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 = 6.0×10^{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.

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**.

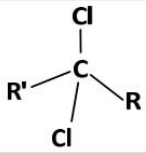
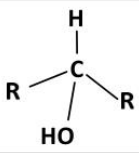
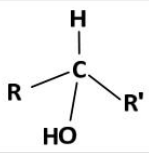
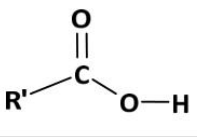
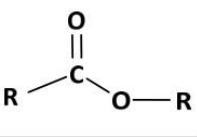
(*ii*) Would you expect a **B–F** bond to be polar or non-polar? Justify your answer.

(*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)

(*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?

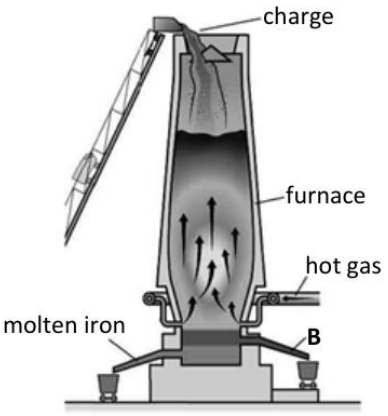
(*iv*) State one main use of CFCs.

(*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.

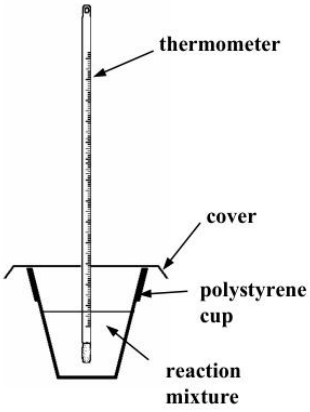
Carbon monoxide acts as a reducing agent in the blast furnace.

(*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)

3. In an experiment to measure the heat of reaction for the reaction between sodium hydroxide with hydrochloric acid, a student added 50 cm^3 of 1.0 M **HCl** solution to the same volume of 1.0 M **NaOH** solution in a polystyrene foam cup.



(*a*) To achieve an appreciable temperature rise during the reaction, quite concentrated solutions of acid and base, carrying the label illustrated, were used.
What word describes the chemical hazard illustrated in this label?
State **one** precaution the student should take when using these solutions. (8)

(*b*) The student had a choice of using either a graduated cylinder or a burette to measure out the solutions used in this experiment.
Which piece of apparatus should have been used to achieve the more accurate result? (3)

(*c*) If the hydrochloric acid and sodium hydroxide solutions had been stored at slightly different temperatures, explain how the initial temperature of the reaction mixture could have been obtained. (6)

(*d*) List **three** precautions which should have been taken in order to obtain an accurate value for the highest temperature reached by the reaction mixture. (9)

(*e*) What was the advantage of mixing the solutions in a polystyrene foam cup rather than in a glass beaker or in a metal calorimeter? (3)

(*f*) Calculate the number of moles of acid neutralised in this experiment.
Taking the total heat capacity of the reaction mixture used in this experiment as 420 J K^{-1}, calculate the heat released in the experiment if a temperature rise of 6.7 ºC was recorded.
Hence calculate the heat of reaction for

$$\mathbf{NaOH + HCl \rightarrow NaCl + H_2O}$$ (18)

(*g*) Name the piece of apparatus used in industry to accurately measure the heats of combustion of foods and fuels. (3)

5. (*a*) The 350th anniversary of Robert Boyle's discovery of the relationship between the pressure and the volume of a fixed mass of gas at constant temperature is commemorated in this Irish stamp issued in 2012.

Boyle also contributed to the development of the use of the term *element* in Chemistry.

What was his understanding of this term? (5)

(*b*) Use Bohr's atomic theory of 1913 to account for the emission spectrum of the hydrogen atom. (15)

Explain, in terms of atomic structure, why different flame colours are observed in flame tests using salts of different metals. (6)

What colour is observed in a flame test on lithium chloride?

Describe the testing procedure. (9)

(*c*) Further research and scientific discoveries, including Heisenberg's uncertainty principle (1927), led to significant modification of Bohr's original atomic structure theory of 1913.

Explain the underlined term.

Give **one** other factor that also contributed to the need for modification of Bohr's 1913 theory.

These modifications included the introduction of the idea of atomic orbitals.
What is an *atomic orbital*? (15)

9. (*a*) What is meant by *chemical equilibrium*? Why is a chemical equilibrium described as *dynamic*? (8)

State *Le Châtelier's principle*. (6)

(*b*) When a yellow solution of iron(III) chloride (**$FeCl_3$**) and a colourless solution of potassium thiocyanate (**KCNS**) were mixed in a test tube, a red colour appeared and the following equilibrium was established:

$$\underset{\text{yellow}}{Fe^{3+}_{(aq)}} + CNS^-_{(aq)} \rightleftharpoons \underset{\text{red}}{Fe(CNS)^{2+}_{(aq)}}$$

Explain

(*i*) the effect on the Fe^{3+} ion concentration of adding **KCNS** to the equilibrium mixture,

(*ii*) why changing the pressure has no effect on this equilibrium. (9)

(*c*) Write the equilibrium constant (K_c) expression for this reaction. (6)

A mixture of 1.0×10^{-3} moles each of iron(III) chloride and potassium thiocyanate was allowed to come to equilibrium in 1 litre of solution at room temperature according to the equation above. It was found that 1.1×10^{-4} moles $Fe(CNS)^{2+}$ were present in the solution at equilibrium.

Calculate the value of the equilibrium constant (K_c) for the reaction. (12)

(*d*) The red colour faded when the test tube containing the equilibrium mixture was placed in an ice-water bath.

State whether the value of K_c for this reaction is bigger or smaller at the lower temperature.

Is the forward reaction exothermic *or* endothermic? Justify your answer. (9)

The information below should be used in your calculations.

Relative atomic masses (rounded): H = 1.0, C = 12, O = 16, K = 39, Ca = 40

Avogadro constant = 6.0×10^{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

1. The total hardness values of a water supply before and after it had been passed through a laboratory deioniser were compared. This was done by adding a suitable indicator and a small volume of a buffer solution to 25.0 cm^3 samples of the water in a conical flask and titrating with a standard **edta** (ethylenediaminetetraacetic acid) salt solution.

The ions that cause hardness (represented by $\mathbf{M^{2+}}$) react with **edta** (represented by $\mathbf{H_2Y^{2-}}$) according to the following balanced equation.

$$\mathbf{M^{2+} + H_2Y^{2-} \rightarrow MY^{2-} + 2H^+}$$

(*a*) (*i*) Identify the two ions (represented by $\mathbf{M^{2+}}$) that most commonly cause hardness when dissolved in water.

(*ii*) Explain the term *total hardness*. (8)

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

(*ii*) What colour change was observed in the conical flask at the end point? (9)

(*c*) (*i*) What pH does the buffer solution maintain in the mixture in the conical flask?

(*ii*) Why is it important to maintain this pH during the titration? (6)

(*d*) Describe the correct procedure for preparing a burette, that had been previously rinsed with deionised water and some 0.010 M **edta** solution, for this titration. (12)

On average, 9.2 cm^3 *less* of the 0.010 M **edta** solution was required to react completely with 25.0 cm^3 portions of the water that had been passed through the deioniser than with 25.0 cm^3 portions of the original hard water supply.

(*e*) Calculate

(*i*) the number of moles of **edta** in 9.2 cm^3 of a 0.010 M solution,

(*ii*) the number of moles of $\mathbf{M^{2+}}$ ion that reacted with this quantity of **edta**,

(*iii*) the number of moles of $\mathbf{M^{2+}}$ ion removed by the deioniser from a litre of the original supply of hard water,

(*iv*) the total hardness removed by the deioniser expressed in g l^{-1} of $\mathbf{CaCO_3}$ *and* in p.p.m. $\mathbf{CaCO_3}$. (15)

The information below should be used in your calculations.

Relative atomic masses (rounded): H = 1.0, C = 12, O = 16, K = 39, Ca = 40

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

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

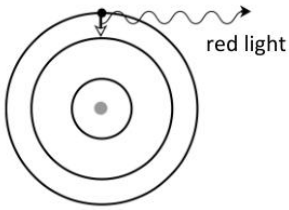
Universal gas constant = 8.3 J K^{-1} mol^{-1}

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

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

(*a*) The set of elements {**Li**, **Na**, **K**} is one of Dobereiner's triads. Refer to this example to explain Dobereiner's contribution to the development of the periodic table.

(*b*) The diagram shows the origin of one of the lines in the Balmer series of the hydrogen emission spectrum. Why is a photon emitted as the electron moves from one energy level to another as shown?



(*c*) Why is the second ionisation energy of lithium significantly larger than its first?

(*d*) What colour is observed in a flame test on a salt of
(*i*) lithium,
(*ii*) copper?

(*e*) State Avogadro's law.

(*f*) One of the largest diamonds ever mined was found in Botswana in June 2021. The diamond had a mass of 1098 carats and contained exactly 18.3 moles of carbon. Assuming this stone contained only carbon, calculate the mass of one carat expressed in grams.

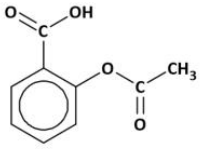
(*g*) What reagents are used to confirm the presence of nitrate ions in an aqueous solution?

(*h*) Identify a substance commonly added during drinking water treatment
(*i*) to cause flocculation in the water,
(*ii*) to fluoridate the water.

(*i*) What elements are the products of the electrolysis of an aqueous solution of potassium iodide (**KI**) using inert electrodes?

(*j*) Which one of the following four compounds would you expect to have the strongest carbon to carbon bonding: ethane, ethene, ethyne, benzene?

(*k*) The structure of aspirin is shown. Calculate the average daily dose (in mg) when a person took a total of 0.146 moles of 'low dose' aspirin over 365 days.



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

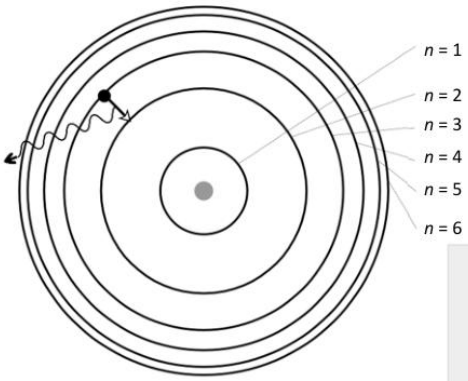
A Write balanced equations to show the dissociation of carbonic acid in water to form first hydrogencarbonate ions and then carbonate ions.

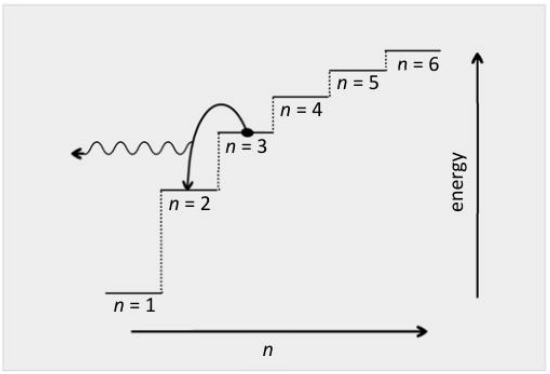
or

B Iodine (I_2) is an example of a molecular crystal.
What distinguishes molecular crystals from other types of crystals?

5. The reactivity of an element is determined by the number and arrangement of electrons around the nucleus in each of its atoms. Around 1913 Bohr proposed that electrons in an atom occupied energy levels. Later sub-levels and orbitals were introduced into atomic theory to account for certain experimental observations.

The diagrams below are two different representations of the first six energy levels in the electron cloud of a hydrogen atom.





(*a*) What is an electron? (5)

(*b*) (*i*) Why might the electron in a hydrogen atom *not* occupy the $n = 1$ energy level?

(*ii*) What colour light is associated with the electron in a hydrogen atom moving from $n = 3$ to $n = 2$?

(*iii*) Name the series of visible lines in the hydrogen emission spectrum. (9)

(*c*) (*i*) How many sub-levels are associated with the $n = 3$ energy level?

(*ii*) What is an atomic orbital?

(*iii*) How many orbitals are associated with the $n = 2$ energy level?

(*iv*) What is the maximum number of electrons that can occupy the $n = 3$ energy level in a multi-electron atom? (15)

(*d*) Write *s*, *p* electron configurations for beryllium, neon, magnesium and krypton.

Refer to these electron configurations to explain

(*i*) why the Group 18 elements neon and krypton are chemically inert,

(*ii*) why the Group 2 elements beryllium and magnesium are reactive.

Why is magnesium more reactive than beryllium? (21)

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.

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.

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

(*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 **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.

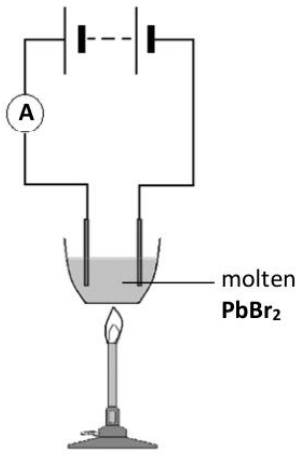
(*iv*) Explain why plants need nitrogen.

(*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 (**$PbBr_2$**) 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)