Grade 11 Chemistry Model Paper 3

ANSWER KEY

Full marks 75 · 3 hours

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

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Group A Multiple choice — 11 marks

Question 1 — 11 × 1 = 11

a. **(iv)** $Al_2(SO_4)_3$

b. **(i)** The air pressure there is lower.

c. **(ii)** CO_2

d. **(iii)** $K_p = K_c(RT)^{-2}$

e. **(ii)** 18 g

f. **(iv)** It carries Na^+ out of the cell and K^+ in, both against their concentration gradients.

g. **(i)** Li^+ is the smallest alkali metal ion, so it polarizes the carbonate ion most.

h. **(iv)** Carbon dioxide

i. **(i)** Because the reaction $2NO + O_2 \rightarrow 2NO_2$ goes faster at lower temperatures

j. **(ii)** Water is reduced far more easily than Na^+.

k. **(iii)** 12.6 tonnes

Group B Short answers, each on one content area — 40 marks

Question 2 — 5 marks

a. The four quantum numbers are the **principal** (n), **azimuthal** (l), **magnetic** (m) and **spin** (s) quantum numbers. **[2]**

Pauli's exclusion principle: no two electrons in an atom can have the same set of all four quantum numbers. So an orbital holds at most two electrons, with opposite spins.

Marking scheme

- The four quantum numbers named (principal, azimuthal, magnetic, spin).
- Pauli: no two electrons in an atom have all four quantum numbers the same.

b. Potassium is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ \mathbf{4s^1}$, so the outermost electron is in the 4s orbital: **[1]**

$n = 4,\ l = 0,\ m = 0,\ s = +\frac{1}{2}$ (or $-\frac{1}{2}$).

Marking scheme

- n = 4, l = 0, m = 0, s = +½ (or −½).

c. The third shell has the 3s, 3p and 3d subshells: 2 + 6 + 10 = 18 electrons. But by the Aufbau principle (the $n + l$ rule), **4s** (n + l = 4) has lower energy than **3d** (n + l = 5), so after 3s and 3p are filled (Na to Ar, 8 elements), the next electron goes into 4s (potassium), starting the fourth period. **[2]**

The 3d subshell fills only after 4s, in the fourth period (scandium to zinc), so the 3d electrons belong to the fourth period's transition elements, not the third period.

Marking scheme

- The third period fills only 3s and 3p (2 + 6 = 8 electrons).

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- 4s is lower in energy than 3d (n + l rule), so 3d fills only after 4s, in the fourth period.

OR

a. **Dalton's law:** the total pressure of a mixture of gases that don't react with one another is the sum of the partial pressures of the gases in it: $P = p_1 + p_2 + p_3 + \ldots$ **[2]**

The **partial pressure** of a gas in a mixture is the pressure it would exert if it alone filled the whole container at the same temperature.

Marking scheme

- Dalton's law: total pressure equals the sum of the partial pressures of non-reacting gases.
- Partial pressure: the pressure a gas would exert if it alone occupied the container at the same temperature.

b. **[1]**

$$p_{O_2} = P\text{total} - p_{H_2O} = 760 - 23.8 = 736.2\,\text{mmHg}$$

Marking scheme

- $760 - 23.8 = 736.2$ mmHg.

c. By Dalton's law, partial pressure = mole fraction × total pressure: **[2]**

$$p_{O_2} = 0.21 \times \tfrac{1}{3}\,\text{atm} = 0.07\,\text{atm}$$

against $0.21 \times 1 = 0.21$ atm at sea level: a third as much.

What the lungs and blood take up depends on the oxygen's **partial pressure**, not its percentage. At a third of the pressure, each breath holds only a third as many oxygen molecules, and too little oxygen passes into the blood, so climbers breathe from bottles to raise it.

Marking scheme

- Partial pressure of oxygen about 0.07 atm ($0.21 \times ⅓$), a third of that at sea level.
- The body's uptake depends on the partial pressure (fewer O_2 molecules per breath), not the percentage.

Question 3 — 5 marks

a. An **oxidizing agent** is a substance that **accepts (gains) electrons** from another substance, and is itself reduced (its oxidation number goes down). **[1]**

Marking scheme

- A substance that gains electrons (and is itself reduced).

b. Oxidation half: **[2]**

$$2\,I^- \longrightarrow I_2 + 2\,e^-$$

Reduction half (Cr +6 → +3; balance O with H_2O and H with H^+):

$$Cr_2O_7{}^{2-} + 14\,H^+ + 6\,e^- \longrightarrow 2\,Cr^{3+} + 7\,H_2O$$

Multiply the oxidation half by 3 so the electrons cancel, and add:

$$Cr_2O_7{}^{2-} + 6\,I^- + 14\,H^+ \longrightarrow 2\,Cr^{3+} + 3\,I_2 + 7\,H_2O$$

Check charges: $-2 - 6 + 14 = +6$ on the left; $2 \times (+3) = +6$ on the right.

Marking scheme

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- Both half-equations correct, electrons balanced (oxidation half × 3).
- Balanced ionic equation: $Cr_2O_7^{2-} + 6I^- + 14H^+ \rightarrow 2Cr^{3+} + 3I_2 + 7H_2O$.

c. Iron is more reactive than copper, so it **displaces** copper from the solution: **[2]**

$$Fe + Cu^{2+} \longrightarrow Fe^{2+} + Cu$$

Iron loses electrons ($0 \rightarrow +2$): it is **oxidized**; Cu^{2+} gains them ($+2 \rightarrow 0$) and is laid on the spoon as red-brown copper. As the blue Cu^{2+} ions are used up, the color fades (Fe^{2+} is pale green).

No. Copper is more reactive than silver, so it would displace silver and the vessel would be eaten away: $Cu + 2\,Ag^+ \longrightarrow Cu^{2+} + 2\,Ag$.

Marking scheme

- $Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$: iron is oxidized, copper deposited and the blue Cu^{2+} used up.
- No: copper displaces silver ($Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$), so the vessel would corrode.

Question 4 — 5 marks

a. **Law of mass action:** at a constant temperature, the rate of a chemical reaction is directly proportional to the product of the molar concentrations (active masses) of the reactants, each raised to the power of its coefficient in the balanced equation. **[2]**

A very large K_c means that at equilibrium the **products** are far more concentrated than the reactants: the reaction goes almost to completion.

Marking scheme

- Rate proportional to the product of the reactants' molar concentrations, each raised to its coefficient (constant temperature).
- Large Kc: mostly products at equilibrium (reaction nearly complete).

b. 0.40 mol of Cl_2 formed, so 0.40 mol of PCl_3 also formed and 0.40 mol of PCl_5 broke up, leaving $1.0 - 0.40 = 0.60$ mol. **[2]**

Concentrations in 2.0 L: $[PCl_5] = 0.30$ mol/L, $[PCl_3] = [Cl_2] = 0.20$ mol/L.

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{0.20 \times 0.20}{0.30} = 0.133\ \text{mol/L}$$

Marking scheme

- Equilibrium concentrations: PCl_5 0.30, PCl_3 and Cl_2 0.20 mol/L.
- Kc = 0.133 mol/L.

c. $K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$ keeps the same value (0.133 mol/L) because the temperature hasn't changed. Adding chlorine raises $[Cl_2]$ in the top of the fraction, making the ratio larger than K_c; to bring it back, some PCl_3 and Cl_2 must combine, so $[PCl_3]$ falls and **$[PCl_5]$ rises** (the equilibrium shifts backward, as Le Chatelier's principle also says). **[1]**

Marking scheme

- Kc is fixed at constant temperature; extra Cl_2 makes the ratio too large, so PCl_3 and Cl_2 combine and PCl_5 increases.

OR

a. Carbon ($2s^2\,2p^2$) first promotes one 2s electron to the empty 2p orbital ($2s^1\,2p^3$), giving four half-filled orbitals. The one 2s and three 2p orbitals then **mix** to give **four equal sp^3 hybrid orbitals**, each with one electron, pointing to the corners of a regular tetrahedron. **[2]**

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Each sp^3 orbital overlaps head-on with the 1s orbital of a hydrogen atom, forming four equal C–H σ bonds: methane is **tetrahedral**, H–C–H angle **109.5°**.

Marking scheme

- One 2s and three 2p orbitals (after promotion) mix into four equal sp^3 orbitals.
- Four C–H σ bonds: tetrahedral, 109.5°.

b. **PCl_5:** phosphorus is **sp^3d** hybridized (one s, three p and one d orbital); five bond pairs give a **trigonal bipyramidal** shape, with angles of **120°** in the equatorial plane and **90°** between the axial and equatorial bonds. **[2]**

SF_6: six bond pairs give an **octahedral** shape, every angle **90°**.

Marking scheme

- PCl_5: sp^3d, trigonal bipyramidal, 120° and 90°.
- SF_6: octahedral, 90°.

c. Sulphur's valence shell (n = 3) has **d orbitals** to use, so it can expand its octet and form six bonds. Oxygen's valence shell (n = 2) has only 2s and 2p orbitals, at most four, so it can't hold more than eight electrons (and its small atom has no room for six fluorines). **[1]**

Marking scheme

- Sulphur (n = 3) can expand its octet using d orbitals; oxygen (n = 2) has no d orbitals, so it can't exceed eight electrons.

Question 5 — 5 marks

a. Because it is made in such large amounts and used in so many industries (fertilizers, other chemicals, detergents, dyes and paints, petroleum refining, metals, batteries) that how much of it a country uses is taken as a measure of its industrial development. **[1]**

Marking scheme

- Made and used in huge amounts in very many industries (a measure of a country's industrial development).

b. Its **dehydrating** nature: it takes the elements of water (hydrogen and oxygen, in the ratio 2 : 1) out of the sugar, leaving black carbon: **[1]**

$$C_{12}H_{22}O_{11} \xrightarrow{\text{conc. } H_2SO_4} 12\,C + 11\,H_2O$$

Marking scheme

- Dehydrating property: it removes H and O as water from the sugar, leaving carbon.

c. **[1]**

$$Cu + 2\,H_2SO_4(\text{conc}\cdot) \xrightarrow{\Delta} CuSO_4 + SO_2\uparrow + 2\,H_2O$$

Marking scheme

- $Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2H_2O$.

d. **Ammonia** is a **base**, and sulphuric acid is an acid: the gas would be absorbed by the acid, not dried, $2\,NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$. **[2]**

Hydrogen sulphide is a **reducing agent**, and concentrated sulphuric acid is an oxidizing agent: the gas would be oxidized to sulphur, $H_2S + H_2SO_4 \longrightarrow S + SO_2 + 2\,H_2O$.

The gases it can dry are neither bases nor reducing agents strong enough to be oxidized by it.

Marking scheme

- Ammonia is a base and reacts with the acid: $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$.
- H_2S is a reducing agent, oxidized by the acid to sulphur: $H_2S + H_2SO_4 \rightarrow S + SO_2 + 2H_2O$.

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Question 6 — 5 marks

a. Sources (any two): old lead **paints**, lead–acid **batteries** and their recycling, lead pipes and solder, glazed pottery and leaded glass, some cosmetics, toys and traditional medicines. **[2]**

Effects on children (any two): damage to the **brain and nerves**, lowering intelligence and causing learning and behavior problems for life; **anemia** (lead blocks enzymes that make heme); convulsions and brain damage at high levels.

Marking scheme

- Two sources of lead.
- Two harmful effects on children.

b. i. **Anemia:** lead takes the place of **zinc** in an enzyme that makes **heme**, and it binds the –SH groups that enzymes need, so the enzyme stops working. Less heme means less hemoglobin and fewer working red blood cells: anemia. **[2]**

ii. **Brain and nerves:** lead takes the place of **calcium** in the nerves, where calcium ions are needed to pass signals from one nerve cell to the next, and it switches off enzymes by binding their –SH groups, so the developing brain's signals and growth are disturbed.

Marking scheme

- Anemia: lead replaces zinc in (or binds the –SH of) an enzyme that makes heme, so less hemoglobin is made.
- Nerves: lead replaces calcium in nerves (and blocks enzymes' –SH groups), disturbing nerve signals.

c. In the water, bacteria turn mercury into **methylmercury**, which living things absorb and store but hardly get rid of. It is passed up the **food chain**: plankton take it in, small fish eat much plankton, and large fish eat many small fish, so its concentration rises at each step (**biomagnification**). The large fish therefore holds thousands of times the water's concentration, and it is the fish, not the water, that poisons people. **[1]**

Marking scheme

- Methylmercury is stored and builds up along the food chain (biomagnification), so the fish holds far more than the water.

Question 7 — 5 marks

a. A ring compound is **aromatic** if it is **cyclic** with a p orbital on every ring atom, **planar**, and has **(4n + 2) π electrons**, where n is a whole number (0, 1, 2, ...): 2, 6, 10 ... π electrons. **[1]**

Marking scheme

- Cyclic, planar, with $(4n + 2)$ π electrons (n a whole number).

b. i. **[2]**

$$C_6H_6 + C_2H_5Cl \xrightarrow{\text{anhyd. } AlCl_3} C_6H_5C_2H_5 + HCl$$

Product: **ethylbenzene**.

ii.

$$C_6H_6 + CH_3COCl \xrightarrow{\text{anhyd. } AlCl_3} C_6H_5COCH_3 + HCl$$

Product: **phenylethanone** (acetophenone). The catalyst in both is **anhydrous aluminium chloride**.

Marking scheme

- Alkylation equation, giving ethylbenzene, with anhydrous $AlCl_3$.
- Acylation equation, giving phenylethanone (acetophenone).

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c. i. **$C_5H_5^-$:** now every ring carbon is sp^2 with a p orbital, and the ring is flat. The two C=C give 4 π electrons and the lone pair in the p orbital 2 more: **6 π electrons**. $4n + 2 = 6$ gives n = 1, a whole number. The anion is **aromatic** (which is why cyclopentadiene gives up that H^+ unusually easily). **[2]**

ii. **C_8H_8:** four C=C give **8 π electrons**; $4n + 2 = 8$ gives $n = 1.5$, not a whole number, and the ring is not flat, so the p orbitals can't overlap all round. It is **not aromatic**.

Marking scheme

- $C_5H_5^-$: flat, a p orbital on every carbon, 6 π electrons (the lone pair counts), n = 1: aromatic.
- C_8H_8: 8 π electrons, n = 1.5, and not flat: not aromatic.

Question 8 — 5 marks

a. **Ozonolysis** is the addition of ozone across the C=C double bond of an alkene, forming an ozonide, which is then broken up (hydrolyzed) to give two carbonyl compounds, aldehydes or ketones, by splitting the molecule at the double bond. **[2]**

Reagents and conditions: **ozone**, O_3, in an inert solvent such as carbon tetrachloride, at **low temperature**, then **zinc and water** (Zn/H_2O).

Marking scheme

- Ozone adds across the C=C to give an ozonide, which is split into aldehydes or ketones at the double bond.
- O_3 in CCl_4 at low temperature, then Zn/H_2O.

b. Split each molecule at the double bond and put =O on each carbon: **[2]**

i. $CH_3–CH=CH_2$ gives **ethanal**, CH_3CHO, and **methanal**, HCHO.

ii. $(CH_3)_2C=CH–CH_3$ gives **propanone**, $(CH_3)_2C=O$, and **ethanal**, CH_3CHO.

Marking scheme

- Propene: ethanal and methanal.
- 2-Methylbut-2-ene: propanone and ethanal.

c. Join the C=O carbons of two propanone molecules with a double bond: $(CH_3)_2C=C(CH_3)_2$, **2,3-dimethylbut-2-ene** (six carbons, C_6H_{12}). **[1]**

Marking scheme

- $(CH_3)_2C=C(CH_3)_2$, 2,3-dimethylbut-2-ene.

Question 9 — 5 marks

a. Any two: relief valves and bursting discs on vessels under pressure; alarms and automatic shut-down; protective clothing and equipment for workers (helmets, goggles, gloves, masks); training and safety drills; regular inspection and maintenance; safe storage and labeling of chemicals, with spill kits and fire-fighting equipment; emergency plans. **[1]**

Marking scheme

- Any two correct safety measures.

b. Plants work with **high temperatures and pressures** and with **toxic, flammable and corrosive** chemicals, and their parts wear out unseen. Without inspection (any two): **[2]**

- pipes and vessels corrode and thin, so toxic or flammable chemicals **leak**, poisoning workers and neighbors or polluting air, water and soil;
- valves stick and seals wear, so a vessel under pressure can **burst or explode**;
- sensors and alarms stop working, so a dangerous fault is not noticed in time.

Marking scheme

- Plants handle dangerous conditions and chemicals, and parts wear unseen.
- Two consequences (leaks, bursts or explosions, failed alarms).

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c. Any two, each with its correction: **[2]**

- **Too much poison in one place:** at Bhopal a large stock of methyl isocyanate made the leak so big. Keep as little as possible, in several small tanks, or make it only as it is used.
- **Too close to homes:** the gas reached the sleeping town before anyone could escape. Build the plant farther from houses, with a buffer zone where no one lives.
- **No plan for the town:** the people of Bhopal had no warning and didn't know what to do. Agree an emergency plan with the town: warning sirens, escape routes and drills, and tell people what the plant holds.

Marking scheme

- One weakness with its correction (large stock in one tank; too near homes; no emergency plan with the town).
- A second, different weakness with its correction.

Group C Long answers, each on one content area — 24 marks

Question 10 — 8 marks

a. The **shielding effect** is the reduction of the nucleus's attraction on an outer electron by the electrons between them (mainly those in inner shells), which repel it. Because of it, an outer electron feels only the **effective nuclear charge**, $Z_{eff} = Z - S$, not the full nuclear charge. **[1]**

Marking scheme

- Inner electrons repel the outer electron and reduce the nucleus's pull on it (so it feels Zeff = Z − S).

b. Mg: $(1s^2)\,(2s^2\,2p^6)\,(3s^2)$. For one 3s electron: **[2]**

- the other electron in its own group (3s 3p): $1 \times 0.35 = 0.35$
- the n − 1 shell (2s 2p): $8 \times 0.85 = 6.80$
- the n − 2 shell (1s): $2 \times 1.00 = 2.00$

$$S = 0.35 + 6.80 + 2.00 = 9.15 \qquad Z\text{eff} = 12 - 9.15 = 2.85$$

Marking scheme

- Shielding constant S = 9.15 from the right contributions.
- Zeff = 2.85.

c. S: $(1s^2)\,(2s^2\,2p^6)\,(3s^2\,3p^4)$. For one 3p electron: **[2]**

- the other five electrons in its own group: $5 \times 0.35 = 1.75$
- the n − 1 shell: $8 \times 0.85 = 6.80$
- the n − 2 shell: $2 \times 1.00 = 2.00$

$$S = 1.75 + 6.80 + 2.00 = 10.55 \qquad Z\text{eff} = 16 - 10.55 = 5.45$$

Marking scheme

- Shielding constant S = 10.55.
- Zeff = 5.45.

d. Both atoms have their outer electrons in the third shell, but sulphur's outer electron feels a much larger effective nuclear charge (5.45 against 2.85): the four extra protons are only partly shielded by electrons in the same shell. **[3]**

i. The stronger pull draws sulphur's outer electrons **closer** to the nucleus, so the sulphur atom is **smaller**.

ii. An electron held by a larger Z_{eff}, closer to the nucleus, needs **more energy** to remove, so sulphur's first ionization energy is **higher**.

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iii. Magnesium's two outer electrons are held weakly (low Z_{eff}), so it **loses** them easily to reach the neon configuration, as Mg^{2+}. Sulphur holds its electrons strongly and attracts more: it **gains** two electrons (high electronegativity and electron affinity) to complete its octet, as S^{2-}.

Marking scheme

- Higher Zeff on sulphur's outer electrons pulls them closer: smaller atom.
- Higher Zeff and closer electrons need more energy to remove: higher ionization energy.
- Mg loses its weakly held two electrons (Mg^{2+}); S, with a high Zeff, gains two to complete its octet (S^{2-}).

Question 11 — 8 marks

a. They react quickly with the **oxygen and moisture** of the air (and violently with water); kerosene doesn't react with them and keeps air and water away. **[3]**

Down the group each atom has one more shell, so its single outer electron is **farther from the nucleus** and better **shielded** by the inner shells. It is held more weakly, the **ionization energy falls**, and the metal gives up its electron more readily.

So the reaction with water grows more vigorous: lithium reacts steadily, sodium vigorously, and potassium so violently that the hydrogen catches fire.

Marking scheme

- Kept under kerosene because they react with oxygen and moisture of the air (kerosene doesn't react and keeps them out).
- Down the group the outer electron is farther away and better shielded, so the ionization energy falls.
- So the metal loses its electron more easily and reacts more violently (Li steadily, Na vigorously, K catches fire).

b. The heat of the flame **excites** the outer electron to a higher energy level; when it falls back, it gives out the energy as light of a particular wavelength, which for sodium is in the yellow part of the visible spectrum. Their low ionization energies make the electrons easy to excite with a flame's heat. **[1]**

Marking scheme

- The flame excites the outer electron, which gives out visible light of a definite color as it falls back.

c. i. **[2]**

$$2\,Na + 2\,H_2O \longrightarrow 2\,NaOH + H_2 \uparrow$$

ii. Heated in air, sodium gives mainly the peroxide:

$$2\,Na + O_2 \xrightarrow{\Delta} Na_2O_2$$

Marking scheme

- $2Na + 2H_2O \rightarrow 2NaOH + H_2$.
- $2Na + O_2 \rightarrow Na_2O_2$ on heating.

d. Sodium hydroxide is **deliquescent**: it takes up so much water vapor from the air that it dissolves in it, so the pellets become wet. **[2]**

The solution then absorbs **carbon dioxide** from the air, forming sodium carbonate, which is left as a white crust:

$$2\,NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

Marking scheme

- Deliquescent: absorbs moisture from the air and dissolves in it.
- Absorbs CO_2 to form sodium carbonate ($2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$), the white crust.

OR

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a. A freshly made solution of **iron(II) sulphate** is added to the nitrate solution in a test tube, and **concentrated sulphuric acid** is poured slowly down the side, so that it sinks and forms a layer at the bottom. **[3]**

At the junction of the two layers, sulphuric acid turns the nitrate into nitric acid, which **oxidizes** some iron(II) to iron(III) and is itself reduced to **nitric oxide**, NO.

The NO joins with more iron(II) to form a **brown complex**, $[Fe(H_2O)_5(NO)]^{2+}$, seen as a brown ring where the layers meet; it shows that the solution contains nitrate ions.

Marking scheme

- Procedure: fresh $FeSO_4$ solution added, concentrated H_2SO_4 poured down the side to form a lower layer.
- At the junction, nitric acid oxidizes Fe^{2+} and is reduced to NO.
- NO with Fe^{2+} forms the brown complex $[Fe(H_2O)_5(NO)]^{2+}$, the brown ring.

b. In light it slowly decomposes, giving nitrogen dioxide and oxygen, $4\,HNO_3 \longrightarrow 4\,NO_2 + O_2 + 2\,H_2O$; the NO_2 dissolves and turns the acid yellow. Brown bottles keep out the light. **[1]**

Marking scheme

- Light decomposes nitric acid (to NO_2, which turns it yellow); brown bottles keep the light out.

c. i. **[2]**

$$Cu + 4\,HNO_3(\text{conc}\cdot) \longrightarrow Cu(NO_3)_2 + 2\,NO_2\uparrow + 2\,H_2O$$

ii.

$$3\,Cu + 8\,HNO_3(\text{dil}\cdot) \longrightarrow 3\,Cu(NO_3)_2 + 2\,NO\uparrow + 4\,H_2O$$

Marking scheme

- $Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$.
- $3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$.

d. **Concentrated:** 2 of the 4 HNO_3 are reduced (to $2NO_2$): **a half**. **Dilute:** 2 of the 8 HNO_3 are reduced (to 2NO): **a quarter**. The rest stay at +5 as the nitrate ions of copper nitrate. **[2]**

Each Cu gives 2 electrons ($0 \rightarrow +2$). In NO_2 nitrogen goes from +5 to **+4**, so each reduced N takes only **1** electron and 2 N are needed per Cu. In NO it goes from +5 to **+2**, so each reduced N takes **3** electrons: for 3 Cu (6 electrons) only 2 N are needed, two-thirds of an N per Cu. The deeper the reduction of nitrogen, the fewer nitric acid molecules have to be reduced.

Marking scheme

- Fraction reduced: a half (2 of 4) with concentrated acid, a quarter (2 of 8) with dilute.
- N $+5 \rightarrow +4$ takes 1 electron each (2 N per Cu), but $+5 \rightarrow +2$ takes 3 each (2 N per 3 Cu), so fewer are reduced with the dilute acid.

Question 12 — 8 marks

a. **Geometrical (cis–trans) isomerism** is the stereoisomerism of compounds with the same structural formula that differ in the arrangement of groups about a double bond (or a ring), because the double bond can't rotate. **[3]**

In **cis-but-2-ene** the two CH_3 groups are on the **same side** of the C=C bond; in **trans-but-2-ene** they are on **opposite sides**. They are different compounds with different physical properties.

A compound shows it when (i) there is **restricted rotation** (a C=C bond or a ring), and (ii) **each** carbon of the double bond carries **two different** atoms or groups.

Marking scheme

- Definition: same structure, different arrangement in space about a double bond (no rotation).
- cis- and trans-but-2-ene: the CH_3 groups on the same or opposite sides.

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- Conditions: restricted rotation, and two different groups on each double-bonded carbon.

b. [2]

- **Propene**, $CH_3–CH=CH_2$: **no**, the end carbon carries two H atoms.
- **2-Methylpropene**, $(CH_3)_2C=CH_2$: **no**, one carbon carries two CH_3 groups and the other two H atoms.
- **Pent-2-ene**, $CH_3–CH=CH–CH_2CH_3$: **yes**, one double-bonded carbon has H and CH_3, the other H and C_2H_5: it has cis and trans forms.

Marking scheme

- Propene and 2-methylpropene: no, a double-bonded carbon carries two identical groups.
- Pent-2-ene: yes, each double-bonded carbon has two different groups.

c. [2]

$$C_{10}H_{22} \longrightarrow C_8H_{18} + C_2H_4$$

The other product is **C_2H_4, ethene**, of formula C_nH_{2n}: an **alkene**.

An alkane C_nH_{2n+2} split into two smaller molecules with a and b carbons (a + b = n) would need $(2a + 2) + (2b + 2) = 2n + 4$ hydrogen atoms for both to be alkanes, but only $2n + 2$ are there. Two hydrogens are missing, so one product must have a double bond: at least one is an alkene.

Marking scheme

- The other product is C_2H_4 (ethene), an alkene (C_nH_{2n}), from $C_{10}H_{22} - C_8H_{18}$.
- Two alkanes would need 2n + 4 H atoms but the alkane has only 2n + 2, so one product must be an alkene.

d. [1]

The Si–O bond (452 kJ/mol) is **twice as strong** as the Si–Si bond (226), so in a world full of oxygen a chain of silicon atoms gives way to Si–O bonds, which release much more energy: silicon ends up bound to oxygen. For carbon, C–C (346) is nearly as strong as C–O (358), so a carbon chain gains little by turning into C–O bonds and stays stable: carbon can catenate.

Marking scheme

- Si–O is far stronger than Si–Si (452 against 226), so silicon bonds to oxygen rather than itself, whereas C–C is about as strong as C–O, so carbon chains last.

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