3 + 4\,H_2O$
- **H_2O_2**: $2H_2O_2 \rightarrow 2H_2O + O_2$; antiseptic, bleach (hair, pulp, cloth), rocket fuel, cleaning old paintings
- **O_2 uses**: oxygen therapy, high altitude, anesthesia, CO poisoning; steel making, welding and cutting (oxy-acetylene), rocket fuel
- **CO is harmful**: binds hemoglobin 200–250 times as strongly as O_2, so the blood carries less oxygen

Ozone

- 15–35 km up; made by UV: $3O_2 \rightarrow 2O_3$; absorbs UV-B
- **Siemens' ozonizer**: silent electric discharge through dry O_2, cold; $3\,O_2 \rightleftharpoons 2\,O_3$, $\Delta H = +284$ kJ
- **structure**: bent, 116.8°, both O–O 127.8 pm (resonance)
- **tests**: starch-iodide paper turns blue-black ($2KI + H_2O + O_3 \rightarrow 2KOH + I_2 + O_2$); mercury loses its meniscus (tailing)
- **depletion**: UV frees Cl• from CFCs; $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$, $ClO\bullet + O \rightarrow Cl\bullet + O_2$ (Cl a catalyst, ~100,000 O_3 each); worst over Antarctica in spring (polar clouds)
- **effects**: skin cancer, cataracts, weaker immunity, harm to crops and plankton
- **control**: Montreal Protocol (1987): CFCs replaced; fewer halons, CCl_4, methyl bromide
- **uses**: purifying water and air, bleaching, ozonolysis

Nitrogen

- **inert**: N≡N, 946 kJ/mol
- **ammonia** (curriculum's list)
  - water: $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ (weak alkali)
  - $CuSO_4$: pale blue $Cu(OH)_2$, then deep blue $[Cu(NH_3)_4]SO_4$ in excess
  - $FeCl_3 + 3NH_4OH \rightarrow Fe(OH)_3\downarrow$ (reddish brown) + $3NH_4Cl$
  - conc. HCl: white fumes of NH_4Cl
  - mercurous nitrate paper turns black (Hg)

- O_2: $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$ (reducing agent); Pt, 850 °C: $4NO$ (Ostwald)

- uses: urea and fertilizers, refrigerant, HNO_3, cleaning; harm: burns eyes, skin, lungs
- **HNO_3 with metals** (the more dilute, the more it is reduced)

	Product	Equation
Zn, conc.	NO_2	$Zn + 4HNO_3 \rightarrow Zn(NO_3)_2 + 2NO_2 + 2H_2O$
Zn, dil.	NO	$3Zn + 8HNO_3 \rightarrow 3Zn(NO_3)_2 + 2NO + 4H_2O$
Zn, v. dil.	NH_4NO_3	$4Zn + 10HNO_3 \rightarrow 4Zn(NO_3)_2 + NH_4NO_3 + 3H_2O$
Mg, Mn, v. dil.	H_2	$Mg + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2$
Cu, conc.	NO_2	$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$
Cu, dil.	NO	$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$
Fe, conc.	passive	(oxide film)

- **non-metals** (conc.): $S + 6HNO_3 \rightarrow H_2SO_4 + 6NO_2 + 2H_2O$; $C + 4HNO_3 \rightarrow CO_2 + 4NO_2 + 2H_2O$; $P_4 \rightarrow H_3PO_4$
- **reducers**: $SO_2 \rightarrow H_2SO_4$; $H_2S \rightarrow S$; $KI \rightarrow I_2$
- **ring test**: nitrate solution + fresh $FeSO_4$, conc. H_2SO_4 down the side: brown ring of $[Fe(H_2O)_5(NO)]^{2+}$

Halogens

	F_2	Cl_2	Br_2	I_2
state	gas	gas	liquid	solid
color	pale yellow	greenish yellow	red-brown	violet-black

- ns^2np^5; strong oxidizers, $F_2 > Cl_2 > Br_2 > I_2$; F only −1
- **making**: $MnO_2 + 4HX \rightarrow MnX_2 + X_2 + 2H_2O$ (X = Cl, Br, I); or $NaX + MnO_2 +$ conc. H_2SO_4; $2KMnO_4 + 16HCl \rightarrow 5Cl_2$ (no heat); Cl_2 frees Br_2 and I_2 from their salts
- **water**: $X_2 + H_2O \rightleftharpoons HX + HOX$ (F_2 gives O_2)
- **alkali**: $Cl_2 + 2NaOH$ (cold, dil.) $\rightarrow NaCl + NaOCl + H_2O$; $3Cl_2 + 6NaOH$ (hot, conc.) $\rightarrow 5NaCl + NaClO_3 + 3H_2O$
- **ammonia**: excess NH_3: $8NH_3 + 3Cl_2 \rightarrow N_2 + 6NH_4Cl$; excess Cl_2: $NH_3 + 3Cl_2 \rightarrow NCl_3 + 3HCl$
- **bleaching**: $Cl_2 + H_2O \rightarrow 2HCl + [O]$; by oxidation, permanent, needs moisture
- **haloacids**: $NaCl + H_2SO_4$ (conc.) $\rightarrow NaHSO_4 + HCl$
  - HBr, HI can't be made so: they reduce conc. H_2SO_4 to SO_2 and come off as Br_2, I_2; use H_3PO_4, or red $P + Br_2$ (I_2) + water
  - reducing power HI > HBr > HCl > HF; acids HI > HBr > HCl ≫ HF (weak)
  - HCl gas is covalent, doesn't turn dry litmus; hydrochloric acid is its solution, ionized ($H_3O^+ + Cl^-$)
  - NH_3 near HCl: dense white fumes of NH_4Cl
  - halide test, $AgNO_3$: AgCl white (dissolves in dil. NH_3), AgBr pale yellow, AgI yellow

Carbon and phosphorus

- **crystalline**: diamond (sp^3, 3D network, hardest, insulator); graphite (sp^2, layers, soft, conducts, lubricant, electrodes); fullerene C_{60} (12 pentagons, 20 hexagons, sp^2; soluble in toluene)
- **amorphous**: coal, coke, gas carbon, lamp black, charcoal (wood, animal, sugar: purest); activated charcoal adsorbs
- **CO**: reduces: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$; $I_2O_5 + 5CO \rightarrow I_2 + 5CO_2$; $Ni + 4CO \rightarrow Ni(CO)_4$ (Mond: 80 °C, splits at 180 °C); $CO + Cl_2 \rightarrow COCl_2$ (phosgene); $CO + 2H_2 \rightarrow CH_3OH$; fuel (water gas)
- **phosphorus**: white (P_4, glows, under water), red, black, violet, scarlet
- **PH_3**: $P_4 + 3NaOH + 3H_2O \rightarrow 3NaH_2PO_2 + PH_3$; weak base: $PH_3 + HI \rightarrow PH_4I$; burns: $PH_3 + 2O_2 \rightarrow H_3PO_4$; $PH_3 + 3Cl_2 \rightarrow PCl_3 + 3HCl$; reduces $AgNO_3$ to Ag; Holmes' signals, smoke screens, AlP grain tablets

Sulphur

- rhombic (α) ⇌ monoclinic (β) at 95.6 °C; plastic, colloidal, milk of sulphur
- uses: H_2SO_4, vulcanizing rubber, matches, gunpowder, fungicide
- **H_2S**: $FeS + H_2SO_4 \rightarrow FeSO_4 + H_2S$ (Kipp's); weak acid; reducer: $2FeCl_3 + H_2S \rightarrow 2FeCl_2 + 2HCl + S$, $KMnO_4$ decolorized
  - reagent: group II (Cu, Pb, Cd) sulphides in dil. HCl; group IV (Zn white, Ni, Co) in ammonia
- **SO_2**: acidic (H_2SO_3); reducer: $SO_2 + 2H_2O + Cl_2 \rightarrow H_2SO_4 + 2HCl$; oxidizer: $2H_2S + SO_2 \rightarrow 2H_2O + 3S$ (SO_2 reduced to S)
  - bleaches by reduction, temporary (color returns in air); preservative, bleach for wool and silk, paper pulp
- **H_2SO_4**: dibasic ($NaHSO_4$, Na_2SO_4)
  - conc. oxidizes, S at +6: $Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2H_2O$; $C + 2H_2SO_4 \rightarrow CO_2 + 2SO_2 + 2H_2O$
  - dilute acts only as an acid: $Zn \rightarrow H_2$
  - dehydrates: $C_{12}H_{22}O_{11} \rightarrow 12C + 11H_2O$; $HCOOH \rightarrow CO + H_2O$
  - precipitant: $BaCl_2 + H_2SO_4 \rightarrow BaSO_4\downarrow$ (white) + 2HCl
  - fertilizers: $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$; $Ca_3(PO_4)_2 + 2H_2SO_4 \rightarrow Ca(H_2PO_4)_2 + 2CaSO_4$ (superphosphate)
- **Contact process** (from iron pyrites)
  1. $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$ (SO_2 purified, dried)
  2. $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (V_2O_5, about 450 °C, 1–2 atm)
  3. $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ (oleum)
  4. $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$
- **$Na_2S_2O_3$** (hypo): $2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI$ (iodometry); fixes photographs; antichlor

COMMON MISTAKES

✗ ozone hole found by NASA in 1995
✓ Farman, Gardiner and Shanklin (British Antarctic Survey), 1985.

✗ ammonia is reduced by O_2
✓ it is oxidized (N −3 → 0).

✗ iodine a brown solid
✓ violet-black (violet vapor).

✗ graphite melts higher than diamond
✓ it sublimes at ~3,650 °C.

✗ hot conc. $H_2SO_4 + Fe \rightarrow FeSO_4$
✓ $Fe_2(SO_4)_3$.

✗ H_2SO_4 ionizes completely in both steps
✓ the second only partly.

✗ conc. H_2SO_4 always oxidizes
✓ dilute acid acts as an acid.