Grade 11 Chemistry Model Paper 1

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.

A practice paper by Science Playground, made to CDC's Specification Grid 2077, Grade 11 Chemistry (Che. 301); not an official CDC or NEB paper.

Group A Multiple choice — 11 marks

Question 1 — 11 × 1 = 11

a. **(ii)** One-twelfth of the mass of one carbon-12 atom

b. **(iv)** $n = 2,\ l = 2,\ m = +1,\ s = +\frac{1}{2}$

c. **(i)** Trigonal pyramidal

d. **(ii)** 1.20×10^{23}

e. **(iii)** 800 mL

f. **(i)** Its triple bond needs a very large energy, 946 kJ/mol, to break.

g. **(iv)** Barium sulphate, because it is almost insoluble, even in the stomach's acid

h. **(iii)** Market demand

i. **(i)** With water it reacts so violently that the acid forms as a mist, which is hard to collect.

j. **(iv)** The porous diaphragm lets brine, salt and all, seep through to the cathode side.

k. **(ii)** 106 kg

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

Question 2 — 5 marks

a. **Isoelectronic species** are atoms and ions that have the same number of electrons (and so the same electronic configuration). **[2]**

Each of these ions has **10 electrons**, $1s^2\ 2s^2\ 2p^6$, the arrangement of **neon**.

Marking scheme

- Isoelectronic: atoms or ions with the same number of electrons.
- 10 electrons each, the configuration of neon ($1s^2\ 2s^2\ 2p^6$).

b. **[1]**

$$Al^{3+} < Mg^{2+} < Na^{+} < F^{-} < O^{2-} < N^{3-}$$

All have 10 electrons, so the one with the most protons (Al^{3+}, 13) pulls them in most and is smallest; the one with the fewest (N^{3-}, 7) is largest.

Marking scheme

- $Al^{3+} < Mg^{2+} < Na^{+} < F^{-} < O^{2-} < N^{3-}$.

c. **The atoms:** sodium (2, 8, 1) has its outer electron in a **third shell**, while fluorine (2, 7) has only two shells, and across period 2 its 9 protons pull those shells in tightly. So the sodium atom is much the larger. **[2]**

The ions: Na^{+} loses its whole third shell and F^{-} gains an electron in its second, so both now have the **same 10 electrons in the same two shells** (2, 8). What differs is the nucleus: **11 protons** in Na^{+} pull on those 10 electrons, only **9** in F^{-}. The stronger pull draws Na^{+}'s electrons closer, so Na^{+} is the smaller ion.

Marking scheme

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- Atoms: Na has three shells and F only two, so the Na atom is larger.
- Ions: both have the same 10 electrons in two shells, but Na^+ has more protons (11 against 9), pulling them closer, so Na^+ is smaller.

OR

a. Any two of these: **[2]**

- The electron revolves round the nucleus only in certain circular orbits of fixed energy (stationary states, energy levels).
- While it stays in an allowed orbit, the electron neither gives out nor takes in energy.
- Only those orbits are allowed in which the electron's angular momentum is a whole-number multiple of $\frac{h}{2\pi}$: $mvr = \frac{nh}{2\pi}$.
- Energy is given out or taken in only when the electron jumps from one orbit to another, as one photon of energy $\Delta E = E_2 - E_1 = h\nu$.

Marking scheme

- One correct postulate.
- A second correct postulate.

b. All jumps that end on n = 2 make the **Balmer series**, which lies in the **visible** region (this line, $3 \to 2$, is the red line, the first of the series). **[1]**

Marking scheme

- Balmer series, visible region.

c. **[2]**

$$\Delta v \geq \frac{h}{4\pi m\,\Delta x} = \frac{6.626 \times 10^{-34}}{4 \times 3.142 \times 9.11 \times 10^{-31} \times 1.0 \times 10^{-14}} = 5.8 \times 10^{9}\ \text{m/s}$$

That uncertainty alone is about **20 times the speed of light**, which nothing can reach. An electron held inside a nucleus would have to move faster than light, so **electrons can't be confined in the nucleus**: the idea is wrong (they are outside it, round it).

Marking scheme

- $\Delta v = h/(4\pi m \Delta x) \approx 5.8 \times 10^9$ m/s.
- Greater than the speed of light, which is impossible, so electrons can't be in the nucleus.

Question 3 — 5 marks

a. **Oxidation** is an increase in the oxidation number of an element; **reduction** is a decrease in the oxidation number of an element. **[1]**

Marking scheme

- Oxidation: increase in oxidation number; reduction: decrease in oxidation number.

b. Oxidation numbers that change: **[2]**

- zinc: 0 in Zn $\to$ +2 in $Zn(NO_3)_2$, an increase of **2**;
- nitrogen: +5 in HNO_3 $\to$ −3 in NH_4^+ (of NH_4NO_3), a decrease of **8**.

To make the increase equal the decrease, take 4 Zn ($4 \times 2 = 8$) for every N reduced:

$$4\,Zn + HNO_3 \longrightarrow 4\,Zn(NO_3)_2 + NH_4NO_3$$

Count the nitrogen on the right: $4 \times 2 = 8$ in zinc nitrate and 2 in ammonium nitrate, 10 in all, so 10 HNO_3. Then hydrogen: 10 on the left, 4 in NH_4^+, so 6 H go into **3 H_2O**:

$$4\,Zn + 10\,HNO_3 \longrightarrow 4\,Zn(NO_3)_2 + NH_4NO_3 + 3\,H_2O$$

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Check oxygen: 30 on the left; $24 + 3 + 3 = 30$ on the right.

Marking scheme

- Changes in oxidation number found: Zn $0 \to +2$ (2) and N $+5 \to -3$ (8), so 4 Zn to 1 N reduced.
- Balanced equation: $4Zn + 10HNO_3 \to 4Zn(NO_3)_2 + NH_4NO_3 + 3H_2O$.

c. **Zinc is the reducing agent** (it is oxidized, giving electrons); **nitric acid is the oxidizing agent** (its nitrogen is reduced). **[2]**

Only **one** of the ten HNO_3 (a tenth) is reduced, to the NH_4^+ ion (+5 to −3). The other **nine** keep nitrogen at +5: eight end up as the nitrate ions of zinc nitrate and one as the nitrate ion of ammonium nitrate. They act only as an **acid**, supplying nitrate ions to the salts, not as an oxidizing agent.

Marking scheme

- Zinc is the reducing agent and nitric acid (its nitrogen) the oxidizing agent.
- Only 1 of the 10 (a tenth) is reduced; the other 9 keep N at +5 and only form the nitrate ions of the salts (act as an acid).

Question 4 — 5 marks

a. At equilibrium the reaction has **not stopped**: N_2O_4 molecules are still splitting into NO_2, and NO_2 molecules are still joining into N_2O_4. The two reactions go on **at the same rate**, so the amount of each gas (and so the color of the flask) stays the same. The equilibrium is a balance of two moving processes, not a standstill. **[2]**

Marking scheme

- Both the forward and the backward reaction still go on at equilibrium.
- Their rates are equal, so the concentrations (and color) stay constant.

b. **[2]**

$$K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

Concentrations: $[N_2O_4] = \frac{0.040}{2.0} = 0.020$ mol/L and $[NO_2] = \frac{0.24}{2.0} = 0.12$ mol/L.

$$K_c = \frac{(0.12)^2}{0.020} = \frac{0.0144}{0.020} = 0.72\ \text{mol/L}$$

Marking scheme

- $K_c = [NO_2]^2/[N_2O_4]$, with concentrations 0.020 and 0.12 mol/L.
- $K_c = 0.72$ mol/L.

c. **Backward, towards N_2O_4.** Squeezing raises the pressure; by Le Chatelier's principle the equilibrium shifts to the side with fewer gas molecules, and one N_2O_4 takes the place of two NO_2. (The brown color first darkens as the gas is compressed, then fades a little as NO_2 joins up.) **[1]**

Marking scheme

- Towards N_2O_4, because higher pressure favors the side with fewer gas molecules (1 against 2).

OR

a. The gas molecules move fast and at random in straight lines, and keep **colliding with the walls**; each collision pushes on the wall, and the pressure is the total force of these collisions on each unit area. **[2]**

Warming the gas raises the **average kinetic energy** of the molecules (it is proportional to the absolute temperature), so they move faster, hit the walls more often and harder, and the pressure rises.

Marking scheme

- Pressure comes from the molecules' collisions with the walls.

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- Higher temperature, faster molecules (greater average kinetic energy): more frequent and harder collisions, so higher pressure.

b. **[2]**

$$n = \frac{3.2}{32} = 0.10\ \text{mol}, \qquad T = 27 + 273 = 300\ \text{K}$$

$$P = \frac{nRT}{V} = \frac{0.10 \times 0.0821 \times 300}{5.0} = 0.49\ \text{atm}$$

Marking scheme

- 0.10 mol of O_2 (molar mass 32) and T = 300 K.
- $P = nRT/V = 0.49$ atm.

c. **Ammonia.** At high pressure the molecules are crowded together, so the attractions between them, which an ideal gas is assumed not to have, begin to matter. Ammonia's molecules are polar and attract one another strongly (they can even hydrogen bond), far more than the weak van der Waals forces between the non-polar H_2 or O_2 molecules, so ammonia departs most (it is also much the easiest of the three to liquefy). **[1]**

Marking scheme

- Ammonia, because its molecules attract one another most strongly (polar, hydrogen bonding), and attractions are what make a gas depart from PV = nRT.

Question 5 — 5 marks

a. 1 mL of the solution gives **20 mL of oxygen** at STP when it decomposes completely (about a 6% solution). **[1]**

Marking scheme

- 1 mL of it gives 20 mL of oxygen at STP on decomposition.

b. The enzyme **catalase** in blood speeds up the decomposition of hydrogen peroxide, $2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$, and the bubbles of oxygen given off make the froth. **[1]**

Marking scheme

- Catalase in blood decomposes it, giving bubbles of oxygen.

c. Each mL gives 20 mL of oxygen, so 5 mL gives $5 \times 20 =$ **100 mL** of oxygen at STP. **[1]**

Marking scheme

- 100 mL.

d. Hydrogen peroxide slowly decomposes, $2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$, and **light and heat speed this up**. In a warm, bright room the oxygen formed escaped from the open bottle, leaving water in place of peroxide, so the solution grew weaker. **[2]**

The volume strength is proportional to the H_2O_2 left: from 20 to 10 volume means **half** the H_2O_2 has decomposed. 100 mL of 20 volume could give 2000 mL of oxygen; now it can give only 1000 mL, so it has lost **1000 mL (1.0 L) of oxygen** at STP.

Marking scheme

- It decomposes to water and oxygen, faster in heat and light, and the oxygen escapes, so the solution weakens.
- Half has decomposed; 100 mL has lost $2000 - 1000 = 1000$ mL (1.0 L) of oxygen at STP.

Question 6 — 5 marks

a. **Metal toxicity** (metal poisoning) is the harm done by metals that build up in the soft tissues of the body, such as the kidneys, liver, brain, nerves and blood. **[2]**

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The arsenic in the Terai's groundwater is **natural**: it dissolves from the **rocks** underground into the water that tube wells draw.

Marking scheme

- Metal toxicity: harm done by metals that build up in the body's tissues.
- The arsenic dissolves naturally from rocks into the groundwater.

b. **(i) Boiling won't help.** Boiling kills germs, but arsenic is an element dissolved in the water as its compounds (arsenite and arsenate); heat doesn't destroy it or drive it off. As water boils away, the same arsenic is left in less water, so the boiled water is even **more** concentrated in arsenic. **[2]**

(ii) Better, but not truly safe. 30 μg/L is within Nepal's limit of 50 μg/L, but still **three times** the WHO's 10 μg/L, and arsenic does its harm by building up over years. It is better than their own well (80 μg/L), but a source below 10 μg/L, or an arsenic filter, would be the safe choice.

Marking scheme

- Boiling doesn't remove dissolved arsenic (an element, not a germ); it concentrates it as water evaporates.
- 30 μg/L meets Nepal's 50 but is three times the WHO's 10: better than 80, but not safe for years of drinking.

c. **No.** The grandfather has **arsenicosis**, chronic arsenic poisoning, which comes from small doses **building up over many years**; its signs appear only after long exposure. The brother has had only two years of the same doses, so the damage may not show yet: no signs now doesn't mean no harm. **[1]**

Marking scheme

- No: arsenicosis is chronic poisoning from doses building up over years, so the absence of signs after two years doesn't show the water is safe.

Question 7 — 5 marks

a. **Functional isomerism** is the isomerism in which compounds have the same molecular formula but **different functional groups** (so they belong to different homologous series), for example an alcohol and an ether. **[1]**

Marking scheme

- Same molecular formula, different functional groups.

b. i. A position isomer has the –OH on another carbon of the same chain: **$CH_3CH(OH)CH_2CH_3$, butan-2-ol**. **[2]**

ii. A functional isomer is an ether: **$CH_3OCH_2CH_2CH_3$, 1-methoxypropane** (or $CH_3CH_2OCH_2CH_3$, ethoxyethane; or $CH_3OCH(CH_3)_2$, 2-methoxypropane).

Marking scheme

- Position isomer with formula and name: butan-2-ol, $CH_3CH(OH)CH_2CH_3$.
- Functional isomer with formula and name: an ether such as 1-methoxypropane, ethoxyethane or 2-methoxypropane.

c. **Butan-2-ol**, $CH_3–C^*H(OH)–CH_2CH_3$. Its carbon 2 holds four different groups, H, OH, CH_3 and C_2H_5: it is a **chiral carbon**, so the molecule has two non-superimposable mirror-image forms that turn plane-polarized light in opposite directions. **[2]**

In the other three no carbon carries four different groups: butan-1-ol's CH_2OH carbon has two H; 2-methylpropan-1-ol's CH carbon has two CH_3; 2-methylpropan-2-ol's central carbon has three CH_3.

Marking scheme

- Butan-2-ol: carbon 2 carries four different groups (H, OH, CH_3, C_2H_5), a chiral carbon.
- In the other three no carbon carries four different groups (two H or two/three CH_3 on the same carbon).

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Question 8 — 5 marks

a. **Markovnikov's rule:** when a polar reagent HX adds to an unsymmetrical alkene, the positive part (H) goes to the carbon of the double bond that already has more hydrogen atoms, and the negative part (X) to the carbon with fewer. **[2]**

Peroxide effect (Kharasch effect): in the presence of a peroxide, HBr adds to an unsymmetrical alkene **against** Markovnikov's rule, the Br going to the carbon with more hydrogen atoms (anti-Markovnikov addition). It works only with HBr.

Marking scheme

- Markovnikov's rule: H of HX to the doubly bonded carbon with more H.
- Peroxide effect: with a peroxide, HBr adds the other way (anti-Markovnikov).

b. i. Without peroxide (Markovnikov addition): **[2]**

$$CH_3{-}CH{=}CH_2 + HBr \longrightarrow CH_3{-}CHBr{-}CH_3$$

2-bromopropane.

ii. With a peroxide (anti-Markovnikov addition):

$$CH_3{-}CH{=}CH_2 + HBr \xrightarrow{\text{peroxide}} CH_3{-}CH_2{-}CH_2Br$$

1-bromopropane.

Marking scheme

- Without peroxide: $CH_3CHBrCH_3$, 2-bromopropane.
- With peroxide: $CH_3CH_2CH_2Br$, 1-bromopropane.

c. Bubble or shake a little of each with **ammoniacal silver nitrate solution**: **but-1-yne gives a white precipitate** (of its silver salt), but-2-yne gives none. Only a hydrogen on a triple-bonded (sp) carbon is acidic enough to be replaced by silver: but-1-yne is a **terminal alkyne** with such a hydrogen (≡C–H), while both carbons of but-2-yne's triple bond carry CH_3 groups, with no hydrogen to replace. (Ammoniacal copper(I) chloride works the same way, a red precipitate with but-1-yne only.) **[1]**

Marking scheme

- Ammoniacal $AgNO_3$ (or Cu_2Cl_2): precipitate with but-1-yne only, because only it has an acidic H on a triple-bonded carbon.

Question 9 — 5 marks

a. **Continuous processing**: a product is made without interruption, raw materials being fed in and product taken out all the time, under steady conditions. **[1]**

Marking scheme

- Continuous processing: raw materials fed in and product taken out without stopping.

b. **High pressure:** 4 volumes of gas give 2, so by Le Chatelier's principle a high pressure shifts the equilibrium towards ammonia (and also speeds up the reaction). It isn't higher still because extra pressure costs energy and thicker, more costly equipment. **[2]**

Iron catalyst (promoted with K_2O and Al_2O_3): it makes the reaction reach equilibrium much faster at the plant's temperature, so ammonia is made quickly; it doesn't change the position of the equilibrium.

Marking scheme

- High pressure: fewer gas molecules on the ammonia side ($4 \rightarrow 2$), so the equilibrium shifts towards ammonia.
- Iron catalyst: makes equilibrium reached faster (rate), without changing the yield at equilibrium.

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c. **For:** the hydrogen would come from water with the country's own wet-season hydroelectricity (now sold to India), instead of imported natural gas, giving ammonia with almost no CO_2, cutting fertilizer imports and the dependence on supply from abroad. **[2]**

Difficulty: electrolysis of water is a costly way to make hydrogen unless electricity is very cheap all year (the plant runs continuously, but the surplus is seasonal); and urea also needs carbon dioxide, which a green plant would have to capture from elsewhere, such as a cement works.

Marking scheme

- An argument for: hydrogen from the country's own surplus hydroelectricity and water, no imported natural gas, little CO_2, fewer imports.
- A difficulty: electrolytic hydrogen is costly unless electricity is cheap (and it is seasonal); or urea needs CO_2 from another source.

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

Question 10 — 8 marks

a. The **limiting reactant** is the reactant that is used up first in a reaction; it decides (limits) how much product can form, and the other reactants are left over in excess. **[1]**

Marking scheme

- The reactant used up first, which decides the amount of product.

b. **[2]**

$$n(\mathrm{Fe_2O_3}) = \frac{16}{2\times 56 + 3\times 16} = \frac{16}{160} = 0.10\ \mathrm{mol}, \qquad n(\mathrm{Al}) = \frac{8.1}{27} = 0.30\ \mathrm{mol}$$

0.10 mol of Fe_2O_3 needs $2 \times 0.10 = 0.20$ mol of Al, and 0.30 mol is available, so aluminium is in excess: **iron(III) oxide is the limiting reactant**.

Marking scheme

- Moles: Fe_2O_3 0.10 mol, Al 0.30 mol.
- Fe_2O_3 needs only 0.20 mol Al, so Fe_2O_3 is limiting.

c. 1 mol of Fe_2O_3 gives 2 mol of Fe, so 0.10 mol gives 0.20 mol of Fe: $0.20 \times 56 =$ **11.2 g of iron**. **[2]**

Aluminium used: 0.20 mol; left over $0.30 - 0.20 = 0.10$ mol: $0.10 \times 27 =$ **2.7 g of aluminium**.

Marking scheme

- Iron formed 11.2 g.
- Aluminium left over 2.7 g.

d. **[3]**

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{9.5}{11.2} \times 100 = 84.8\%$$

No, more aluminium won't help. Iron(III) oxide is the limiting reactant and the aluminium is already in excess (0.10 mol more than needed), so the most iron the charge can give stays 11.2 g however much aluminium is added; the extra aluminium would only be wasted.

The missing 1.7 g is more likely **lost** than never formed: molten iron splashing out, iron left mixed with the aluminium oxide slag, or powders not well mixed so that some oxide never met aluminium. Better mixing and collection would raise the yield.

Marking scheme

- Percentage yield about 85% (84.8%).
- More aluminium can't help: Fe_2O_3 is limiting and Al is already in excess, so the theoretical yield stays 11.2 g.

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- The shortfall is from losses (splashing, iron in the slag) or poor mixing, not too little aluminium.

Question 11 — 8 marks

a. **[3]**

$$2\,NH_4Cl + Ca(OH)_2 \xrightarrow{\Delta} CaCl_2 + 2\,NH_3 \uparrow + 2\,H_2O$$

Ammonia is **lighter than air** and **very soluble in water**, so it is collected by downward displacement of air in an upside-down jar, not over water.

It is a **base**, so it would react with an acidic drying agent such as concentrated sulphuric acid (forming ammonium sulphate); quicklime, CaO, is a base itself and dries it without reacting.

Marking scheme

- Balanced equation: $2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O$.
- Upside-down jar: ammonia is lighter than air (and too soluble to collect over water).
- Quicklime: ammonia is a base and would react with the acid (forming ammonium sulphate).

b. Ammonia dissolves in the water of the moist paper to form ammonium hydroxide, which gives OH^- ions: $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$. The solution is **basic**, so it turns red litmus blue. **[1]**

Marking scheme

- Ammonia dissolves in water giving OH^- (NH_4OH), a base, which turns red litmus blue.

c. i. Dense **white fumes** of ammonium chloride: **[2]**

$$NH_3 + HCl \longrightarrow NH_4Cl$$

ii. First a pale blue precipitate of copper(II) hydroxide, which dissolves in excess ammonia to give a **deep blue** solution of tetraamminecopper(II) sulphate:

$$CuSO_4 + 2\,NH_4OH \longrightarrow Cu(OH)_2 \downarrow + (NH_4)_2SO_4$$

$$Cu(OH)_2 + (NH_4)_2SO_4 + 2\,NH_4OH \longrightarrow [Cu(NH_3)_4]SO_4 + 4\,H_2O$$

(overall, $CuSO_4 + 4\,NH_3 \longrightarrow [Cu(NH_3)_4]SO_4$).

Marking scheme

- $NH_3 + HCl \rightarrow NH_4Cl$ (white fumes).
- Deep blue $[Cu(NH_3)_4]SO_4$ formed (with excess ammonia), with a correct equation.

d. **Dry flask and gas:** ammonia is so soluble that any water already in the flask would dissolve much of it **before** the experiment starts, so the pressure would already be low, and the few drops squirted in would dissolve too little gas to make a strong fountain. **[2]**

Air in the ammonia: the fountain works because the dissolving ammonia leaves almost empty space behind, and air pressure pushes water in to fill it. Air hardly dissolves in water, so it stays as gas and takes up its share of the flask: the water rises only until it fills the space the ammonia left, and stops short of the top.

Marking scheme

- Water present beforehand would dissolve the ammonia early (it is extremely soluble), so there is too little gas left to dissolve and the pressure drop is small.
- Air doesn't dissolve, so it stays and fills part of the flask: water fills only the ammonia's share.

OR

a. **[3]**

$$MnO_2 + 4\,HCl(\text{conc}\cdot) \xrightarrow{\Delta} MnCl_2 + Cl_2 \uparrow + 2\,H_2O$$

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The **water** removes the **hydrogen chloride** gas that escapes with the chlorine (HCl is far more soluble in water than chlorine).

The **concentrated sulphuric acid** absorbs the **moisture**, drying the chlorine; chlorine, an acidic gas, doesn't react with it.

Marking scheme

- Balanced equation: $MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$.
- Water removes HCl gas.
- Concentrated H_2SO_4 dries the chlorine (removes water vapor).

b. Chlorine is about **2.5 times as dense as air** (molar mass 71 g/mol against about 29 for air), so it sinks and fills an upright jar by upward displacement of air; it dissolves in water, so it can't be collected over water. **[1]**

Marking scheme

- Heavier than air (and soluble in water), so upward displacement of air.

c. i. **[2]**

$$3\,Cl_2 + 6\,NaOH(\text{hot, conc.}) \longrightarrow 5\,NaCl + NaClO_3 + 3\,H_2O$$

(sodium chloride and sodium chlorate).

ii.

$$Cl_2 + 2\,NaOH(\text{cold, dil}\cdot) \longrightarrow NaCl + NaOCl + H_2O$$

(sodium chloride and sodium hypochlorite).

Marking scheme

- $3Cl_2 + 6NaOH$ (hot, conc.) $\rightarrow 5NaCl + NaClO_3 + 3H_2O$.
- $Cl_2 + 2NaOH$ (cold, dilute) $\rightarrow NaCl + NaOCl + H_2O$.

d. **Red:** chlorine dissolves in the water on the paper and reacts with it, giving two acids, hydrochloric and hypochlorous acid, which turn blue litmus red: **[2]**

$$Cl_2 + H_2O \longrightarrow HCl + HOCl$$

White: hypochlorous acid is unstable and gives nascent oxygen, which **oxidizes** the litmus dye to a colorless product, so the red paper is bleached:

$$HOCl \longrightarrow HCl + [O], \qquad \text{dye} + [O] \longrightarrow \text{colorless product}$$

Marking scheme

- Red: $Cl_2 + H_2O \rightarrow HCl + HOCl$, acids that turn blue litmus red.
- White: $HOCl \rightarrow HCl + [O]$; the nascent oxygen oxidizes (bleaches) the dye.

Question 12 — 8 marks

a. Any three of these: **[3]**

- **Bond lengths:** with fixed bonds, the ring would have three short C=C bonds (134 pm) and three long C–C bonds (154 pm); in fact all six carbon–carbon bonds are the same length, 139 pm.
- **Unreactivity:** with three double bonds, benzene should add bromine and decolorize bromine water and cold alkaline $KMnO_4$ as alkenes do; it doesn't, and it reacts mainly by substitution.
- **Stability:** benzene is far more stable than a molecule with three double bonds: its heat of hydrogenation is much less than three times that of one C=C bond.

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- **Ortho isomers:** with fixed bonds there should be two different 1,2-disubstituted benzenes (the substituents on carbons joined by a single bond, or by a double bond), but only one is ever found.

Marking scheme

- One fact: all six C–C bonds the same length (139 pm).
- A second fact: it doesn't add like an alkene (no decolorizing of bromine water); it substitutes.
- A third fact: extra stability (low heat of hydrogenation), or only one 1,2-disubstituted isomer.

b. **[2]**

$$C_6H_6 + HNO_3 \xrightarrow[50\text{-}60\ ^\circ C]{\text{conc. } H2SO4} C_6H_5NO_2 + H_2O$$

Benzene is warmed with a mixture of concentrated nitric and sulphuric acids (the nitrating mixture), giving **nitrobenzene**. The electrophile is the **nitronium ion, NO_2^+**, formed when sulphuric acid protonates nitric acid: $HNO_3 + 2\,H_2SO_4 \longrightarrow NO_2^+ + H_3O^+ + 2\,HSO_4^-$.

Marking scheme

- Equation with conc. HNO_3 and conc. H_2SO_4 at about 50–60 °C, giving nitrobenzene.
- Electrophile: the nitronium ion, NO_2^+.

c. Benzene's six π electrons are **delocalized** over the whole ring (resonance), which gives it a special stability (aromatic stability, the resonance energy). **[2]**

In **substitution**, the electrophile takes the place of an H and the ring keeps its six delocalized π electrons, so the stable aromatic ring is kept. **Addition** would use up π electrons and destroy the aromatic ring, losing that stability; so substitution is the easier path.

Marking scheme

- The π electrons are delocalized round the ring, giving extra (aromatic) stability.
- Substitution keeps the aromatic ring, whereas addition would destroy it, so substitution is favored.

d. Aromatic compounds have **very high octane numbers** (toluene's is over 100); they resist igniting by themselves under compression, so adding them raises the petrol's octane number and reduces **knocking** in the engine. Straight-chain alkanes knock easily. **[1]**

Marking scheme

- Aromatics have high octane numbers, so the petrol knocks less (straight chains knock easily).

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