Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2025

CHEMISTRY – HIGHER LEVEL

TUESDAY, 17 JUNE – AFTERNOON, 2:00 to 5:00

400 MARKS

Answer any **eight** questions.

All questions carry equal marks (50).

The information below should be used in your calculations.

Relative atomic masses (rounded): H = 1, C = 12, N = 14, O = 16, Na = 23, Fe = 56 , Br = 80

Molar volume at room temperature and pressure = 24.0 litres

Avogadro constant = 6.0×10^{23} mol^{-1}

The use of the *Formulae and Tables* booklet approved for use in the State Examinations is permitted. A copy may be obtained from the superintendent.

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Section A

See page 1 for instructions regarding the number of questions to be answered.

1. A student carried out an experiment to determine the iron(II) content of an iron supplement tablet. Six iron tablets with a total mass of 2.496 g were dissolved in dilute sulfuric acid. The solution and the washings were transferred to a 250 cm^3 volumetric flask and made up to the mark using deionised water. A 25.0 cm^3 portion of this solution was transferred into a conical flask and some sulfuric acid was added. The solution was then titrated against a previously standardised solution of potassium manganate(VII) (**$KMnO_4$**). A number of titrations were carried out.

The titration reaction is described by the following balanced equation:

$$\mathbf{MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O}$$

(*a*) Identify a primary standard that the student could have used to standardise the solution of potassium manganate(VII). (5)

(*b*) (*i*) Outline the correct procedure for bringing the solution in the volumetric flask precisely to the 250 cm^3 mark.

(*ii*) Explain why using more than one iron tablet in the 250 cm^3 of solution increases the accuracy of the analysis. (9)

(*c*) (*i*) Name the piece of apparatus used to accurately measure and transfer the 25.0 cm^3 portion of iron(II) solution into the conical flask.

(*ii*) Describe how this piece of apparatus was rinsed before use. (9)

(*d*) (*i*) Explain why the addition of an indicator into the conical flask was not required.

(*ii*) Describe what the student observed at the end point.

(*iii*) Describe what would be observed in the conical flask if insufficient acid was present during the titration. Explain your answer. (12)

(*e*) On average, 22.5 cm^3 of 0.010 M potassium manganate(VII) solution were required for complete reaction with 25.0 cm^3 of the solution of the iron(II) in excess acid.

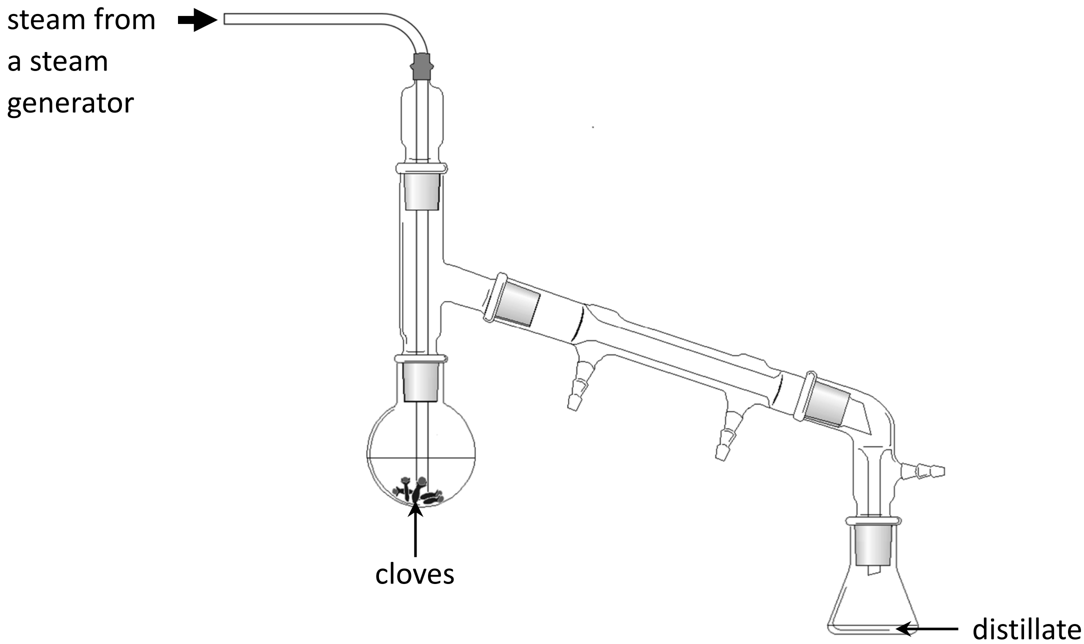
(*i*) Calculate the number of moles of manganate(VII) ions present in 22.5 cm^3 of 0.010 M potassium manganate(VII) solution.

(*ii*) Calculate the number of moles of iron(II) present in the 250 cm^3 solution in the volumetric flask.

(*iii*) Calculate the average mass of iron(II) in one tablet.

(*iv*) Calculate the percentage by mass of iron(II) in one tablet. (15)

2. Clove oil is an essential oil with a wide number of uses. Clove oil can be extracted from dried clove buds by steam distillation using apparatus like that shown below.



(*a*) The distillate produced consists of clove oil and another substance **A**.

(*i*) Identify substance **A**.

(*ii*) State and explain the appearance of the distillate collected.

(*iii*) State one advantage of extracting clove oil using steam distillation. (12)

(*b*) Eugenol may be extracted from the distillate by liquid-liquid extraction using the solvent cyclohexane.

(*i*) Describe, with the aid of a labelled diagram, a suitable procedure for the extraction and collection of eugenol from the distillate.

(*ii*) State two properties of cyclohexane that make it a solvent suitable for use in the liquid-liquid extraction of eugenol.

(*iii*) State one precaution that could be taken during the liquid-liquid extraction to maximise the yield of eugenol.

(*iv*) Describe how eugenol can be isolated from the dried eugenol-cyclohexane mixture. (21)

(*c*) (*i*) Suggest one use of eugenol.

(*ii*) Draw the structure of a molecule of eugenol.

(*iii*) Name a spectroscopic technique that could be used to confirm the identity of a sample of eugenol.

(*iv*) Calculate the volume of dry eugenol (density 1.06 g cm^{-3}) obtained from 18.0 g of cloves, given that the percentage yield was 7%. (17)

3. A student monitored the rate of production of oxygen gas (**O_2**) from hydrogen peroxide (**H_2O_2**), using manganese(IV) oxide (**MnO_2**) as a catalyst.

A 5.0 cm^3 portion of hydrogen peroxide solution was diluted to exactly 20 cm^3 with deionised water and then transferred into a reaction flask. 0.5 g of finely-powdered manganese(IV) oxide was added.

The volume of oxygen produced was recorded at intervals over six minutes.

The reaction is described by the following balanced chemical equation:

$$\mathbf{2H_2O_2 \rightarrow O_2 + 2H_2O}$$

The results are given in the table below.

Time (minutes)	0.0	1.0	2.0	3.0	4.0	5.0	6.0
Volume of oxygen (cm^3)	0.0	60.0	82.0	92.0	98.0	100.0	100.0

(*a*) (*i*) Plot a graph on graph paper to show the volume of oxygen produced versus time.

(*ii*) Use your graph to find the instantaneous rate of production of oxygen at 2.5 minutes. (18)

(*b*) (*i*) Use your graph to find the average rate of production of oxygen in cm^3 per minute over the first 2.5 minutes.

(*ii*) Would you expect the average rate over the first 2.5 minutes to increase, decrease or stay the same if 0.5 g of granular manganese(IV) oxide was used instead of the fine powder?
Justify your answer.

(*iii*) Would you expect the average rate over the first 2.5 minutes to increase, decrease or stay the same if a more concentrated hydrogen peroxide solution was used?
Justify your answer. (15)

(*c*) (*i*) Use the data given to determine the average rate of production of oxygen in cm^3 per minute over the first minute.

(*ii*) Use the data given to determine the average rate of production of oxygen in cm^3 per minute over the second minute (from t = 1 to t = 2 minutes).

(*iii*) Account for the difference between the average rate of production of oxygen over the first and the second minutes of the reaction. (9)

(*d*) (*i*) Explain how a catalyst alters the rate of a chemical reaction.

(*ii*) Identify the type of catalysis involved in the production of oxygen from hydrogen peroxide using manganese(IV) oxide as the catalyst.
Justify your answer. (8)

Section B

See page 1 for instructions regarding the number of questions to be answered.

4. Answer **eight** of the following (*a*), (*b*), (*c*), etc. (50)

(*a*) Describe the arrangement of the elements in Mendeleev's 1869 periodic table of the elements.

(*b*) How many (*i*) protons and (*ii*) electrons are there in a $^{52}_{24}\mathbf{Cr^{3+}}$ ion?

(*c*) Write the chemical formulae for:

(*i*) calcium hydroxide,

(*ii*) aluminium sulfate.

(*d*) Write the full *s*, *p*, *d* electron configuration for an atom of vanadium (**V**) in its ground state.

(*e*) A synthetic aromatic molecule is composed of 57.84% carbon, 3.61% hydrogen and 38.55% oxygen by mass. Find by calculation the empirical formula of this molecule.

(*f*) State Avogadro's law.

(*g*) Draw the molecular structure of two isomers of C_4H_{10}, including all atoms and bonds.

(*h*) A dog of mass 8.3 kg is to be given 140 mg per kg of body mass of a 5.0% (w/v) solution of a certain dog medicine. Calculate the volume of solution which should be given to the dog.

(*i*) Explain the term biochemical oxygen demand (BOD).

(*j*) State two ways in which you would expect the melting point of impure benzoic acid to differ from that of pure benzoic acid.

(*k*) Assign oxidation numbers and determine which element is reduced in the reaction described by the following balanced equation:

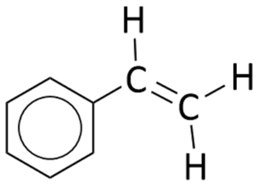
$$\mathbf{3Cu + 2NO_3^- + 8H^+ \rightarrow 3Cu^{2+} + 2NO + 4H_2O}$$

(*l*) Answer part **A** *or* part **B**.

A Explain how oxygen gas is separated industrially from air.

or

B Monomers for two addition polymers are shown on the right.
Identify each of the corresponding addition polymers.



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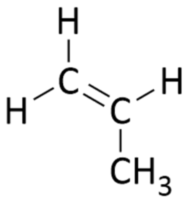

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5. (*a*) A naturally-occurring sample of bromine (**Br**) analysed by a forensic scientist was found to contain two isotopes, 50.69% with mass number 79 and 49.31% with mass number 81.

(*i*) Name the analytical instrument used to determine the percentage abundance of isotopes of given mass number of an element.

(*ii*) Compare the composition of the nucleus of a bromine–79 atom with the nucleus of a bromine–81 atom.

(*iii*) Explain what is meant by the relative atomic mass of an element.

(*iv*) Use the data above to calculate the relative atomic mass of bromine, correct to two decimal places. (20)

(*b*) An atomic orbital diagram for a bromine atom in its ground state is shown on the right.

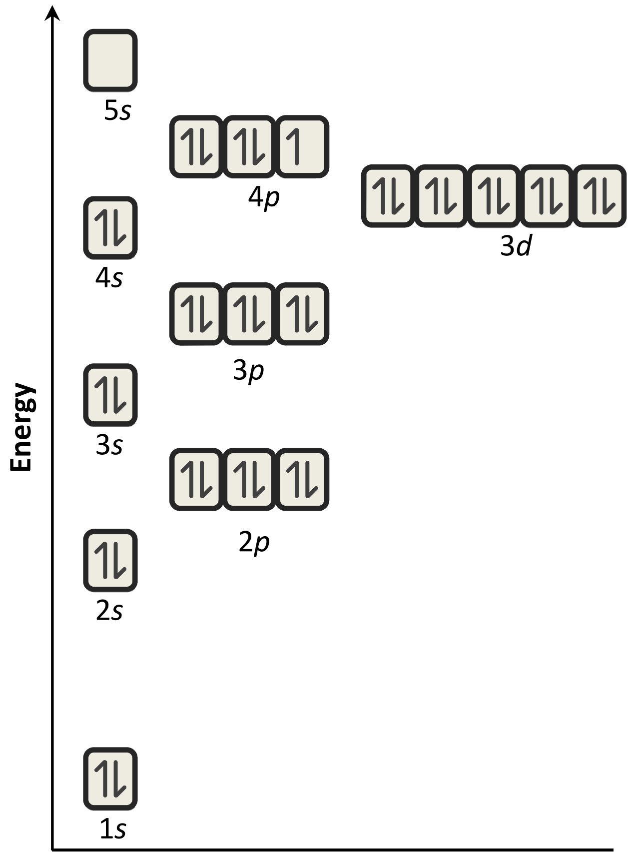
(*i*) What is an atomic orbital?

(*ii*) Draw the shape of the atomic orbital of lowest energy in a bromine atom in its ground state.

(*iii*) State the maximum number of electrons that can be accommodated in a *p*-orbital.

(*iv*) Describe how two or more atomic orbitals of equal energy are filled with electrons.

(*v*) Under what circumstance might an electron in a bromine atom temporarily occupy a higher energy orbital? (18)



(*c*) (*i*) Explain what is meant by atomic (covalent) radius.

(*ii*) Explain why the atomic (covalent) radius of bromine is greater than that of chlorine.

(*iii*) Explain why the atomic (covalent) radius of bromine is smaller than that of selenium.

(12)

6. (*a*) Crude oil is a complex mixture of mostly saturated hydrocarbon molecules. In an oil refinery this mixture is separated into different fractions such as refinery gas and gasoline by a process called fractional distillation.

(*i*) State what is meant by saturated, as applied to hydrocarbons.

(*ii*) Describe, with the aid of a labelled diagram, how refinery gas may be obtained by the fractional distillation of crude oil in an oil refinery.

(*iii*) Identify the two major hydrocarbon components of liquid petroleum gas (LPG), a fuel obtained from refinery gas.

Some fractions undergo further chemical processing in order to make them more useful.

(*iv*) Name the chemical process that can convert octane into 2,2,4-trimethylpentane.

(*v*) Identify the inorganic co-product of the chemical process in which hexane is converted into cyclohexane. (24)

(*b*) The high heat of combustion of hydrogen gas makes it a potentially suitable alternative to hydrocarbon fuels.

(*i*) What is meant by the heat of combustion of a fuel?

(*ii*) Name an instrument that can be used to accurately measure the heat of combustion of a fuel.

(*iii*) State two methods used to produce hydrogen gas industrially. (12)

(*c*) Hydrazine (**N_2H_4**), another fuel, is formed in a reaction between ammonia and hydrogen peroxide. This reaction may be described by the following balanced chemical equation:

$$\mathbf{2NH_3 + H_2O_2 \rightarrow N_2H_4 + 2H_2O}$$

Calculate the heat change for this reaction given that the heats of formation of ammonia, hydrogen peroxide, hydrazine, and water are —45.9 kJ mol^{-1}, —187.8 kJ mol^{-1}, 50.6 kJ mol^{-1} and —285.8 kJ mol^{-1}, respectively. (14)

7. (*a*) (*i*) Explain how an acid differs from a base according to the Brønsted-Lowry theory.

(*ii*) Explain how a strong acid differs from a weak acid according to the Brønsted-Lowry theory.

(*iii*) What is a conjugate acid-base pair?

(*iv*) Identify the conjugate acid-base pairs in the following reaction:

$$\mathbf{HCO_3^-}_{(aq)} + \mathbf{H_2O}_{(l)} \rightleftharpoons \mathbf{H_2CO_3}_{(aq)} + \mathbf{OH^-}_{(aq)}$$ (13)

(*b*) (*i*) Explain what is meant by pH.

(*ii*) Calculate the H_3O^+ ion concentration, in moles per litre, of a solution of a strong acid with pH = 1.4.

(*iii*) Calculate the pH of a 0.015 M solution of a weak monobasic acid with $K_a = 3.2 \times 10^{-4}$ at 25 °C. (15)

(*c*) (*i*) Write an expression for the ionic product of water (K_w).

The ionic product of water (K_w) at 60 °C is 9.61×10^{-14} mol^2 l^{-2}.

(*ii*) Calculate the pH of pure water at 60 °C. (12)

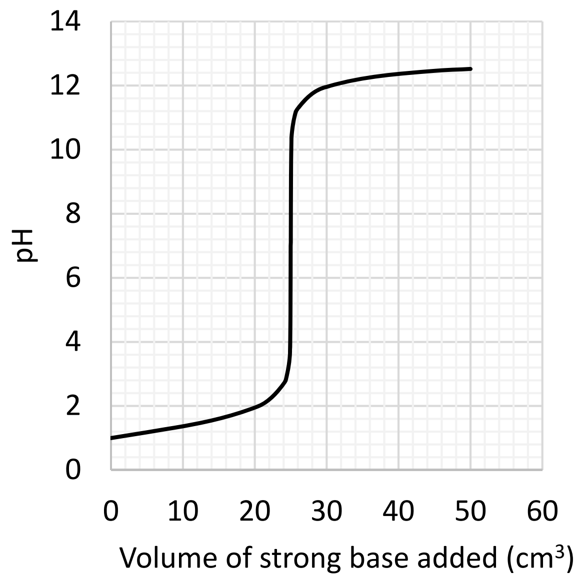
(*d*) A certain water-soluble acid-base indicator, represented by **HA**, is a weak acid which dissociates in water as described by the following balanced equation:

$$\underset{\text{yellow}}{\mathbf{HA}} + \mathbf{H_2O} \rightleftharpoons \mathbf{H_3O^+} + \underset{\text{blue}}{\mathbf{A^-}}$$

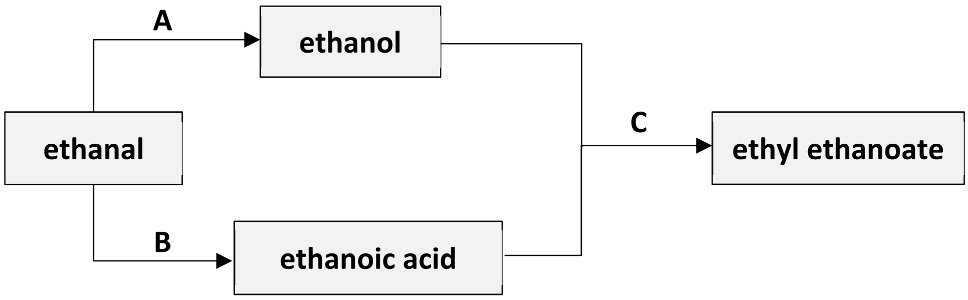
(*i*) State the colour you would expect to observe when a few drops of **HA** are added to a solution of a strong base. Justify your answer.

The pH curve on the right shows the change of pH as 50 cm^3 of a solution of a strong base were added to 25 cm^3 of a solution of a strong monobasic acid.
The indicator **HA** changes colour in the pH range of 4.2 to 5.4.

(*ii*) Would the indicator **HA** be a suitable choice of indicator for the titration? Justify your answer. (10)



8. Study the reaction scheme below and answer the questions that follow.



(*a*) Identify a reaction (**A** to **C**) in the scheme above that is:

(*i*) a substitution reaction,

(*ii*) an oxidation reaction,

(*iii*) a reduction reaction. (6)

(*b*) (*i*) Name the homologous series to which ethanal belongs.

(*ii*) State the colour change observed when ethanal is warmed gently with Fehling's reagent.

(*iii*) Identify the reagent and transition metal catalyst used to convert ethanal to ethanol. (15)

(*c*) Ethanol containing the radioactive isotope oxygen–18, represented by **O***, reacts with non-radioactive ethanoic acid to form ethyl ethanoate. No radioactive water is formed in the process and all the ethyl ethanoate formed contains the oxygen–18 isotope.

The reaction is described by the following balanced chemical equation:

$$\mathbf{C_2H_5O^*H + CH_3COOH \rightleftharpoons CH_3COO^*C_2H_5 + H_2O}$$

(*i*) Draw the structure of a molecule of ethyl ethanoate, showing all atoms and bonds.

(*ii*) Indicate clearly on your diagram the position of the **O*** atom in ethyl ethanoate.

(*iii*) Indicate clearly on your diagram the bond that was formed during the formation of ethyl ethanoate.

In a single molecule of ethyl ethanoate:

(*iv*) State the number of electrons involved in sigma bonds.

(*v*) State the number of electrons involved in pi bonds.

(*vi*) State the number of lone pairs of electrons present. (20)

(*d*) Both ethanol and ethanoic acid demonstrate acidic properties.

(*i*) Write a balanced chemical equation for the reaction of ethanol with sodium.

(*ii*) Explain why the ethanoate ion (**CH_3COO^-**) is a weaker conjugate base than the ethoxide ion (**$C_2H_5O^-$**). (9)

9. Nitrosyl bromide (**NOBr**) decomposes to form nitrogen monoxide (**NO**) and bromine gas in a reversible reaction which is described by the following balanced chemical equation:

$$\mathbf{2NOBr}_{(g)} \rightleftharpoons \mathbf{2NO}_{(g)} + \mathbf{Br_2}_{(g)}$$

(*a*) (*i*) Explain what is meant by a reversible reaction.

(*ii*) Explain why the concentrations of reactants and products remain constant when dynamic equilibrium is established in a reversible reaction. (8)

(*b*) When 55 g of nitrosyl bromide were sealed into a 2 litre closed container, 78% of the nitrosyl bromide had decomposed at equilibrium at temperature *T*.

(*i*) Calculate the number of moles of nitrosyl bromide sealed into the container, initially.

(*ii*) Calculate the number of moles of nitrosyl bromide present in the container at equilibrium.

(*iii*) Write an expression for the equilibrium constant $\boldsymbol{K}_c$ for this reaction.

(*iv*) Calculate the value of $\boldsymbol{K}_c$ for the equilibrium at temperature *T*. (24)

(*c*) (*i*) State Le Châtelier's principle.

(*ii*) State the effect, if any, on the number of moles of bromine gas present at equilibrium if the pressure was increased while keeping the temperature *T* constant.
Justify your answer.

The value of $\boldsymbol{K}_c$ for the reaction increases with an increase in temperature.

(*iii*) State whether the decomposition of nitrosyl bromide is an endothermic or an exothermic reaction. Justify your answer. (18)

10. Answer any **two** of the parts (*a*), (*b*) and (*c*). (2 × 25)

(*a*) Nitrogen trifluoride (**NF_3**) is a synthetic gas used in the manufacturing of smartphones.

(*i*) Use electronegativity values to predict the type of bonding in **NF_3**.

(*ii*) Draw a dot and cross diagram to show the arrangement of all the valence electrons in a molecule of **NF_3**.

(*iii*) Name and account for the shape of the **NF_3** molecule.

(*iv*) Draw a diagram to show how intermolecular forces arise between two molecules of **NF_3** in the liquid state.

(*v*) Name the type of intermolecular forces you would expect to find in **NF_3**.

Both **BF_3** and **NF_3** molecules contain a central atom bonded to three fluorine atoms.

(*vi*) Explain why **BF_3** is a non-polar molecule while **NF_3** is a polar molecule. (25)

(*b*) Ethene can react with chlorine by ionic addition to form 1,2-dichloroethane.

(*i*) Draw the structure of a molecule of ethene, showing all atoms and bonds.

(*ii*) Indicate clearly on your diagram which of the bonds in ethene are broken during the addition reaction.

(*iii*) Identify the two chlorine species formed following the polarisation and the breaking of the Cl—Cl bond.

(*iv*) Draw the structure of the intermediate ionic species formed during the above reaction. Your diagram should include all atoms, bonds and relevant charges.

(*v*) Describe how the intermediate ionic species is converted to 1,2-dichloroethane.

(*vi*) Identify the inorganic molecule that is eliminated when 1,2-dichloroethane is converted to the monomer used to produce the polymer PVC. (25)

(*c*) Effervescent tablets typically contain a dry mixture of citric acid (**$C_6H_8O_7$**), tartaric acid (**$C_4H_6O_6$**) and sodium hydrogencarbonate (**$NaHCO_3$**). This mixture reacts when the tablet is placed in water, producing carbon dioxide gas, according to the following balanced chemical equations:

$$C_6H_8O_7 + 3NaHCO_3 \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2$$

$$C_4H_6O_6 + 2NaHCO_3 \rightarrow Na_2C_4H_4O_6 + 2H_2O + 2CO_2$$

An effervescent tablet contains 0.096 g of citric acid and 0.15 g of tartaric acid.

(*i*) Calculate the total mass of **$NaHCO_3$** required for complete reaction with the two acids in the effervescent tablet.

(*ii*) Calculate the maximum volume of **CO_2** produced from the tablet at room temperature and pressure.

(*iii*) Calculate the number of **H_2O** molecules produced from 0.096 g of citric acid. (25)

11. Answer any **two** of the parts (*a*), (*b*), (*c*) and (*d*). (2 × 25)

(*a*) The Environmental Protection Agency (EPA) recommend that household wells are checked for water quality.

A water sample from a hard water area may be tested for total hardness.

(*i*) What is meant by total hardness?

(*ii*) Write the full name for **edta**, a reagent used to determine total hardness.

(*iii*) Name a suitable method for removing total hardness from water for domestic use.

A water sample from an agricultural area may contain nitrate ions.

(*iv*) Describe a chemical test to confirm the presence of nitrate ions in a water sample.

Lead ions from the disposal of batteries may enter a water supply.

(*v*) Identify an instrumental method of analysis that could be used to detect and measure the concentration of lead ions in a water sample.

(*vi*) Describe how lead ions can be removed from a water supply.

Chlorination may be carried out on a water supply from a household well using a solution of sodium hypochlorite (**NaClO**). This solution is prepared by diluting 5.0 litres of a 1% (w/v) solution of sodium hypochlorite to 25 litres with water.

(*vii*) Calculate the final concentration in p.p.m. (mg per litre) of the sodium hypochlorite solution after dilution to 25 litres. (25)

(*b*) In an experiment to measure the heat of reaction (ΔH) of hydrochloric acid with sodium hydroxide, 80 cm^3 of 1.0 M hydrochloric acid solution at room temperature were added to 80 cm^3 of 1.0 M sodium hydroxide solution, also at room temperature in a suitable container. The temperature of the mixture rose by 6.8 K and then began to fall.
The reaction is described by the following balanced chemical equation:

$$\mathbf{HCl + NaOH \rightarrow NaCl + H_2O}$$

(*i*) Why did the temperature rise when the solutions were mixed?

(*ii*) Explain what is meant by the term heat of reaction.

(*iii*) Calculate the number of moles of hydrochloric acid in 80 cm^3 of 1.0 M hydrochloric acid solution.

(*iv*) Calculate the heat energy produced in the reaction mixture, assuming the density of the resultant sodium chloride solution is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.2 kJ kg^{-1} K^{-1}.

(*v*) Calculate the value of ΔH, the heat of reaction.

(25)

This question continues on the next page.

(*c*) Between 1908 and 1948 luminous paints containing compounds of radioactive radium–226 were used on the inside of watches and clocks so that they could be read in the dark.

Radium–226 emits alpha radiation. It has a half-life of 1600 years.

(*i*) Name one scientist credited with the discovery of the element radium.

(*ii*) What is an alpha particle?

(*iii*) Identify the radioisotope produced when radium–226 emits an alpha particle.

(*iv*) Explain why a person wearing a watch containing this luminous paint is not at risk from the alpha radiation emitted by the radium–226.

(*v*) State a reason why a radium watch manufactured 100 years ago is still considered a source of ionising radiation.

The nuclear equation below represents the beta-particle decay of another isotope of radium, radium–225.

$$^{225}_{88}\mathbf{Ra} \rightarrow {}^{X}_{Y}\mathbf{Z} + {}^{\;0}_{-1}\mathbf{e}$$

(*vi*) Identify the number **X**.

(*vii*) Identify the number **Y**.

(*viii*) Identify the element **Z**.

(25)

This question continues on the next page.

(*d*) Answer part **A** *or* part **B**.

A The nitrogen cycle on Earth is a biogeochemical process which transforms inert nitrogen gas in the atmosphere to a more usable form for living organisms.

(*i*) Explain why nitrogen gas in the atmosphere is chemically inert.

(*ii*) Write balanced chemical equations for the natural fixation by lightning of atmospheric nitrogen converting it first to **NO** and then to $\mathbf{NO_2}$.

(*iii*) Identify the two acids formed when nitrogen dioxide reacts with water.

Nitrate ions found in soil are a usable form of nitrogen for plants.

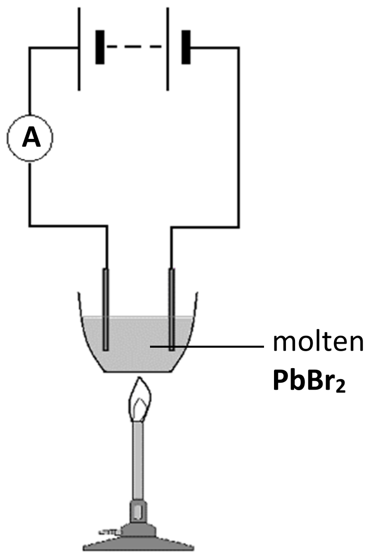
(*iv*) Explain why plants need nitrogen.

(*v*) Describe how nitrate ions in the soil are recycled to nitrogen gas in the atmosphere.

(*vi*) Describe one pathway by which nitrogen compounds in living organisms are recycled to nitrogen gas in the atmosphere. (25)

or

B The electrolysis of lead(II) bromide ($\mathbf{PbBr_2}$) produces lead and bromine.
The electrolysis can be carried out in an arrangement of apparatus as shown, using a pair of inert electrodes immersed in molten lead bromide.



(*i*) Explain what is meant by electrolysis.

(*ii*) Identify a suitable material to use for the inert electrodes.

(*iii*) Compare the electrical conductivity of solid lead(II) bromide to molten lead(II) bromide.
Explain your answer.

During the electrolysis, oxidation occurs at the anode.

(*iv*) Explain what is meant by oxidation in terms of electron transfer.

(*v*) Identify which element is formed at the anode.

(*vi*) Write a balanced half-equation for the reaction that occurs at the anode. (25)

Acknowledgements

Images

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Leaving Certificate – Higher level

Chemistry

Tuesday, 17 June

Afternoon, 2:00 – 5:00