

1 Experimental chemistry

Content

- 1.1 Experimental design
- 1.2 Methods of purification and analysis
- 1.3 Identification of ions and gases

It is expected that any course in chemistry will be based on experimental work. Teachers are encouraged to develop appropriate practical work for candidates to facilitate a greater understanding of the subject. Candidates should be aware of the hazards and appropriate safety precautions to follow when handling the reagents mentioned in this section.

Learning outcomes

Candidates should be able to:

1.1 Experimental design

- (a) name appropriate apparatus for the measurement of time, temperature, mass and volume, including burettes, pipettes, measuring cylinders and gas syringes
- (b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including collection of gases and measurement of rates of reaction

1.2 Methods of purification and analysis

- (a) describe methods of purification by the use of a suitable solvent, filtration and crystallisation, distillation and fractional distillation, with particular references to the fractional distillation of crude oil, liquid air and mixtures of liquids
- (b) suggest suitable methods of purification, given information about the substances involved
- (c) describe paper chromatography and interpret chromatograms including comparison with 'known' samples and the use of R_f values
- (d) explain the need to use locating agents in the chromatography of colourless compounds
- (e) deduce from given melting point and boiling point information, the identities of substances and their purity
- (f) explain that the measurement of purity in substances used in everyday life, e.g. foodstuffs and drugs, is important

1.3 Identification of ions and gases

- (a) describe the use of aqueous sodium hydroxide and aqueous ammonia to identify the following aqueous cations: aluminium, ammonium, calcium, chromium(III), copper(II), iron(II), iron(III) and zinc (formulae of complex ions are **not** required)
- (b) describe tests to identify the following anions: carbonate (by the addition of dilute acid and subsequent use of limewater); chloride (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); iodide (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); nitrate (by reduction with aluminium and aqueous sodium hydroxide to ammonia and subsequent use of litmus paper), sulfate (by reaction of an aqueous solution with nitric acid and aqueous barium nitrate), and sulfite (by warming with dilute acid)
- (c) describe tests to identify the following gases: ammonia (using damp red litmus paper); carbon dioxide (using limewater); chlorine (using damp litmus paper); hydrogen (using a burning splint); oxygen (using a glowing splint) and sulfur dioxide (using acidified potassium manganate(VII))
- (d) describe a chemical test for water

2 The particulate nature of matter

Content

- 2.1 Kinetic particle theory
- 2.2 Atomic structure
- 2.3 Structure and properties of materials
- 2.4 Ionic bonding
- 2.5 Covalent bonding
- 2.6 Metallic bonding

Learning outcomes

Candidates should be able to:

2.1 Kinetic particle theory

- (a) describe the solid, liquid and gaseous states of matter and explain their interconversion in terms of the kinetic particle theory and of the energy changes involved
- (b) describe and explain evidence for the movement of particles in liquids and gases (the treatment of Brownian motion is not required)
- (c) explain everyday effects of diffusion in terms of particles, e.g. the spread of perfumes and cooking aromas; tea and coffee grains in water
- (d) state qualitatively the effect of molecular mass on the rate of diffusion and explain the dependence of rate of diffusion on temperature
- (e) state qualitatively and explain the effects of temperature and pressure on the volumes of gases

2.2 Atomic structure

- (a) state the relative charges and approximate relative masses of a proton, a neutron and an electron
- (b) describe, with the aid of diagrams, the structure of an atom as containing protons and neutrons (nucleons) in the nucleus and electrons arranged in shells (energy levels) (no knowledge of s, p, d and f classification will be expected; a copy of the Periodic Table will be available in Papers 1 and 2)
- (c) define proton number and nucleon number
- (d) interpret and use symbols such as $^{12}_6\text{C}$
- (e) define the term *isotopes*
- (f) deduce the numbers of protons, neutrons and electrons in atoms and ions from proton and nucleon numbers

2.3 Structure and properties of materials

- (a) describe the differences between elements, compounds and mixtures
- (b) compare the structure of simple molecular substances, e.g. methane, iodine, with those of giant covalent substances, e.g. sand (silicon dioxide), diamond, graphite in order to deduce their properties
- (c) compare the bonding and structures of diamond and graphite in order to deduce properties such as electrical conductivity, lubricating or cutting action (candidates will not be required to draw the structures)
- (d) deduce the physical and chemical properties of substances from their structures and bonding and *vice versa*

2.4 Ionic bonding

- (a) describe the formation of ions by electron loss/gain in order to obtain the electronic configuration of an inert gas
- (b) describe the formation of ionic bonds between metals and non-metals, e.g. NaCl ; MgCl_2
- (c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. NaCl (candidates will not be required to draw diagrams of ionic lattices)
- (d) relate the physical properties (including electrical property) of ionic compounds to their lattice structure

2.5 Covalent bonding

- (a) describe the formation of a covalent bond by the sharing of a pair of electrons in order to gain the electronic configuration of an inert gas
- (b) describe, using dot-and-cross diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2 ; Cl_2 ; O_2 ; HCl ; N_2 ; H_2O ; CH_4 ; C_2H_4 ; CO_2
- (c) deduce the arrangement of electrons in other covalent molecules
- (d) relate the physical properties (including electrical properties) of covalent compounds to their structure and bonding

2.6 Metallic bonding

- (a) describe metallic bonding as the electrostatic attraction between positive ions in a lattice and a 'sea of electrons'
- (b) relate the malleability of metals to their structure and the electrical conductivity of metals to the mobility of the electrons in the structure

3 Formulae, stoichiometry and the mole concept

Candidates should be able to:

- (a) state the symbols of the elements and formulae of the compounds mentioned in the syllabus
- (b) deduce the formulae of simple compounds from the relative numbers of atoms present and *vice versa*
- (c) deduce the formulae of ionic compounds from the charges on the ions present and *vice versa*
- (d) interpret and construct chemical equations, with state symbols, including ionic equations
- (e) define relative atomic mass, A_r
- (f) define relative molecular mass, M_r , and calculate relative molecular mass (and relative formula mass) as the sum of relative atomic masses
- (g) calculate the percentage mass of an element in a compound when given appropriate information
- (h) calculate empirical and molecular formulae from relevant data
- (i) calculate stoichiometric reacting masses; use Avogadro's law in calculations involving gas volume (one mole of gas occupies 24 dm^3 at room temperature and pressure); calculations involving the idea of limiting reactants may be set (questions on the gas laws and the calculations of gaseous volumes at different temperatures and pressures will not be set)
- (j) apply the concept of solution concentration (in mol/dm^3 or g/dm^3) to process the results of volumetric experiments and to solve simple problems (appropriate guidance will be provided where unfamiliar reactions are involved)
- (k) calculate % yield and % purity

4 Electrolysis

Candidates should be able to:

- (a) describe electrolysis as the conduction of electricity by an ionic compound (an electrolyte), when molten or dissolved in water, leading to the decomposition of the electrolyte
- (b) describe electrolysis as evidence for the existence of ions which are held in a lattice when solid but which are free to move when molten or in solution
- (c) describe, in terms of the mobility of ions present and the electrode products, the electrolysis of molten lead bromide, using inert electrodes
- (d) predict the likely products of the electrolysis of a molten compound
- (e) apply the idea of selective discharge (linked to the reactivity series for cations, see 9.2) to deduce the electrolysis products of aqueous solutions; describe the electrolysis of concentrated aqueous sodium chloride, aqueous copper(II) sulfate and dilute sulfuric acid using inert electrodes
- (f) predict the likely products of the electrolysis of an aqueous electrolyte, given relevant information
- (g) construct equations for the reactions occurring at each electrode (anode and cathode) during electrolysis
- (h) describe the electrolysis of purified aluminium oxide dissolved in molten cryolite as the method of extraction of aluminium (see 9.5(a))
- (i) describe the electrolysis of aqueous copper(II) sulfate with copper electrodes as a means of purifying copper
- (j) describe the electroplating of metals, including copper plating, and recall one use of electroplating
- (k) describe the production of electrical energy from simple cells (i.e. two electrodes in an electrolyte) linked to the reactivity series (see 9.2)

5 Energy from chemicals

Candidates should be able to:

- (a) describe the meaning of enthalpy change in terms of exothermic (ΔH negative) and endothermic (ΔH positive) reactions
- (b) represent energy changes by energy profile diagrams, including reaction enthalpy changes and activation energies (see 6.1(c))
- (c) describe bond breaking as an endothermic process and bond making as an exothermic process
- (d) explain overall enthalpy changes in terms of the energy changes associated with the breaking and making of covalent bonds
- (e) describe combustion of fuels as exothermic, e.g. wood, coal, oil, natural gas and hydrogen
- (f) describe hydrogen, derived from water or hydrocarbons, as a fuel, reacting with oxygen to generate electricity directly in a fuel cell (details of the construction and operation of a fuel cell are **not** required) and discuss the advantages and disadvantages of this
- (g) name natural gas, mainly methane, and petroleum (crude oil) as sources of energy
- (h) describe petroleum (crude oil) as a mixture of hydrocarbons and its separation into useful fractions by fractional distillation
- (i) name the following fractions and state their uses
 - (i) petrol (gasoline) as a fuel in cars
 - (ii) naphtha as feedstock for the chemical industry
 - (iii) paraffin (kerosene) as a fuel for heating and cooking and for aircraft engines
 - (iv) diesel as a fuel for diesel engines
 - (v) lubricating oils as lubricants and as a source of polishes and waxes
 - (vi) bitumen for making road surfaces
- (j) describe photosynthesis as the reaction between carbon dioxide and water in the presence of chlorophyll, using sunlight (energy) to produce glucose and explain how this can provide a renewable energy source

6 Chemical reactions

Content

- 6.1 Rate of reaction
- 6.2 Redox
- 6.3 Reversible reactions

Learning outcomes

Candidates should be able to:

6.1 Rate of reaction

- (a) describe the effect of concentration, pressure, particle size and temperature on the rates of reactions and explain these effects in terms of collisions between reacting particles
- (b) define the term *catalyst* and describe the effect of catalysts (including enzymes) on the rates of reactions
- (c) explain how pathways with lower activation energies account for the increase in rates of reactions
- (d) state that transition elements and their compounds act as catalysts (see 8.3) in a range of industrial processes and that enzymes are biological catalysts
- (e) suggest a suitable method for investigating the effect of a given variable on the rate of a reaction
- (f) interpret data obtained from experiments concerned with rate of reaction

6.2 Redox

- (a) define oxidation and reduction (redox) in terms of oxygen/hydrogen gain/loss
- (b) define redox in terms of electron transfer
- (c) identify redox reactions in terms of oxygen/hydrogen, and/or electron, gain/loss (calculation of oxidation numbers is **not** required)
- (d) describe the use of aqueous potassium iodide in testing for oxidising agents and acidified potassium manganate(VII) in testing for reducing agents from the resulting colour changes

6.3 Reversible reactions

- (a) describe the idea that some chemical reactions can be reversed by changing the reaction conditions
- (b) describe the idea that some reversible reactions can reach dynamic equilibrium and predict and explain the effect of changing the conditions (see 7.3(b) and 7.3(c))

7 The chemistry and uses of acids, bases and salts

Content

- 7.1 The characteristic properties of acids and bases
- 7.2 Preparation of salts
- 7.3 Properties and uses of ammonia
- 7.4 Sulfuric acid

Learning outcomes

Candidates should be able to:

7.1 The characteristic properties of acids and bases

- (a) describe the meanings of the terms acid and alkali in terms of the ions they contain or produce in aqueous solution and their effects on Universal Indicator paper
- (b) describe how to test hydrogen ion concentration and hence relative acidity using Universal Indicator paper and the pH scale
- (c) describe the characteristic properties of acids as in reactions with metals, bases and carbonates
- (d) describe qualitatively the difference between strong and weak acids in terms of the extent of dissociation
- (e) describe neutralisation as a reaction between hydrogen ions and hydroxide ions to produce water, $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$
- (f) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide
- (g) describe the characteristic properties of bases in reactions with acids and with ammonium salts
- (h) classify oxides as acidic, basic or amphoteric, based on metallic/non-metallic character

7.2 Preparation of salts

- (a) describe the techniques used in the preparation, separation and purification of salts as examples of some of the techniques specified in Section 1.2(a)
(methods for preparation should include precipitation and titration together with reactions of acids with metals, insoluble bases and insoluble carbonates)
- (b) describe the general rules of solubility for common salts to include nitrates, chlorides (including silver and lead), sulfates (including barium, calcium and lead), carbonates, hydroxides, Group I cations and ammonium salts
- (c) suggest a method of preparing a given salt from suitable starting materials, given appropriate information
- (d) describe the meanings of the terms hydrated, anhydrous and water of crystallisation

7.3 Properties and uses of ammonia

- (a) describe the use of nitrogen, from air, and hydrogen, from cracking hydrocarbons, in the manufacture of ammonia
- (b) state that some chemical reactions are reversible (e.g. manufacture of ammonia)
- (c) describe and explain the essential conditions for the manufacture of ammonia by the Haber process
- (d) describe the use of nitrogenous fertilisers in promoting plant growth and crop yield
- (e) compare nitrogen content of salts used for fertilisers by calculating percentage masses
- (f) describe eutrophication and water pollution problems caused by nitrates leaching from farm land and explain why the high solubility of nitrates increases these problems
- (g) describe the displacement of ammonia from its salts and explain why adding calcium hydroxide to soil can cause the loss of nitrogen from added nitrogenous fertiliser

7.4 Sulfuric acid

- (a) describe the manufacture of sulfuric acid from the raw materials sulfur, air and water in the contact process
- (b) state the use of sulfur dioxide as a bleach, in the manufacture of wood pulp for paper and as a food preservative (by killing bacteria)
- (c) state the uses of sulfuric acid in the manufacture of detergents and fertilisers, and as a battery acid

8 The Periodic Table

Content

- 8.1 Periodic trends
- 8.2 Group properties
- 8.3 Transition elements

Learning outcomes

Candidates should be able to:

8.1 Periodic trends

- (a) describe the Periodic Table as an arrangement of the elements in the order of increasing proton (atomic) number
- (b) describe how the position of an element in the Periodic Table is related to proton number and electronic configuration
- (c) describe the relationship between group number and the ionic charge of an element
- (d) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic configuration
- (e) describe the change from metallic to non-metallic character from left to right across a period of the Periodic Table
- (f) describe the relationship between group number, number of valence electrons and metallic/non-metallic character
- (g) predict the properties of elements in Group I, VII and the transition elements using the Periodic Table

8.2 Group properties

- (a) describe lithium, sodium and potassium in Group I (the alkali metals) as a collection of relatively soft, low-density metals showing a trend in melting point and in their reaction with water
- (b) describe chlorine, bromine and iodine in Group VII (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with solutions of other halide ions
- (c) describe the elements in Group VIII (the noble gases, also known as Group 0) as a collection of monatomic elements that are chemically unreactive and hence important in providing an inert atmosphere, e.g. argon and neon in light bulbs; helium in balloons; argon in the manufacture of steel
- (d) describe the lack of reactivity of the noble gases in terms of their electronic configuration

8.3 Transition elements

- (a) describe the central block of elements (transition metals) as metals having high melting points, high density, variable oxidation state and forming coloured compounds
- (b) state the use of these elements and/or their compounds as catalysts, e.g. iron in the Haber process; vanadium(V) oxide in the contact process; nickel in the hydrogenation of alkenes, and how catalysts are used in industry to lower energy demands and hence are economically advantageous and help conserve energy sources

9 Metals

Content

- 9.1 Properties of metals
- 9.2 Reactivity series
- 9.3 Extraction of metals
- 9.4 Iron
- 9.5 Aluminium

Learning outcomes

Candidates should be able to:

9.1 Properties of metals

- (a) describe the general physical properties of metals (as solids having high melting and boiling points; malleable; good conductors of heat and electricity) in terms of their structure
- (b) describe an alloy as a mixture of a metal with another element, e.g. brass; stainless steel
- (c) identify representations of metals and alloys from diagrams of structures
- (d) explain why alloys have different physical properties from their constituent elements

9.2 Reactivity series

- (a) place in order of reactivity: aluminium (see also 9.5(b)), calcium, copper, (hydrogen), iron, lead, magnesium, potassium, silver, sodium and zinc by reference to
 - (i) the reactions, if any, of the metals with water, oxygen, steam and dilute hydrochloric acid,
 - (ii) the reduction, if any, of their oxides by carbon and/or by hydrogen
- (b) describe the reactivity series as related to the tendency of a metal to form its positive ion, illustrated by its reaction with
 - (i) the aqueous ions of the other listed metals
 - (ii) the oxides of the other listed metals
- (c) deduce the order of reactivity from a given set of experimental results
- (d) describe the action of heat on the carbonates of the listed metals and relate thermal stability to the reactivity series

9.3 Extraction of metals

- (a) describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series
- (b) describe metal ores as a finite resource and hence the need to recycle metals
- (c) discuss the social, economic and environmental advantages and disadvantages of recycling metals, e.g. aluminium and copper

9.4 Iron

- (a) describe and explain the essential reactions in the extraction of iron using haematite, limestone and coke in the blast furnace
- (b) describe steels as alloys which are a mixture of iron with carbon and often other metals and how controlled use of these additives changes the properties of the iron, e.g. high carbon steels are strong but brittle whereas low carbon steels are softer and more easily shaped
- (c) state the uses of mild steel (e.g. car bodies; machinery) and stainless steel (e.g. chemical plant; cutlery; surgical instruments)
- (d) describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can be achieved by placing a barrier around the metal (e.g. painting; greasing; plastic coating; galvanising)
- (e) describe the sacrificial protection of iron by a more reactive metal in terms of the reactivity series where the more reactive metal corrodes preferentially (e.g. underwater pipes have a piece of magnesium attached to them)

9.5 Aluminium

- (a) outline the manufacture of aluminium from pure aluminium oxide dissolved in cryolite (starting materials and essential conditions, including identity of electrodes should be given together with equations for the electrode reactions but no technical details or diagrams are required)
- (b) explain the apparent lack of reactivity of aluminium
- (c) state the uses of aluminium and relate the uses to the properties of this metal and its alloys, e.g. the manufacture of aircraft; food containers; electrical cables

10 Atmosphere and environment**Content**

10.1 Air

10.2 Water

Learning outcomes*Candidates should be able to:***10.1 Air**

- (a) describe the volume composition of gases present in dry air as 78% nitrogen, 21% oxygen and the remainder being noble gases (with argon as the main constituent) and carbon dioxide
- (b) describe the separation of oxygen, nitrogen and the noble gases from liquid air by fractional distillation
- (c) state the uses of oxygen (e.g. in making steel; oxygen tents in hospitals; in welding)
- (d) name some common atmospheric pollutants (e.g. carbon monoxide; methane; nitrogen oxides (NO and NO_2); ozone; sulfur dioxide; unburned hydrocarbons)
- (e) state the sources of these pollutants as
 - (i) carbon monoxide from incomplete combustion of carbon-containing substances
 - (ii) methane from bacterial decay of vegetable matter
 - (iii) nitrogen oxides from lightning activity and internal combustion engines
 - (iv) ozone from photochemical reactions responsible for the formation of photochemical smog
 - (v) sulfur dioxide from volcanoes and combustion of fossil fuels
 - (vi) unburned hydrocarbons from internal combustion engines

- (f) describe the reactions used in possible solutions to the problems arising from some of the pollutants named in (d)
 - (i) the redox reactions in catalytic converters to remove combustion pollutants
 - (ii) the use of calcium carbonate to reduce the effect of 'acid rain' and in flue gas desulfurisation
- (g) discuss some of the effects of these pollutants on health and on the environment
 - (i) the poisonous nature of carbon monoxide
 - (ii) the role of nitrogen dioxide and sulfur dioxide in the formation of 'acid rain' and its effects on organisms and buildings
- (h) discuss the importance of the ozone layer and the problems involved with the depletion of ozone by reaction with chlorine-containing compounds, chlorofluorocarbons (CFCs)
- (i) describe the carbon cycle in simple terms, to include
 - (i) the processes of combustion, respiration and photosynthesis
 - (ii) how the carbon cycle regulates the amount of carbon dioxide in the atmosphere
- (j) state that carbon dioxide and methane are greenhouse gases and may contribute to global warming, give the sources of these gases and discuss the possible consequences of an increase in global warming

10.2 Water

- (a) state that water from natural sources contains a variety of dissolved substances
 - (i) naturally occurring (mineral salts; oxygen; organic matter)
 - (ii) pollutant (metal compounds; sewage; nitrates from fertilisers; phosphates from fertilisers and detergents; harmful microbes)
- (b) discuss the environmental effects of the dissolved substances named in (a)
 - (i) beneficial, e.g. oxygen and mineral salts for aquatic life
 - (ii) pollutant, e.g. hazards to health; eutrophication
- (c) outline the purification of the water supply in terms of
 - (i) filtration to remove solids
 - (ii) use of carbon to remove tastes and odours
 - (iii) chlorination to disinfect the water
- (d) describe how sea water can be converted into drinkable water by desalination

11 Organic chemistry

Content

- 11.1 Alkanes
- 11.2 Alkenes
- 11.3 Alcohols
- 11.4 Carboxylic acids
- 11.5 Polymers

*The use of molecular models is recommended to enable students to appreciate the three-dimensional structures of molecules.

Learning outcomes

Candidates should be able to:

- (a) state that the naphtha fraction from petroleum (crude oil) is the main source of hydrocarbons used as the feedstock for the production of a wide range of organic compounds
- (b) describe the issues relating to the competing uses of oil as an energy source and as a chemical feedstock

11.1 Alkanes

- (a) describe a homologous series as a group of compounds with a general formula, similar chemical properties and showing a gradation in physical properties as a result of increase in the size and mass of the molecules, e.g. melting and boiling points; viscosity
- (b) describe the alkanes as a homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}
- (c) draw the structures of branched and unbranched alkanes, C1 to C4, and name the unbranched alkanes, methane to butane
- (d) define isomerism and identify isomers
- (e) describe the properties of alkanes (exemplified by methane) as being generally unreactive except in terms of burning and substitution by chlorine

11.2 Alkenes

- (a) describe the alkenes as a homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n} and containing the C=C functional group
- (b) draw the structures of branched and unbranched alkenes, C2 to C4, and name the unbranched alkenes, ethene to butene
- (c) describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the fractional distillation of petroleum (crude oil)
- (d) describe the difference between saturated and unsaturated hydrocarbons in terms of their structures and in their reaction with aqueous bromine
- (e) describe the properties of alkenes in terms of combustion, polymerisation and their addition reactions with bromine, steam and hydrogen
- (f) state the meaning of *polyunsaturated* when applied to food products
- (g) describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product

11.3 Alcohols

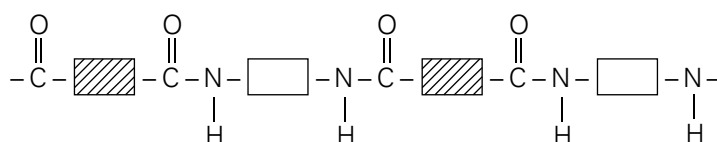
- (a) describe the alcohols as a homologous series containing the -OH functional group
- (b) draw the structures of alcohols, C1 to C4, and name the unbranched alcohols, methanol to butanol
- (c) describe the properties of alcohols in terms of combustion and oxidation to carboxylic acids
- (d) describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose
- (e) state some uses of ethanol, e.g. as a solvent; as a renewable fuel; in the production of vinegar

11.4 Carboxylic acids

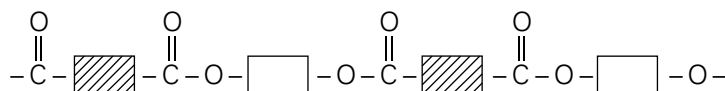
- (a) describe the carboxylic acids as a homologous series containing the $\text{-CO}_2\text{H}$ functional group
- (b) draw the structures of carboxylic acids, methanoic acid to butanoic acid, and name the unbranched acids, methanoic to butanoic acids
- (c) describe the carboxylic acids as weak acids, reacting with carbonates, bases and some metals
- (d) describe the formation of ethanoic acid by the oxidation of ethanol by acidified potassium manganate(VII) and the formation of vinegar by bacterial oxidation
- (e) describe the reaction of carboxylic acids from C1 to C4 with alcohols from C1 to C4 to form esters
- (f) draw the structures of and name the esters formed from carboxylic acids (see 11.4 (b)) and alcohols (see 11.3 (b))
- (g) state some commercial uses of esters, e.g. perfumes; flavourings; solvents

11.5 Polymers

- (a) describe polymers as large molecules made from many small units called monomers, different polymers having different repeat units and/or different linkages
- (b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer
- (c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm
- (d) describe nylon, a polyamide, and *Terylene*, a polyester, as condensation polymers, the partial structure of nylon being represented as



and the partial structure of *Terylene* as



(details of manufacture and mechanisms of these polymerisations are **not** required)

- (e) state some typical uses of synthetic fibres such as nylon and *Terylene*, e.g. clothing; curtain materials; fishing line; parachutes; sleeping bags
- (f) deduce the partial structure of the polymer product from a given monomer and vice versa
- (g) describe the pollution problems caused by the disposal of non-biodegradable plastics
- (h) identify proteins and complex carbohydrates (polysaccharides, e.g. starch) as natural polymers
- (i) describe proteins as polymers possessing the same amide linkages as nylon but formed from different monomers
- (j) describe fats as molecules possessing the same ester linkages as *Terylene*
- (k) describe the hydrolysis of proteins to amino acids and complex carbohydrates (polysaccharides, e.g. starch) to simple sugars

6.6 Guidance for the preparation of reagents

Hazard	Label	Identity	Instructions
	dilute hydrochloric acid	1.0 mol/dm ³ HCl	Dilute 85 cm ³ of concentrated (35–37%; approximately 11 mol/dm ³) hydrochloric acid [C] [MH] to 1 dm ³ .
[C]	dilute nitric acid	1.0 mol/dm ³ HNO ₃	Dilute 64 cm ³ of concentrated (70% w/v) nitric acid [C] [O] to 1 dm ³ .
[MH]	dilute sulfuric acid	0.5 mol/dm ³ H ₂ SO ₄	Cautiously pour 28 cm ³ of concentrated (98%) sulfuric acid [C] into 500 cm ³ of distilled water with continuous stirring. Make the solution up to 1 dm ³ with distilled water. Care: concentrated H ₂ SO ₄ is very corrosive.
[MH] [N]	aqueous ammonia	1.0 mol/dm ³ NH ₃	Dilute 66 cm ³ of concentrated (35%) ammonia [C] [MH] [N] to 1 dm ³ .
[C]	aqueous sodium hydroxide	1.0 mol/dm ³ NaOH	Dissolve 40.0 g of NaOH [C] in each dm ³ of solution. Care: the process of solution is exothermic and any concentrated solution is very corrosive.
	aqueous barium chloride or aqueous barium nitrate	0.1 mol/dm ³ barium chloride or 0.1 mol/dm ³ barium nitrate	Dissolve 24.4 g of BaCl ₂ · 2H ₂ O [T] in each dm ³ of solution or dissolve 26.1 g of Ba(NO ₃) ₂ [MH] [O] in each dm ³ of solution.
	aqueous silver nitrate	0.05 mol/dm ³ silver nitrate	Dissolve 8.5 g of AgNO ₃ [C] [N] [O] in each dm ³ of solution.
[MH]	limewater	saturated aqueous calcium hydroxide, Ca(OH) ₂	Prepare fresh limewater by leaving distilled water to stand over solid calcium hydroxide [C] [MH] for several days, shaking occasionally. Decant or filter the solution.
	aqueous potassium iodide	0.1 mol/dm ³ KI	Dissolve 16.6 g of KI in each dm ³ of solution.
	aqueous potassium manganate(VII)	0.02 mol/dm ³ KMnO ₄	Dissolve 3.16 g of KMnO ₄ [O] [MH] [N] in each dm ³ of solution.
[MH]	acidified aqueous potassium manganate(VII)	0.01 mol/dm ³ KMnO ₄ 0.5 mol/dm ³ sulfuric acid	Mix equal volumes of 0.02 mol/dm ³ KMnO ₄ and 1.0 mol/dm ³ H ₂ SO ₄ [MH] .
[F] [HH] [MH] [T] [N] [C]	methyl orange indicator	methyl orange indicator (pH range 2.9 to 4.6)	Use commercially produced solution or dissolve 0.4 g of solid indicator [T] [HH] [MH] [C] [N] in 200 cm ³ of ethanol (IDA) [F] [MH] [HH] and make up to 1 dm ³ with distilled water.
	starch indicator	freshly prepared aqueous starch indicator (approx 2% solution w/v)	Mix 2 g of soluble starch with a little cold water until a smooth paste is obtained. Add 100 cm ³ boiling water and stir. Boil until a clear solution is obtained (about 5 minutes).

7. Appendix

7.1 Qualitative Analysis Notes

Tests for anions

anion	test	test result
carbonate (CO_3^{2-})	add dilute acid	effervescence, carbon dioxide produced
chloride (Cl^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	white ppt.
iodide (I^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	yellow ppt.
nitrate (NO_3^-) [in solution]	add aqueous sodium hydroxide, then add aluminium foil; warm carefully	ammonia produced
sulfate (SO_4^{2-}) [in solution]	acidify with dilute nitric acid, then add aqueous barium nitrate	white ppt., insoluble in excess dilute nitric acid

Tests for aqueous cations

cation	effect of aqueous sodium hydroxide	effect of aqueous ammonia
aluminium (Al^{3+})	white ppt., soluble in excess, giving a colourless solution	white ppt., insoluble in excess
ammonium (NH_4^+)	ammonia produced on warming	–
calcium (Ca^{2+})	white ppt., insoluble in excess	no ppt.
chromium(III) (Cr^{3+})	green ppt., soluble in excess, giving a green solution	green ppt., insoluble in excess
copper(II) (Cu^{2+})	light blue ppt., insoluble in excess	light blue ppt., soluble in excess, giving a dark blue solution
iron(II) (Fe^{2+})	green ppt., insoluble in excess	green ppt., insoluble in excess
iron(III) (Fe^{3+})	red-brown ppt., insoluble in excess	red-brown ppt., insoluble in excess
zinc (Zn^{2+})	white ppt., soluble in excess, giving a colourless solution	white ppt., soluble in excess, giving a colourless solution

Tests for gases

gas	test and test result
ammonia (NH_3)	turns damp red litmus paper blue
carbon dioxide (CO_2)	turns limewater milky
chlorine (Cl_2)	bleaches damp litmus paper
hydrogen (H_2)	'pops' with a lighted splint
oxygen (O_2)	relights a glowing splint

7.2 The Periodic Table of Elements

Group																				
I	II	1 H hydrogen 1										III	IV	V	VI	VII	VIII			
3 Li lithium 7	4 Be beryllium 9	<div>Key</div> <div>atomic number atomic symbol name relative atomic mass</div>										5 B boron 11	6 C carbon 12	7 N nitrogen 14	8 O oxygen 16	9 F fluorine 19	10 Ne neon 20			
	11 Na sodium 23												12 Mg magnesium 24	13 Al aluminium 27	14 Si silicon 28	15 P phosphorus 31		16 S sulfur 32	17 Cl chlorine 35.5	18 Ar argon 40
	19 K potassium 39												20 Ca calcium 40	21 Sc scandium 45	22 Ti titanium 48	23 V vanadium 51		24 Cr chromium 52	25 Mn manganese 55	26 Fe iron 56
37 Rb rubidium 85	38 Sr strontium 88	39 Y yttrium 89	40 Zr zirconium 91	41 Nb niobium 93	42 Mo molybdenum 96	43 Tc technetium —	44 Ru ruthenium 101	45 Rh rhodium 103	46 Pd palladium 106	47 Ag silver 108	48 Cd cadmium 112	49 In indium 115	50 Sn tin 119	51 Sb antimony 122	52 Te tellurium 128	53 I iodine 127	54 Xe xenon 131			
55 Cs caesium 133	56 Ba barium 137	57–71 lanthanoids	72 Hf hafnium 178	73 Ta tantalum 181	74 W tungsten 184	75 Re rhenium 186	76 Os osmium 190	77 Ir iridium 192	78 Pt platinum 195	79 Au gold 197	80 Hg mercury 201	81 Tl thallium 204	82 Pb lead 207	83 Bi bismuth 209	84 Po polonium —	85 At astatine —	86 Rn radon —			
87 Fr francium —	88 Ra radium —	89–103 actinoids	104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —		114 Fl flerovium —		116 Lv livermorium —					

lanthanoids	57 La lanthanum 139	58 Ce cerium 140	59 Pr praseodymium 141	60 Nd neodymium 144	61 Pm promethium —	62 Sm samarium 150	63 Eu europium 152	64 Gd gadolinium 157	65 Tb terbium 159	66 Dy dysprosium 163	67 Ho holmium 165	68 Er erbium 167	69 Tm thulium 169	70 Yb ytterbium 173	71 Lu lutetium 175
actinoids	89 Ac actinium —	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —

The volume of one mole of any gas is 24 dm³ at room temperature and pressure (r.t.p.)