Coimisiún na Scrúduithe Stáit
State Examinations Commission

## LEAVING CERTIFICATE EXAMINATION, 2024

# CHEMISTRY – HIGHER LEVEL

TUESDAY, 18 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, He = 4, C = 12, N = 14, O = 16, Cl = 35.5, Fe = 56, Ra = 226

Avogadro constant = $6.0 \times 10^{23}$ mol$^{-1}$

Molar volume at s.t.p. = 22.4 litres

Universal gas constant = 8.3 J K$^{-1}$ mol$^{-1}$

Ionic product (dissociation constant) of water, $K_w$ = $1.0 \times 10^{-14}$ mol$^2$ l$^{-2}$ at 25 °C

**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.**

Do not hand this up.

This document will not be returned to the State Examinations Commission.

## 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 concentration of ethanoic acid in vinegar. A 10.0 $cm^3$ portion of the vinegar was first diluted to exactly 50.0 $cm^3$. The diluted vinegar solution was titrated against a 0.09 M sodium hydroxide solution in a conical flask. On average, 12.4 $cm^3$ of the *diluted* vinegar were required to neutralise 25.0 $cm^3$ of the **NaOH** solution.

The titration reaction is described by the following balanced chemical equation:

$$\mathbf{CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O}$$

(*a*) (*i*) Name the piece of apparatus used to measure accurately the 10.0 $cm^3$ portion of the original vinegar.

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

(*iii*) Describe a suitable method to dilute the 10.0 $cm^3$ portion of the original vinegar to exactly 50.0 $cm^3$. (15)

(*b*) (*i*) Calculate the volume of *undiluted* vinegar which would be required to neutralise 25.0 $cm^3$ of the 0.09 M **NaOH** solution.

(*ii*) Outline an advantage of diluting the vinegar before carrying out the titration. (9)

(*c*) (*i*) Name a suitable indicator for this titration.

(*ii*) State the colour change observed at the end point. (9)

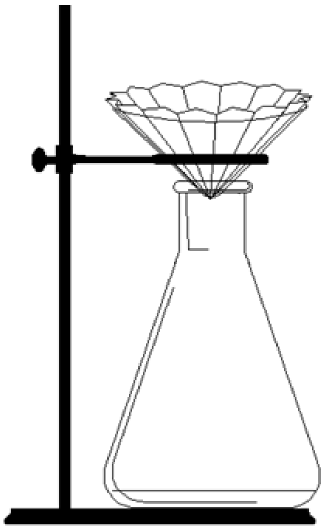
(*d*) (*i*) Calculate the number of moles of sodium hydroxide in each 25.0 $cm^3$ portion.

(*ii*) Calculate the number of moles of ethanoic acid in each $cm^3$ of the *diluted* vinegar.

(*iii*) Calculate the concentration of ethanoic acid in the original vinegar in moles per litre.

(*iv*) Calculate the concentration of ethanoic acid in the original vinegar in % (w/v). (17)

**2.** (*a*) A student carried out an experiment to purify benzoic acid by recrystallisation, using water as the solvent.



(*i*) Explain why water is a suitable solvent for carrying out this recrystallisation.

(*ii*) Explain the purpose of the first (hot) filtration.

(*iii*) Fluted filter paper in a warm funnel, as shown on the right, is used in the hot filtration.
Explain why this arrangement is suitable for hot filtration.

(*iv*) Explain why the second filtration is only carried out after a sufficient period of cooling.

(*v*) What observation would the student make that shows that the recrystallised benzoic acid was pure? (20)

(*b*) A second student carried out a test to show that ethanal is easily oxidised.

(*i*) Identify the reagent(s) which the student could have used.

(*ii*) State the colour change observed for the reagent(s) you have identified.

(*iii*) Identify the organic substance produced in this test.

(*iv*) Write a half equation for the reduction of the inorganic reagent used in this test. (15)

(*c*) A third student prepared soap in the laboratory.

(*i*) Identify the reactants used in the preparation of soap.

(*ii*) Identify the solvent used in the preparation of soap.

(*ii*) Name the co-product formed when soap is prepared in this way.
Draw the molecular structure of this co-product, including all atoms and bonds. (15)

**3.** The reaction of sodium thiosulfate with hydrochloric acid is described by the following balanced chemical equation:

$$Na_2S_2O_3 + 2HCl \rightarrow 2NaCl + SO_2 + S + H_2O$$

To investigate the effect of *concentration* on the rate of this reaction, the experiment was carried out for a number of different concentrations of sodium thiosulfate solution. For each run, a stopwatch was started when 100 $cm^3$ of $Na_2S_2O_3$ were mixed with 10 $cm^3$ of 3 M **HCl**.

For each run, the reaction was carried out at room temperature and the time taken for the same mass of sulfur to precipitate was measured. The inverse of that time was taken as a measure of the initial rate of reaction.

The results are shown in the table below.

| Concentration of $Na_2S_2O_3$ (M) | 0.10 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 |
|---|---|---|---|---|---|---|---|---|
| Time (s) | 50 | 56 | 63 | 72 | 84 | 100 | 125 | 168 |
| Rate = $\frac{1}{Time}$ ($s^{-1}$) | 0.020 | 0.018 | | | | | | |

(*a*) (*i*) Describe a method that could be used to know when the same mass of sulfur had been precipitated in each run.

(*ii*) Describe how a 0.10 M solution of $Na_2S_2O_3$ could be used to prepare a 100 $cm^3$ portion of 0.09 M $Na_2S_2O_3$ solution. (12)

(*b*) (*i*) Copy and complete the third row of the table into your answerbook by filling in the missing rate values, correct to three decimal places.

(*ii*) Draw a graph on graph paper to show how the rate of the reaction varies with the concentration of sodium thiosulfate solution.

(*iii*) What can be concluded from your graph? (20)

(*c*) (*i*) Use your graph to estimate the rate of reaction if 100 $cm^3$ of 0.015 M $Na_2S_2O_3$ solution had been used.

(*ii*) Calculate the time taken for the sulfur to precipitate in this case. (8)

(*d*) To investigate the effect of *temperature* on the rate of this reaction, the time taken for the same mass of sulfur to precipitate was measured at three different temperatures, using fixed volumes and concentrations of the reactants.

The results are shown in the table below.

| Temperature (°C) | $T_1$ | $T_2$ | $T_3$ |
|---|---|---|---|
| Time (s) | 40 | 10 | 25 |

(*i*) Describe a suitable method for heating the reactants and measuring the reaction temperature. A labelled diagram may help your answer.

(*ii*) Which temperature ($T_1$, $T_2$ or $T_3$) was the highest? Justify your answer. (10)

## Section B

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

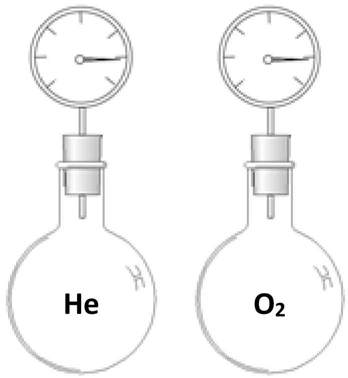
**4.** Answer **eight** of the following (*a*), (*b*), (*c*), etc. (50)

(*a*) How many (*i*) protons, (*ii*) neutrons, are there in a nucleus of helium–3?

(*b*) Identify two reagents needed to test for the presence of phosphate ions in aqueous solution.

(*c*) State two reasons why real gases deviate from ideal behaviour.

(*d*) The diagram on the right shows two identical flasks, one filled with helium gas and the other filled with oxygen gas.
The flasks are kept at the same temperature and pressure.
There are 2.4 g of gas in the flask of oxygen.
Calculate the mass of helium present.




(*e*) State the standard units of:
- (*i*) first ionisation energy,
- (*ii*) biochemical oxygen demand (BOD).

(*f*) Name three homologous series of organic compounds that contain a carbonyl group.

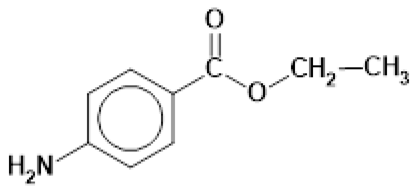
(*g*) Oxygenates are often added to petrol.
- (*i*) Explain why oxygenates are often added to petrol.
- (*ii*) Identify an oxygenate suitable for this purpose.

(*h*) What is the specific purpose of adding aluminium sulfate:
- (*i*) during water treatment,
- (*ii*) during the tertiary stage of sewage treatment?

(*i*) Write a balanced chemical half equation for the reaction that occurs at the cathode when an electric current is passed through an aqueous solution of sodium sulfate.

(*j*) Explain the fundamental principle of chromatography.

(*k*) The structure of the painkiller benzocaine is shown on the right. Calculate the percentage yield of a reaction in which 2412.3 g of pure benzocaine was obtained when the theoretical yield was 21.5 moles.



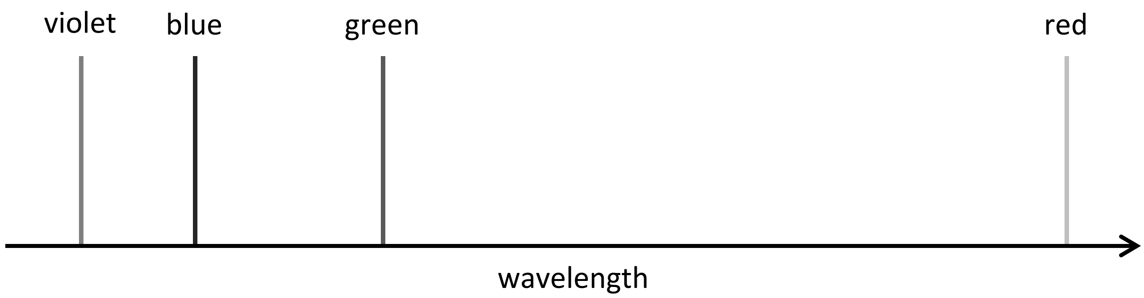

(*l*) Answer part **A** *or* part **B**.

**A** Identify three chemical species formed when carbon dioxide gas dissolves in pure water.

*or*

**B** Outline the contributions of each of the following to crystallography:
- (*i*) Lawrence Bragg
- (*ii*) Dorothy Hodgkin

**5.** In 1885 the Swiss mathematician Johann Balmer wrote a mathematical formula to describe the wavelengths of the visible line spectrum of atomic hydrogen, which is now named after him. However there was no explanation for the existence of these lines until 1913.




In 1913 Bohr's model of the hydrogen atom was shown to be consistent with the Balmer series. Bohr's model was therefore supported by experimental evidence.

(*a*) (*i*) Bohr proposed that the electrons in an atom occupy energy levels. Explain what is meant by the term energy level.

(*ii*) Distinguish between the ground state and the excited states of the electron in a hydrogen atom.

(*iii*) Explain what happens when an electron moves from an excited state to its ground state.

(*iv*) Name the instrument used to examine the line spectrum of an element. (21)

In time, Bohr's model was shown to be an over-simplification of the structure of multi-electron atoms. Furthermore, modern atomic theory takes into account the wave nature of the electron and the Heisenberg uncertainty principle, which were not understood in 1913.

(*b*) (*i*) Explain how the Heisenberg uncertainty principle applies to an electron in an atom.

(*ii*) Write the full *s, p* electron configuration for an atom of neon (**Ne**) in its ground state, including the number of electrons in each atomic orbital.

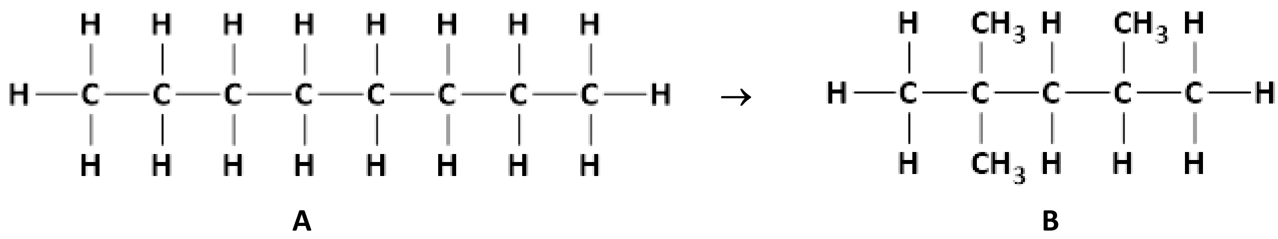
(*iii*) By reference to the electron configuration for neon, distinguish between an energy sublevel and an atomic orbital.

(*iv*) Neon is chemically unreactive. Explain this property by reference to its electron configuration.

(*v*) Explain how the successive ionisation energy values of neon provide evidence supporting the existence of energy levels.

(*vi*) Draw the shape of a *p* orbital. (29)

**6.** Hydrocarbon **A** may be converted to hydrocarbon **B**, as shown below.



(*a*) Hydrocarbon **A** is obtained in the naphtha fraction when crude oil is fractionally distilled during oil refining.

(*i*) Describe one property which hydrocarbon **A** has in common with the other hydrocarbons in the naphtha fraction.

(*ii*) State the systematic IUPAC names of compounds **A** and **B**.

(*iii*) Explain why compounds **A** and **B** are referred to as saturated alkanes. (12)

(*b*) The conversion of compound **A** to compound **B** occurs in a process that takes place in some oil refineries after fractional distillation.

(*i*) Name the process that can convert compound **A** to compound **B**.

(*ii*) Why is this conversion carried out? (6)

(*c*) A molecule of compound **A** can undergo catalytic cracking to produce a molecule of methylpropane and a molecule of compound **C**.

(*i*) Draw the molecular structure of methylpropane, including all atoms and bonds.

(*ii*) State the systematic IUPAC name of three of the possible isomers of compound **C**. In each case, draw the molecular structure of the isomer, including all atoms and bonds. (18)

(*d*) The complete combustion of compound **A** may be described by the following balanced chemical equation:

$$CH_3(CH_2)_6CH_{3(l)} + 12\frac{1}{2}O_{2(g)} \rightarrow 8CO_{2(g)} + 9H_2O_{(l)}$$

(*i*) The heat of formation of compound **A** is –250.3 kJ mol$^{-1}$. The heats of formation of carbon dioxide and water are –393.5 kJ mol$^{-1}$ and –285.8 kJ mol$^{-1}$ respectively. Calculate the heat of combustion of compound **A**.

(*ii*) The heat of formation of compound **B** is –260.5 kJ mol$^{-1}$. Calculate the heat of reaction for the conversion of compound **A** to compound **B**. (14)

**7.** When 4.0 moles of steam and 1.0 moles of carbon monoxide were mixed together at temperature *T* in a container of fixed volume *V*, they reacted to produce hydrogen and carbon dioxide.
An equilibrium was established which is described by the following balanced chemical equation:

$$\mathbf{H_2O_{(\mathit{g})} + CO_{(\mathit{g})} \rightleftharpoons H_{2(\mathit{g})} + CO_{2(\mathit{g})}} \qquad \Delta H = -38.8 \text{ kJ mol}^{-1}$$

(*a*) (*i*) Explain what is meant by chemical equilibrium.

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

(*iii*) At equilibrium at temperature *T*, there were 0.8 moles of hydrogen gas in the container. Calculate the value of $\boldsymbol{K}_c$ for the equilibrium at this temperature. (20)

(*b*) (*i*) If the same reaction had been carried out at the same temperature *T* in the same container, but with an initial mixture of 2.5 moles of steam and 2.5 moles of carbon monoxide, the value of $\boldsymbol{K}_c$ would not change from the value calculated in (*a*)(*iii*) above.
Explain why the value of $\boldsymbol{K}_c$ would not change.

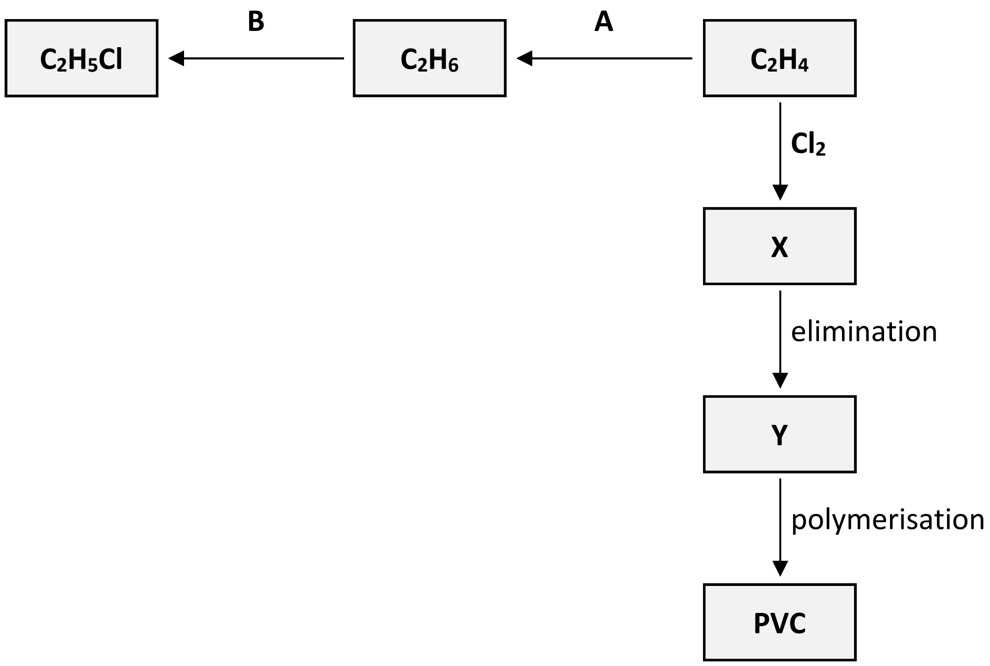
(*ii*) Calculate the mass of carbon dioxide present in the container at equilibrium in the case described in (*b*)(*i*). (15)

(*c*) (*i*) State the effect, if any, of decreasing the pressure in the container on the percentage conversion of steam to hydrogen.
Justify your answer.

(*ii*) How could the value of $\boldsymbol{K}_c$ be increased for this equilibrium reaction?
Justify your answer.

(*iii*) In an industrial context, a catalyst is usually used to ensure that equilibrium is established as quickly as possible for this reaction.
State the effect of using a catalyst on the value of $\boldsymbol{K}_c$ at temperature *T*.
Justify your answer. (15)

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




(*a*) How does the geometry around the carbon atoms change during reaction **A**? (5)

Reaction **B** takes place in the presence of chlorine (**$Cl_2$**) gas and ultraviolet light.

(*b*) (*i*) Should reaction **B** be classified as an addition reaction, a substitution reaction or an elimination reaction?

(*ii*) Describe the mechanism for reaction **B**.

(*iii*) A trace quantity of **$C_4H_{10}$** is formed during reaction **B**. Explain how the formation of **$C_4H_{10}$** is evidence for the mechanism described.

(*iv*) Apart from the formation of **$C_4H_{10}$**, state one other piece of evidence for this mechanism. (21)

(*c*) Polyvinylchloride (**PVC**) is synthesised in three steps from **$C_2H_4$**. These steps are an addition reaction to form compound **X**, then an elimination reaction to form compound **Y** and finally the polymerisation of **Y** to form **PVC**, as outlined in the reaction scheme above.

(*i*) State the systematic IUPAC name for compound **X**.

(*ii*) Name the inorganic compound that is eliminated when **X** is converted to **Y**.

(*iii*) Draw the structure of a molecule of **X** showing all of its atoms and all of its bonds and indicate clearly which of its bonds are broken during the elimination reaction.

(*iv*) Draw the structure of a molecule of **Y** showing all of its atoms and all of its bonds and indicate clearly which of its bonds are formed during the elimination reaction.

(*v*) Draw two repeating units of the polymer **PVC**. (24)

**9.** (*a*) (*i*) Explain why ammonia (**$NH_3$**) is considered to be a base according to the Brønsted-Lowry theory but is not considered to be a base according to the Arrhenius theory.

The self-ionisation of liquid ammonia is described by the following balanced chemical equation:

$$\mathbf{NH_3 + NH_3 \rightleftharpoons NH_4^+ + NH_2^-}$$

(*ii*) Identify the conjugate acid of **$NH_3$** in this equilibrium.

(*iii*) Identify the conjugate base of **$NH_3$** in this equilibrium. (12)

(*b*) (*i*) Define pH.

(*ii*) The pH of pure water is 7 at 25 °C. Explain why the pH of pure water is not 7 at 50 °C.

(*iii*) A 10 $cm^3$ sample of strong monobasic acid **X** was diluted by mixing it with deionised water until it had a new volume of 100 $cm^3$. What is the change in the pH?

(*iv*) Weak monobasic acid **Y** has an acid dissociation constant $K_a = 1.8 \times 10^{-5}$. A sample of acid **Y** has a pH of 2.98. Calculate the concentration of the sample. (21)

(*c*) A certain water-soluble acid-base indicator can be represented as **HIn**. Its dissociation in water is described by the following balanced chemical equation:

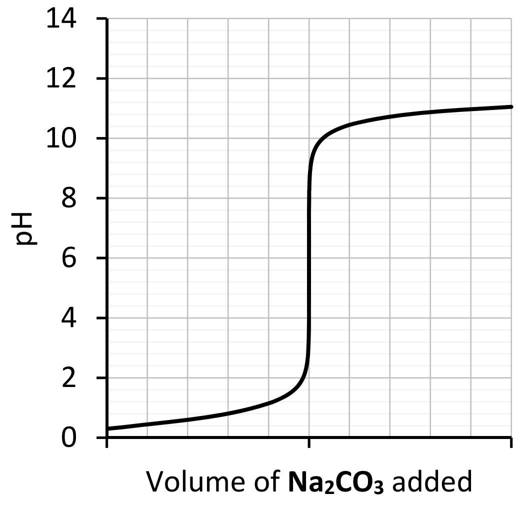
$$\mathbf{HIn \rightleftharpoons H^+ + In^-}$$

blue green

The undissociated **HIn** is blue. The **$In^-$** ion is green.

What colour change is observed when a few drops of a solution of **HIn** are added to 25 $cm^3$ of a 0.1 M solution of potassium hydroxide (**KOH**)? Justify your answer. (8)

(*d*) Acid **Z** is titrated against a solution of sodium carbonate (**$Na_2CO_3$**). The titration curve is shown in the diagram.




(*i*) What evidence is there that acid **Z** is a strong acid?

An indicator with pH range of 8 to 10 was used in this titration.

(*ii*) Would you expect the indicator to change colour before the point of neutralisation, after the point of neutralisation, or coinciding with the point of neutralisation?
Justify your answer. (9)

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

(*a*) (*i*) Define oxidation in terms of electron transfer.

(*ii*) State the oxidation number of phosphorus in $\mathbf{P_4}$ and $\mathbf{PO_4^{3-}}$.

(*iii*) State the oxidation number of nitrogen in $\mathbf{NO_3^-}$ and **NO**.

(*iv*) Hence or otherwise, balance the chemical equation:

$$P_4 + NO_3^- + H_2O \rightarrow PO_4^{3-} + NO + H^+$$

(*v*) Identify the reducing agent in the reaction above. (25)

(*b*) The elements radium (**Ra**) and polonium (**Po**) were discovered on the basis of their radioactivity through the work of Marie and Pierre Curie. In 1902 they obtained 0.1 g of pure $\mathbf{RaCl_2}$ from a tonne of pitchblende, the material remaining after uranium is extracted from its ore. In 1910 Marie Curie isolated pure radium. However she never succeeded in isolating pure polonium, in part because of its short half-life.

(*i*) What is meant by radioactivity?

(*ii*) What is meant by the half-life of a radioisotope?

The nuclear equation below represents the alpha decay of polonium–210.

$$^{210}_{84}\mathrm{Po} \rightarrow {}^{X}_{Y}\mathrm{Z} + {}^{4}_{2}\alpha$$

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

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

(*v*) Identify the element represented by **Z**.

(*vi*) Identify the two noble gas radioisotopes formed when a radium–226 nucleus undergoes alpha decay.

(*vii*) Calculate the maximum mass of radium that could be isolated from 0.1 g of $\mathbf{RaCl_2}$. (25)

(*c*) Rusting of iron involves several different reactions that take place in the presence of moist air. The mass of an iron object and its overall volume increase because of these rusting reactions occurring on the surface of the object. One of the reactions is described by the following balanced chemical equation:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

The mass of an iron object increased by 1.92 g as a result of this reaction.

(*i*) Calculate the volume of oxygen gas, measured at s.t.p., that reacted with the iron.

(*ii*) Calculate the mass of $\mathbf{Fe_2O_3}$ produced.

(*iii*) Calculate the number of iron atoms that reacted.

(*iv*) Calculate the increase in the volume of the iron object, taking the density of **Fe** to be 7.86 g $cm^{-3}$ and the density of $\mathbf{Fe_2O_3}$ to be 5.25 g $cm^{-3}$. (25)

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

(*a*) Boron trifluoride (**$BF_3$**) is a colourless gas with an unpleasant odour.

(*i*) Draw a dot and cross diagram to show the arrangement of the valence electrons in a molecule of **$BF_3$**.

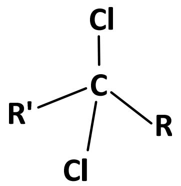
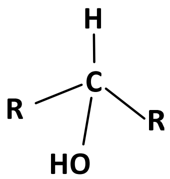
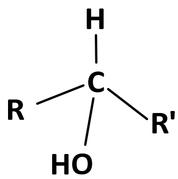
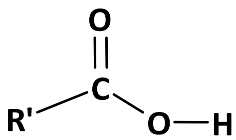
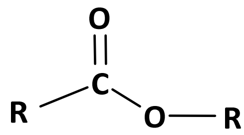
(*ii*) Would you expect a **B–F** bond to be polar or non-polar? Justify your answer.

(*iii*) Would you expect a **$BF_3$** molecule to be polar or non-polar? Justify your answer.

(*iv*) Phosphane (**$PH_3$**) is a colourless, flammable, highly toxic gas used in the semiconductor industry. Predict the shape of a molecule of **$PH_3$**. Explain your prediction.

(*v*) Neither **$BF_3$** nor **$PH_3$** is very soluble in water. Explain why. (25)

(*b*) The table below shows compounds **A** to **E**, where **R** represents a **$CH_3$** group and **R'** represents a **$C_2H_5$** group.

| A | B | C | D | E |
|---|---|---|---|---|
|  |  |  |  |  |

(*i*) State the systematic IUPAC names for compounds **A**, **B**, **C**, **D** and **E**.

(*ii*) Classify compound **B** as a primary alcohol or a secondary alcohol. Justify your answer.

(*iii*) Are compounds **D** and **E** structural isomers? Justify your answer. (25)

(*c*) Water hardness is caused by certain dissolved metal ions.

(*i*) Write the chemical formulae for the two metal ions that most commonly cause hardness when dissolved in water.

(*ii*) Identify an anion which is commonly dissolved in water with these metal ions when temporary hardness is involved.

(*iii*) Identify an anion which is commonly dissolved in water with these metal ions when permanent hardness is involved.

When hard water is boiled in a kettle, limescale deposits build up on the heating element.

(*iv*) Write a balanced chemical equation to describe the formation of limescale when hard water is boiled.

Hard water may be softened by deionising it.

(*v*) Explain how water may be deionised using ion exchange resins.

(*vi*) Explain why deionised water is not as pure as distilled water. (25)

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

**A** Unlike many other environmental problems, stratospheric ozone depletion has been largely remedied by international agreement about the use of CFCs. The damaging effect of CFCs on the ozone layer was predicted by the Mexican chemist Mario Molina before the 'hole' in the ozone layer was observed.

(*i*) What is ozone?

(*ii*) Explain how ozone is formed in the stratosphere.

(*iii*) What are CFCs?

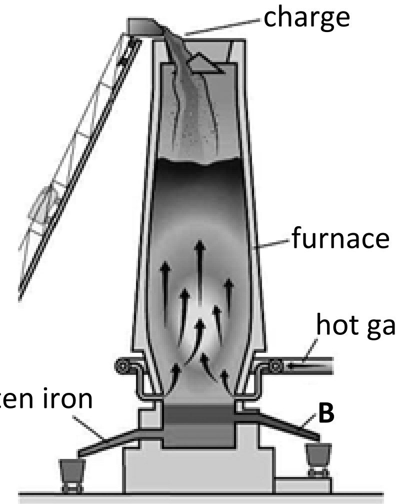
(*iv*) State one main use of CFCs.

(*v*) Explain how CFCs in the stratosphere damage the ozone layer.

(*vi*) Identify one example of an ozone-friendly CFC replacement. (25)

*or*

**B** Iron metal is extracted from its ores by reduction in a blast furnace like that illustrated in the diagram on the right.




(*i*) Identify the two solid materials that are continually added with the iron ore in the charge at the top of the furnace.

(*ii*) Identify the hot gas that is blown into the furnace above the hearth during production.

(*iii*) Identify by-product **B** that is removed at the bottom of the furnace.

Carbon monoxide acts as a reducing agent in the blast furnace.

(*iv*) Write a balanced chemical equation for the reaction of carbon monoxide with iron(III) oxide.

Steel is an alloy of iron.

(*v*) Name the main stages in the manufacture of steel using the electric arc process. (25)

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**Acknowledgements**

**Images**

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| Images on page 13 | nobelprize.org/prizes/chemistry/1995/molina/photo-gallery/<br>api.semanticscholar.org/CorpusID:137917314 |

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Leaving Certificate – Higher level

# Chemistry

Tuesday, 18 June

Afternoon, 2:00 – 5:00