Grade 11 Chemistry Model Paper 2

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. **(ii)** atomic numbers

b. **(i)** sp

c. **(iv)** The amounts don't change; both reactions speed up equally.

d. **(iii)** +6

e. **(iii)** 46.7%

f. **(i)** They lose their single outer electron very easily (low ionization energy).

g. **(ii)** It is made again in the second step, so it acts as a catalyst.

h. **(iv)** Idea generation

i. **(i)** To remove arsenic oxide, which would poison the vanadium(V) oxide catalyst

j. **(iv)** It has the most nitrogen of any solid nitrogen fertilizer.

k. **(iii)** 30 tonnes

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

Question 2 — 5 marks

a. **Aufbau principle:** in the ground state, electrons fill the orbitals in order of increasing energy, the lowest-energy orbital first (the order given by the $n + l$ rule: 1s, 2s, 2p, 3s, 3p, 4s, 3d, …). **[2]**

Hund's rule: when electrons fill orbitals of equal energy (such as the three p or five d orbitals), they go one into each orbital, with parallel spins, before any orbital takes a second electron.

Marking scheme

- Aufbau: orbitals are filled in order of increasing energy.
- Hund's rule: in orbitals of equal energy, pairing starts only after each has one electron (spins parallel).

b. Fe is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$ ([Ar] $4s^2\ 3d^6$). The ion loses the two 4s electrons first, then one 3d electron: **[1]**

Fe^{3+}: $\mathbf{1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5}$, or [Ar] $3d^5$.

Marking scheme

- Fe^{3+}: [Ar] $3d^5$ ($1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$), the 4s electrons removed first.

c. In chromium, the 4s and 3d orbitals are very close in energy. Moving one 4s electron into 3d gives a **half-filled 3d subshell** ($3d^5$, one electron in each of the five d orbitals, all spins parallel) and a half-filled 4s; half-filled (and full) subshells are extra stable, because of their symmetry and the larger exchange energy, so $4s^1\ 3d^5$ has the lower energy. **[2]**

Fe^{2+} is [Ar] $3d^6$; losing one more electron gives Fe^{3+}, [Ar] $\mathbf{3d^5}$, the same stable half-filled subshell. So Fe^{2+} is easily oxidized to the more stable Fe^{3+} in air.

Marking scheme

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- Chromium: $4s^1\ 3d^5$ gives a half-filled 3d subshell, which is extra stable (lower energy).
- Fe^{2+} ($3d^6$) loses one electron to reach the stable half-filled $3d^5$ of Fe^{3+}.

OR

a. The **(first) electron affinity** is the energy released when one mole of electrons is added to one mole of isolated gaseous atoms to form one mole of gaseous ions of charge -1: $\mathrm{X(g) + e^- \longrightarrow X^-(g)}$. **[2]**

Down a group it generally **decreases** (less energy is released), because the atoms get larger and the incoming electron is held farther from the nucleus.

Marking scheme

- Electron affinity: energy released when an electron is added to an isolated gaseous atom (per mole) to form a -1 ion.
- Decreases down a group (larger atoms, electron farther from the nucleus).

b. **[1]**

$$n = \frac{1.6}{32} = 0.050\ \text{mol}, \qquad \text{energy released} = 0.050 \times 200 = 10\ \text{kJ}$$

Marking scheme

- $0.050\ \text{mol} \times 200\ \text{kJ/mol} = 10\ \text{kJ}$.

c. **Sulphur to tellurium:** each element down the group has one more shell. The incoming electron enters an outer shell that is **farther from the nucleus** and better shielded by the inner shells, so it is attracted less and less energy is released. **[2]**

Oxygen: by size alone oxygen should release the most. But its atom is so small that its 2p subshell is **crowded**: the incoming electron is squeezed close to the six electrons already in the second shell and is strongly **repelled** by them, so less energy is released than for sulphur, whose larger 3p subshell has more room. (Fluorine and chlorine show the same thing in Group 17.)

Marking scheme

- Down from S to Te: larger atoms, the added electron farther from the nucleus and better shielded, so less energy released.
- Oxygen: its small, crowded 2p subshell repels the incoming electron strongly, so it releases less than sulphur.

Question 3 — 5 marks

a. The mass of a substance deposited or liberated at an electrode is **directly proportional to the quantity of electricity** (charge) passed through the electrolyte: $m = ZQ = ZIt$, where Z is the electrochemical equivalent. **[1]**

Marking scheme

- Mass deposited is directly proportional to the quantity of electricity passed ($\mathrm{m = ZIt}$).

b. **[2]**

$$Q = It = 1.5 \times (40 \times 60) = 3600\ \text{C}$$

$\mathrm{Cu^{2+} + 2\,e^- \longrightarrow Cu}$: $2 \times 96{,}500$ C deposit one mole, 63.5 g, of copper. So

$$m = \frac{63.5}{2 \times 96\,500} \times 3600 = 1.18\ \text{g}$$

About 1.18 g of copper.

Marking scheme

- Charge passed 3600 C (time in seconds).

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- Mass of copper 1.18 g, using 2 F per mole of Cu.

c. The key must be the **cathode** (joined to the negative terminal): Cu^{2+} ions in the solution gain electrons there, $Cu^{2+} + 2\,e^- \longrightarrow Cu$, and copper is laid on it. **[2]**

The copper strip is the **anode**. A copper anode gives up electrons more easily than OH^- or SO_4^{2-} ions do, so the anode itself dissolves, $Cu \longrightarrow Cu^{2+} + 2\,e^-$: it gets thinner, and for every Cu^{2+} ion that leaves the solution at the cathode, one enters it at the anode. The concentration of Cu^{2+}, and so the blue color, stays the same.

Marking scheme

- The key is the cathode, where Cu^{2+} is reduced to copper.
- The copper anode dissolves ($Cu \rightarrow Cu^{2+} + 2e^-$), replacing the Cu^{2+} removed, so the concentration (color) stays the same.

Question 4 — 5 marks

a. In a **coordinate (dative) bond**, both electrons of the shared pair come from **one** atom. In ammonia the nitrogen has a lone pair; a hydrogen ion, H^+, has an empty 1s orbital and no electrons. The nitrogen donates its lone pair to the H^+, and the pair is shared between them: $H_3N: + H^+ \longrightarrow [NH_4]^+$. Once formed, the four N–H bonds of NH_4^+ are all alike. **[2]**

Marking scheme

- Both shared electrons come from one atom (the donor).
- In NH_4^+ the N of NH_3 donates its lone pair to H^+, which has an empty orbital.

b. **BF_3:** boron has three bond pairs and no lone pair; three pairs spread as far apart as possible in a plane: **trigonal planar**, F–B–F angle **120°**. **[2]**

H_2O: oxygen has two bond pairs and two lone pairs, four pairs in a tetrahedral arrangement; the lone pairs repel more strongly and squeeze the bonds together: **bent (angular, V-shaped)**, H–O–H angle about **104.5°**.

Marking scheme

- BF_3: trigonal planar, 120° (three bond pairs, no lone pair).
- H_2O: bent (angular), about 104.5° (two bond pairs, two lone pairs).

c. Ethanol has a hydrogen joined to oxygen (an O–H group), so its molecules are held together by **hydrogen bonds**, the H of one molecule's O–H to the O of the next, which take much energy to break. In methoxymethane every hydrogen is joined to carbon, so although its oxygen has lone pairs, there is no O–H hydrogen to form hydrogen bonds between its molecules: they are held only by weak dipole and van der Waals forces, and it boils far lower. **[1]**

Marking scheme

- Ethanol has an O–H group, so hydrogen bonds hold its molecules; methoxymethane's hydrogens are all on carbon, so it has only weak forces between molecules.

OR

a. **Graham's law:** at the same temperature and pressure, the rate of diffusion of a gas is inversely proportional to the square root of its density (or its molar mass): $r \propto \frac{1}{\sqrt{d}}$, $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$. **[2]**

At the same temperature all gases have the same average kinetic energy, $\frac{1}{2}mv^2$; so molecules of smaller mass must move **faster**, and they spread out (and escape through small holes) faster.

Marking scheme

- Rate of diffusion inversely proportional to the square root of density (molar mass), at the same temperature and pressure.
- Same average kinetic energy at the same temperature, so lighter molecules move faster.

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b. The time taken is inversely proportional to the rate, so $\frac{t_{H_2}}{t_{O_2}} = \sqrt{\frac{M_{H_2}}{M_{O_2}}} = \sqrt{\frac{2}{32}} = \frac{1}{4}$. **[2]**

$$t_{H_2} = \frac{80}{4} = 20\ \text{s}$$

Marking scheme

- Ratio of times (or rates) from the square roots of the molar masses, 2 and 32: hydrogen four times faster.
- 20 s.

c. Rubber has tiny pores. Hydrogen (M = 2) diffuses out through them much faster than the oxygen and nitrogen of air (M about 29, roughly 3.8 times slower by Graham's law), so the hydrogen balloon loses its gas sooner. **[1]**

Marking scheme

- Hydrogen, much lighter, diffuses out through the rubber's pores faster than air (Graham's law).

Question 5 — 5 marks

a. **Isotopes** are atoms of the same element (the same atomic number) with different mass numbers, because they have different numbers of neutrons: hydrogen has three, protium $^{1}_{1}H$, deuterium $^{2}_{1}H$ and tritium $^{3}_{1}H$. **[1]**

Marking scheme

- Atoms of the same element (same atomic number) with different mass numbers (different numbers of neutrons).

b. Protium and deuterium have the **same electronic configuration** ($1s^1$), and chemical properties depend on electrons, so they react alike; but deuterium is **twice as heavy**, and properties that depend on mass (density, melting and boiling points, rates of reaction) differ. **[1]**

Marking scheme

- Same electronic configuration (same chemistry), but different masses, which change physical properties.

c. 2.0 kg of hydrogen gives $2000 \times 143 = 2.86 \times 10^5$ kJ. Petrol for the same: $\frac{2.86 \times 10^5}{50} = 5720$ g, about **5.7 kg** (nearly three times the mass of hydrogen). **[1]**

Marking scheme

- About 5.7 kg (5720 g) of petrol.

d. **Air pollution: Anjila is right**, wherever the hydrogen comes from. A fuel cell's only product is **water**, so the buses would give out no smoke, carbon monoxide or carbon dioxide in the city's streets. **[2]**

Imports: it depends on how the hydrogen is made. Nepal has no natural gas, so hydrogen made from it would have to be imported, or made from imported gas, and making it gives out CO_2 at the plant: on that the friend is right. But hydrogen made by the **electrolysis of water with Nepal's own hydroelectricity** would replace imported diesel, so the claim holds only for that route.

Marking scheme

- Air pollution: true whatever the source, since the fuel cell's only exhaust is water.
- Imports: hydrogen from natural gas would itself be imported (and give CO_2 where it is made); only hydrogen from water by Nepal's hydroelectricity cuts imports.

Question 6 — 5 marks

a. **Micronutrients** are nutrients the body needs in small amounts (milligrams or micrograms a day): the vitamins and minerals, for example iron, zinc, iodine or vitamin A. **[2]**

Macronutrients are nutrients needed in large amounts (grams a day): carbohydrates, proteins and fats (for example the starch of rice).

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Marking scheme

- Micronutrients: needed in small amounts, with an example (iron, zinc, iodine, a vitamin).
- Macronutrients: needed in large amounts, with an example (carbohydrate, protein, fat).

b. **Salt water without glucose:** in a gut with diarrhea, sodium is taken in mainly by the **sodium–glucose cotransporter**, which carries Na^+ and glucose into the cells **together**. With no glucose, little sodium is absorbed, so little water follows it into the body: the salt and water mostly pass out again. **[2]**

The packet in too little water: the drink is four times too concentrated, more concentrated than the body's fluids. Water moves by **osmosis** towards the more concentrated side, so water is drawn **out of the body into the gut**, and the child loses even more water.

Marking scheme

- Without glucose the cotransporter takes in little sodium (they go in together), so little water follows.
- Too concentrated: osmosis draws water from the body into the gut, so more water is lost.

c. CO and O_2 compete for the same iron of hemoglobin, and the binding is reversible: $Hb{-}CO + O_2 \rightleftharpoons Hb{-}O_2 + CO$. Air is only about 21% oxygen; pure oxygen raises the oxygen's concentration about five times, which **shifts the balance towards Hb–O_2**, pushing CO off the iron faster so that it is breathed out and the blood can carry oxygen again. **[1]**

Marking scheme

- CO and O_2 compete reversibly for hemoglobin's iron; a much higher oxygen concentration shifts the balance, displacing CO so the blood carries oxygen again.

Question 7 — 5 marks

a. Fusing with sodium turns the nitrogen, sulphur and halogen, held by **covalent** bonds in the compound, into **ionic** sodium compounds (NaCN, Na_2S, NaX), which dissolve in water and can be tested for as ions. **[1]**

Marking scheme

- To convert the covalently bonded N, S and halogens into ionic, water-soluble sodium salts (NaCN, Na_2S, NaX).

b. **Chlorine.** (A white, curdy precipitate that dissolves easily in dilute ammonia is silver chloride.) **[2]**

During fusion: $Na + Cl \xrightarrow{\Delta} NaCl$ (the chlorine of the compound joins the sodium).

In the test: $NaCl + AgNO_3 \longrightarrow AgCl\downarrow + NaNO_3$ (white precipitate).

Marking scheme

- Chlorine, with the fusion equation $Na + Cl \rightarrow NaCl$.
- $NaCl + AgNO_3 \rightarrow AgCl$ (white precipitate) $+ NaNO_3$.

c. **The compound contains nitrogen but no halogen.** Without boiling, a cyanide in the extract (NaCN, formed from the compound's nitrogen during fusion) gives a white precipitate of **silver cyanide**, $NaCN + AgNO_3 \longrightarrow AgCN\downarrow + NaNO_3$. Boiling with nitric acid drives the cyanide off as HCN gas, $NaCN + HNO_3 \longrightarrow NaNO_3 + HCN\uparrow$. After boiling there is no precipitate, so there is **no halide** in the extract: the first precipitate was not a silver halide. (A sulphide would have given black Ag_2S, not white.) **[2]**

Marking scheme

- The first white precipitate was AgCN from cyanide: the compound contains nitrogen.
- Boiling removes the cyanide (as HCN); no precipitate after it, so no halogen is present.

Question 8 — 5 marks

a. **Decarboxylation** is the removal of the carboxyl group (as CO_2, here trapped as sodium carbonate) from a carboxylic acid or its salt, so the alkane formed has one carbon fewer than the salt. **[2]**

The reagent is **soda lime** (sodium hydroxide with quicklime, NaOH + CaO), heated with the dry salt.

Marking scheme

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- Removal of the –COOH (–COONa) group as CO_2 (Na_2CO_3), giving an alkane with one carbon fewer.
- Soda lime (NaOH + CaO), heated.

b. i. **[2]**

$$CH_3CH_2COONa + NaOH \xrightarrow[\Delta]{CaO} CH_3CH_3 + Na_2CO_3$$

ii. Kolbe's electrolysis of a concentrated aqueous solution of sodium ethanoate gives ethane at the anode:

$$2\,CH_3COONa + 2\,H_2O \xrightarrow{\text{electrolysis}} CH_3CH_3 + 2\,CO_2 + 2\,NaOH + H_2$$

(ethane and carbon dioxide at the anode; hydrogen and sodium hydroxide at the cathode).

Marking scheme

- Decarboxylation of sodium propanoate to ethane, balanced.
- Kolbe's electrolysis of sodium ethanoate to ethane (with CO_2, NaOH and H_2), balanced.

c. **No.** A long straight chain like cetane ignites very readily under compression: that is what a diesel engine needs, since it has no spark. A petrol engine needs a fuel that **resists** igniting by itself until the spark lights it; cetane would ignite early and **knock** badly (straight chains have very low octane numbers). **[1]**

Marking scheme

- No: it ignites easily under compression (good for diesel), so in a petrol engine it would knock (low octane number).

Question 9 — 5 marks

a. They are the percentages of the three primary nutrients: **20% nitrogen (N), 20% phosphorus counted as P_2O_5 and 10% potassium counted as K_2O**. **[1]**

Marking scheme

- Percentages of N, of P (as P_2O_5) and of K (as K_2O): 20, 20 and 10.

b. Any two, each with its reason: **[2]**

- **Soluble in water**, so that plants can take up its nutrients easily.
- **Contains enough of the nutrients** it is meant to supply.
- **Safe for plants**: it doesn't burn roots or seedlings and has no toxic impurities.
- **Stable**: it doesn't lose its nutrients in storage, and releases them when the plants need them.
- **Does not make the soil acidic**, since acidic soil holds fewer nutrients.
- **Affordable** to farmers.

Marking scheme

- One characteristic, explained.
- A second characteristic, explained.

c. NPK: 20% of 100 kg = 20 kg of nitrogen. Urea: 46% of 50 kg = 23 kg. In all **43 kg**, about **18 kg more** than the crop can use (and the urea alone nearly supplied the crop's need). **[2]**

The crop can't take up the extra, so the monsoon rain washed the surplus **nitrate** (with phosphate) into the pond. These nutrients fed a huge growth of **algae** (an algal bloom), turning the water green; when the algae died, the bacteria decomposing them used up the water's **dissolved oxygen**, and the fish suffocated (**eutrophication**).

Marking scheme

- Nitrogen added 20 + 23 = 43 kg, about 18 kg more than the crop needs.
- The surplus nitrate is washed into the pond: algal bloom, decomposition uses up the oxygen, fish die (eutrophication).

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

Question 10 — 8 marks

a. The **empirical formula** gives only the simplest whole-number ratio of the atoms of each element in a compound; the **molecular formula** gives the actual number of atoms of each element in one molecule. The molecular formula is a whole-number multiple of the empirical formula (glucose: CH_2O and $C_6H_{12}O_6$). **[1]**

Marking scheme

- Empirical: simplest whole-number ratio of atoms; molecular: actual numbers of atoms in a molecule (a multiple of the empirical).

b. **[2]**

Element	%	÷ atomic mass	÷ smallest
C	40.0	$40.0 \div 12 = 3.33$	1
H	6.7	$6.7 \div 1 = 6.7$	2
O	53.3	$53.3 \div 16 = 3.33$	1

Empirical formula: $\mathbf{CH_2O}$.

Marking scheme

- Relative numbers of moles of atoms: 3.33, 6.7, 3.33.
- Simplest ratio 1 : 2 : 1, empirical formula CH_2O.

c. Molecular mass $= 2 \times$ vapor density $= 2 \times 30 = 60$. **[2]**

Empirical formula mass of $CH_2O = 12 + 2 + 16 = 30$, so $n = \dfrac{60}{30} = 2$.

Molecular formula: $(CH_2O)_2 = \mathbf{C_2H_4O_2}$ (ethanoic acid, CH_3COOH).

Marking scheme

- Molecular mass 60 ($2 \times$ vapor density).
- n = 2, molecular formula $C_2H_4O_2$.

d. **[3]**

$$CH_3COOH + 2\,O_2 \longrightarrow 2\,CO_2 + 2\,H_2O$$

6.0 g is $\dfrac{6.0}{60} = 0.10$ mol of acid. It uses $2 \times 0.10 = 0.20$ mol of O_2 and gives 0.20 mol of CO_2 ($0.20 \times 22.4 = 4.48$ L at STP): the **moles** are indeed equal.

But the oxygen is measured at 27 °C (300 K), not 0 °C, and a gas expands when warmer:

$$V(O_2) = \frac{nRT}{P} = \frac{0.20 \times 0.0821 \times 300}{1} = 4.93\ \text{L}$$

So the claim is **wrong**: equal moles give equal volumes only at the same temperature and pressure.

Marking scheme

- Balanced equation: $CH_3COOH + 2O_2 \rightarrow 2CO_2 + 2H_2O$.
- 0.10 mol of acid uses 0.20 mol of O_2, the same moles as the CO_2 formed.
- At 300 K the 0.20 mol of O_2 occupies 4.93 L, not 4.48 L: the claim is wrong, as volume depends on temperature.

Question 11 — 8 marks

a. The powdered ore is mixed with water in a tank with a little **pine oil** (the frother) and a **collector** such as potassium ethyl xanthate. The collector clings to the sulphide grains and makes their surface **water-repelling** (hydrophobic), while the rock grains stay wetted by water. **[3]**

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Air is blown in and the mixture is stirred hard. The air bubbles stick to the water-repelling sulphide grains and carry them up into a **froth**, kept stable by the oil, which overflows and is collected.

The rock (gangue), wetted by water, **sinks** to the bottom and is removed.

Marking scheme

- Powdered ore with water, oil (frother) and a collector that makes the sulphide grains water-repelling.
- Air bubbles carry the sulphide grains up into the froth, which is collected.
- The gangue, wetted by water, sinks.

b. A sulphide must lose its sulphur to become an oxide, and that needs **oxygen**: roasting heats it in **excess air**. Calcination, done with little or no air, only drives off CO_2 or water from carbonate and hydrated ores. **[1]**

Marking scheme

- A sulphide needs oxygen (excess air) to become the oxide; calcination has little or no air.

c. Roasting: **[2]**

$$2\,ZnS + 3\,O_2 \xrightarrow{\Delta} 2\,ZnO + 2\,SO_2$$

Reduction (smelting) with coke:

$$ZnO + C \xrightarrow{\Delta} Zn + CO$$

Marking scheme

- $2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$.
- $ZnO + C \rightarrow Zn + CO$.

d. Sodium is one of the most reactive metals: it holds on to chlorine and oxygen **more strongly than carbon** can pull them away, so heating its compounds with coke gives no sodium. **[2]**

In **aqueous** solution, water is reduced at the cathode more easily than Na^+, so **hydrogen** is given off instead of sodium (and any sodium formed would react with the water at once).

So sodium is extracted by the **electrolysis of molten (fused) sodium chloride**, with calcium chloride added to lower its melting point; sodium collects at the cathode and chlorine at the anode.

Marking scheme

- Carbon can't reduce sodium's compounds (sodium holds Cl and O more strongly than carbon).
- In water, hydrogen is discharged instead of sodium; so it is made by electrolysis of fused NaCl (with $CaCl_2$).

OR

a. **[3]**

$$CaCO_3 \xrightarrow{900\,^\circ C} CaO + CO_2$$

$$CaO + H_2O \longrightarrow Ca(OH)_2 + \text{heat}$$

The kiln must reach about **900 °C** because calcium carbonate is a stable compound that breaks up (thermal decomposition) only at a high temperature, giving off carbon dioxide.

Slaking is strongly **exothermic**: quicklime combines with water with the release of much heat, so the heap gets hot (and hisses and crumbles to powdery slaked lime).

Marking scheme

- Both equations: $CaCO_3 \rightarrow CaO + CO_2$, and $CaO + H_2O \rightarrow Ca(OH)_2$.
- The kiln: calcium carbonate decomposes only on strong heating (about 900 °C).

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- Slaking releases heat (exothermic).

b. Carbon dioxide reacts with calcium hydroxide to form **calcium carbonate**, which is insoluble in water, so its fine white particles make the solution milky: $Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 \downarrow + H_2O$. **[1]**

Marking scheme

- Insoluble calcium carbonate forms ($Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$).

c. i. **[2]**

$$Ca(OH)_2 + Cl_2 \longrightarrow CaOCl_2 + H_2O$$

ii. Gypsum heated gently, to about 120 °C:

$$2\,CaSO_4 \cdot 2\,H_2O \xrightarrow{120\,^\circ C} (CaSO_4)_2 \cdot H_2O + 3\,H_2O$$

(plaster of Paris, $CaSO_4 \cdot ½H_2O$).

Marking scheme

- $Ca(OH)_2 + Cl_2 \rightarrow CaOCl_2 + H_2O$.
- $2CaSO_4 \cdot 2H_2O \rightarrow (CaSO_4)_2 \cdot H_2O + 3H_2O$ on gentle heating (about 120 °C).

d. Lime (CaO or $Ca(OH)_2$) is a **base**: it neutralizes the acid in the soil, reducing its acidity, so the soil holds more nutrients and grows better crops. **[2]**

No, it is not wise. A base with an ammonium salt gives off **ammonia gas**, $(NH_4)_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + 2\,NH_3 \uparrow + 2\,H_2O$, so the nitrogen the fertilizer was meant to supply escapes into the air and is wasted.

Marking scheme

- Lime is basic and neutralizes the soil's acidity.
- Not wise: lime and an ammonium salt release ammonia, so the fertilizer's nitrogen is lost.

Question 12 — 8 marks

a. **Homolytic fission:** the bond breaks **evenly**, each atom taking one electron of the shared pair, giving two **free radicals** (neutral, each with an unpaired electron). It happens with non-polar bonds, in light or heat: $Br{-}Br \xrightarrow{\text{light}} Br^\bullet + Br^\bullet$ **[3]**

Heterolytic fission: the bond breaks **unevenly**, the more electronegative atom taking both electrons, giving a **cation and an anion** (for carbon, a carbocation or a carbanion). It happens with polar bonds, in polar solvents: $CH_3{-}Cl \longrightarrow CH_3{}^+ + Cl^-$

Marking scheme

- Homolytic: each atom keeps one electron, giving free radicals.
- Heterolytic: one atom takes both electrons, giving a cation and an anion.
- A correct example of each (e.g. $Br_2 \rightarrow 2Br\bullet$; $CH_3Cl \rightarrow CH_3{}^+ + Cl^-$).

b. **Initiation:** $Cl_2 \xrightarrow{\text{light}} 2\,Cl^\bullet$ **[2]**

Propagation:

$$CH_4 + Cl^\bullet \longrightarrow CH_3{}^\bullet + HCl$$

$$CH_3{}^\bullet + Cl_2 \longrightarrow CH_3Cl + Cl^\bullet$$

The chlorine atom made in the second step starts the first again, so the chain goes on.

Marking scheme

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- Initiation: $Cl_2 \rightarrow 2Cl\bullet$ in light.
- Both propagation steps, $CH_4 + Cl\bullet \rightarrow CH_3\bullet + HCl$ and $CH_3\bullet + Cl_2 \rightarrow CH_3Cl + Cl\bullet$.

c. An acid is stronger when its anion, $RCOO^-$, is more stable. **Chlorine has a −I effect**: it pulls electrons away along the bonds, spreading out the negative charge of $ClCH_2COO^-$ and stabilizing it, so chloroethanoic acid gives up H^+ more readily. **[2]**

The **methyl group has a +I effect**: it pushes electrons towards the carboxyl group, concentrating the negative charge of CH_3COO^- and making it less stable. Methanoic acid has an H in its place, which pushes no electrons, so methanoic acid is the stronger.

Marking scheme

- Cl (−I) withdraws electrons, stabilizing the anion, so chloroethanoic acid is stronger.
- CH_3 (+I) releases electrons, destabilizing the anion, so ethanoic acid is weaker than methanoic acid.

d. The methyl group **pushes electrons into the ring**, making it richer in electrons than benzene's, so the electrophile NO_2^+ attacks it faster (the CH_3 group activates the ring), and the electron density is raised most at the ortho and para positions, where the nitro group goes. **[1]**

Marking scheme

- CH_3 releases electrons into the ring (activating it, an ortho–para director), so the electrophile attacks faster at the ortho and para positions.

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