Answers to revision questions

1 The states of matter

1. - All matter is composed of particles.
   - The particles are in constant motion and temperature affects their speed of motion.
   - The particles have empty spaces between them.
   - The particles have forces of attraction between them.
2. **a)** Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration until the particles are evenly distributed.
   b) Osmosis is the movement of water molecules through a differentially permeable membrane from a solution containing a lot of water molecules to a solution containing fewer water molecules.
   c) Melting point is the constant temperature at which a solid changes state into a liquid.
   d) Boiling point is the constant temperature at which a liquid changes state into a gas.
3. **a)** The red crystal particles gradually separate from each other and diffuse into the spaces between the water particles. As they diffuse through the water, the water becomes red.
   b) The membranes around the potato cells are differentially permeable and the cytoplasm inside the cells contains more water than the concentrated sucrose solution, so water moves out of the cells into the solution by osmosis. This causes each cell to shrink slightly, which causes the length of the potato strip to decrease.
4. Sodium chloride draws water out of the cells of the food items by osmosis. This prevents the food from decaying because water is unavailable in cells for the chemical reactions which cause the decay. It also draws water out of the microorganisms that cause decay by osmosis. This inhibits the growth of these organisms and thereby prevents the food from decaying.
5. **a)** The particles in nitrogen gas have large spaces between them, so they can be pushed closer together when pressure is applied.
   b) The particles in a solid lump of lead are packed closely together in a regular way and do not move out of their fixed positions – this creates a fixed shape.
6. The particles in ice are packed closely together in a regular way, whereas those in liquid water have small spaces between them and are randomly arranged, and those in steam have large spaces between them and are randomly arranged. The particles in ice vibrate in their fixed positions, whereas those in liquid water move slowly past each other and those in steam move around freely and rapidly. The forces of attraction between the particles in ice are strong, whereas those between the particles in liquid water are weaker and those between the particles in steam are very weak.
7. - Evaporation can take place at any temperature, whereas boiling occurs at a specific temperature.
   - Evaporation takes place at the surface of the liquid only, whereas boiling takes place throughout the liquid.
8. The substance changes directly from a solid to a gas when it is heated.

2 Pure substances, mixtures and separations

1.

Pure substance	Mixture
Its composition is fixed and constant	Its composition can vary
Its properties are fixed and constant	Its properties are variable
The component parts cannot be separated by any physical means	The component parts can be separated by physical means

2. **a)** An element is a pure substance that cannot be broken down into simpler substances by using any ordinary physical or chemical process.
   b) A compound is a pure substance that is formed from two or more different types of element which are chemically bonded together in fixed proportions and in a way that their properties have changed.
   c) A solution is a homogeneous mixture of two or more substances; one substance is usually a liquid.
   d) A suspension is a heterogeneous mixture in which minute, visible particles of one substance are dispersed in another substance which is usually a liquid.
3. The particles in a solution are extremely small, whereas those in a colloid are larger and those in a suspension are larger than those in a colloid. Light usually passes through a solution, whereas most colloids scatter light and suspensions do not allow light to pass through. The components of a solution and the dispersed particles in a colloid do not separate if left undisturbed, whereas the suspended particles in a suspension settle if left undisturbed.

   Example of a solution: sea water or white vinegar or soda water or air or any other suitable example.

   Example of a colloid: gelatin or jelly or mayonnaise or milk or hand cream or whipped cream or shaving cream or smoke or fog or aerosol sprays or clouds or any other suitable example.

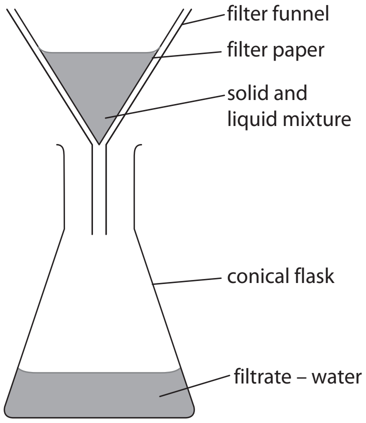
   Example of a suspension: muddy water or powdered chalk in water or oil shaken in water or dust in air or any other suitable example.
4. Solubility is the mass of solute that will saturate 100 g of solvent at a specified temperature.
5. At 28 °C, 9.0 g of $KClO_3$ saturates 100 g of water.

   At 74 °C, 32.0 g of $KClO_3$ saturates 100 g of water.

$\therefore$ mass of $KClO_3$ to be added to resaturate a solution containing 100 g of water = 32.0 – 9.0 g
= 23.0 g

and mass of $KClO_3$ to be added to resaturate a solution containing 350 g of water = $\frac{23.0}{100} \times 350$ g
= 80.5 g

6.

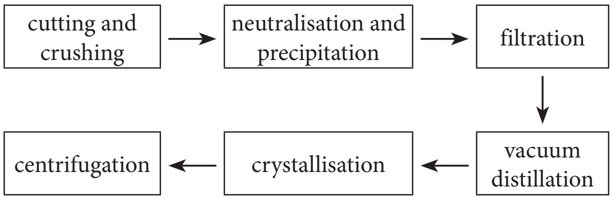


7. The apparatus would be set up for simple distillation. Tap water would be placed in the distillation flask and it would be heated so it boils. The steam produced would move into the condenser, where it would condense and the distillate would run into the conical flask. Any impurities in the tap water would remain in the distillation flask. The thermometer would be monitored during the process to ensure the temperature of the steam entering the condenser remains at the boiling point of pure water, i.e. 100 °C, thus ensuring the distillate would be pure water. The Liebig condenser, being long and having the water running in the opposite direction to the steam, would provide a permanently cold surface on which the steam would condense.

8. **a)** Cooking oil and water are immiscible and the water has a higher density than the oil. When a mixture containing both is placed into a separating funnel, the oil floats on the water. By opening the tap of the funnel, the water can be run off into a conical flask, leaving the oil in the funnel.

b) The different dyes in a drop of black ink have different solubilities in water and are attracted to absorbent paper with different strengths. When a drop of ink is placed on a piece of absorbent paper and water is allowed to move through the paper, the dye which is most soluble and least attracted to the paper moves fastest, and the dye which is least soluble and most strongly attracted to the paper moves slowest.

9.



3 Atomic structure

1. An atom is the smallest particle of an element that can exist by itself and still have the same chemical properties as the element.

2. - Protons
- Neutrons
- Electrons

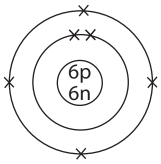
Protons and neutrons have a relative mass of 1, whereas electrons have a relative mass of $\frac{1}{1840}$.

Protons have a relative charge of +1, neutrons have no charge and electrons have a relative charge of –1.

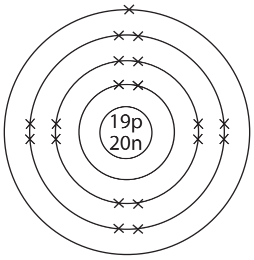
3. **a)** Atomic number is the number of protons in the nucleus of one atom of an element.

b) Mass number is the total number of protons and neutrons in the nucleus of one atom of an element.

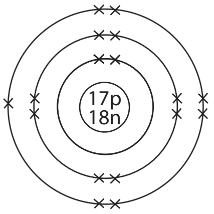
4. **a)** Carbon
A carbon atom has 6 protons, 6 neutrons and 6 electrons
Electronic configuration is 2,4



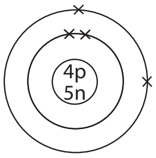
b) Potassium
A potassium atom has 19 protons, 20 neutrons and 19 electrons
Electronic configuration is 2,8,8,1



c) Chlorine
A chlorine atom has 17 protons, 18 neutrons and 17 electrons
Electronic configuration is 2,8,7



d) Beryllium
A beryllium atom has 4 protons, 5 neutrons and 4 electrons
Electronic configuration is 2,2



5. Isotopy is the occurrence of atoms of a single element that have the same number of protons in their nuclei, but different numbers of neutrons.

6. a) Naturally occurring boron has two isotopes. One isotope, $^{10}_{5}B$, has 5 protons, 5 neutrons and 5 electrons and the other, $^{11}_{5}B$, has 5 protons, 6 neutrons and 5 electrons.

b) Average mass number $= \left(\frac{20}{100} \times 10\right) + \left(\frac{80}{100} \times 11\right)$
$= 10.8$

7. Radioactive isotopes are isotopes which have unstable nuclei. These nuclei spontaneously undergo radioactive decay during which they eject small particles and radiation.

8. a) Electricity is generated in nuclear power stations using radioactive uranium-235. If a uranium-235 atom is struck by a moving neutron, it splits into two smaller atoms. As it splits, two or three neutrons and a large amount of heat energy are released. The neutrons can then strike other atoms, causing them to split and release more neutrons and energy. This causes a chain reaction which releases very large amounts of heat energy that can be used to generate electricity.

b) The age of a fossil can be determined by carbon-14 dating. The percentage of carbon-14 in a living organism's body remains constant at 0.01%. When an organism dies, it stops taking in carbon and the percentage of carbon-14 in its body decreases as it undergoes radioactive decay. By measuring the percentage of radioactive carbon-14 in the fossil and using the fact that the half-life of carbon-14 is 5700 years, its age can be determined.

c) Cancerous cells in tumours can be destroyed by directing a controlled beam of radiation from radioactive cobalt-60 at the cells. Alternatively, a radioactive isotope can be injected directly into the cancerous tumour.

9. Relative atomic mass is the average mass of one atom of an element compared to one-twelfth the mass of an atom of carbon-12.

Relative atomic mass is used to determine the mass of atoms because atoms are so small their absolute masses are very difficult to measure. By using relative atomic mass their masses can be compared.

4 The periodic table and periodicity

1. a) Johann Döbereiner proposed the Law of Triads. He noticed that certain groups of three elements, which he called triads, showed similar chemical and physical properties, and if the elements in any triad were arranged in increasing relative atomic mass, the relative atomic mass of the middle element was close to the average of the first and third elements.

b) John Newlands proposed the Law of Octaves. He arranged the elements that had been discovered at the time in order of increasing relative atomic mass and found that each element exhibited similar chemical and physical properties to the element eight places ahead of it in the list.

c) Dmitri Mendeleev published his Periodic Classification of Elements in which he arranged elements in increasing relative atomic mass, placed elements with similar chemical and physical properties together in vertical columns, left gaps when it appeared that elements had not yet been discovered and occasionally ignored the order suggested by relative atomic mass and exchanged adjacent elements so they were better classified into chemical families. Mendeleev is credited with creating the first version of the periodic table.

2. The elements in the modern periodic table are arranged on the basis of increasing atomic number, the electronic configuration of their atoms and their chemical properties.

3. a) Elements in the same group all have the same number of valence electrons.

b) Elements in the same period all have the same number of occupied electron shells.

4. Group number of element X is V.

Period number of element X is 3.

5. Calcium would react more vigorously.

Calcium is below magnesium in Group II so has a larger atomic radius. Calcium's valence electrons are further from the attractive pull of the positive nucleus and are more easily lost, so it ionises more easily than magnesium.

6. The state changes from gas to liquid to solid. The top two elements are gases at room temperature, the one below is a liquid and the one below that is a solid.

7. A reaction would occur.

Chlorine is above bromine in group VII so it has a smaller atomic radius and the attractive pull of the positive nucleus on the electron to be gained is stronger in chlorine. As a result, chlorine has a greater strength of oxidising power and readily takes electrons from the Br^- ions causing them to be converted to bromine atoms.

8. The metallic nature of the elements decreases.

9. Chlorine would be more reactive.

Chlorine is to the right of sulfur in Period 3, so it has a smaller atomic radius and one more positive proton. The attractive pull of the positive nucleus on the electron to be gained is stronger in chlorine, therefore it ionises more easily than sulfur.

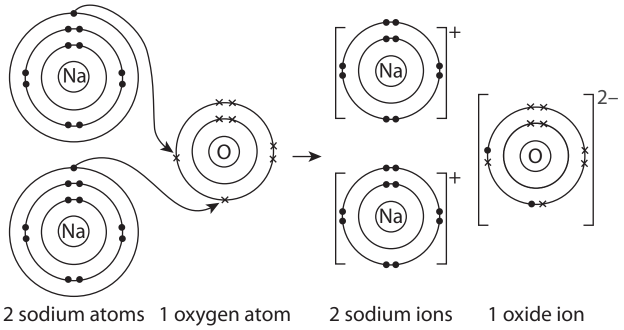
5 Structure and bonding

1. Elements form compounds to fill their outer valence electron shells and become stable.

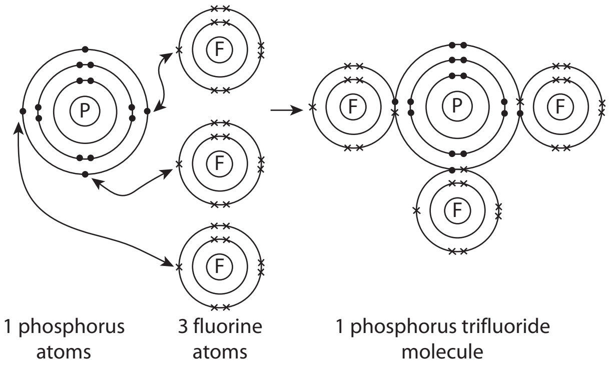
2. - Ionic bonding.
- Covalent bonding.
- Metallic bonding.

3. a) $ZnCl_2$ – ionic bonding.
b) $Mg_3(PO_4)_2$ – ionic bonding.
c) SiF_4 – covalent bonding.
d) CS_2 – covalent bonding.
e) $(NH_4)_2CO_3$ – ionic bonding.
f) $Al(OH)_3$ – ionic bonding.
g) K_2SO_4 – ionic bonding.

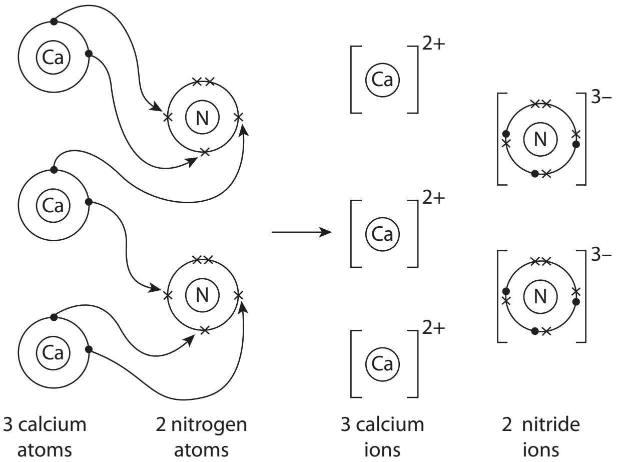
4. a) Type of compound: ionic
Ions present: Na^+, O^{2-}
Formula: Na_2O



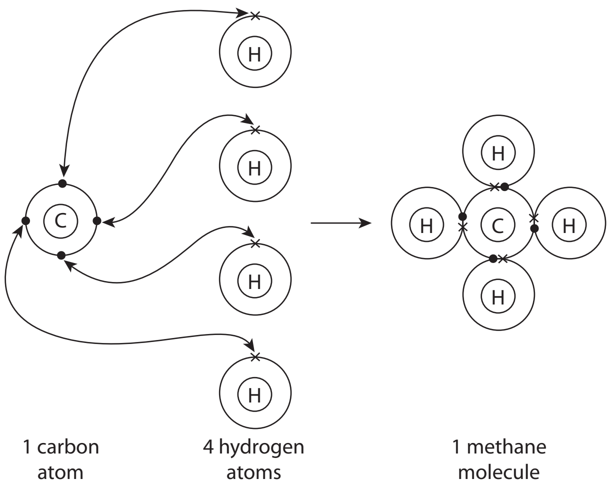
b) Type of compound: covalent
Valencies: P = 3, F = 1
Formula: PF_3



c) Type of compound: ionic
Ions present: Ca^{2+}, N^{3-}
Formula: Ca_3N_2



d) Type of compound: covalent
Valencies: C = 4, H = 1
Formula: CH_4



5. The magnesium atoms are packed tightly together in rows to form a metal lattice and their valence electrons become delocalised. This forms positive magnesium cations and a sea of mobile electrons. The metal lattice is held together by the electrostatic forces of attraction between the delocalised electrons and the magnesium cations called the metallic bond.

6. a) The strong electrostatic forces of attraction between the cations and delocalised electrons require large amounts of heat energy to break.

b) The delocalised electrons are free to move and carry electricity through the metal.

c) The atoms of a metal are all of the same type and size, so if force is applied the atoms can slide past each other into new positions without the metallic bond breaking.

7. Ionic solids have high melting points, whereas simple molecular solids have low melting points. Most ionic solids are soluble in water but insoluble in non-polar organic solvents, whereas most simple molecular solids are soluble in non-polar organic solvents but insoluble in water. Ionic solids do not conduct electricity in the solid state, but they do conduct electricity when they are molten or dissolved in water, whereas simple molecular solids do not conduct electricity in any state.

8. Allotropy is the existence of different structural forms of a single element in the same physical state.

9. a) The partial negative ends of polar water molecules attract the positive Na^+ ions and the partial positive ends attract the negative Cl^- ions in the sodium chloride crystal. This pulls the ions out of the lattice causing the crystal to dissolve.

b) Diamond is extremely hard because strong covalent bonds exist between the carbon atoms throughout the structure.

c) The fourth valence electron from each carbon atom in graphite is delocalised and free to move and carry the electricity.

d) The weak forces that exist between the layers of carbon atoms in graphite allow the layers to slip off and leave dark marks on the paper.

6 Chemical equations

1. **a)** $Br_2(aq) + 2KI(aq) \longrightarrow 2KBr(aq) + I_2(aq)$
   b) $2Fe(s) + 3Cl_2(g) \longrightarrow 2FeCl_3(s)$
   c) $2Al(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$
   d) $C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(g)$
   e) $2NaOH(aq) + (NH_4)_2SO_4(aq) \longrightarrow$
   $Na_2SO_4(aq) + 2NH_3(g) + 2H_2O(l)$
2. **a)** silver nitrate – soluble
   b) potassium phosphate – soluble
   c) zinc hydroxide – insoluble
   d) aluminium sulfate – soluble
   e) lead(II) chloride – insoluble in cold water, moderately soluble in hot water
   f) copper(II) oxide – insoluble
   g) calcium carbonate – insoluble
   h) sodium ethanoate – soluble
3. **a)** $Mg(OH)_2(s) + 2HNO_3(aq) \longrightarrow$
   $Mg(NO_3)_2(aq) + 2H_2O(l)$
   b) $Pb(NO_3)_2(aq) + 2NaCl(aq) \longrightarrow$
   $PbCl_2(s) + 2NaNO_3(aq)$
   c) $Ca(HCO_3)_2(aq) + 2HCl(aq) \longrightarrow$
   $CaCl_2(aq) + 2CO_2(g) + 2H_2O(l)$
   d) $2Zn(NO_3)_2(s) \longrightarrow 2ZnO(s) + 4NO_2(g) + O_2(g)$
4. **1a)** $Br_2(aq) + \cancel{2K^+(aq)} + 2I^-(aq) \longrightarrow$
   $\cancel{2K^+(aq)} + 2Br^-(aq) + I_2(aq)$
   Ionic equation: $Br_2(aq) + 2I^-(aq) \longrightarrow$
   $2Br^-(aq) + I_2(aq)$
   1c) $2Al(s) + 6H^+(aq) + \cancel{3SO_4^{2-}(aq)} \longrightarrow$
   $2Al^{3+}(aq) + \cancel{3SO_4^{2-}(aq)} + 3H_2(g)$
   Ionic equation: $2Al(s) + 6H^+(aq) \longrightarrow$
   $2Al^{3+}(aq) + 3H_2(g)$
   1e) $\cancel{2Na^+(aq)} + 2OH^-(aq) + 2NH_4^+(aq) + SO_4^{2-}(aq) \longrightarrow$
   $\cancel{2Na^+(aq)} + SO_4^{2-}(aq) + 2NH_3(g) + 2H_2O(l)$
   Ionic equation: $OH^-(aq) + NH_4^+(aq) \longrightarrow$
   $NH_3(g) + H_2O(l)$
   3b) $Pb^{2+}(aq) + \cancel{2NO_3^-(aq)} + \cancel{2Na^+(aq)} + 2Cl^-(aq) \longrightarrow$
   $PbCl_2(s) + \cancel{2Na^+(aq)} + \cancel{2NO_3^-(aq)}$
   Ionic equation: $Pb^{2+}(aq) + 2Cl^-(aq) \longrightarrow PbCl_2(s)$
   3c) $\cancel{Ca^{2+}(aq)} + 2HCO_3^-(aq) + 2H^+(aq) + \cancel{2Cl^-(aq)} \longrightarrow$
   $\cancel{Ca^{2+}(aq)} + \cancel{2Cl^-(aq)} + 2CO_2(g) + 2H_2O(l)$
   Ionic equation: $HCO_3^-(aq) + H^+(aq) \longrightarrow$
   $CO_2(g) + H_2O(l)$

7 Types of chemical reaction

1. **a)** Displacement reaction.
   b) Synthesis reaction.
   c) Neutralisation reaction.
   d) Decomposition reaction.
   e) Ionic precipitation reaction.
   f) Displacement reaction.

8 The mole concept

1. **a)** Relative atomic mass is the average mass of one atom of an element compared to one twelfth the mass of an atom of carbon-12.
   b) A mole is the amount of a substance that contains 6.0×10^{23} particles of the substance.
   c) Molar mass is the mass, in grams, of one mole of a chemical substance.
   d) Molar volume is the volume occupied by one mole of a gas.
2. **a)** Mass of 1 mol $(NH_4)_3PO_4 = (3 \times 14) + (3 \times 4 \times 1) + 31$
   $+ (4 \times 16)$ g
   $= 149$ g
   $\therefore$ mass of 0.3 mol $(NH_4)_3PO_4 = 0.3 \times 149$ g
   $= \mathbf{44.7\ g}$
   b) Mass of 1 mol $CuSO_4 = 64 + 32 + (4 \times 16)$ g
   $= 160$ g
   $\therefore$ number of moles in 3.2 g $CuSO_4 = \frac{3.2}{160}$ mol
   $= \mathbf{0.02\ mol}$
   c) 1 mol Al_2O_3 contains 6.0×10^{23} Al_2O_3 formula units
   $\therefore$ number of moles in 2.4×10^{22} Al_2O_3 formula units
   $= \frac{2.4 \times 10^{22}}{6.0 \times 10^{23}}$ mol
   $= \mathbf{0.04\ mol}$
   d) Mass of 1 mol $CO_2 = 12 + (2 \times 16)$ g
   $= 44$ g
   $\therefore$ number of moles in 11 g $= \frac{11}{44}$ mol
   $= 0.25$ mol
   1 mol CO_2 contains 6.0×10^{23} CO_2 molecules
   $\therefore$ 0.25 mol CO_2 contains $0.25 \times 6.0 \times 10^{23}$ CO_2 molecules
   $= \mathbf{1.5 \times 10^{23}\ CO_2\ molecules}$
3. Equal volumes of all gases, under the same conditions of temperature and pressure, contain the same number of molecules.
4. **a)** Volume of 1 mol O_2 at stp $= 22\,400\ cm^3$
   $\therefore$ number of moles in $560\ cm^3 = \frac{560}{22\,400}$ mol
   $= \mathbf{0.025\ mol}$
   b) Volume of 1 mol CO at rtp $= 24.0\ dm^3$
   $\therefore$ volume of 0.15 mol CO $= 0.15 \times 24.0\ dm^3$
   $= \mathbf{3.6\ dm^3}$
   c) Mass of 1 mol $NH_3 = 14 + (3 \times 1)$ g
   $= 17$ g
   $\therefore$ number of moles in 3.4 g $NH_3 = \frac{3.4}{17}$ mol
   $= 0.2$ mol

   Volume of 1 mol NH_3 at rtp $= 24.0\ dm^3$
   $\therefore$ volume of 0.2 mol $NH_3 = 0.2 \times 24.0\ dm^3$
   $= \mathbf{4.8\ dm^3}$
   d) Volume of 1 mol H_2 at stp $= 22.4\ dm^3$
   $\therefore$ number of moles in $1.68\ dm^3 = \frac{1.68}{22.4}$ mol
   $= 0.075$ mol
   1 mol H_2 contains 6.0×10^{23} H_2 molecules
   $\therefore$ 0.075 mol H_2 contains $0.075 \times 6.0 \times 10^{23}$ H_2 molecules
   $= \mathbf{4.5 \times 10^{22}\ H_2\ molecules}$

5. **a)** Mass of oxygen in the compound =
56.0 – (23.0 + 18.9) g = 14.1 g

Element	K	S	O
Mass	23.0 g	18.9 g	14.1 g
Mass of 1 mole	39 g	32 g	16 g
Number of moles	$\frac{23.0}{39}$ mol = 0.59 mol	$\frac{18.9}{32}$ mol = 0.59 mol	$\frac{14.1}{16}$ mol = 0.88 mol
Simplest mole ratio	1 mol = **2 mol**	1 mol = **2 mol**	1.5 mol = **3 mol**

Empirical formula is $\mathbf{K_2S_2O_3}$

b)

Element	C	H	Br
Percentage	22.2%	3.7%	74.1%
Mass in 100 g	22.2 g	3.7 g	74.1 g
Mass of 1 mole	12 g	1 g	80 g
Number of moles	$\frac{22.2}{12}$ mol = 1.85 mol	$\frac{3.7}{1}$ mol = 3.7 mol	$\frac{74.1}{80}$ mol = 0.93 mol
Simplest mole ratio	**2 mol**	**4 mol**	**1 mol**

Empirical formula is $\mathbf{C_2H_4Br}$
Relative molecular mass of C_2H_4Br = (2 × 12) + (4 × 1) + 80
= 108

Relative molecular mass of compound = 216
and ratio between relative molecular masses = $\frac{216}{108}$
= **2**

∴ the molecular formula is **2** × the empirical formula

Molecular formula of the compound is $\mathbf{C_4H_8Br_2}$

6. Mass of 1 mol $Pb(NO_3)_2$ = 207 + (2 × 14) + (2 × 3 × 16) g
= 331 g

Mass of oxygen in 1 mol $Pb(NO_3)_2$ = 2 × 3 × 16 g
= 96 g

∴ percentage of oxygen in $Pb(NO_3)_2$ = $\frac{96}{331}$ × 100%
= **29.0%**

7. A solution whose concentration is known accurately.

8. **a)** 1000 cm³ K_2CO_3(aq) contains 0.2 mol K_2CO_3
∴ 250 cm³ K_2CO_3(aq) contains $\frac{0.2}{1000}$ × 250 mol K_2CO_3
= 0.05 mol K_2CO_3

Mass of 1 mol K_2CO_3 = (2 × 39) + 12 + (3 × 16) g
= 138 g

Mass of 0.05 mol K_2CO_3 = 0.05 × 138 g
= 6.9 g

Mass of potassium carbonate required = **6.9 g**

b) 1000 cm³ NaOH(aq) contains 16.5 g NaOH
∴ 200 cm³ NaOH(aq) contains $\frac{16.5}{1000}$ × 200 g NaOH
= 3.3 g NaOH

Mass of 1 mol NaOH = 23 + 16 + 1 g
= 40 g

∴ number of moles in 3.3 g = $\frac{3.3}{40}$ mol
= **0.0825 mol**

c) 400 cm³ $Ca(NO_3)_2$(aq) contains 32.8 g $Ca(NO_3)_2$
∴ 1000 cm³ $Ca(NO_3)_2$(aq) contains
$\frac{32.8}{400}$ × 1000 g $Ca(NO_3)_2$
= 82.0 g $Ca(NO_3)_2$

Mass of 1 mol $Ca(NO_3)_2$ = 40 + (2 × 14) + (2 × 3 × 16) g
= 164 g

∴ number of moles in 82.0 g = $\frac{82.0}{164}$ mol
= 0.5 mol

Molar concentration of the solution = **0.5 mol dm⁻³**

9. Matter can neither be created nor destroyed during a chemical reaction.

10. $3KOH(aq) + H_3PO_4(aq) \longrightarrow K_3PO_4(aq) + 3H_2O(l)$
25.2 g ? mass

Mass of 1 mol KOH = 39 + 16 + 1 g
= 56 g

∴ number of moles in 25.2 g KOH = $\frac{25.2}{56}$ mol
= 0.45 mol

3 mol KOH form 1 mol K_3PO_4
∴ 0.45 mol KOH forms $\frac{1}{3}$ × 0.45 mol K_3PO_4
= 0.15 mol K_3PO_4

Mass of 1 mol K_3PO_4 = (3 × 39) + 31 + (4 × 16) g
= 212 g

∴ mass of 0.15 mol K_3PO_4 = 0.15 × 212 g
= **31.8 g**

11. $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$
? volume at stp 672 cm³

Volume of 1 mol H_2O(g) at stp = 22 400 cm³
∴ number of moles in 672 cm³ H_2O(l) = $\frac{672}{22\,400}$ mol
= 0.03 mol

1 mol O_2 forms 2 mol H_2O
∴ $\frac{1}{2}$ × 0.03 mol O_2 forms 0.03 mol H_2O
= 0.015 mol O_2

Volume of 1 mol O_2 at stp = 22 400 cm³
∴ volume of 0.015 mol O_2 = 0.015 × 22 400 cm³
= **336 cm³**

12. $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
25 cm³ ? mass
2.4 mol dm³

1000 cm³ HCl(aq) contains 2.4 mol HCl
∴ 25 cm³ HCl(aq) contains $\frac{2.4}{1000}$ × 25 mol HCl
= 0.06 mol HCl

2 mol HCl form 1 mol $ZnCl_2$
∴ 0.06 mol HCl forms $\frac{1}{2}$ × 0.06 mol $ZnCl_2$
= 0.03 mol $ZnCl_2$

Mass of 1 mol $ZnCl_2$ = 65 + (2 × 35.5) g

= 136 g

∴ mass of 0.03 mol $ZnCl_2$ = 0.03 × 136 g

= **4.08 g**

13. $Na_2CO_3(aq) + 2HNO_3(aq) \longrightarrow 2NaNO_3(aq) + CO_2(g) + H_2O(l)$

50 cm^3 ? volume

2.0 mol dm^{-3} at rtp

1000 cm^3 $HNO_3(aq)$ contains 2.0 mol HNO_3

∴ 50 cm^3 $HNO_3(aq)$ contains $\frac{2.0}{1000}$ × 50 mol HNO_3

= 0.1 mol HNO_3

2 mol HNO_3 form 1 mol CO_2

∴ 0.1 mol HNO_3 forms $\frac{1}{2}$ × 0.1 mol CO_2

= 0.05 mol CO_2

Volume of 1 mol CO_2 at rtp = 24.0 dm^3

∴ volume of 0.05 mol CO_2 = 0.05 × 24.0 dm^3

= **1.2 dm^3**

14. $2Mg(NO_3)_2(aq) \longrightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$

5.92 g ? mass

Mass of 1 mol $Mg(NO_3)_2$ = 24 + (2 × 14) + (2 × 3 × 16) g

= 148 g

∴ number of moles in 5.92 g KOH = $\frac{5.92}{148}$ mol

= 0.04 mol

2 mol $Mg(NO_3)_2$ form 2 mol MgO

∴ 0.04 mol $Mg(NO_3)_2$ forms 0.04 mol MgO

Mass of 1 mol MgO = 24 + 16 g

= 40 g

∴ mass of 0.04 mol MgO = 0.04 × 40 g

= 1.6 g

Decrease in mass = 5.92 – 1.6 g

= **4.32 g**

9 Acids, bases and salts

1. When an acid dissolves in water its molecules ionise to form H^+ ions and negative anions. The H^+ ions are single protons and when an acid reacts it gives its H^+ ions or protons to the other reactant.

2. *Any four of the following:*
- Acids have a sour taste.
- Acids are corrosive.
- Acids change blue litmus to red.
- Acids have a pH value of less than 7.
- Acids conduct an electric current or acids are electrolytes.

3. a) $K_2CO_3(aq) + 2HNO_3(aq) \longrightarrow 2KNO_3(aq) + CO_2(g) + H_2O(l)$

b) $2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

c) $Ca(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2(g)$

d) $Mg(HCO_3)_2(aq) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + 2CO_2(g) + 2H_2O(l)$

4. a) $CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow CO_2(g) + H_2O(l)$

b) $OH^-(aq) + H^+(aq) \longrightarrow H_2O(l)$

c) $Ca(s) + 2H^+(aq) \longrightarrow Ca^{2+}(aq) + H_2(g)$

d) $HCO_3^-(aq) + H^+(aq) \longrightarrow CO_2(g) + H_2O(l)$

5. a) An acid anhydride is a compound that reacts with water to form an acid.

b) *Any two of the following:*
- Carbon dioxide
- Sulfur dioxide
- Sulfur trioxide
- Nitrogen dioxide

6. a) The citric acid in the lime juice reacts with the iron(III) oxide in the rust stains. The reaction makes a soluble compound which washes out of the clothes, removing the rusty yellow Fe^{3+} ions.

b) The ethanoic acid in vinegar gives it a low pH which denatures the enzymes that cause decay and inhibits the growth of microorganisms which also cause decay.

7. a) Hydrochloric acid – pH 0, 1 or 2
Ethanoic acid – pH 5 or 6

b) Hydrochloric acid is a strong acid which is fully ionised when dissolved in water. Its solution contains a high concentration of H^+ ions.
Ethanoic acid is a weak acid which is only partially ionised when dissolved in water. Its solution contains a low concentration of H^+ ions.

8. a) A base is a proton donor.

b) An alkali is a base which dissolves in water to form a solution that contains OH^- ions.

9. *Any four of the following:*
- Alkalis have a bitter taste.
- Alkalis are corrosive.
- Alkalis feel soapy.
- Alkalis change red litmus to blue.
- Alkalis have a pH value greater than 7.
- Alkalis conduct an electric current or alkalis are electrolytes.

10. a) $MgO(s) + 2NH_4NO_3(s) \longrightarrow Mg(NO_3)_2(s) + 2NH_3(g) + H_2O(l)$

b) $2NaOH(s) + (NH_4)_2SO_4(s) \longrightarrow Na_2SO_4(s) + 2NH_3(g) + 2H_2O(l)$

11.
- Acidic oxides
  Acidic oxides are oxides of some non-metals which react with alkalis to form a salt and water.
  Example: carbon dioxide or sulfur dioxide or sulfur trioxide or nitrogen dioxide or silicon dioxide.
- Basic oxides
  Basic oxides are oxides of metals which react with acids to form a salt and water.
  Example: potassium oxide or sodium oxide or calcium oxide or magnesium oxide or iron(II) oxide or iron(III) oxide or copper(II) oxide or any other metal oxide except aluminium oxide, zinc oxide and lead(II) oxide.
- Amphoteric oxides
  Amphoteric oxides are oxides of some metals which react with both acids and strong alkalis to form a salt and water.
  Example: aluminium oxide or zinc oxide or lead(II) oxide.
- Neutral oxides
  Neutral oxides are oxides of some non-metals which do not react with acids or alkalis.
  Example: carbon monoxide or nitrogen monoxide or dinitrogen monoxide.

12. A salt is a compound formed when some or all of the hydrogen ions in an acid are replaced by metal or ammonium ions.

13. A normal salt is formed when all of the hydrogen ions in an acid are replaced by metal or ammonium ions. Example: any metal chloride or any metal nitrate or any metal ethanoate or any metal sulfate or any metal carbonate or any metal phosphate.

An acid salt is formed when the hydrogen ions in an acid are only partially replaced by metal or ammonium ions. Example: any metal hydrogensulfate or any metal hydrogencarbonate or any metal hydrogenphosphate or any metal dihydrogenphosphate.

14. Water of crystallisation is a fixed proportion of water molecules held within the crystal lattice of some salts.

15. a) Add the zinc carbonate to nitric acid until effervescence stops and there is excess zinc carbonate present. Dip a piece of blue litmus paper into the solution; it should remain blue. Filter the mixture to remove the excess carbonate, collect the filtrate and evaporate the water, or evaporate some water and leave to crystallise.

$ZnCO_3(s) + 2HNO_3(aq) \longrightarrow$
$Zn(NO_3)_2(aq) + CO_2(g) + H_2O(l)$

b) Dissolve barium nitrate and either potassium sulfate or sodium sulfate in distilled water to make two solutions. Mix the solutions to form a precipitate and filter the mixture to separate the precipitate. Wash the precipitate (residue) with distilled water and leave it to dry.

$Ba(NO_3)_2(aq) + Na_2SO_4(aq) \longrightarrow$
$BaSO_4(s) + 2NaNO_3(aq)$

c) Measure a fixed volume of potassium hydroxide solution using a pipette, run it into a conical flask and add a suitable indicator. Place sulfuric acid into a burette and perform a titration to determine the volume of acid needed to neutralise the fixed volume of potassium hydroxide solution. Add the volume of acid determined in the titration to the fixed volume of potassium hydroxide solution without the indicator. Evaporate the water from the solution, or evaporate some water and leave to crystallise.

$2KOH(aq) + H_2SO_4(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$

d) Heat a sample of iron in a stream of chlorine gas in a fume cupboard.

$2Fe(s) + 3Cl_2(g) \longrightarrow 2FeCl_3(s)$

16. *Any four of the following:*

- Sodium hydrogencarbonate
  Used as a component of baking powder to make cakes rise.
- Calcium carbonate
  Used to manufacture cement for use in the construction industry.
- Sodium chloride or sodium nitrate or sodium nitrite or sodium benzoate
  Used to preserve food.
- Calcium sulfate
  Used to manufacture plaster of Paris which is used as a building material or to make orthopaedic casts for setting broken bones.
- Magnesium sulfate
  Used for various medicinal purposes, for example to relieve stress or ease aches and pains or reduce inflammation or cure skin problems or as a laxative.
  Or used in agriculture to improve plant growth.

17. a) A neutralisation reaction is a reaction between a base and an acid to form a salt and water.

b) The neutralisation point is the point in a neutralisation reaction where the OH^- ions from the alkali have fully reacted with the H^+ ions from the acid and neither ion is present in excess.

18. Tooth decay is caused by acid in the mouth reacting with the calcium hydroxyapatite in tooth enamel. Toothpaste contains sodium hydrogencarbonate and sodium monofluorophosphate. The sodium hydrogencarbonate neutralises any acid present in the mouth and the F^- ions in the sodium monofluorophosphate displace the OH^- ions in the calcium hydroxyapatite, forming calcium fluoroapatite. Calcium fluoroapatite which does not react with acid, so the tooth enamel is protected from decaying.

19. $Na_2CO_3(aq) + 2HCl(aq) \longrightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$
15.0 cm^3 7.5 cm^3
53.0 g dm^{-3} 2.0 mol dm^{-3}

1000 cm^3 $Na_2CO_3(aq)$ contains 53.0 g Na_2CO_3

$\therefore$ 15.0 cm^3 $Na_2CO_3(aq)$ contains $\frac{53.0}{1000} \times 15.0$ g Na_2CO_3
= 0.795 g Na_2CO_3

Mass of 1 mol Na_2CO_3 = (2 × 23) + 12 (3 × 16) g
= 106 g

Number of moles in 0.795 g Na_2CO_3 = $\frac{0.795}{106}$ mol Na_2CO_3
= 0.0075 mol Na_2CO_3

1000 cm^3 HCl(aq) contains 2.0 mol HCl

$\therefore$ 7.5 cm^3 HCl(aq) contains $\frac{2.0}{1000} \times 7.5$ mol HCl
= 0.015 mol HCl

0.0075 mol Na_2CO_3 reacts with 0.015 mol HCl

$\therefore$ **1 mol** Na_2CO_3 reacts with **2 mol** HCl

20. $2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$
40.0 cm^3 25.0 cm^3
? concentration 0.2 mol dm^{-3}

1000 cm^3 $H_2SO_4(aq)$ contains 0.2 mol H_2SO_4

$\therefore$ 25.0 cm^3 $H_2SO_4(aq)$ contains $\frac{0.2}{1000} \times 25.0$ mol H_2SO_4
= 0.005 mol H_2SO_4

2 mol NaOH react with 1 mol H_2SO_4

$\therefore$ 2 × 0.005 mol NaOH reacts with 0.005 mol H_2SO_4
= 0.01 mol NaOH

40.0 cm^3 NaOH contains 0.01 mol NaOH

$\therefore$ 1000 cm^3 NaOH(aq) contains $\frac{0.01}{40.0} \times 1000$ mol NaOH
= 0.25 mol NaOH

Mass of 1 mol NaOH = 23 + 16 + 1 g
= 40 g

$\therefore$ mass of 0.25 mol NaOH = 0.25 × 40 g
= 10.0 g

Mass concentration of NaOH(aq) = **10.0 g dm^{-3}**

10 Oxidation-reduction reactions

1. a) Oxidation is the loss of electrons by an element in its free state or an element in a compound.
b) Reduction is the gain of electrons by an element in its free state or an element in a compound.
c) An oxidising agent causes an element in its free state or an element in a compound to lose electrons.
d) A reducing agent causes an element in its free state or an element in a compound to gain electrons.

2. a) Reduction.
Each iodine atom in the iodine molecule gained an electron to form an I^- ion.
b) Oxidation.
The Cu^+ ion lost an electron to form the Cu^{2+} ion.
c) Oxidation.
Each Br^- ion lost an electron to form a bromine atom.

3. a) BrO_2
Br + 2(–2) = 0
Br + (–4) = 0
Oxidation number of bromine = **+4**

BrO_3^- ion
Br + 3(–2) = –1
Br + (–6) = –1
Br = –1 + 6
Oxidation number of bromine = **+5**

BrO^- ion
Br + (–2) = –1
Br = –1 + 2
Oxidation number of bromine = **+1**

b) NH_3
N + 3(+1) = 0
N + (+3) = 0
Oxidation number of nitrogen = **–3**

NO_2^-
N + 2(–2) = –1
N + (–4) = –1
N = –1 + 4
Oxidation number of nitrogen = **+3**

N_2O
2N + (–2) = 0
2N = +2
Oxidation number of nitrogen = **+1**

c) CO
C + (–2) = 0
Oxidation number of carbon = **+2**

CO_3^{2-} ion
C + 3(–2) = –2
C + (–6) = –2
C = –2 + 6
Oxidation number of carbon = **+4**

CH_4
C + 4(+1) = 0
C + (+4) = 0
Oxidation number of carbon = **–4**

C_3H_6
3C + 6(+1) = 0
3C + (+6) = 0
3C = –6
Oxidation number of carbon = **–2**

HCO_3^- ion
(+1) + C + 3(–2) = –1
(+1) + C + (–6) = –1
C + (–5) = –1
C = –1 + 5
Oxidation number of carbon = **+4**

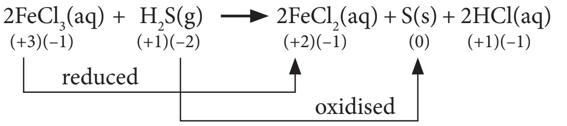
4. a) SO_3^{2-} ion
S + 3(–2) = –2
S + (–6) = –2
S = –2 + 6
Oxidation number of sulfur = **+4**
Name of the ion is the sulfate(IV) ion.

SO_4^{2-} ion
S + 4(–2) = –2
S + (–8) = –2
S = –2 + 8
Oxidation number of sulfur = **+6**
Name of the ion is the sulfate(VI) ion.

b) NO
N + (–2) = 0
Oxidation number of nitrogen = **+2**
Alternative name is nitrogen(II) oxide.

5. a) Oxidation is the increase in oxidation number of an element in its free state or an element in a compound.
b) Reduction is the decrease in oxidation number of an element in its free state or an element in a compound.
c) An oxidising agent causes the oxidation number of an element in its free state or an element in a compound to increase.
d) A reducing agent causes the oxidation number of an element in its free state or an element in a compound to decrease.

6. a)

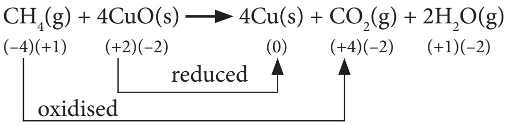


$$\underset{(+3)(-1)}{2FeCl_3(aq)} + \underset{(+1)(-2)}{H_2S(g)} \longrightarrow \underset{(+2)(-1)}{2FeCl_2(aq)} + \underset{(0)}{S(s)} + \underset{(+1)(-1)}{2HCl(aq)}$$

Hydrogen sulfide has been oxidised because the oxidation number of the sulfur atom in the hydrogen sulfide molecule has increased from –2 to 0.

Iron(III) chloride has been reduced because the oxidation number of the Fe^{3+} ion in the iron(III) chloride has decreased from +3 to +2.

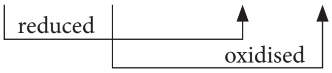
b)



$$\underset{(-4)(+1)}{CH_4(g)} + \underset{(+2)(-2)}{4CuO(s)} \longrightarrow \underset{(0)}{4Cu(s)} + \underset{(+4)(-2)}{CO_2(g)} + \underset{(+1)(-2)}{2H_2O(g)}$$

Methane has been oxidised because the oxidation number of the carbon atom in the methane molecule has increased from –4 to +4.
Copper(II) oxide has been reduced because the oxidation number of each Cu^{2+} ion in the copper(II) oxide has decreased from +2 to 0.

7. $$\underset{(+3)(-2)}{Fe_2O_3}(s) + 3\underset{(0)}{H_2}(g) \longrightarrow 2\underset{(0)}{Fe}(s) + 3\underset{(+1)(-2)}{H_2O}(l)$$



Iron(III) oxide is the reducing agent because it caused the oxidation number of each hydrogen atom in the hydrogen molecules to increase from 0 to +1.

Hydrogen is the reducing agent because it caused the oxidation number of each Fe^{3+} ion in the iron(III) oxide to decrease from +3 to 0.

8. - Acidified potassium managnate(VII) solution
   The colour would change from purple to colourless because the reducing agent would reduce the purple MnO_4^- ion to the colourless Mn^{2+} ion.
   - Acidified potassium dichromate(VI) solution
   The colour would change from orange to green because the reducing agent would reduce the orange $Cr_2O_7^{2-}$ ion to the green Cr^{3+} ion.

9. Acidified hydrogen peroxide.

   Sulfur dioxide.

11 Electrochemistry

1. **a)** A reaction will occur.
   $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
   b) No reaction will occur.
   c) A reaction will occur.
   $Al(s) + 3AgNO_3(aq) \longrightarrow Al(NO_3)_3(aq) + 3Ag(s)$
   d) No reaction will occur.
   e) No reaction will occur.
   f) A reaction will occur.
   $Br_2(g) + 2NaI(aq) \longrightarrow 2NaBr(aq) + I_2(aq)$

2. A conductor allows an electric current to pass through. A non-conductor does not allow an electric current to pass through.

   An example of a conductor: any metal or graphite or any molten ionic compound or any aqueous solution of an ionic compound or any aqueous acid or any aqueous alkali.

   An example of a non-conductor: any non-metal except graphite or any covalent substance or any solid ionic compound or any plastic.

3. **a)** An electrolyte is a liquid or solution that can conduct electricity and is formed when an ionic compound melts or dissolves in water.
   b) - Mobile electrons, present in the electron pool, carry the electric current through a metal. Mobile ions which are no longer held together by ionic bonds carry the electric current through an electrolyte.
   - A metal remains chemically unchanged when an electric current passes through. An electrolyte decomposes when an electric current passes through.

4. A strong electrolyte is fully ionised when it dissolves in water. A weak electrolyte is partially ionised when it dissolves in water.

   An example of a strong electrolyte: hydrochloric acid or any other strong acid, or sodium hydroxide or any other strong alkali, or sodium chloride solution or any other aqueous solution of an ionic compound.

   An example of a weak electrolyte: ethanoic acid or any other weak acid, or ammonia or any other weak alkali.

5. **a)** Electrolysis is the chemical change occurring when an electric current passes through an electrolyte.
   b) An anion is a negative ion formed when an atom or small group of atoms gains one or more electrons.
   c) A cation is a positive ion formed when an atom or small group of atoms loses one or more electrons.
   d) The anode is the positive electrode that is connected to the positive terminal of the power supply.
   e) The cathode is the negative electrode that is connected to the negative terminal of the power supply.

6. - The type of anode, i.e. whether the anode is inert or active.
   - The concentration of the electrolyte, particularly if the solution contains halide ions.
   - The position of the ion in the electrochemical series.

7. Ions present:
   From H_2SO_4: $H^+(aq)$, $SO_4^{2-}(aq)$
   From H_2O: $H^+(aq)$, $OH^-(aq)$
   At the anode:
   The OH^- ions are preferentially discharged because they are lower in the electrochemical series than the SO_4^{2-} ions:

   $4OH^-(aq) \longrightarrow 2H_2O(l) + O_2(g) + 4e^-$

   Effervescence occurs as oxygen gas is evolved.
   At cathode:
   H^+ ions are discharged:

   $2H^+(aq) + 2e^- \longrightarrow H_2(g)$

   Effervescence occurs as hydrogen gas is evolved.
   Changes in the electrolyte:
   The electrolyte becomes more concentrated because H^+ and OH^- ions are removed leaving H^+ and SO_4^{2-} ions in excess, i.e. water is removed.

8. Ions present in both solutions:
   From NaCl: $Na^+(aq)$, $Cl^-(aq)$
   From H_2O: $H^+(aq)$, $OH^-(aq)$

   At the anode when electrolysing dilute sodium chloride solution:

   The OH^- ions are preferentially discharged because they are lower in the electrochemical series than the Cl^- ions.

   $4OH^-(aq) \longrightarrow 2H_2O(l) + O_2(g) + 4e^-$

   Effervescence occurs as oxygen gas is evolved.

   At the anode when electrolysing concentrated sodium chloride solution:

   The Cl^- ions are preferentially discharged because they are halide ions in a concentrated solution.

   $2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$

Effervescence occurs as chlorine gas is evolved.

At the cathode when electrolysing both solutions:

The H^+ ions are preferentially discharged because they are lower in the electrochemical series than the Na^+ ions:

$2H^+(aq) + 2e^- \longrightarrow H_2(g)$

Effervescence occurs as hydrogen gas is evolved.

9. The Faraday constant is the size of the electrical charge on one mole of electrons. It has a value of 96 500 C mol^{-1}.

10. Time = (48 × 60) + 15 s
= 2895 s

Quantity of electricity = 8.0 × 2895 C
= 23 160 C

a) $4OH^-(aq) \longrightarrow 2H_2O(aq) + O_2(g) + 4e^-$
1 mol 4 mol

4 mol electrons are lost in forming 1 mol O_2
∴ 4 × 96 500 C form 1 mol O_2
i.e. 386 000 C form 1 mol O_2
∴ 23 160 C form $\frac{1}{386\,000} \times 23\,160$ mol O_2
= 0.06 mol O_2
Volume of 1 mol O_2 at rtp = 24.0 dm^3
∴ volume of 0.06 mol O_2 = 0.06 × 24.0 dm^3
= **1.44 dm^3**

b) $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$
2 mol 1 mol
2 mol electrons are required to form 1 mol Cu
∴ 2 × 96 500 C form 1 mol Cu
i.e. 193 000 C form 1 mol Cu
∴ 23 160 C form $\frac{1}{193\,000} \times 23\,160$ mol Cu
= 0.12 mol Cu

Mass of 1 mol Cu = 64 g
∴ mass of 0.12 mol Cu = 0.12 × 64 g
= **7.68 g**

11. Volume of 1 mol Cl_2 at stp = 22 400 cm^3
∴ number of moles in 112 cm^3 Cl_2 = $\frac{112}{22\,400}$ mol
= 0.005 mol

$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$
1 mol 2 mol

2 mol electrons are lost in forming 1 mol Cl_2
∴ 2 × 96 500 C form 1 mol Cl_2
i.e. 193 000 C form 1 mol Cl_2
∴ 0.005 × 193 000 C form 0.005 mol Cl_2
= 965 C

Quantity of electricity = current × time
965 C = 0.5 × time
∴ time = $\frac{965}{0.5}$ s
= **1930 s**
= **32 minutes 10 seconds**

12. a) At the anode: $Ag(s) \longrightarrow Ag^+(aq) + e^-$
At the cathode: $Ag^+(aq) + e^- \longrightarrow Ag(s)$

b) Time = (4 × 60 × 60) + (17 × 60) + 20 s
= 15 440 s
Quantity of electricity = 2.5 × 15 440 C
= 38 600 C

$Ag^+(aq) + e^- \longrightarrow Ag(s)$
1 mol 1 mol

1 mol electrons is required to form 1 mol Ag
∴ 96 500 C form 1 mol Ag
and 38 600 C form $\frac{1}{96\,500} \times 38\,600$ mol Ag
= 0.4 mol Ag

Mass of 1 mol Ag = 108 g
∴ mass of 0.4 mol Ag = 0.4 × 108 g
= **43.2 g**

13. A pure lump of nickel would be used as the anode, the spoon would be placed as the cathode and the nickel sulfate solution would be used as the electrolyte.

Nickel atoms from the anode ionise and the Ni^{2+} ions enter the electrolyte:

$Ni(s) \longrightarrow Ni^{2+}(aq) + 2e^-$

Ni^{2+} ions are preferentially discharged at the cathode forming a coating of nickel on the spoon:

$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$

14. Anodising is used to increase the thickness of an unreactive oxide layer on the surface of a metal. It is usually used to increase the thickness of the aluminium oxide layer on the surface of aluminium objects. The cleaned aluminium object is placed as the anode and dilute sulfuric acid is usually used as the electrolyte. The aluminium anode ionises to form Al^{3+} ion and, at the same time, the SO_4^{2-} ions and OH^- ions in the electrolyte move towards the anode. The Al^{3+} ions react with the OH^- ions and form a layer of aluminium oxide on the surface of the aluminium object.

12 Rates of reaction

1. The rate of reaction is a measured change in the concentration of a reactant or product with time at a given temperature.

2. During a chemical reaction the particles of the reactants must collide with each other so that the bonds in the reactants can be broken and new bonds can form in the products. For the bonds in the reactants to break, the collisions must occur with sufficient energy. The reactant particles must also collide with the correct orientation so that the bonds can break and reform in the required way.

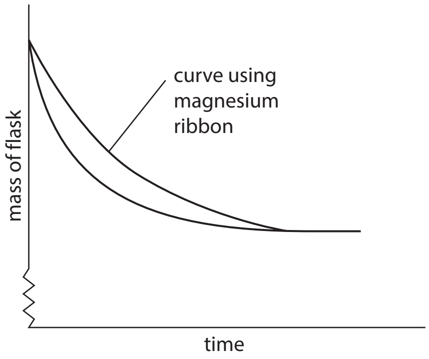
3. a) The rate of a reaction decreases as the reaction progresses until it eventually stops.

b) The reaction is fastest at the beginning because the concentration of the reactant particles is at its highest, so the frequency of collision between particles is at its highest. As the reaction proceeds the rate decreases because the concentration of the reactant particles gradually decreases, causing the frequency of collision between the particles to gradually decrease. The reaction eventually reaches completion and stops because one reactant has been used up and there are no more of its particles left to collide.

4. - Concentration
- Temperature
- Surface area or particle size
- Presence or absence of a catalyst

5. **a)** Increasing the concentration of a reactant increases the rate of a reaction because it increases the number of particles in a unit volume of solution. As a result, the particles collide more frequently which increases the chances of effective collisions.
   b) Increasing the temperature of a reaction increases its rate because it gives the reactant particles more kinetic energy. This causes the particles to move faster, so they collide more frequently. It also causes the particles to collide with more energy so more collisions take place with enough activation energy for the particles to react. A combination of these two increases the chances of effective collisions.

6. **a)**



   b) The magnesium ribbon has a smaller total surface area than the magnesium filings, so has less area exposed to the hydrochloric acid. As a result the particles collide less frequently which reduces the chances of effective collisions.

7. The flour in a flour mill is flammable. A slight spark from a cigarette can start a reaction between the flour and the oxygen in the air which can be explosive because of the large surface area of the finely divided flour particles.

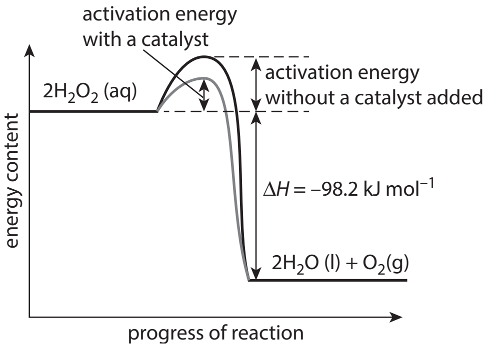
8. **a)** A catalyst alters the rate of a reaction without itself undergoing any permanent chemical change.
   b) The catalyst provides an alternative pathway that requires a lower activation energy than the normal pathway. As a result, more collisions occur with enough activation energy for the particles to react and this increases the chances of effective collisions.

13 Energetics

1. An exothermic reaction releases energy to its surroundings. An endothermic reaction absorbs energy from its surroundings.

2. In an exothermic reaction more energy is released when new bonds are formed in the products than is absorbed to break the existing bonds in the reactants. The extra energy is released to the surroundings.

3. **a)** The reaction is exothermic because the value of ΔH is less than zero, or ΔH is negative, indicating that it lost energy to the surroundings.
   b) The enthalpy of the reactant is greater than the total enthalpy of the products. The extra energy is released to the surroundings.
   c) and **d)**



4. A calorimeter.

5. heat change = mass of reactants × specific heat capacity × temperature change

6. - The density of a dilute aqueous solution is the same as pure water, i.e. 1 g cm^{-3}.
   - The specific heat capacity of a dilute aqueous solution is the same as pure water, i.e. 4.2 J g^{-1} °C^{-1}.
   - A negligible amount of heat is lost to, or absorbed from, the surroundings during the reaction.

7. **a)** Heat of solution is the heat change when 1 mol of solute dissolves in such a volume of solvent that further dilution by the solvent produces no further heat change.
   b) The reaction was endothermic because the temperature decreased, indicating it absorbed energy from its surroundings.
   c) Mass of 1 mol NH_4Cl = 14 + (4 × 1) + 35.5 g
   = 53.5 g

   $\therefore$ number of moles in 7.49 g = $\frac{7.49}{53.5}$ mol
   = 0.14 mol

   Volume of water = 100 cm^3
   $\therefore$ mass of water = 100 g
   Final mass of solution = 100 + 7.49 g
   = 107.49 g

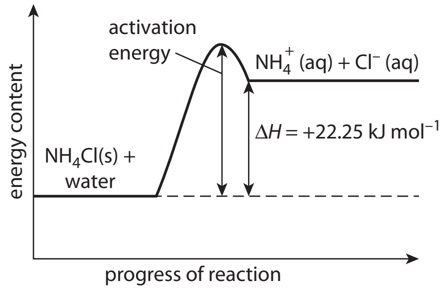
   Temperature decrease = 29.7 – 22.8 °C
   = 6.9 °C

   $\therefore$ heat absorbed in dissolving 0.14 mol NH_4Cl
   = 107.49 × 4.2 × 6.9 J
   = 3115 J

   and heat absorbed in dissolving 1 mol NH_4Cl = $\frac{3115}{0.14}$ J
   = 22 250 J
   = 22.25 kJ

   Heat of solution, ΔH = **+22.25 kJ mol^{-1}**

   d)



8. **a)** Heat of neutralisation is the heat change when 1 mol of water is produced in a neutralisation reaction between an alkali and an acid.

b) The heat of neutralisation for the two reactions has the same value because the energy change is for the reaction occurring between the OH^- ions of the alkali and the H^+ ions of the acid in both cases, as shown in the ionic equation:

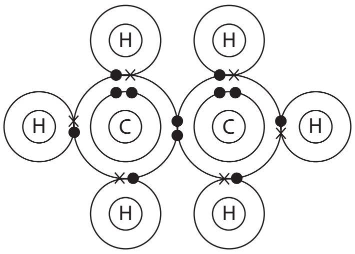
$OH^-(aq) + H^+(aq) \longrightarrow H_2O(l)$

14 Organic chemistry – an introduction

1. Organic compounds are compounds which contain carbon. Most also contain hydrogen, many contain oxygen and some also contain other elements.

2. a) A carbon atom has four valence electrons, so can form four covalent bonds with other carbon atoms or atoms of other elements.

b)



3. a) A functional group is part of an organic molecule composed of a particular atom, group of atoms, or bond between adjacent carbon atoms. The chemical properties of a compound are determined by the reactions of the functional group.

b) A fully displayed structural formula shows the arrangement of atoms in one molecule of a compound in two-dimensional diagrammatic form.

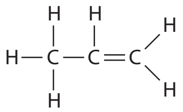
c) A homologous series is a group of organic compounds which all possess the same functional group and can be represented by the same general formula.

4. a) *Any four of the following:*
- All members have the same functional group.
- All members can be represented by the same general formula.
- Each member differs from the member before or after it by a —CH_2— group, and by relative molecular mass of 14.
- All members possess similar chemical properties, however the reactivity decreases as the number of carbon atoms per molecule increases or as the molar mass increases.
- Members show a gradual change in their physical properties as the number of carbon atoms per molecule increases. In general, melting point, boiling point and density increase as molar mass increases.
- All members can be prepared using the same general method.

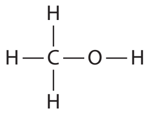
b) The first part of the name depends on the total number of carbon atoms in one molecule and the second part of the name depends on the functional group present.

5. a) $C_nH_{2n+1}OH$
b) C_nH_{2n}
c) $C_nH_{2n+1}COOH$
d) C_nH_{2n+2}

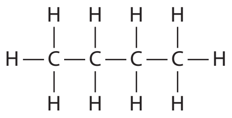
6. a) Propene



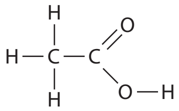
b) Methanol



c) Butane



d) Ethanoic acid



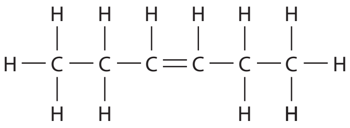
7. a) Homologous series: Alcohol
Name: Pentanol
b) Homologous series: Alkane
Name: Ethane
c) Homologous series: Alkanoic acid
Name: Propanoic acid
d) Homologous series: Alkene
Name: Butene

8. Structural isomerism is the occurrence of two or more organic compounds with the same molecular formula but different structural formulae.

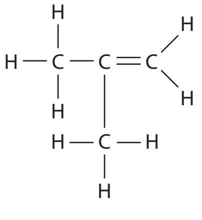
9. a) 2-methylbutane
b) pent-1-ene or 1-pentene
c) propan-2-ol or 2-propanol

10.

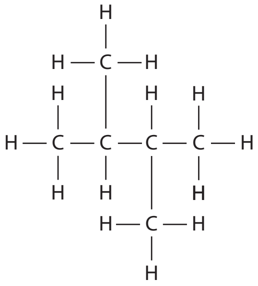
a)



b)



c)



15 Sources of hydrocarbon compounds

1. Hydrocarbons are organic compounds composed of carbon and hydrogen atoms only.

2. - Natural gas
- Petroleum

3. Impurities are removed from the petroleum and it is heated to about 400 °C which produces a mixture of liquid and vapour. This mixture is piped into the bottom part of a fractionating tower and the viscous liquid fraction, known as bitumen or asphalt, sinks to the bottom of the tower and is tapped off. The vapours rise up the tower and pass through bubble caps and trays where they may condense. The temperature of the tower decreases upwards and the lower the boiling point of the hydrocarbon, the further the vapour will rise before condensing. The liquids produced by condensation of the vapours are tapped off at the different levels and the gases that do not condense are removed at the top of the tower as refinery gas.

4. *Any four of the following:*
- Refinery gas
  Use: As fuel for domestic use or to manufacture various petrochemicals.
- Petrol or gasoline
  Use: As fuel for internal combustion engines.
- Naphtha
  Use: To manufacture various petrochemicals.
- Kerosene or paraffin oil
  Use: As fuel for jet engines or for cooking or for heating or for lighting.
- Diesel oil
  Use: As fuel for diesel engines.
- Fuel oils
  Use: As fuel for ships or for factories or for power stations or for heating.
- Lubricating oils and waxes
  Use: As lubricants in machinery and vehicle engines, or used to make polishing waxes or petroleum jelly or candles.
- Bitumen or asphalt
  Use: For surfacing roads or car parks or airport runways, or for roofing.

5. a) During cracking, long-chain hydrocarbon molecules are broken down into shorter chain hydrocarbon molecules by breaking carbon–carbon bonds.

b) - Cracking increases the production of the smaller, more useful hydrocarbons, such as petrol. Fractional distillation produces insufficient of these smaller molecules to meet current demands.
- Cracking produces the very reactive alkenes which are used in the petrochemical industry to manufacture many other useful organic compounds. Fractional distillation does not produce alkenes, whereas cracking always results in the formation of at least one alkene.

6. $C_5H_{12} \longrightarrow \underset{\text{methane}}{CH_4} + \underset{\text{butene}}{C_4H_8}$

$C_5H_{12} \longrightarrow \underset{\text{ethane}}{C_2H_6} + \underset{\text{propene}}{C_3H_6}$

$C_5H_{12} \longrightarrow \underset{\text{propane}}{C_3H_8} + \underset{\text{ethene}}{C_2H_4}$

16 Reactions of carbon compounds

1. A saturated hydrocarbon only has single bonds between adjacent carbon atoms. An unsaturated hydrocarbon has at least one double bond between adjacent carbon atoms.

2. a) Ethane burning in air:

$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(g)$

Ethene burning in air:

$C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(g)$

b) Ethene would produce the smokiest flame. Ethene has a higher ratio of carbon to hydrogen atoms in its molecules than ethane. Not all the carbon is converted to carbon dioxide and the unreacted carbon remains giving the flame a yellow, smoky appearance.

3. $CH_4(g) + Cl_2(g) \longrightarrow CH_3Cl(g) + HCl(g)$

$CH_3Cl(g) + Cl_2(g) \longrightarrow CH_2Cl_2(l) + HCl(g)$

$CH_2Cl_2(l) + Cl_2(g) \longrightarrow CHCl_3(l) + HCl(g)$

$CHCl_3(l) + Cl_2(g) \longrightarrow CCl_4(l) + HCl(g)$

Type of reaction: Substitution

4. Alkenes are more reactive than alkanes because they each contain one carbon–carbon double bond, whereas alkanes contain only carbon–carbon single bonds. One of the bonds in each double bond of alkene molecules can break, enabling them to bond with atoms of other elements.

5. Reaction with hydrogen:

a) Addition reaction
b) Catalyst of nickel
Pressure of 5 atm
Temperature of 150 °C
c) Ethane
d) $C_2H_4(g) + H_2(g) \longrightarrow C_2H_6(g)$

Reaction with water:

a) Addition reaction
b) Water must be in the form of steam
Catalyst of phosphoric acid in sand
Pressure of 70 atm
Temperature of 300 °C
c) Ethanol
d) $C_2H_4(g) + H_2O(g) \longrightarrow C_2H_5OH(l)$

6. *Any one of the following:*
- Add bromine solution to each under standard laboratory conditions. The solution would remain red–brown with ethane and would change colour rapidly from red–brown to colourless with ethene.

  $C_2H_4(g) + Br_2(g) \longrightarrow C_2H_4Br_2(l)$

- Add acidified potassium manganate(VII) to each. The solution would remain purple with ethane and would change colour rapidly from purple to colourless with ethene.

  $C_2H_4(g) + H_2O(l) + [O] \longrightarrow C_2H_4(OH)_2(l)$

7. Alkanes:
- Alkanes are used as fuels.
- Alkanes are used as solvents.

Alkenes:
- Alkenes are used as starting materials in the manufacture of many chemicals such as alcohols, haloalkanes, antifreezes and synthetic rubbers.
- Alkenes are used to manufacture many plastics.

8. a) Hydroxyl group
Formula: —OH

b) Carboxyl group
Formula: —COOH

c) Ester group
Formula: —COO—

9. a) Ethanol molecules are polar because they possess the polar —OH group which causes the forces of attraction between ethanol molecules to be stronger than between the non-polar ethane molecules.

b) Ethanol is soluble in water because both ethanol and water molecules are polar, and polar solutes dissolve in polar solvents.

10. a) Ethene
b) Dehydration

11. The breathalyser test is used to determine the alcohol content of a driver's breath. The driver blows over orange acidified potassium dichromate(VI) crystals. If ethanol vapour is present in the driver's breath, it reduces the orange dichromate(VI) ion ($Cr_2O_7^{2-}$) to the green chromium(III) ion (Cr^{3+}), which turns the crystals green.

12. a) Fermentation or anaerobic respiration
b) Yeast
c) Air should not come into contact with wine because certain aerobic bacteria can oxidise the ethanol to ethanoic acid, or vinegar, causing the wine to become sour.

13. a) $2Al(s) + 6CH_3COOH(aq) \longrightarrow 2(CH_3COOH)_3Al(aq) + 3H_2(g)$

b) $Ca(OH)_2(s) + 2CH_3COOH(aq) \longrightarrow (CH_3COOH)_2Ca(aq) + 2H_2O(l)$

c) $ZnO(s) + 2CH_3COOH(aq) \longrightarrow (CH_3COOH)_2Zn(aq) + H_2O(l)$

d) $MgCO_3(s) + 2CH_3COOH(aq) \longrightarrow (CH_3COOH)_2Mg(aq) + CO_2(g) + H_2O(l)$

14. a) $CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$
Conditions required: Concentrated sulfuric acid and heat
b) Condensation reaction.

15. a) Ethyl propanoate
b) Butyl methanoate
c) Methyl butanoate
d) Propyl ethanoate

16. a) $C_3H_7COOC_3H_7$
b) $C_2H_5COOCH_3$
c) $CH_3COOC_4H_9$
d) $HCOOC_2H_5$

17. Animal fats and vegetable oils are boiled with concentrated potassium or sodium hydroxide solution. This causes the large ester molecules found in the fats and oils to undergo alkaline hydrolysis and produce soap which is the potassium or sodium salt of a long-chain alkanoic acid (fatty acid). The reaction also produces the alcohol, glycerol.

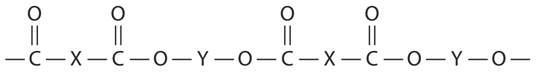
18. *Any three of the following:*
- Soapy detergents are made from fats and oils. Soapless detergents are made from petroleum.
- Soapy detergents do not lather easily with hard water, instead they form scum. Soapless detergents lather easily in hard water and do not form scum.
- Soapy detergents are biodegradable so they do not form foam on waterways or in sewage systems. Some soapless detergents are non-biodegradable and form foam on waterways and in sewage systems.
- Soapy detergents do not contain phosphates so do not cause eutrophication in aquatic environments. Some soapless detergents contain phosphates which cause eutrophication.

17 Polymers

1. A polymer is a macromolecule formed by linking together 50 or more small molecules, known as monomers, usually in chains.

2.
- The polymer is the only product of addition polymerisation. The polymer and another compound made of small molecules are produced by condensation polymerisation.
- The polymer produced by addition polymerisation is made from monomers which are all the same. The polymer produced by condensation polymerisation is often made from more than one type of monomer.
- The empirical formula of the polymer produced by addition polymerisation is the same as the monomer from which it was formed. The empirical formula of the polymer produced by condensation polymerisation is different from the monomers from which it was formed.

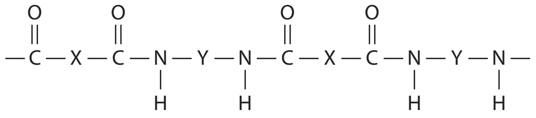
3. a)



$$-\overset{\overset{O}{\|}}{C}-X-\overset{\overset{O}{\|}}{C}-O-Y-O-\overset{\overset{O}{\|}}{C}-X-\overset{\overset{O}{\|}}{C}-O-Y-O-$$

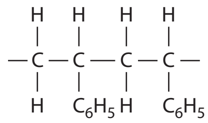
Type of polymer: Polyester
Type of linkage: Ester linkage

b)



$$-\overset{\overset{O}{\|}}{C}-X-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{N}-Y-\underset{\underset{H}{|}}{N}-\overset{\overset{O}{\|}}{C}-X-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{N}-Y-\underset{\underset{H}{|}}{N}-$$

Type of polymer: Polyamide
Type of linkage: Amide linkage or peptide linkage

c) 

$$-\underset{H}{\overset{H}{C}}-\underset{C_6H_5}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{C_6H_5}{\overset{H}{C}}-$$

Type of polymer: Polyalkene
Type of linkage: Alkane linkage

4. —O—X—O—X—O—X—

5. a) *Any one of the following:*

- Polyethene
  Any two of the following uses:
  To make plastic bags.
  To make plastic bottles.
  To make washing up bowls.
  To make buckets.
  To make packaging for food.
  To make cling film.
- Polychloroethene or polyvinyl chloride
  Any two of the following uses:
  To make water and sewer pipes.
  To make guttering.
  To make window and door frames.
  To make insulation for electrical wires and cables.
- Polypropene
  Any two of the following uses:
  To make ropes.
  To make carpets.
  To make plastic toys.
  To make plastic food containers.
  To make furniture.
- Polystyrene or Styrofoam
  Any two of the following uses:
  To make containers for fast food and drinks.
  To make packaging materials.
  To make insulation materials.

b) Polyethylene terephthalate or Terylene or Dacron
Two uses:
To make PET bottles for soft drinks.
To make fibres which are used to make clothing or boat sails or carpets or fibre filling for winter clothing, sleeping bags and pillows.

c) Protein
Two uses:
To build body cells, hair and nails.
To make enzymes or antibodies.

6. a) Nylon

Use: To make fibres which are used to make fishing lines and nets or ropes or carpets or parachutes or clothing, especially if stretch is required.

b) *Any one of the following:*

- Starch or glycogen
  Use: Stored as a food reserve in living organisms.
- Cellulose
  Use: To build plant cell walls.

18 Characteristics of metals

1. *Any four of the following:*

- Metals have high melting and boiling points.
- Metals are solid at room temperature (except mercury).
- Metals are good conductors of electricity and heat.
- Metals are malleable and ductile.
- Metals are shiny in appearance.
- Metals have high densities.

2. When a metal reacts it behaves as a reducing agent because it ionises by losing electrons. These electrons are given to the other reactant, so it causes the other reactant to gain electrons.

3.

- Metals react with dilute hydrochloric acid and dilute sulfuric acid to form a salt and hydrogen.
- Metals react with oxygen to form metal oxides.
- Metals react with water or steam. When a metal reacts with water it forms the metal hydroxide and hydrogen. When a metal reacts with steam it forms the metal oxide and hydrogen.

4. a) $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
Products: zinc chloride and hydrogen

b) $2Na(s) + 2H_2O(l) \longrightarrow 2NaOH + H_2(g)$
Products: sodium hydroxide and hydrogen

c) $Mg(s) + H_2O(g) \longrightarrow MgO(s) + H_2(g)$
Products: magnesium oxide and hydrogen

d) $4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$
Product: Aluminium oxide

5.

- $CaO(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l)$
- $Ca(OH)_2(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l)$
- $CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

6. a) Copper(II) carbonate decomposes to form copper(II) oxide and carbon dioxide.
$CuCO_3(s) \longrightarrow CuO(s) + CO_2(g)$

b) Lead(II) nitrate decomposes to form lead(II) oxide, nitrogen dioxide and oxygen.
$2Pb(NO_3)_2(s) \longrightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$

c) Sodium carbonate does not decompose when heated.

d) Magnesium hydroxide decomposes to form magnesium oxide and water as steam.
$Mg(OH)_2(s) \longrightarrow MgO(s) + H_2O(g)$

e) Potassium nitrate decomposes to form potassium nitrite and oxygen.
$2KNO_3(s) \longrightarrow 2KNO_2(s) + O_2(g)$

f) Sodium hydroxide does not decompose when heated.

19 The reactivity, extraction and uses of metals

1. How vigorously the metals react with dilute hydrochloric or sulfuric acid, oxygen and water, how easily compounds of the metals are decomposed when heated and whether or not a metal will displace another metal from its compounds.

2. **a)** Sodium, magnesium, aluminium, zinc, X, copper, silver.
   b) $X(s) + Cu(NO_3)_2(aq) \longrightarrow X(NO_3)_2(aq) + Cu(s)$
   c) X is higher in the reactivity series than copper, therefore is more reactive than copper. X ionises to form X^{2+} ions and the Cu^{2+} ions are discharged to form copper atoms.
   X is lower in the reactivity series than zinc, therefore is less reactive than zinc. X does not ionise and the Zn^{2+} ions are not discharged.

3. During the extraction of a metal, the metal cations are discharged to form atoms by gaining electrons, making it a reduction process.

4. Metal Y would be extracted by electrolysis of its molten ore. Metal Y is fairly high in the reactivity series so forms stable ions which are difficult to reduce. They require a powerful method of reduction, this being electrolysis.

   Metal Z would be extracted by heating its ore with a reducing agent such as carbon, carbon monoxide or hydrogen. Metal Z is lower in the reactivity series than Y so forms less stable ions which are easier to reduce. They require a less powerful method of reduction, this being heating the ore with a reducing agent.

5. **a)** Name: Bauxite
   Formula: $Al_2O_3.xH_2O$
   b) The bauxite is purified to form pure, anhydrous aluminium oxide or alumina. The alumina is dissolved in molten cryolite at about 950 °C. The molten mixture of alumina and cryolite is electrolysed in an electrolytic cell. The aluminium ions move towards the cathode and are reduced to form aluminium atoms.

   $$Al^{3+}(l) + 3e^- \longrightarrow Al(l)$$

   The molten aluminium collects at the bottom of the cell, is tapped off and made into blocks or sheets.

6. **a)** - $C(s) + O_2(g) \longrightarrow CO_2(g)$
   - $CO_2(g) + C(s) \longrightarrow 2CO(g)$
   - $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$

   b) Limestone is added to remove the impurity, silicon dioxide, from the iron ores. In the top part of the furnace the heat causes the calcium carbonate to decompose to form calcium oxide and carbon dioxide.

   $$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$$

   Calcium oxide, being basic, reacts with the silicon dioxide which is acidic, to form calcium silicate or slag.

   $$CaO(s) + SiO_2(s) CaSiO_3(l)$$

   The molten slag runs to the bottom of the furnace where it floats on the molten iron and is tapped off separately.

7. **a)** An alloy is a mixture of two or more metals. A few alloys also contain non-metals.
   b) Alloys are often used in place of the pure metal because they are usually harder, stronger and more resistant to corrosion than the pure metal.

8. **a)** *Any two of the following:*
   - Aluminium is resistant to corrosion.
   - Aluminium is malleable, so is easily shaped.
   - Aluminium is non-toxic.
   - Aluminium has a low density so is light in weight.

   b) - Lead is a good conductor of electricity.
   - Lead is very resistant to corrosion.

   c) *Any two of the following:*
   - Stainless steel is much more resistant to rusting than carbon steels.
   - Stainless steel is malleable, ductile and easy to work with.
   - Stainless steel has a very shiny, attractive appearance.

   d) - Solder has a low melting point so melts easily when joining metals.
   - Solder is as resistant to corrosion as lead, but harder and stronger.

20 Impact of metals on living systems and the environment

1. The surface of a metal is gradually worn away by reacting with chemicals in the environment, mainly oxygen, moisture and certain pollutants.

2. Oxygen and moisture.

3. When aluminium corrodes it forms a layer of aluminium oxide which is relatively unreactive and adheres to the metal surface. This layer protects the aluminium from further corrosion since it does not flake off. When iron corrodes it forms hydrated iron(III) oxide or rust. Rust does not adhere to the iron, it flakes off and this exposes fresh iron to oxygen and moisture in the air. The exposed iron then rusts and the rust flakes off. The process continues and the iron is gradually worn away.

4. **a)** Magnesium is essential for green plants to produce the green pigment, chlorophyll. Chlorophyll is essential for the plants to absorb sunlight energy so that they can manufacture their own food by photosynthesis. Magnesium ions also help many enzymes in the human body to function.
   b) Iron is essential for animals to produce the red pigment, haemoglobin, found in red blood cells. Haemoglobin is necessary to carry oxygen around the body for the body cells to use in respiration to produce energy.
   c) Calcium is essential for animals to produce calcium hydroxyapatite which is the main constituent of bones and teeth. This keeps bones and teeth strong and healthy.
   d) Zinc is important for the functioning of the immune system, for wounds to heal, and for the growth and repair of cells and tissues.

5. Minamata disease is caused by ingesting mercury. When mercury enters the environment as a pollutant it persists in the environment and becomes higher in concentration

moving up food chains until it reaches harmful levels in top consumers, including tuna. If tuna are then consumed by humans this can lead to Minamata disease.

6. **a)** Lead damages various body tissues and organs including the kidneys, liver, bones and nervous system, particularly the brain. It also interferes with the normal formation of red blood cells which leads to anaemia and is particularly harmful to young children since it reduces IQ, and causes behavioural problems and learning disorders.

b) Arsenic causes changes in pigmentation and thickening of the skin, can cause cancer and damages the nervous system, heart, lungs and blood vessels.

c) Cadmium damages the respiratory system, liver and kidneys, and can cause bones to become weakened and fragile, leading to osteoporosis.

21 Non-metals

1. *Any four of the following:*
- Most non-metals have low melting and boiling points.
- Non-metals can be solid, liquid or gas at room temperature.
- Non-metals are poor conductors of electricity and heat (except graphite).
- Non-metals in the solid state are weak and brittle.
- Non-metals in the solid state are dull in appearance.
- Non-metals usually have low densities.

2. Non-metals behave as oxidising agents when they react with metals.

When a non-metal reacts with a metal it ionises by gaining electrons. These electrons are removed from the metal, so it causes the metal to lose electrons.

3. - Hydrogen behaves as an oxidising agent when it reacts with metals to form metal hydrides. For example, it reacts with magnesium to form magnesium hydride.

$$Mg(s) + H_2(g) \longrightarrow MgH_2(g)$$

- Hydrogen behaves as a reducing agent when it reacts with oxygen to form water as steam.

$$2H_2(g) + O_2(g) \longrightarrow H_2O(g)$$

Or

Hydrogen behaves as a reducing agent when it reacts with chlorine to form hydrogen chloride:

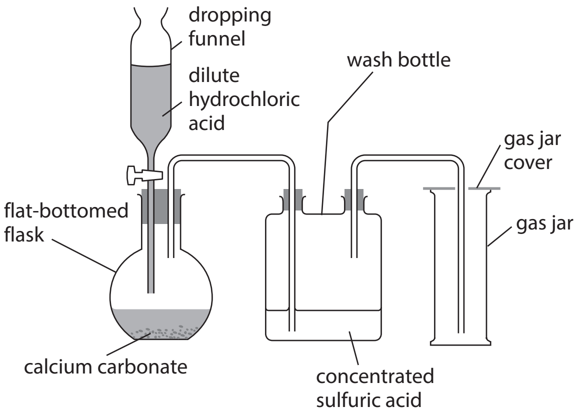
$$H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$$

Or

Hydrogen behaves as a reducing agent when it reacts with metal oxides and reduces the metal ions to atoms. For example, it reacts with lead(II) oxide to form lead and water.

$$PbO(s) + H_2(g) \longrightarrow Pb(s) + H_2O(l)$$

4. **a)**



b) Anhydrous calcium chloride.

c) Carbon dioxide is denser than air so it sinks in the gas jar and displaces the air upwards.

5. *Any three of the following:*

- In fire extinguishers
  Any one of the following reasons:
  Carbon dioxide is non-flammable.
  Carbon dioxide is denser than air so it sinks and smothers the flames, and keeps out oxygen
- To make carbonated soft drinks.
  Any one of the following reasons:
  Carbon dioxide dissolves in the drink under pressure and bubbles out when pressure is released.
  Carbon dioxide adds a pleasant tingle and taste to the drink.
- As a refrigerant when in the solid state.
  Carbon dioxide sublimes at −78.5 °C so keeps frozen food items extremely cold and does not leave a liquid residue when it sublimes to a gas.
- As an aerosol propellant for certain food items.
  Carbon dioxide is relatively inert so does not react with the food items.

6. **a)** Sulfur
The rubber is hardened.

b)
- Sulfur
  Ammonium sulfate
- Phosphorus
  Ammonium phosphate
- Nitrogen
  Ammonium nitrate or ammonium sulfate or ammonium phosphate

7. **a)** *Any two of the following:*
- Diamond is used to cut and engrave glass and other diamonds.
- Diamond is used in jewellery
- Diamond is used in the tips of drills.
- Carbon fibres are used to make carbon-fibre reinforced plastic which is used to make sporting equipment and in the aerospace and automotive industries.
- Graphite is used to make the lead in pencils.
- Graphite is used as a solid lubricant.
- Graphite is used to make electrodes which are used in industry.

b) *Any two of the following:*
- Chlorine is used to make antiseptics.
- Chlorine is used to make dry-cleaning fluids.
- Chlorine is used to treat drinking water to kill bacteria.
- Chlorine is used to make insecticides.
- Chlorine is used to make sodium chlorate(I) and calcium chlorate(I) which are used to sterilise drinking and swimming pool water, as bleaching agents and disinfectants.

c) *Any two of the following:*
- Nitrogen is used as a refrigerant to quick freeze foods.
- Nitrogen is used in food packaging to provide an inert atmosphere which prevents decay.
- Nitrogen is used to manufacture ammonia which is used in household cleaners and to make fertilisers.

d)
- Silicon is used to make silicon chips which are used in electronic devices such as computers.
- Silicon is used to make silicone implants for plastic and reconstructive surgery.

8. a) Sulfur dioxide causes respiratory problems and reduces the growth of plants. It dissolves in rainwater forming acid rain which decreases the pH of the soil, damages plants, harms animals, corrodes buildings, and causes lakes, streams and rivers to become acidic and unsuitable for aquatic organisms. It also combines with water vapour and smoke, forming smog, which causes respiratory problems.

b) Carbon dioxide builds up in the upper atmosphere enhancing the greenhouse effect and global warming, which is causing polar ice caps and glaciers to melt, sea levels to rise, low-lying coastal areas to flood, changes in global climate and more severe weather patterns to develop. Some is also absorbed by oceans causing ocean acidification which is expected to affect the ability of shellfish to produce their shells and of reef building corals to produce their skeletons.

c) Clorofluorocarbons break down the ozone layer in the upper atmosphere allowing more ultraviolet light to reach the Earth's surface which is leading to more people developing skin cancer, cataracts and depressed immune systems.

d) Nitrate ions cause eutrophication which is the rapid growth of green plants and algae in lakes, ponds and rivers. This causes the water to turn green and the plants and algae then begin to die and are decomposed by aerobic bacteria which multiply and use up the dissolved oxygen. This causes other aquatic organisms, such as fish, to die.

22 Water

1. Water has unique properties because its molecules are polar and the hydrogen bonds between the water molecules are generally stronger than the intermolecular forces between other molecules.

2. a) As water cools to 4 °C it contracts and becomes denser. However, as it cools below 4 °C it expands and becomes less dense and it continues to expand until it freezes at 0 °C, so ice at 0 °C floats on the denser, warmer water as it forms.

b) A lot of heat energy is required to change liquid water to water vapour, so when water in sweat evaporates from the surface of an organism it removes a lot of heat energy from the organism which cools it down.

3.
- The bodies of living organisms contain between 60% and 70% water and, because water has a high specific heat capacity, organisms can absorb a lot of heat energy without their body temperatures changing very much, so can survive in extremes of temperature.
- Because water has a high specific heat capacity, as atmospheric temperatures change, the temperatures of large bodies of water such as lakes and seas do not change very much, so aquatic organisms do not experience extreme fluctuations in the temperature of their environment.

4. a)
- It dissolves chemicals in the cells of organisms so that chemical reactions can occur.
- It dissolves useful substances so they can be absorbed into the bodies of organisms and transported around their bodies.
- It dissolves waste and harmful substances so that they can be excreted from organisms.

b)
- It can become hard.
- It can become polluted.
- Mineral salts can be leached out of the soil making it less fertile.

5. a) Hard water is water that does not lather easily with soap.

b) Dissolved calcium and magnesium hydrogencarbonates and sulfates cause water to become hard.

6. a) Boiling causes dissolved calcium hydrogencarbonate and magnesium hydrogencarbonate to decompose. The insoluble carbonates precipitate out, thereby removing the Ca^{2+} and Mg^{2+} ions.

$$Ca(HCO_3)_2(aq) \longrightarrow CaCO_3(s) + H_2O(l) + CO_2(g)$$

b) Sodium carbonate causes dissolved Ca^{2+} or Mg^{2+} ions to precipitate out as insoluble calcium carbonate and magnesium carbonate:

$$Ca(HCO_3)_2(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + 2NaHCO_3(aq)$$

Or

$$CaSO_4(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + Na_2SO_4(aq)$$

c) Water is slowly passed through an ion-exchange column in a water-softening device which contains an ion-exchange resin called zeolite. The Ca^{2+} or Mg^{2+} ions displace the Na^+ ions in the zeolite and are absorbed into the zeolite. The displaced Na^+ ions enter the water but do not cause it to be hard

$$Ca^{2+}(aq) + Na_2Z(s) \longrightarrow CaZ(s) + 2Na^+(aq)$$

7.
- Boiling
- Filtering
- Chlorinating

23 Green Chemistry

1. Green Chemistry is the utilisation of a set of principles in the design, manufacture and application of chemical products that reduces or eliminates the use and generation of hazardous substances.
2. *Any four of the following:*
   - It reduces the use of energy.
   - It reduces pollution.
   - It reduces wastage.
   - It reduces the use of natural resources.
   - It produces safer consumer products.
   - It improves the competitiveness of chemical manufacturers.
3. *Any four of the following:*
   - Prevent waste.
   - Maximise atom economy.
   - Design less hazardous chemical syntheses.
   - Design safer chemicals and products.
   - Use safer solvents and auxiliaries.
   - Increase energy efficiency.
   - Use renewable feedstocks.
   - Reduce derivatives.
   - Use catalysts rather than stoichiometric reagents.
   - Design for degradation.
   - Analyse in real-time to prevent pollution.
   - Minimise the potential for accidents.

24 Qualitative analysis

1. a) The Al^{3+} ions reacted with the OH^- in the sodium hydroxide ions to form insoluble, white aluminium hydroxide.

$Al^{3+}(aq) + 3OH^-(aq) \longrightarrow Al(OH)_3(s)$

b) The precipitate dissolved because aluminium hydroxide is amphoteric so it reacted with the excess sodium hydroxide forming a soluble salt which dissolved.

2. a) The Fe^{2+} ion or the iron(II) ion.

b) The Fe^{2+} ions reacted with the OH^- ions in the aqueous ammonia to form insoluble, green iron(II) hydroxide.

$Fe^{2+}(aq) + 2OH^-(aq) \longrightarrow Fe(OH)_2(s)$

c) The precipitate remained because iron(II) hydroxide does not react with aqueous ammonia.

3. a) The brown gas was nitrogen dioxide and the gas that relit the glowing splint was oxygen.

b) The NO_3^- ion or the nitrate ion.

4. a) Sulfur dioxide.

b) The SO_3^{2-} ion or the sulfite ion.

c) Sulfur dioxide is a reducing agent so it reduced the purple MnO_4^- ion in the acidified potassium manganate(VII) to the colourless Mn^{2+} ion.

5. a) Make a solution of each compound in distilled water and add aqueous ammonia to each dropwise and then in excess. Look to see if the precipitate that initially forms remains or dissolves in the excess.
If the compound is lead(II) nitrate, a white precipitate forms and then remains in excess.

$Pb^{2+}(aq) + 2OH^-(aq) \longrightarrow Pb(OH)_2(s)$

If the compound is zinc nitrate, a white precipitate forms and dissolves in excess forming a colourless solution.

$Zn^{2+}(aq) + 2OH^-(aq) \longrightarrow Zn(OH)_2(s)$

b) Make a solution of each compound in distilled water, add a few drops of potassium iodide solution to each and look for the appearance of a precipitate.
If the compound is lead(II) nitrate, a bright yellow precipitate forms.

$Pb^{2+}(aq) + 2I^-(aq) \longrightarrow PbI_2(s)$

If the compound is aluminium nitrate, no precipitate forms and the solution remains colourless.

c) Add a few drops of concentrated sulfuric acid to a small amount of the solid in a dry test tube and test the gas evolved.
If the compound is potassium chloride, white fumes form when the gas is tested for hydrogen chloride by bringing a drop of concentrated ammonia solution close to it. If the compound is potassium iodide, a grey–black solid forms which sublimes to a purple vapour if heated.

Or

Make a solution of the solid in dilute nitric acid. Add a few drops of silver nitrate solution and observe the colour of the precipitate. Add aqueous ammonia and look to see if the precipitate dissolves.
If the compound is potassium chloride, a white precipitate forms which dissolves in aqueous ammonia forming a colourless solution.

$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$

If the compound is potassium iodide, a pale yellow precipitate forms which remains in aqueous ammonia.

$Ag^+(aq) + I^-(aq) \longrightarrow AgI(s)$

d) Make a solution of the solid in distilled water. Add a few drops of barium nitrate or chloride solution and observe the precipitate. Add dilute nitric or hydrochloric acid, heat if necessary, look to see if the precipitate dissolves and test any gas evolved.
If the compound is sodium sulfate a white precipitate forms which remains when acid is added.

$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$

If the compound is sodium sulfite, a white precipitate forms which dissolves in the acid on heating to form a gas which causes acidified potassium manganate(VII) solution to change from purple to colourless.

$Ba^{2+}(aq) + SO_3^{2-}(aq) \longrightarrow BaSO_3(s)$

$SO_3^{2-}(s) + 2H^+(aq) \longrightarrow SO_2(g) + H_2O(l)$

6. a) Place a lighted splint into the gas. If the gas is hydrogen the splint will make a squeaky pop and will be extinguished.

b) Place a piece of moist red litmus paper into the gas. If the gas is ammonia the litmus paper will turn blue.

Or

Bring a drop of concentrated hydrochloric acid near to the gas. If the gas is ammonia, white fumes will form.

c) Place a piece of moist blue litmus paper into the gas. If the gas is chlorine, the litmus paper will turn red and then be bleached white.

d) Place a piece of dry cobalt chloride paper into the gas. If the gas is water vapour, it will turn the paper from blue to pink.

Or

Pass the gas over some anhydrous copper(II) sulfate. If the gas is water vapour it will turn the copper(II) sulfate from white to blue.

7. W is carbon dioxide.

Limewater is calcium hydroxide solution and the carbon dioxide reacts with the calcium hydroxide to form a precipitate of insoluble, white calcium carbonate

$Ca(OH)_2(aq) + CO_2(g) \longrightarrow CaCO_3(s) + H_2O(l)$

The calcium carbonate then reacts with more carbon dioxide and water to form soluble calcium hydrogencarbonate which dissolves forming a colourless solution.

$CaCO_3(s) + H_2O(l) + CO_2(g) \longrightarrow Ca(HCO_3)_2(aq)$

Exam-style questions – Chapters 1 to 13

STRUCTURED QUESTIONS

1. a) i) A: melting
B: evaporation or boiling
C: freezing
D: condensation **(2 marks)**

ii) The particles gain kinetic energy and begin to move out of their fixed positions as the forces of attraction between them weaken. The particles begin to move around slowly and randomly with small spaces between them and the solid becomes a liquid. **(3 marks)**

iii) Carbon dioxide or iodine or naphthalene **(1 mark)**

b) i) Ammonium chloride. **(1 mark)**

ii) $NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$ **(1 mark)**

iii) The ring formed at S.
The ammonia particles diffused faster than the hydrogen chloride particles so the particles collided and reacted closer to the source of the hydrogen chloride, i.e. the cotton wool soaked in concentrated hydrochloric acid. **(3 marks)**

c) i) The particles in oxygen possess large amounts of kinetic energy and move around freely and rapidly so they spread out to fill every available space in the container and, as a result, the gas takes the shape of the container. **(2 marks)**

ii) The particles in the perfume diffuse from an area of high concentration which is around my sister, to an area of low concentration which is around me. Some of the particles diffuse into my nose enabling me to smell the perfume. **(2 marks)**

Total 15 marks

2. a) i) Solubility is the mass of solute that will saturate 100 g of solvent at a specified temperature. **(1 mark)**

ii) As temperature increases, the solubility of potassium dichromate(VI) increases. **(1 mark)**

iii) Solubility of potassium dichromate(VI) at 44.0 °C = 25 g per 100 g water **(1 mark)**

iv) At 62.0 °C, 40 g of potassium dichromate(VI) saturate 100 g water
At 26.0 °C, 14 g of potassium dichromate(VI) saturate 100 g water
∴ mass of potassium dichromate(VI) crystallising out of a solution containing 100 g water
= 40 – 14 g
= 26 g
and mass of potassium dichromate(VI) crystallising out of a solution containing 250 g water
= $\frac{26}{100} \times 250$ g
= 65 g **(3 marks)**

b) *Any two of the following:*
- The particles in a suspension are larger than those in a colloid.
  Or
  The particles in a suspension are visible to the naked eye, whereas the particles in a colloid are not visible, even with a microscope.
- If left undisturbed, the dispersed particles will settle in a suspension, whereas they will not settle in a colloid.
- Light does not pass through a suspension, whereas most colloids will scatter light.
  Or
  A suspension appears opaque, whereas a colloid appears either translucent or may be opaque.

(2 marks)

c) i) The mixture is heterogeneous because it is non-uniform. It is possible to distinguish the sand from the sea water. **(2 marks)**

ii) Apparatus: filter funnel, filter paper, conical flasks, distillation flask, thermometer, Liebig condenser
Method: Jason would line the filter funnel with filter paper, filter the mixture and collect the filtrate in a conical flask. He would wash the residue with distilled water and leave it to dry to obtain a dry sample of sand. He would pour the filtrate into the distillation flask and distil it, collecting the distillate that distils at 100 °C. The distillate would be pure water. **(5 marks)**

Total 15 marks

3. a) Electronic configuration of G is 2,8,5 **(1 mark)**

b) i) J would be more reactive than magnesium.
J ionises more easily than magnesium because its atoms have a larger atomic radius, so its valence electrons are further from the attractive pull of the positive nucleus and are more easily lost. **(3 marks)**

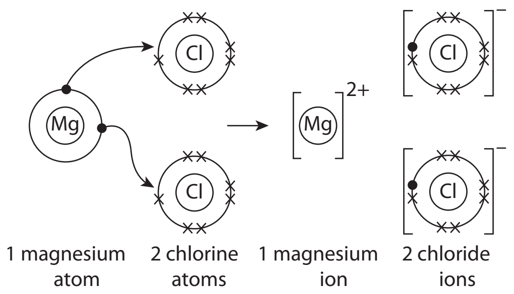
ii) $Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$ **(2 marks)**

c) Chlorine has a greater strength of oxidising power than Q. Chlorine ionises more easily than Q because its atoms have a smaller atomic radius so the attractive pull of the positive nucleus on the electron to be gained is stronger. Chlorine will, therefore, take electrons from the other reactant more readily than Q. **(3 marks)**

d) i) *Any one of the following pairs:*
- Magnesium and chlorine
- Magnesium and Q
- J and chlorine
- J and Q **(1 mark)**

ii) $MgCl_2$ or MgQ_2 or JCl_2 or JQ_2 **(1 mark)**

iii)



Or a similar diagram replacing 'Mg' and 'magnesium' with 'J' where appropriate, and replacing 'Cl', 'chlorine' and 'chloride' with 'Q' where appropriate.

(2 marks)

e) *Any two of the following:*

- J would be a solid at room temperature. Q would be a liquid at room temperature.
- J would have high melting and boiling points. Q would have low melting and boiling points.
- J would have a high density. Q would have a lower density.
- J would be a good conductor of electricity and heat. Q would be a poor conductor of electricity and heat.

(2 marks)

Total 15 marks

4. a) Table 1. Information about three particles

Particle	Atomic number	Number of			Group number	Period number
		protons	neutrons	electrons		
^{18}X	9	**9**	**9**	**9**	**VII**	**2**
^{19}X	**9**	9	**10**	9	**VII**	**2**
$^{27}Y^{3+}$	**13**	13	**14**	**10**		

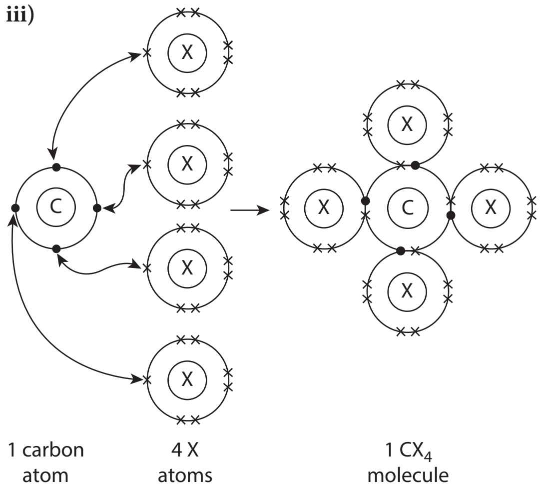
(5 marks)

b) ^{18}X and ^{19}X are isotopes. **(1 mark)**

c) i) A covalent compound **(1 mark)**

ii) CX_4 **(1 mark)**

iii)



(2 marks)

d) i) An ionic compound **(1 mark)**

ii) Formula of the compound is YX_3

Relative atomic mass of Y = 27

Relative atomic mass of ^{19}X = 19

Relative atomic mass of YX_3 = 27 + (3 × 19)

= 84 **(2 marks)**

iii) *Any two of the following:*

- CX_4 would have a low melting point. YX_3 would have a high melting point.
- CX_4 would be insoluble in water, but soluble in non-polar solvents. YX_3 would be soluble in water, but insoluble in non-polar solvents.
- CX_4 would not conduct electricity in any state. YX_3 would not conduct electricity when solid, but would conduct electricity when molten or dissolved in water. **(2 marks)**

Total 15 marks

5. a) i) Neutralisation point is the point in a neutralisation reaction where the OH^- ions from the alkali have fully reacted with the H^+ ions from the acid and neither ion is present in excess. **(2 marks)**

ii)
- Using an indicator.
- Using temperature change. **(2 marks)**

b) i)

	Titration number		
	Rough	**1**	**2**
Final burette reading/cm³	**14.7**	**16.4**	**15.9**
Initial burette reading/cm³	**0.3**	**2.1**	**1.6**
Volume of acid added/cm³	**14.4**	**14.3**	**14.3**

(3 marks)

ii) Volume of sulfuric acid needed = 14.3 cm³ **(1 mark)**

iii) Mass of 1 mol KOH = 39 + 16 + 1 g

= 56 g

∴ number of moles in 13.44 g KOH = $\frac{13.44}{56}$ mol

= 0.24 mol

Concentration of the potassium hydroxide solution = 0.24 mol dm⁻³ **(1 marks)**

iv) 1000 cm³ KOH(aq) contains 0.24 mol KOH

∴ 25.0 cm³ KOH(aq) contains $\frac{0.24}{1000} \times 25.0$ mol KOH

= 0.006 mol KOH **(1 mark)**

v) $2KOH(aq) + H_2SO_4(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$ **(2 marks)**

vi) 2 mol KOH reacts with 1 mol H_2SO_4

∴ 0.006 mol KOH reacts with $\frac{1}{2} \times 0.006$ mol H_2SO_4

= 0.003 mol H_2SO_4 **(1 mark)**

vii) 14.3 cm³ H_2SO_4(aq) contains 0.003 mol H_2SO_4

∴ 1000 cm³ H_2SO_4(aq) contains

$\frac{0.003}{14.3} \times 1000$ mol H_2SO_4

= 0.21 mol H_2SO_4

Molar concentration of the sulfuric acid = 0.21 mol dm⁻³ **(1 mark)**

c) *Any one of the following:*
- To neutralise stomach acid by taking antacid tablets.
- To neutralise acid in the mouth by brushing teeth with toothpaste.
- To neutralise acid in the soil by adding lime to the soil. **(1 mark)**

Total 15 marks

6. a) i)
- Volume of gas produced in the first minute
  $= 130\ \text{cm}^3$
  Rate in the first minute $= \frac{130}{60}\ \text{cm}^3\ \text{s}^{-1}$
  $= 2.167\ \text{cm}^3\ \text{s}^{-1}$
- Volume of gas produced in the second minute
  $= 200 - 130\ \text{cm}^3$
  $= 70\ \text{cm}^3$
  Rate in the second minute $= \frac{70}{60}\ \text{cm}^3\ \text{s}^{-1}$
  $= 1.167\ \text{cm}^3\ \text{s}^{-1}$

(2 marks)

ii) In the first minute the rate of reaction is high because there is a high concentration of reactant particles, so the frequency of collisions between the particles is high. In the second minute the rate of reaction is lower because the concentration of reactant particles has decreased, so the frequency of collision between the particles is lower. **(4 marks)**

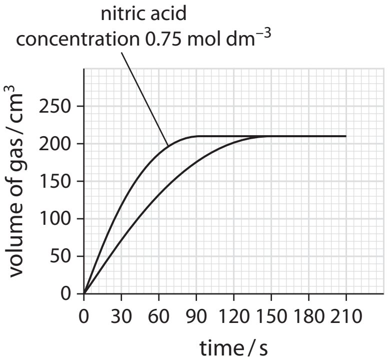
b) $CaCO_3(s) + 2HNO_3(aq) \longrightarrow$
$Ca(NO_3)_2(aq) + CO_2(g) + H_2O(l)$ **(2 marks)**

c) i) Volume evolved = 210 cm^3 **(1 mark)**

ii) Volume of 1 mol CO_2 at rtp = 24 000 cm^3
$\therefore$ number of moles in 210 cm^3 $CO_2 = \frac{210}{24\,000}$ mol
$= 0.00875$ mol

and 1 mol $CaCO_3$ forms 1 mol CO_2
$\therefore$ 0.00875 mol $CaCO_3$ forms 0.00875 mol CO_2
Mass of 1 mol $CaCO_3 = 40 + 12\ (3 \times 16)$ g
$= 100$ g
$\therefore$ mass of 0.00875 mol $CaCO_3 = 0.00875 \times 100$ g
$= 0.875$ g **(2 marks)**

d)



(2 marks)

e) The rate would increase because the powdered calcium carbonate would have a larger total surface area exposed to the nitric acid than the crystals. As a result, the frequency of collision of particles and chances of effective collisions would be higher. **(2 marks)**

Total 15 marks

EXTENDED-RESPONSE QUESTIONS

7. a) i) R is a metallic crystal
S is an ionic crystal
T is a simple molecular crystal
U is a giant molecular crystal **(2 marks)**

ii) R conducts electricity because each metal atom loses its valence electrons to a sea of delocalised electrons. These electrons are free to move and conduct electricity though the metal.
S does not conduct electricity in the solid state because the ions are held together by ionic bonds and cannot move. S conducts electricity when it is molten because the heat causes the ionic bonds between the ions to break, so the ions are free to move and conduct electricity. **(5 marks)**

iii) U has a high melting point because strong covalent bonds bond the atoms together throughout the structure and they require a lot of heat energy to break. **(2 marks)**

b) Each carbon atom in diamond is bonded covalently to four others throughout the structure. Because all the valence electrons form covalent bonds and they are not free to move, diamond does not conduct electricity. Because the covalent bonds between the atoms are strong, diamond is extremely hard.
Each carbon atom in graphite is bonded covalently to three others to form hexagonal rings of carbon atoms bonded together in layers. The layers are held together by weak forces of attraction and the fourth electron from each atom becomes delocalised. Because each carbon atom loses one valence electron to a sea of delocalised electrons which are free to move, graphite conducts electricity. Because the forces of attraction between the layers of carbon atoms are weak, the layers can easily slide over each other and flake off, making graphite soft and flaky. **(6 marks)**

Total 15 marks

8. a) i) A normal salt is formed when all of the H^+ ions in an acid have been replaced by metal or ammonium ions. An acid salt is formed when the H^+ ions in an acid have been only partially replaced by metal or ammonium ions. **(2 marks)**

ii) Formation of a normal salt:
$2NaOH(aq) + H_2SO_4(aq) \longrightarrow$
$Na_2SO_4(aq) + 2H_2O(l)$
Formation of an acid salt:
$NaOH(aq) + H_2SO_4(aq) \longrightarrow$
$NaHSO_4(aq) + 2H_2O(l)$ **(3 marks)**

b) i) Epsom salt has the following two uses:
- It is used for medicinal purposes, e.g. added to bath water it relieves stress and aches and pains or it reduces inflammation or it helps cure skin problems or it works as a laxative.
- It is used in agriculture to improve the growth of plants. **(2 marks)**

ii) Hydrated means that the salt contains water of crystallisation. **(1 mark)**

iii) The sulfuric acid would be placed in a beaker and the magnesium carbonate would be added until effervescence stops and excess carbonate is present. Blue litmus paper would be dipped into the solution to ensure it is neutral and the litmus paper should remain blue. The mixture would be filtered to remove the excess carbonate. The filtrate would be collected and heated over a beaker of boiling water to evaporate the water. **(3 marks)**

iv) $MgCO_3(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + CO_2(g) + H_2O(l)$

H_2SO_4: 50 cm³, 1.4 mol dm⁻³; $MgSO_4$: ? mass

1000 cm³ $H_2SO_4(aq)$ contains 1.4 mol H_2SO_4

$\therefore$ 50 cm³ $H_2SO_4(aq)$ contains $\frac{1.4}{1000} \times 50$ mol H_2SO_4

= 0.07 mol H_2SO_4

1 mol H_2SO_4 produces 1 mol $MgSO_4$

$\therefore$ 0.07 mol H_2SO_4 produces 0.07 mol $MgSO_4$

Mass of 1 mol $MgSO_4 = 24 + 32 + (4 \times 16)$ g

= 120 g

$\therefore$ mass of 0.07 mol $MgSO_4 = 0.07 \times 120$ g

= 8.4 g

Maximum mass of magnesium sulfate = 8.4 g

(4 marks)

Total 15 marks

9. a) i) Each I^- ion has been oxidised to form an iodine atom because its oxidation number increased from −1 to 0 due to the loss of one electron. **(2 marks)**

ii) The Fe^{3+} ion has been oxidised to form an Fe^{2+} ion because its oxidation number decreased from +3 to +2 due to the gain of an electron. **(2 marks)**

b) i) $\underset{(+2)(-2)}{2ZnO(s)} + C(s) \longrightarrow \underset{(0)}{2Zn(s)} + \underset{(-2)}{CO_2(g)}$

reduced

The non-metal carbon is acting as a reducing agent because it caused the oxidation number of each Zn^{2+} ion in the zinc oxide to decrease from +2 to 0 **(2 marks)**

ii) $Cl_2(g) + \underset{(+1)(-1)}{2KBr(aq)} \longrightarrow \underset{(+1)}{2KCl(aq)} + \underset{(0)}{Br_2(aq)}$

oxidised

The non-metal chlorine is acting as an oxidising agent because it caused the oxidation number of each Br^- ion in the potassium bromide to increase from −1 to 0. **(2 marks)**

c) i) Solution X can behave as both an oxidising agent and a reducing agent. **(1 mark)**

ii) Solution X behaved as a reducing agent when mixed with acidified potassium manganate(VII) solution and reduced the purple MnO_4^- ion to the colourless Mn^{2+} ion. Solution X behaved as an oxidising agent when mixed with potassium iodide solution and oxidised the colourless I^- ion to iodine which dissolved forming a brown solution. **(4 marks)**

d) When the apple was cut and exposed to oxygen in the air, enzymes in the cells of the cut surface oxidised certain chemicals in the cells to brown compounds call melanins. The melanins caused the surface to turn brown. **(2 marks)**

Total 15 marks

10. a) During electrolysis, the anions in the electrolyte are attracted to the anode where they are discharged to form atoms by losing electrons. For example, when molten lead(II) bromide is electrolysed, the Br^- ions are attracted to the anode and discharged to form bromine.

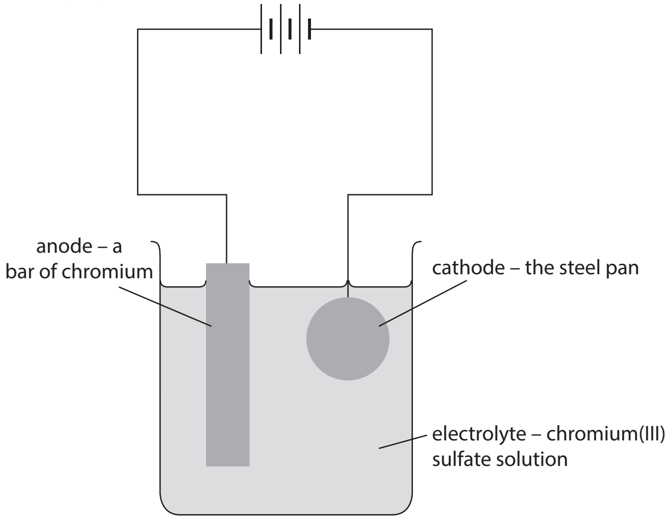
$2Br^-(l) \longrightarrow Br_2(g) + 2e^-$

The cations in the electrolyte are attracted to the cathode where they are discharged to form atoms by gaining electrons. For example when lead(II) bromide is electrolysed, the Pb^{2+} ions are attracted to the cathode and discharged forming lead.

$Pb^{2+}(l) + 2e^- \longrightarrow Pb(l)$ **(4 marks)**

b) When copper(II) sulfate solution is electrolysed using graphite electrodes the OH^- ions are preferentially discharged at the anode because they are lower in the electrochemical series than the SO_4^{2-} ions. When OH^- ions are discharged, oxygen gas is produced.
When copper(II) sulfate solution is electrolysed using a graphite anode, the anode ionises to form Cu^{2+} ions because this requires less energy than discharging the OH^- ions. This results in the anode decreasing in size as the Cu^{2+} ions enter the solution. **(4 marks)**

c) i)



(3 marks)

ii) Time in seconds = (8 × 60 × 60) + (2 × 60) + 30 s

= 28 950 s

Quantity of electricity = 8.0 × 28 950 C

= 231 600 C

Equation for the reaction at the cathode:

$Cr^{3+}(aq) + 3e^- \longrightarrow Cr(s)$

3 mol 1 mol

3 mol electrons are required to form 1 mol Cr

$\therefore$ 3 × 96 500 C form 1 mol Cr

i.e. 289 500 C form 1 mol Cr

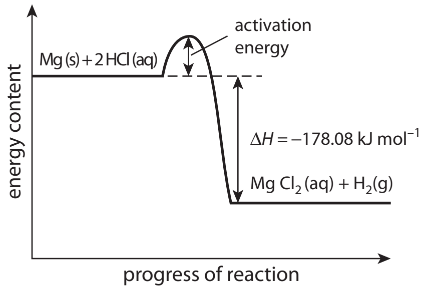
$\therefore$ 231 600 C form $\frac{1}{289\ 500} \times 231\ 600$ mol Cr
= 0.8 mol Cr
Mass of 1 mol Cr = 52 g
$\therefore$ mass of 0.8 mol Cr = 0.8 × 52 g
= 41.6 g
Increase in mass = 41.6 g **(4 marks)**
Total 15 marks

11. a) i) Volume of hydrochloric acid = 25 cm^3
$\therefore$ mass of hydrochloric acid = 25 g
Temperature increase = 49.8 – 28.6 °C
= 21.2 °C
Heat change = 25 × 21.2 × 4.2 J
= 2226 J **(3 marks)**

ii)
- The density of the hydrochloric acid is the same as water, 1 g cm^{-3}
- A negligible amount of heat is lost to the environment. **(2 marks)**

iii) 1000 cm^3 HCl(aq) contains 0.5 mol HCl
$\therefore$ 25 cm^3 HCl(aq) contains $\frac{0.5}{1000} \times 25$ mol HCl
= 0.0125 mol HCl
Heat change for reacting 0.0125 mol HCl = 2226 J
$\therefore$ heat change for reacting 1 mol HCl = $\frac{2226}{0.0125}$ J
= 178 080 J
= 178.08 kJ
(2 marks)

iv)



(3 marks)

b) i) $2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$
$KOH(aq) + 2HNO_3(aq) \longrightarrow KNO_3(aq) + H_2O(l)$
(3 marks)

ii) Heat change for the reaction between sodium hydroxide and sulfuric acid = 2 × 57.2 kJ
= 114.4 kJ
Heat change for the reaction between potassium hydroxide and nitric acid = 57.2 kJ **(2 marks)**
Total 15 marks

Exam-style questions – Chapters 14 to 17

STRUCTURED QUESTIONS

1. a) i) Fractional distillation. **(1 mark)**

ii) *Any two of the following, ensuring the same use is not given twice:*
- Refinery gas
  Use: As fuel for domestic use or to manufacture various petrochemicals.
- Petrol or gasoline
  Use: As fuel for internal combustion engines.
- Naphtha
  Use: To manufacture various petrochemicals.
- Kerosene or paraffin oil
  Use: As fuel for jet engines or for cooking or for heating or for lighting.
- Diesel oil
  Use: As fuel for diesel engines.
- Fuel oils
  Use: As fuel for ships or for factories or for power stations or for heating.
- Lubricating oils and waxes
  Use: As lubricants in machinery and vehicle engines, or used to make polishing waxes or petroleum jelly or candles.
- Bitumen or asphalt
  Use: For surfacing roads or car parks or airport runways, or for roofing. **(2 marks)**

b) i) Cracking is the process by which long-chain hydrocarbon molecules are broken down into shorter chain hydrocarbon molecules by breaking carbon–carbon bonds. **(1 mark)**

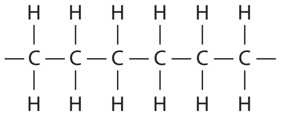
ii) $C_7H_{16} \longrightarrow C_5H_{12} + C_2H_4$
The other product is pentane. **(2 marks)**

iii) $C_2H_4(g) + Cl_2(g) \longrightarrow C_2H_4Cl_2(l)$ **(1 mark)**

c) i) A polymer is a macromolecule formed by linking together 50 or more small molecules, known as monomers, usually in chains. **(1 mark)**

ii) Addition polymerisation. **(1 mark)**

iii)



$$\begin{array}{ccccccccccccc} & H & & H & & H & & H & & H & & H & \\ & | & & | & & | & & | & & | & & | & \\ — & C & — & C & — & C & — & C & — & C & — & C & — \\ & | & & | & & | & & | & & | & & | & \\ & H & & H & & H & & H & & H & & H & \end{array}$$

(1 mark)

iv) *Any two of the following:*
- To make plastic bags.
- To make plastic bottles.
- To make washing up bowls.
- To make buckets.
- To make packaging for food.
- To make cling wrap. **(2 marks)**

d) i)

Element	C	H
Percentage	85.7%	14.3%
Mass in 100 g	85.7 g	14.3 g
Mass of 1 mole	12 g	1 g
Number of moles	$\frac{85.7}{12}$ mol = 7.142 mol	$\frac{14.3}{1}$ mol = 14.3 mol
Simplest mole ratio	1 mol	2 mol

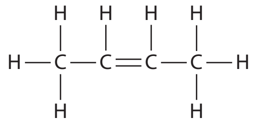
Empirical formula is CH_2 **(2 marks)**

ii) The alkene series. **(1 mark)**
Total 15 marks

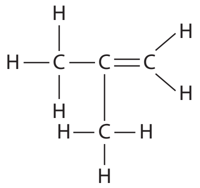
2. a) B belongs to the alcohol series because it contains the hydroxyl functional group. **(2 marks)**

b) i) Structural isomerism is the occurrence of two or more organic compounds with the same molecular formula but different structural formulae. **(1 mark)**

ii) *Any one of the following:*



but-2-ene
or 2-butene



2-methylpropene

(2 marks)

c) *Any one of the following:*

- React both compounds with bromine solution under standard laboratory conditions. The solution will change colour rapidly from red–brown to colourless with A, but will remain red–brown with C.
- React both compounds with acidified potassium manganate(VII) solution. The solution will change colour rapidly from purple to colourless with A, but will remain purple with C. **(2 marks)**

d) i) $2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$ **(2 marks)**

ii) Compound C would produce the cleanest flame because the ratio of carbon to hydrogen atoms in its molecules is lower than in A. All the carbon in C would be converted to carbon dioxide and none would remain to make the flame smoky. **(2 marks)**

e) i) The reaction would require concentrated sulfuric acid and heat. **(1 mark)**

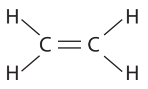
ii) $C_2H_5COOH(l) + CH_3OH(l) \rightleftharpoons C_2H_5COOCH_3(l) + H_2O(l)$

The organic product is called methyl propanoate. **(2 marks)**

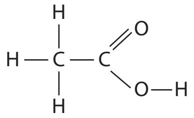
iii) Esterification **(1 mark)**

Total 15 marks

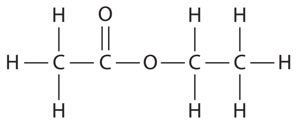
3. a)



ethene
F



ethanoic acid
K



ethyl ethanoate
L

(6 marks)

b) i) Dehydration. **(1 mark)**

ii) Addition. **(1 mark)**

iii) Oxidation. **(1 mark)**

c) A nickel catalyst, a temperature of 150°C and a pressure of 5 atmospheres. **(1 mark)**

d) i) $2C_2H_5OH(l) + 2Na(s) \longrightarrow 2C_2H_5Na(alc\ sol) + H_2(g)$ **(2 marks)**

ii) $Ca(s) + 2CH_3COOH(aq) \longrightarrow (CH_3COO)_2Ca(aq) + H_2(g)$ **(2 marks)**

e) The breathalyser test is used to determine the alcohol content of a driver's breath. **(1 mark)**

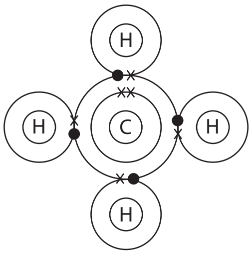
Total 15 marks

EXTENDED-RESPONSE QUESTIONS

4. a) i) *Any two of the following:*

- All members have the same functional group.
- All members can be represented by the same general formula.
- Each member differs from the member before or after it by a —CH_2— group, and by relative molecular mass of 14.
- All members possess similar chemical properties, however the reactivity decreases as the number of carbon atoms per molecule increases or as the molar mass increases.
- Members show a gradual change in their physical properties as the number of carbon atoms per molecule increases. In general, melting point, boiling point and density increase as molar mass increases.
- All members can be prepared using the same general method. **(2 marks)**

ii)



(2 marks)

iii) *Any two of the following:*

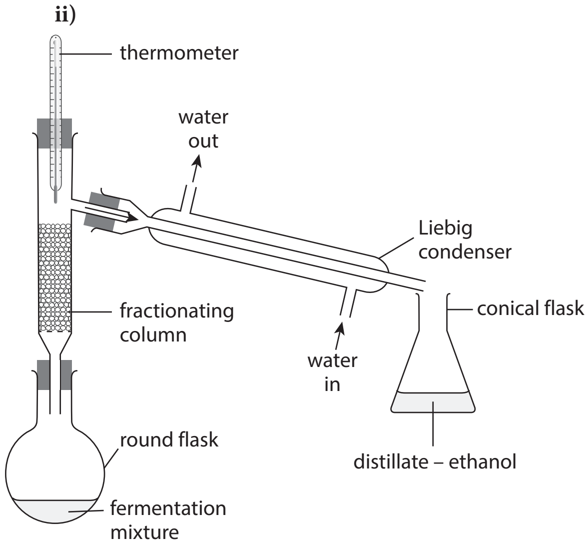
- Alkanes burn very easily.
- Alkanes release large amounts of energy when they burn because the reactions are exothermic.
- Alkanes burn with clean blue flames which contain very little soot.
- Alkanes are easy to transport, store and distribute. **(2 marks)**

b) i) A solution of glucose would be made in a conical flask and a yeast paste made with dried yeast and a small amount of water would be added to it. The flask would be corked with a delivery tube running through the cork into a test tube containing water, to let the carbon dioxide out of the flask and to prevent air from getting in.

$$C_6H_{12}O_6(aq) \xrightarrow{\text{zymase in yeast}} 2C_2H_5OH(aq) + 2CO_2(g)$$

(3 marks)

ii)



(4 marks)

iii) Aerobic bacteria entered Susan's wine and oxidised the ethanol to ethanoic acid which caused the wine to become sour.

$$C_2H_5OH(aq) + O_2(g) \xrightarrow{\text{aerobic bacteria}} CH_3COOH(aq) + H_2O(l)$$

(2 marks)

Total 15 marks

5. a) i) X belongs to the ester series.
The products of the reaction are butanoic acid, formula C_3H_7COOH, and methanol, formula CH_3OH.
The type of reaction is acid hydrolysis. **(4 marks)**

iii) Sodium butanoate would have been produced instead of butanoic acid. Methanol would still have been produced. **(2 marks)**

b) i) Soap is produced from the fat glyceryl octadecanoate by boiling the fat with concentrated potassium or sodium hydroxide solution. The reaction produces potassium or sodium octadecanoate, both of which are also known as soap.

$$(C_{17}H_{35}COO)_3C_3H_5(l) + 3NaOH(aq) \longrightarrow 3C_{17}H_{35}COONa(aq) + C_3H_5(OH)_3(aq)$$

The process is saponification. **(4 marks)**

ii) Glycerol would be soluble in water because each molecule contains three hydroxyl groups making it polar. Polar solutes dissolve in polar solvents and water is a polar solvent. **(2 marks)**

iii) A soapy detergent would be chosen for the following reasons:

- Soapy detergents are made from fats and oils which are renewable resources. Soapless detergents are made from petroleum which is a non-renewable resource and will eventually run out.
- Soapy detergents are biodegradable so they break down in the environment and do not cause foam to form on waterways. Some soapless detergents are non-biodegradable so they cause foam to form on waterways which prevents oxygen dissolving and leads to the death of aquatic organisms.
- Soapy detergents do not contain phosphates, so they do not pollute aquatic environments. Some soapless detergents contain phosphates which cause pollution of aquatic environments by eutrophication. **(3 marks)**

Total 15 marks

Exam-style questions – Chapters 18 to 24

STRUCTURED QUESTIONS

1. a) i) X is carbon.
Y is carbon dioxide.
Z is carbon monoxide. **(3 marks)**

ii) The supply of oxygen available. **(1 mark)**

b) i) $Mg(s) + H_2(g) \longrightarrow MgH_2(s)$ **(1 mark)**

ii) Hydrogen is behaving as an oxidising agent because each hydrogen atom in the hydrogen molecule removed an electron from the magnesium atom, causing the magnesium atom to lose electrons. **(2 marks)**

c) Table 1. Observations and inferences from tests on R

Test	Observations	Inferences
A sample of R was heated strongly in a dry test tube and a glowing splint was placed in the mouth of the tube.	• Brown fumes were seen. • The glowing splint relit.	• Nitrogen dioxide was produced. • Oxygen was produced. • NO_3^- ions are present. **(3 marks)**
Aqueous sodium hydroxide was added to a solution of R until in excess.	• A white precipitate formed which dissolved in excess to form a colourless solution.	• Al^{3+} ions or Zn^{2+} ions or Pb^{2+} ions are present. **(1 mark)**
Aqueous ammonia was added to a solution of R until in excess.	• A white precipitate formed which dissolved in excess to form a colourless solution.	• Zn^{2+} ions are present Ionic equation required: $Zn^{2+}(aq) + 2OH^-(aq) \longrightarrow Zn(OH)_2(s)$ **(2 marks)**
A solution of R was made in dilute nitric acid and a few drops of silver nitrate solution were added, followed by aqueous ammonia.	• A white precipitate formed which dissolved in aqueous ammonia forming a colourless solution. **(1 mark)**	• Cl^- ions present. Ionic equation required: $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$ **(1 mark)**

Total 15 marks

2. a) i) Calcium hydroxide and ammonium chloride. Or any other suitable base and ammonium salt. **(1 mark)**

ii)
- Ammonia is alkaline so it would react with the concentrated sulfuric acid in the wash bottle reducing the volume reaching the gas jar.
- Ammonia is less dense than air so would rise in the gas jar and would not displace the air, therefore very little would be collected in the jar.

(2 marks)

iii) *Any one of the following:*
- Tom could place a piece of moist red litmus paper into the gas. If the gas is ammonia it would turn the litmus paper blue.
  $NH_3(g) + H_2O(l) \rightleftharpoons NH_4OH(aq)$
- Tom could bring a drop of concentrated hydrochloric acid on a glass rod near to the gas. If the gas is ammonia white fumes would form.
  $NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$ **(3 marks)**

b) i) Calcium carbonate and hydrochloric acid. Or any other suitable carbonate and acid which would form a soluble salt. **(1 mark)**

ii) *Any one of the following:*
- Use: In fire extinguishers.
  Property: It is non-flammable, or it is denser than air so smothers the flames and keeps oxygen out.
- Use: To make carbonated soft drinks.
  Property: It dissolves in the drink under pressure and bubbles out when pressure is released, or it adds a pleasant tingle and taste to the drink.
- Use: As a refrigerant when solid.
  Property: It sublimes at –78.5 °C so keeps frozen foods at very low temperatures and does not leave a liquid residue when it sublimes to a gas.
- Use: As an aerosol propellant for some food items.
  Property: It is relatively inert. **(2 marks)**

iii) The complete combustion of fossil fuels. **(1 mark)**

iv) *Any two of the following:*
- Global temperatures will increase causing polar ice caps and glaciers to melt.
- Sea levels will rise.
- Low lying coastal areas will flood.
- Climates will change globally.
- More severe weather patterns will develop.
- Oceans will become acidic which will affect the ability of shellfish to produce their shells, and of reef building corals to produce their skeletons. **(2 marks)**

c) Chemical fertilisers contain NO^{3-} and PO_4^{3-} ions. These ions can dissolve in rainwater and wash off the agricultural land into aquatic environments where they cause eutrophication, i.e. the rapid growth of green plants and algae. The plants and algae then die and are decomposed by aerobic bacteria which multiply and use up the dissolved oxygen. This causes other aquatic organisms, such as fish, to die. **(3 marks)**

Total 15 marks

EXTENDED-RESPONSE QUESTIONS

3. a) i) Q, magnesium, aluminium, iron, P and silver. **(3 marks)**

ii)
- The reaction between P and silver nitrate solution:
  $P(s) + 2AgNO_3(aq) \longrightarrow P(NO_3)_2(aq) + 2Ag(s)$
- The reaction between Q and water:
  $2Q(s) + 2H_2O(l)$ ç $2QOH(aq) + H_2(g)$

(4 marks)

iii) Q would be extracted by electrolysis of its molten ore. Because Q reacts vigorously with water, it would be fairly high in the reactivity series and would form stable ions which would be difficult to reduce. A powerful method of reduction would, therefore, be needed to extract Q from its ores, this being electrolysis. **(2 marks)**

b) i) Iron is extracted from its ores, iron(III) oxide and iron(II, III) oxide, in a blast furnace. The charge composed of a mixture of the iron ores, coke (carbon) and limestone (calcium carbonate) is added through the top of the furnace and hot air is blown in through the bottom. At the bottom of the furnace, the coke burns in the hot air to form carbon dioxide. The carbon dioxide moves up and it reacts with more coke in the middle of the furnace to form carbon monoxide. The carbon monoxide then moves up and reduces the iron ores to iron in the top part of the furnace. The iron produced is molten and it runs down to the bottom of the furnace and is tapped off. **(4 marks)**

ii) *Any one of the following:*
- It is much more resistant to corrosion than iron.
- It has a much shinier, more attractive appearance than iron. **(1 mark)**

iii) *Any one of the following:*
- To make ornamental iron work.
- To construct buildings, bridges, oil rigs, ships, trains and motor vehicles.
- To make tin cans to store food.
- To make cutting tools, chisels, knives, drill bits and masonry nails.
- To make small castings, e.g. cylinder blocks in engines, railings, gates, manhole covers, hinges and cast iron cookware. **(1 mark)**

Total 15 marks

4. a) Copper, silver and gold are used for making coins because they are low down in the reactivity series and are relatively unreactive. They do not react with oxygen in the air or water so the coins remain unchanged for their lifetime. Magnesium, sodium and calcium are not used for making coins because they are high up in the reactivity series so are very reactive. They react with oxygen in the air forming oxides and with moisture in the air forming hydroxides. Coins made out of them would rapidly change to the metal oxides or hydroxides and the coins would cease to exist. **(4 marks)**

b) Sodium nitrate would be decomposed by heat to form sodium nitrite and oxygen.
$2NaNO_3(s) \longrightarrow 2NaNO_2(s) + O_2(g)$

Lead(II) nitrate would be decomposed on heating to form lead(II) oxide, nitrogen dioxide and oxygen.
$2Pb(NO_3)_2(s) \longrightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$
(4 marks)

c) i) Pollution is the contamination of the natural environment by the release of unpleasant and harmful substances into the environment. **(1 mark)**

ii)
- Magnesium is essential for green plants to produce the green pigment, chlorophyll, which they use to absorb sunlight energy so they can manufacture their own food by photosynthesis. Over 300 biochemical reactions in the human body also require magnesium ions because they help many enzymes to function.
- Iron is essential for animals to produce the red pigment, haemoglobin, which is found in red blood cells and is used to carry oxygen around the body for the body cells to use in respiration to produce energy. **(4 marks)**

iii) Fish such as marlin, tuna and shark could contain harmful levels of certain organometallic compounds which are toxic to humans, mainly compounds of mercury. Mercury ions remain in the environment, and they become higher in concentration moving up food chains and can reach harmful levels in top consumers such as large fish. **(2 marks)**

Total 15 marks

5. a) *Any three of the following:*
- Water has a maximum density at 4 °C which means that as ice forms at 0 °C it floats on the denser, warmer water below. When ponds, lakes or rivers freeze in winter, ice forms at the surface and the warmer, denser water remains below so aquatic organisms are able to survive in the water beneath the ice.
- Water has a high specific heat capacity so it requires a lot of heat energy to increase the temperature of water by 1 °C. Since the bodies of living organisms contain between 60% and 70% water, they can absorb a lot of heat energy without their body temperatures changing very much, so can survive in extremes of temperature. Also, as atmospheric temperatures change, the temperatures of lakes and seas do not change very much, so aquatic organisms do not experience extreme fluctuations in the temperature of their environment.
- Water has a high heat of vaporisation so a lot of heat energy is required to change liquid water to water vapour. When water evaporates from the surface of an organism it removes a lot of heat energy from the organism which cools it down.
- Water has relatively high melting and boiling points compared with other molecules of a similar size so, at the temperatures experienced on Earth, most water is in the liquid state meaning that lakes, rivers and seas exist and provide an environment for aquatic organisms.
- Water dissolves a large number of substances which is important because it dissolves chemicals in the cells of organisms so that chemical reactions can occur, it dissolves useful substances so they can be absorbed into the bodies of organisms and transported around their bodies, and it dissolves waste and harmful substances so they can be excreted from organisms. **(6 marks)**

b) i) The water was hard and contained dissolved calcium and magnesium salts. Soap is made of sodium octadecanoate and when this was added to the water containing Ca^{2+} or Mg^{2+} ions, insoluble calcium and magnesium octadecanoate, known as scum, formed and the soap did not lather.
(3 marks)

ii) *Any one of the following:*
- She could boil the water which would cause dissolved calcium hydrogencarbonate and magnesium hydrogencarbonate to decompose forming insoluble calcium carbonate and magnesium carbonate which would precipitate out.
  $Ca(HCO_3)_2(aq) \longrightarrow CaCO_3(s) + H_2O(l) + CO_2(g)$
- She could add sodium carbonate which would cause the dissolved Ca^{2+} or Mg^{2+} ions to precipitate out as insoluble calcium carbonate and magnesium carbonate.
  $Ca(HCO_3)_2(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + 2NaHCO_3(aq)$
  Or
  $CaSO_4(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + Na_2SO_4(aq)$
- She could pass the water through an ion-exchange column in a water-softening device and the Ca^{2+} or Mg^{2+} ions would displace the Na^+ ions in the ion-exchange resin or zeolite and be absorbed into the zeolite. The displaced Na^+ ions would enter the water but not cause it to be hard.
  $Ca^{2+}(aq) + Na_2Z(s) \longrightarrow CaZ(s) + 2Na^+(aq)$
  (2 marks)

c) i) Green Chemistry is the utilisation of a set of principles in the design, manufacture and application of chemical products that reduces or eliminates the use and generation of hazardous substances. **(1 mark)**

ii) *Any two of the following:*
- Design processes that prevent waste from being produced rather than having to treat waste or clean it up afterwards.
- Design processes which incorporate most or all of the starting materials into the final products so that few atoms are wasted.
- Design processes which use and generate substances which are as non-toxic as possible to humans and the environment.

- Design chemical products that are as effective as possible whilst being as non-toxic as possible.
- Avoid using solvents, separating agents and other auxiliary chemicals, or replace them with safer alternatives.
- Use the minimum amount of energy; whenever possible carry out processes at room temperature and pressure.
- Use raw materials which are renewable and reduce the use of non-renewable raw materials to a minimum.
- Avoid derivatisation because it requires additional reagents and can generate waste.
- Use catalysts whenever possible because they are effective in small amounts, can carry out a single reaction many times, cause reactions to occur faster and at lower temperatures, and reduce the production of unwanted and hazardous by-products.
- Design chemical products so that when their functional life ends they break down into harmless products which do not persist in the environment.
- Monitor the progress of any process to prevent the formation of any unwanted or hazardous by-products.
- Choose reagents to be used in chemical processes which keep the possibility of chemical accidents to a minimum such as explosions, fires and the release of toxic substances.

(2 marks)

iii) *Any one of the following:*

- It reduces the use of energy.
- It reduces pollution.
- It reduces wastage.
- It reduces the use of natural resources.
- It produces safer consumer products.
- It improves the competitiveness of chemical manufacturers. **(1 mark)**

Total 15 marks