Statistics

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General comments

Paper One Part A assessed Knowledge and simple application and Part B assessed Scientific processes. Part A consisted of 10 multiple-choice questions and eight short-response questions covering all eight syllabus topics. Marks allocated were in proportion to syllabus topic weightings. Part B contained five Scientific processes questions assessed by criteria specific to each question. In Part B, candidates were required to respond to any four of the five questions.

Paper Two assessed Complex reasoning processes and contained five questions assessed by specific criteria. Candidates were required to respond to any four of the five questions.

Paper One

Part A — Knowledge and simple application

Multiple-choice questions

<table>
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<tr>
<th>Question</th>
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<td>D</td>
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<td>B</td>
<td>A</td>
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<td>D</td>
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Short-response questions

This part of the examination required candidates to demonstrate their knowledge and ability regarding simple application of the eight syllabus topics. Many responses indicated that candidates had attempted to learn information without a full understanding of the underlying chemical principles and processes. Many candidates failed to respond to all parts of questions.

Question 11

a: Elements were recognised to contain atoms of the same type but many candidates did not list the involvement of an electron pair to link atoms in a covalent bond.

b: The majority of candidates were unable to clearly specify the different bond types in the two substances and therefore could not link bonding with properties.

c: Most candidates identified the majority of errors and made appropriate corrections.

d: Most candidates appreciated that charged particles must be free to move in order for conductivity to occur.

e: Most candidates provided the correct formula.

f: Most candidates successfully named the compound.

Question 12

a: Most candidates attempted explanations but clarity varied widely.

b: Most candidates successfully balanced the equation.

c: Most candidates successfully calculated the mass of aluminium hydroxide.

d: Most candidates understood the significance of an empirical formula and were successful in the calculation.

e: Most candidates did not recall that gases react in whole number ratios by volume and thus attempted conversions of volumes to moles.

Question 13

a: The use of a “salt bridge” proved a challenge for many candidates.

b: Most candidates successfully determined the oxidation number.

c: Many candidates failed to recognise that a reducing agent is itself oxidised and thus did not look for an increase in oxidation number of a species.

d: Most candidates could distinguish between a voltaic and an electrolytic cell.

e: A Faraday’s law calculation was completed successfully by many candidates.

Question 14

a: Very few candidates could explain “addition polymerisation” or “homologous series”.

b: Most candidates could draw structural isomers.

c: Many candidates could not draw the structure of propanone.

d: Many candidates could not write the correct name for carboxylic acid.

e: The concept of an elimination reaction was not understood by many candidates.
Question 15

a: Many candidates identified the correct group and period.
b: Many candidates successfully linked valence electron number and group in the Periodic Table.
c: Most candidates could identify an acidic oxide and the noble gases.

Question 16

a: The concept of real gases was not well understood.
b: Most candidates successfully solved the problem involving the ideal gas equation.
c: Many candidates successfully sketched a graph to represent Boyle’s Law.
d: Many candidates failed to recognise that the pressure exerted was in proportion to moles of gases present.

Question 17

a: Most candidates could define “activation energy” and “combustion”.
b: Most candidates were unable to determine the change in enthalpy associated with the chemical change.
c: Most candidates did not display an understanding of reaction mechanisms.
d: Many candidates could not use heats of formation to determine enthalpy change.

Question 18

a: The concepts of “weak”, “dilute”, “steady state” and “dynamic equilibrium” were well understood.
b: Most candidates could not explain the change to the closed system.
c: Many candidates responded in general terms rather than using a quantitative comparison.
d: Most candidates were unable to successfully perform the equilibrium calculation.
e: Most candidates could not determine the pH of the alkaline solution.

Part B — Scientific processes

Candidates were instructed to respond to only four of the five questions provided. It was apparent that many candidates had devoted more than the suggested time to the completion of Part A and thus were under time pressure to respond completely to Part B questions.

Question 1

The majority of candidates disregarded the clear directions to “use the results in the previous page” and instead consulted the solubilities provided in the resource booklet. Many candidates failed to balance ionic equations or did not write them at all.
Question 2
Many candidates were unfamiliar with simple experimental design. Vague descriptions of apparatus were provided, the method employed often did not involve replications and safety issues were not specified.

Question 3
Nearly all candidates attempted this question and demonstrated familiarity with the aspects of acid–base titrations. Many did not understand that an indicator changes colour across a known pH range.

Question 4
Few candidates were able to successfully represent fundamental syntheses of organic chemicals. In particular the oxidation of alcohols to carboxylic acids and the process of esterification were not well communicated.

Question 5
Most candidates attempted this question. While many candidates were able to successfully plot the required graph, a smaller proportion was able to use the slope of the graph to determine a value for the gas constant.

In summary, the majority of candidates did not respond fully to the majority of the tasks. Scientific processes is one of the three Chemistry assessment criteria and it is important that candidates demonstrate an ability to successfully engage in simple scientific process tasks by processing information, making simple judgments and communicating information in various forms.

Paper Two — Complex reasoning processes

Question 1
The majority of candidates attempted this question and were able to make some progress in their determination of the mass of nitrogen produced. Many candidates were unable to identify the limiting reagent and also disregarded the efficiency of the process.

Question 2
A small number of candidates attempted this question. Many displayed a genuine understanding of redox processes and successfully identified the species being oxidised and reduced in each scenario.

Question 3
The majority of candidates attempted this item and made some progress in their additivity of heats of reaction. Common errors included ignoring the moles of reactants, reversing reactions but not changing sign of the change in enthalpy and lacking in neatness of presentation so that cancellation of reactants and products was difficult.
Question 4
Most candidates attempted this item and a considerable number made significant progress. Determining the concentration of calcium ions presented a challenge for some, as did the representation of the formation of “scum”.

Question 5
Nearly all candidates attempted this item with varying levels of success. Many candidates responded at length but failed to provide an understanding of reaction kinetics, reaction mechanisms and equilibrium considerations. In contrast, a number of candidates provided carefully-crafted responses which clearly showed the application of critical thinking. Credit was given for the demonstration of logical reasoning and critical thinking and not for the simple recall of knowledge.

Sample solutions

The sample solutions on the following pages show possible ways of successfully responding to the questions. They do not provide the only valid responses. Other approaches and problem-solving strategies may be equally valid.

In Complex reasoning processes questions, a valid response must include a demonstration of logical reasoning and critical thinking with reference to the chemistry applicable to the task.
Question 11 — Materials: Properties, bonding and structure

a. Define the following terms:

i. element

Contains atoms of the same type (atomic number) or Cannot be broken down by any chemical process into simpler substances

ii. single covalent bond

Forms by the equal sharing of one pair of $e^-$

b. Explain why $\text{CO}_2$ is a gas at 25 °C while $\text{SiO}_2$ is a crystalline substance with a high melting point at the same temperature.

$\text{CO}_2$ — exists as molecules without intermolecular dipole forces — gas at 25°C

$\text{SiO}_2$ — covalent lattice — held together in three dimensions by strong covalent bonds — solid at 25°C

(2 marks)

c. The following statement contains four mistakes.

“The symbol for the element potassium is Po, as is clearly illustrated in the equation for the compound potassium chloride, which is PoCl.”

Complete the following table to show each mistake and its correction.

<table>
<thead>
<tr>
<th>Mistake</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_0$</td>
<td>$K$</td>
</tr>
<tr>
<td>equation</td>
<td>Formula</td>
</tr>
<tr>
<td>chlorine</td>
<td>chloride</td>
</tr>
<tr>
<td>$Po, Cl$</td>
<td>$K, Cl$</td>
</tr>
</tbody>
</table>

(2 marks)
d. Explain why metals conduct electricity in both solid and molten states but ionic substances can only conduct electricity in the molten state.

For conductivity, charged particles must be free to move.
Metals – conductivity due to freely moving delocalised $e^-$ in the solid state
Ionic conductivity is only possible when the ionic bonds are broken to allow ion movement.

(2 marks)

e. Give the formula for the nitrate ion.

$\text{NO}_3^-$

(1 mark)

f. Name the substance represented by the formula $\text{Fe}_2\text{O}_3$.

Iron (III) oxide or Ferrie oxide

(1 mark)

**Question 12 — Reacting quantities and chemical analysis**

a. Explain the following terms:

i. mole

Represents a subatomic number of particles of that substance

ii. molecular formula

Shows the actual number and types of atoms present in a molecule of that substance

(2 marks)

b. Rewrite the following as a balanced equation.

$$\text{Ca}_3(\text{PO}_4)_2(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(s) + \text{H}_3\text{PO}_4(aq)$$

$$\text{Ca}_3(\text{PO}_4)_2 + 3\text{H}_2\text{SO}_4 \rightarrow 3\text{CaSO}_4 + 2\text{H}_3\text{PO}_4$$

(2 marks)
e. Calculate the mass of 1.5 mole of aluminium hydroxide Al(OH)₃.

\[
\text{1 mole } \text{Al(OH)}_3 = 270 + 3(17) = 78 \text{ g/mole}
\]

\[
1.5 \text{ moles } = 1.5 \times 78 = 117 \text{ g}
\]

(2 marks)

d. A compound was analysed and found to have the following composition by mass.

Carbon 23.5%
Hydrogen 1.9%
Fluorine 74.6%.

What is the empirical formula of this compound?

\[
\text{Assume } 100 \text{g}
\]

\[
\text{Moles C} = \frac{23.5}{12} = 1.96
\]

\[
\text{Moles H} = \frac{1.9}{1} = 1.9
\]

\[
\text{Moles F} = \frac{74.6}{19} = 3.93
\]

Simplified whole number ratio = \( \text{CHF}_2 \)

(3 marks)

e. When a spark is applied, hydrogen gas reacts with oxygen gas to produce water vapour according to the following equation.

\[
2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})
\]

If a mixture consisting of 300 mL hydrogen and 200 mL oxygen is ignited, what is the volume and composition of the final product?

(Assume all volumes are measured at 100 °C and 1 atmosphere pressure.)

\[
2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})
\]

\[
300\text{mL} + 150\text{mL} \rightarrow 300\text{mL}
\]

300 mL \( \text{H}_2\text{O}(\text{g}) \) forms + 50 mL \( \text{O}_2 \) left unreacted

(2 marks)
Question 13 — Oxidation and reduction

a. Describe the following:

i. Oxidation

Process involving the complete or partial loss of electrons

ii. The purpose of a salt bridge

Allows ion movement between half cells to complete the circuit but stops solutions from mixing completely

(2 marks)

b. Determine the oxidation number of Cr in $X_2Cr_2O_7$.

$+6$

(1 mark)

c. Identify the reducing agent in the following chemical reaction. Explain your choice.

$KIO_4(aq) + 7KI(aq) + HCl(aq) \rightarrow 8KCl(aq) + 4I_2(s) + 4H_2O(l)$

The $I^-$ in $KI$ changes oxidation number from $-1$ (in $KI$) to $0$ (in $I_2$). It is oxidised and therefore is the reducing agent.

(2 marks)

d. State one way in which an electrolytic cell differs from a voltaic (galvanic) cell.

Several possibilities. Electrolytic cells require chemical change to be brought about by the supply of electrical energy.

(1 mark)

e. A group of students set up an electrolytic cell in order to obtain pure copper from an impure sample.

What mass of copper will be formed on the pure copper cathode if a 2.5 ampere current is run through the cell for five hours?

(1 ampere = 1 coulomb sec$^{-1}$)

$Q = It = 2.5 \times 5 \times 60 \times 60 = 45000 \text{ C}$

$n = \frac{45000}{96500} \approx 0.47 \text{ moles}$

Moles $Cu = 0.47 \times 63.5 = 14.67$

Allowed $Cu^+ + 2e^- \rightarrow Cu$ if equation specifies.

(2 marks)
Question 14 — Organic chemistry

a. Explain the following terms:
   
i. addition polymerisation
   
   The process of joining of small molecules (monomers) which each possess a multiple bond to form a large molecule. Also allows the joining process without the elimination of small molecules.

   ii. homologous series
   
   A group of compounds in which there is a constant increment of change in molecular structure.

b. Draw two structural isomers of the molecular formula $C_4H_6O$.

   ![Structural isomers](image)

(2 marks)

c. Draw the structure of propanone.

   ![Propanone structure](image)

(1 mark)

d. Name the organic substance with the following structure.

   ![Bromobutanoic acid structure](image)

   $\text{4-bromobutanoic acid}$

(1 mark)
e. The following structure is formed as a first step in an elimination polymerisation reaction.

\[
\begin{align*}
H & \quad H \\
H & \quad O \\
O & \quad H \\
O & \quad H \\
O & \\
\text{HO-} & \quad \text{C-} & \quad \text{C-} & \quad \text{O-} & \quad \text{C-} & \quad \text{C-} & \quad \text{O-} \\
H & \quad \text{H} \\
H & \quad \text{H} \\
H & \quad \text{H} \\
H & \quad \text{H} \\
H & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

Draw the structures of the 2 monomers involved.

(2 marks)

**Question 15 — Chemical periodicity**

a. For each of the following electron configurations, identify the element and state its period or group in the periodic table.

<table>
<thead>
<tr>
<th>Species</th>
<th>Electron configuration</th>
<th>Element</th>
<th>Period</th>
<th>Group</th>
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</thead>
<tbody>
<tr>
<td>A neutral atom</td>
<td>1s(^2) ... 4p(^3)</td>
<td>As</td>
<td>4</td>
<td>17 (7)</td>
</tr>
<tr>
<td>An ion with one negative charge</td>
<td>1s(^2) ... 3p(^6)</td>
<td>Cl</td>
<td>17 (7)</td>
<td></td>
</tr>
</tbody>
</table>

(2 marks)

b. State the relationship between the number of valence electrons for an element and its group in the periodic table.

The number of valence electrons equals the group number.

(2 marks)

c. Name:

i. an acidic oxide

\[\text{Various possibilities... eg. CO}_2\]

(1 mark)

ii. the group of elements for which the outermost energy level is full

\[\text{Noble gases... Group 18 (8)}\]

(1 mark)
Question 16 — Gases and the atmosphere

a. Under what conditions is the behaviour of a real gas likely to approach the behaviour of an ideal gas?

\[ \text{Low pressure} \hspace{2cm} \text{High temperature} \]

(1 mark)

b. 0.453 mol of a gas which fills a 15.0 L container exerts a pressure of 1.24 atm on the container walls. What is the temperature of the gas?

\[ \frac{PV}{nR} = T \]

\[ T = \frac{PV}{nR} = \frac{1.24 \times 15.0}{0.453 \times 0.082} \approx 500.7 \text{ K} \]

(1 mark)

c. Sketch a graph to show the relationship between the volume of a given mass of gas at constant temperature under different conditions of pressure.

![Graph showing the relationship between volume and pressure]

(1 mark)

d. A gaseous mixture contains 16 g of methane (CH₄) together with 16 g of oxygen (O₂). The partial pressure of the methane is 50 kPa. Calculate the partial pressure of the oxygen.

Pressure is proportional to moles present

\[ \text{Moles CH}_4 = \frac{16}{16} = 1 \]

\[ \text{Moles O}_2 = \frac{16}{32} = 0.5 \]

\[ P_{CH_4} = \frac{50 \text{ kPa}}{2} = 25 \text{ kPa} \]

(2 marks)
Question 17 — Energy and rates of chemical reactions

a. Define the following terms:

i. activation energy
minimum energy that colliding particles (per pair) must have in order to react

ii. combustion
a chemical change in which oxygen reacts with another substance releasing energy in the form of light and heat.

b. What is the change in enthalpy associated with the formation of 50 g of nitrogen gas according to the following equation?

\[2\text{NH}_3(g) + 3\text{N}_2\text{O}(g) \rightarrow 4\text{N}_2(g) + 3\text{H}_2\text{O}(g) \quad \Delta H = -1010\text{kJ}\]

\[\text{Moles } \text{N}_2 = \frac{50}{28} = 1.79 \text{ moles}\]

\[1 \text{ mole } \text{N}_2 \text{ releases } \frac{1010}{1} \text{kJ}\]

\[\text{to form } 1.79 = 1.79 \times \frac{1010}{1} = 452\text{kJ released}\]

(2 marks)

c. Explain how a slight increase in temperature can cause a significant increase in the rate of exothermic reactions.

Associated with the addition of a small amount of energy, which allows significantly more reacting particles to obtain the energy requisite for successful collisions. Exothermic reactions will have subsequent heat release to continue the process.

(2 marks)
d. Use appropriate data from the table below to calculate the change in enthalpy associated with the following chemical change and state whether the reaction is exothermic or endothermic.

\[ C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g) \]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th>( \Delta H^\circ ) (kJ mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetylene</td>
<td>C(_2)H(_2)(g)</td>
<td>226.7</td>
</tr>
<tr>
<td>ammonia</td>
<td>NH(_3)(aq)</td>
<td>-80.7</td>
</tr>
<tr>
<td>benzene</td>
<td>C(_6)H(_6)(l)</td>
<td>49.0</td>
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<tr>
<td>carbon dioxide (gas)</td>
<td>CO(_2)(g)</td>
<td>-393.5</td>
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<tr>
<td>carbon dioxide (liquid)</td>
<td>CO(_2)(l)</td>
<td>-413.8</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>CO(_{(g)})</td>
<td>-110.0</td>
</tr>
<tr>
<td>ethane</td>
<td>C(_2)H(_6)(g)</td>
<td>-84.7</td>
</tr>
<tr>
<td>glucose</td>
<td>C(<em>6)H(</em>{12})O(_6)(s)</td>
<td>-1260.0</td>
</tr>
<tr>
<td>methane</td>
<td>CH(_4)(g)</td>
<td>-74.85</td>
</tr>
<tr>
<td>sucrose</td>
<td>C(<em>{12})H(</em>{22})O(_{11})(s)</td>
<td>-2221.0</td>
</tr>
<tr>
<td>water</td>
<td>H(<em>2)O(</em>(l))</td>
<td>-285.8</td>
</tr>
<tr>
<td>water vapour</td>
<td>H(<em>2)O(</em>(g))</td>
<td>-241.8</td>
</tr>
</tbody>
</table>

\[ \Delta H = \sum \Delta H^\circ \text{prod} - \sum \Delta H^\circ \text{reactants} \]

\[ = (6 \times -393.5 + 6 \times -241.8) - (-1260) \]

\[ = -251.8 \text{ kJ} \]

Reaction is exothermic

Heat of formation of O\(_2\)(g) is not supplied as it is an element — Heat of formation = 0

(2 marks)
Question 18 — Chemical equilibrium

a. Explain the differences between:
   i. dilute and weak acids

   **Dilute**: High ratio of solvent to solute

   **Weak**: Only a small proportion of molecules dissociate to form ions

   ii. steady state and dynamic equilibrium

   **Steady State**: Open system — constancy of macroscopic properties is achieved by addition or removal from the system

   **Dynamic equilibrium**: Closed system — constancy of macroscopic properties due to equal and opposite rates of reaction

   (4 marks)

b. The graph below shows the variation in concentration of reactant and products as a function of time for the following closed system.

\[
\text{COCl}_2(g) \rightleftharpoons \text{Cl}_2(g) + \text{CO}(g) \quad \Delta H = +108 \text{ kJ}
\]

![Graph showing concentration changes over time]

Identify and explain any change in conditions at the 4 minute mark that has shaped the curves during the time the system was observed.

At minute 4, change in conditions — addition of heat which favours the forward reaction, to partially counteract the change to the system.

(2 marks)
c. A soft drink has a pH of 3 and black coffee has a pH of 5. Compare the acidity of the two solutions.

\[
\begin{align*}
\text{Soft drink} & \quad \text{pH} = 3 \quad \left[ H_3O^+ \right] = 1 \times 10^{-3} \text{ M} \\
\text{Coffee} & \quad \text{pH} = 5 \quad \left[ H_3O^+ \right] = 1 \times 10^{-5} \text{ M} 
\end{align*}
\]

Qualitative description of the above was also allowed. (2 marks)

d. At a particular temperature, 8.0 mol NO_2 is placed into an empty 1.0 L container and the NO_2
dissociates according to the following reaction.

\[ 2\text{NO}_2(g) \rightleftharpoons 2\text{NO}(g) + \text{O}_2(g) \]

At equilibrium, the concentration of NO is 2.0 M.
Calculate the value of the equilibrium constant at that particular temperature.

\[
\begin{array}{c|c|c}
 & \text{NO}_2 & \text{NO} & \text{O}_2 \\
\hline
\text{I} & 8 & 0 & 0 \\
\text{C} & 2 & 2 & 1 \\
\text{E} & 6 & 2 & 1 \\
\end{array}
\]

\[
K_{eq} = \frac{[\text{NO}^2]^2 \cdot [\text{O}_2]}{[\text{NO}_2]^2} = 2^2 \times 1 = 0.11
\]

(3 marks)

e. Find the pH of the solution which results from dissolving 1.0 g of NaOH in 1.0 L of pure water.

\[
\text{Moles NaOH} = \frac{1}{14} = 0.071 \text{ mol}
\]

\[
\left[ \text{OH}^- \right] = \frac{0.025}{1} = 0.025 \text{ M}
\]

\[
\text{pOH} = -\log_{10}[\text{OH}^-] = 1.6
\]

\[
\text{pH} = 14 - \text{pOH} = 12.4
\]

(2 marks)

End of Section 2

End of Part A
Question 1

A solid that forms as a product of a chemical reaction between two aqueous solutions is called a precipitate.

A student mixes 5 mL each of 0.1 M solution of substances A and B, and obtains the following results.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Solution A</th>
<th>Solution B</th>
<th>Results of mixing A and B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ba(NO₃)₂</td>
<td>Na₂SO₄</td>
<td>white precipitate forms</td>
</tr>
<tr>
<td>2</td>
<td>Ba(NO₃)₂</td>
<td>Al₂(SO₄)₃</td>
<td>white precipitate forms</td>
</tr>
<tr>
<td>3</td>
<td>Ba(NO₃)₂</td>
<td>Mg(NO₃)₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>4</td>
<td>Ba(NO₃)₂</td>
<td>MgCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>5</td>
<td>Ba(NO₃)₂</td>
<td>AlCl₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>6</td>
<td>Na₂SO₄</td>
<td>Al₂(SO₄)₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>7</td>
<td>Na₂SO₄</td>
<td>Mg(NO₃)₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>8</td>
<td>Na₂SO₄</td>
<td>MgCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>9</td>
<td>Na₂SO₄</td>
<td>AlCl₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>10</td>
<td>Al₂(SO₄)₃</td>
<td>Mg(NO₃)₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>11</td>
<td>Al₂(SO₄)₃</td>
<td>MgCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>12</td>
<td>Al₂(SO₄)₃</td>
<td>AlCl₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>13</td>
<td>Mg(NO₃)₂</td>
<td>MgCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>14</td>
<td>Mg(NO₃)₂</td>
<td>AlCl₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>15</td>
<td>MgCl₂</td>
<td>AlCl₃</td>
<td>no precipitate</td>
</tr>
<tr>
<td>16</td>
<td>KCl</td>
<td>MgCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>17</td>
<td>KCl</td>
<td>Na₂SO₄</td>
<td>no precipitate</td>
</tr>
<tr>
<td>18</td>
<td>KCl</td>
<td>NaOH</td>
<td>no precipitate</td>
</tr>
<tr>
<td>19</td>
<td>KCl</td>
<td>BaCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>20</td>
<td>KCl</td>
<td>MgSO₄</td>
<td>no precipitate</td>
</tr>
<tr>
<td>21</td>
<td>MgCl₂</td>
<td>Na₂SO₄</td>
<td>no precipitate</td>
</tr>
<tr>
<td>22</td>
<td>MgCl₂</td>
<td>NaOH</td>
<td>white precipitate forms</td>
</tr>
<tr>
<td>23</td>
<td>MgCl₂</td>
<td>BaCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>24</td>
<td>MgCl₂</td>
<td>MgSO₄</td>
<td>no precipitate</td>
</tr>
<tr>
<td>25</td>
<td>Na₂SO₄</td>
<td>NaOH</td>
<td>no precipitate</td>
</tr>
<tr>
<td>26</td>
<td>Na₂SO₄</td>
<td>BaCl₂</td>
<td>white precipitate forms</td>
</tr>
<tr>
<td>27</td>
<td>Na₂SO₄</td>
<td>MgSO₄</td>
<td>no precipitate</td>
</tr>
<tr>
<td>28</td>
<td>NaOH</td>
<td>BaCl₂</td>
<td>no precipitate</td>
</tr>
<tr>
<td>29</td>
<td>NaOH</td>
<td>MgSO₄</td>
<td>white precipitate forms</td>
</tr>
<tr>
<td>30</td>
<td>BaCl₂</td>
<td>MgSO₄</td>
<td>white precipitate forms</td>
</tr>
</tbody>
</table>
a. Use the results in the table on the previous page to explain why a precipitate did not form in:

i. Trial 3:

\[ \text{NO new ion pairs form} \]

ii. Trial 4:

Possibilities are \( \text{BaCl}_2 \) or \( \text{Mg(NO}_3)_2 \)

\( \text{BaCl}_2 \) is soluble (Trial 19)

\( \text{Mg(NO}_3)_2 \) is soluble (Trial 3)

b. Use the results in the table on the previous page to complete the following.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Formula of precipitate</th>
<th>Reason for choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \text{BaSO}_4 )</td>
<td>Trial 7, ( \text{Na}_2 \text{NO}_3 ) is soluble</td>
</tr>
<tr>
<td>29</td>
<td>( \text{Mg(OH)}_2 )</td>
<td>Trial 1, ( \text{Na}_2 \text{SO}_4 ) is soluble</td>
</tr>
</tbody>
</table>

c. Write an ionic equation to represent the chemical reaction in:

i. Trial 22:

\[ \text{Mg}^{2+}(aq) + 2\text{Cl}^-(aq) + 2\text{Na}^+(aq) + 2\text{OH}^-(aq) \rightarrow \]

\[ \text{Mg(OH)}_2(s) + 2\text{Na}^+(aq) + 2\text{Cl}^-(aq) \]

ii. Trial 2:

\[ 3 \text{Ba}^{2+}(aq) + 6\text{NO}_3^-(aq) + 2\text{Al}^{3+}(aq) + 3\text{SO}_4^{2-}(aq) \]

\[ \rightarrow 3 \text{BaSO}_4(s) + 2\text{Al}^{3+}(aq) + 6\text{NO}_3^-(aq) \]
Question 2  A VARIETY OF ACCEPTABLE SOLUTIONS

After reading in a textbook that “acid-base reactions are exothermic”, a student decided to design a scientific investigation relating to that topic.

a. Formulate a hypothesis relevant to the topic.

When an acid reacts with a base, then the temperature of the solution will increase.

b. List the apparatus required.

- Calorimeter
- Thermometer
- 400 mL beakers
- Safety glasses
- 1 M NaOH
- 1 M HCl, H₂SO₄, HNO₃, CH₂COOH

c. In point form, describe the method employed.

- Assemble calorimeter (may include diagram).
- 200 mL of 0.1 M NaOH in beaker - measure temperature.
- Add 50 mL of 0.1 M HCl.
- Note highest temp reached - calculate ΔT.
- Repeat 2 more times.
- Repeat with 3 different acids and duplicate each.

d. Identify one safety issue.

Heat release may cause spilling of the reaction mixture.

e. What collected data would support the above hypothesis?

If each set of trials showed an increase in temperature, then the hypothesis would be supported.
Question 3

Citric acid in fruit juice can be determined by a reaction with a solution of sodium hydroxide using a suitable indicator to detect the end-point. The reaction occurring will be:

\[ \text{C}_3\text{H}_5\text{O}(\text{COOH})_3(\text{aq}) + 3\text{OH}^-_{(\text{aq})} \rightarrow \text{C}_3\text{H}_5\text{O}(\text{COO})_3^{3-} \text{aq} + 3\text{H}_2\text{O}(\text{l}) \]

In such an experiment, 10 mL of a commercial fruit juice was poured into a clean conical flask and diluted with 30 mL of distilled water. Three drops of phenolphthalein indicator were added and the diluted fruit juice was titrated with 0.5 mol L\(^{-1}\) sodium hydroxide. The procedure was repeated three more times to obtain the following data.

<table>
<thead>
<tr>
<th>Titration</th>
<th>Burette reading (mL)</th>
<th>Titre (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Trial</td>
<td>0.8</td>
<td>18.9</td>
</tr>
<tr>
<td>1</td>
<td>18.9</td>
<td>33.9</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>17.6</td>
</tr>
<tr>
<td>3</td>
<td>17.6</td>
<td>32.8</td>
</tr>
</tbody>
</table>

a. Why would phenolphthalein be chosen as a suitable indicator for the above titration?

\[ \text{Colour change (at the end point) at a pH range suitable for strong base - weak acid titration.} \]

b. What is the purpose of the trial titration?

\[ \text{Allows the finding of approximate titration volume in a short time.} \]

c. Why are the titre values different for titrations 1, 2 and 3?

\[ \text{The colour change persisting in a coloured juice can be difficult to precisely determine.} \]
\[ \text{Accuracy of measuring instrument employed.} \]
\[ \text{Parallax error.} \]
d. What is the concentration of citric acid in the fruit juice?

Average titre = 15.1 mL

\[ \text{Moles OH}^- = 0.5 \times \frac{15.1}{1000} = 0.00755 \]

\[ \text{Moles acid} = \frac{0.00755}{3} = 0.0025 \]

\[ [\text{acid}] = \frac{0.0025 \text{ mol}}{0.1 \text{ L}} = 0.025 \text{ M} \]
Question 4

The following raw materials are available in their standard states in the laboratory at room temperature.

\[
\begin{align*}
\text{H} & - \text{C} = \text{C} - \text{H} \\
\text{H} & - \text{C} - \text{Br} - \text{Br} \\
\text{H}_2\text{O} & \quad \text{HBr} \quad \text{NaOH} \\
\text{CH}_3\text{OH} & \quad \text{Br}_2 \quad \text{KMnO}_4 \quad \text{H}_2\text{SO}_4 \quad \text{CO}_2
\end{align*}
\]

Select the appropriate starting materials and write equations to show the synthesis of each of the compounds indicated below. (You can use products from syntheses in early parts of the question as raw materials for syntheses in later parts of the question.)

(a) $\text{C}_2\text{H}_5\text{Br}$

(b) $\text{C}_2\text{H}_5\text{OH}$

(c) $\text{H} - \text{C} - \text{C} - \text{H}$

(d) $\text{CH}_3\text{COOH}$

(e) $\text{H} - \text{C} - \text{H}$

\[
\begin{align*}
(\text{a}) & \quad \text{C} = \text{C} - \overset{\ooalign{\smash{\step}{\smash{-}}
\vphantom{\text{H}_2}}}{\underset{\text{HBr}}{\text{Br}}} \quad \rightarrow \quad \text{C} - \text{C} - \text{Br} \\
(\text{b}) & \quad \text{C} - \text{C} - \text{Br} + \text{NaOH} \quad \rightarrow \quad \text{C} - \text{C} - \text{O}^+ \quad + \quad \text{Na}^+ + \text{Br}^- \\
(\text{c}) & \quad \text{C} = \text{C} - \overset{\ooalign{\smash{\step}{\smash{-}}
\vphantom{\text{H}_2}}}{\underset{\text{Br}}{\text{Br}}} \quad \rightarrow \quad \text{Br} - \text{C} - \text{C} - \text{Br} \\
(\text{d}) & \quad 5 \cdot \text{C}_2\text{H}_5\text{OH} + 4\text{MnO}_4^- + 12\text{H}^+ \rightarrow 5 \cdot \text{C} - \text{C} - \text{OH}^+ + 4\text{Mn}^{2+} + 11\text{H}_2\text{O} \\
(\text{e}) & \quad \text{C} - \text{C} - \overset{\ooalign{\smash{\step}{\smash{-}}
\vphantom{\text{H}_2}}}{\underset{\text{OH}}{\text{OH}}} + \text{CH}_3\text{OH} \quad \underset{\text{conc H}_2\text{SO}_4}{\underset{\text{CH}_3}{\rightarrow}} \quad \text{C} - \text{C} - \overset{\ooalign{\smash{\step}{\smash{-}}
\vphantom{\text{H}_2}}}{\underset{\text{CH}_3}{\text{OH}}} + \text{H}_2\text{O}
\end{align*}
\]
Question 5

A group of students measured the pressure and volume of a 3 mole sample of H₂ gas at different temperatures. Their results are shown below.

<table>
<thead>
<tr>
<th>Pressure (atm)</th>
<th>Volume (L)</th>
<th>Temperature (°C)</th>
<th>P x V (atm.L)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.81</td>
<td>11.2</td>
<td>-50</td>
<td>53.9</td>
<td>223</td>
</tr>
<tr>
<td>3.96</td>
<td>16.9</td>
<td>0</td>
<td>66.9</td>
<td>273</td>
</tr>
<tr>
<td>5.66</td>
<td>14.1</td>
<td>50</td>
<td>79.8</td>
<td>323</td>
</tr>
<tr>
<td>9.25</td>
<td>10.1</td>
<td>100</td>
<td>93.4</td>
<td>373</td>
</tr>
</tbody>
</table>

a. Complete the table above.

b. On the graph paper provided on the following page, plot a graph of P x V against T (in Kelvin).

c. Calculate the slope (gradient) of the graph.

\[
\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{75 - 25}{300 - 100} = 0.25
\]

d. **Use the above value of the slope** and the ideal gas equation to calculate a value for the gas constant R.

\[
R = \frac{PV}{nT} = \frac{PV}{T} \times \frac{1}{n} = \frac{\text{Slope}}{n}
\]

\[
R = \frac{0.25}{3} = 0.083
\]
Paper Two

Question 1

\[ 3 \text{CuO(s)} + 2\text{NH}_3(g) \rightarrow \text{N}_2(g) + 3\text{Cu}(s) + 3\text{H}_2\text{O}(g) \]

Moles \( \text{NH}_3 = \frac{181}{17} = 10.65 \)

Moles \( \text{CuO} = \frac{190.4}{79.5} = 2.39 \)

\( \text{CuO is the limiting reagent} \)

\[ 3\text{CuO} \rightarrow 1\text{N}_2 \]

2.39 moles \( \rightarrow 0.796 \text{ mol N}_2 \)

Mass \( \text{N}_2 = 0.796 \times 28 \)

= 22.3 g

Process is 65% efficient

Mass \( \text{N}_2 = 0.65 \times 22.3 \)

= 14.5 g
Question 2

\[
\begin{align*}
Y^{3+} + 3e^- & \rightarrow Y \quad [0.14\text{V}] \\
X^{2+} + 2e^- & \rightarrow X \\
A^{2+} + 2e^- & \rightarrow A \quad [0.78\text{V}] \\
2e^- & \rightarrow Z \\
Z^{+} + 2e^- & \rightarrow Z \quad [0.74\text{V}] \\
X^{2+} + 2e^- & \rightarrow X \\
A^{2+} + 2e^- & \rightarrow A \quad [1.52\text{V}] \\
X^{2+} + 2e^- & \rightarrow X \\
\end{align*}
\]

\[
\begin{align*}
A^{2+} & \rightarrow A \quad [0.34\text{V}] \\
H^+ & \rightarrow H \quad [0.78\text{V}] \\
Z^{2+} & \rightarrow Z \quad [0.74\text{V}] \\
Y^{3+} & \rightarrow Y \quad [0.44\text{V}] \\
X^{2+} & \rightarrow X \\
\end{align*}
\]
Question 2

With reference to $2H^+ + 2e^- \rightarrow H_2, E^\circ = 0\ V$

- $A^{2+} + 2e^- \rightarrow A \quad + 0.34\ V$
- $2H^+ + 2e^- \rightarrow H_2 \quad + 0.00\ V$
- $Z^{2+} + 2e^- \rightarrow Z \quad - 0.44\ V$
- $Y^{3+} + 3e^- \rightarrow Y \quad - 0.74\ V$
- $X^{2+} + 2e^- \rightarrow X \quad - 1.18\ V$
\[ \text{Question 3} \]

\[ \Delta H (\text{kJ}) \]

\[ \text{N}_2 \text{H}_4 (l) + H_2 O (l) \rightarrow 2 N \text{H}_3 (g) + \frac{1}{2} O_2 (g) + 143 \]

\[ 2 N \text{H}_3 (g) + 3 N_2 O_3 (g) \rightarrow 4 N_2 (g) + 3 H_2 O (l) \quad -1010 \]

\[ 3 \text{N}_2 H_4 (l) + 3 H_2 O (l) \rightarrow 3 N_2 O_3 (l) + 9 H_2 (g) \quad 8 \times 317 \]

\[ 9 H_2 (g) + \frac{9}{2} O_2 (g) \rightarrow 9 H_2 O (l) \quad 9 \times -286 \]

\[ 12 N_2 H_4 (l) + 12 O_2 (g) \rightarrow 4 N_2 (g) + 8 H_2 O (l) \]

\[ \Delta H = (143 + 951) - (1010 + 286) \]

\[ = -2490 \text{ kJ} \]

\[ \therefore \Delta H \text{ for equilibrium reaction} = -2490 \text{ kJ} \]

\[ = -6225 \text{ kJ} \]
\[
\text{CaSO}_4(s) \rightleftharpoons \text{Ca}^{2+}(aq) + \text{SO}_4^{2-}(aq)
\]

\[
K_{sp} = 9 \times 10^{-6} = [\text{Ca}^{2+}(aq)][\text{SO}_4^{2-}(aq)]
\]

\[
\Rightarrow [\text{Ca}^{2+}] \text{ in bath water} = 3 \times 10^{-3} \text{ M}
\]

\[
\text{Bath volume} = 4.55 \times 60 = 273 \text{ L}
\]

\[
\text{Moles Ca}^{2+} \text{ present} = 3 \times 10^{-3} \times 273
\]
\[
= 8.2 \times 10^{-1}
\]

\text{To form scum,}
\[
\text{Ca}^{2+} + 2 \text{CH}_3(\text{CH}_2)_6\text{COO}^- \rightarrow \text{Ca}\left[\text{CH}_3(\text{CH}_2)_6\text{COO}\right]_2
\]

\[
\text{Moles Scum} = 2 \times \text{Moles Ca}^{2+}
\]
\[
= 2 \times 8.2 \times 10^{-1}
\]
\[
= 1.64
\]

\[
\text{Mass Scum} = 1.64 \times 306
\]
\[
= 502.3
\]
Question 5

Candidates are required to use complex reasoning in a challenging situation involving the candidate's understanding of subject matter.

Credit is not awarded to the restatement of knowledge of subject matter which may have been copied during the open book examination.

Many possibilities exist but responses should demonstrate reference to and an understanding of much of the following:

**STEP 1.**

- High temperature - suggests that the activation energy associated with the rate determining step is very high.
- The equation is the sum of all the 2 particle collisions involved and does not show the mechanism or reaction intermediates.
- Consideration of rate of production of product compared to equilibrium yield.

- Equilibrium considerations in product formation. High temperature and pressure do not favour the formation of product - be careful with considerations.
Question 5

- System involves the removal of product to drive the forward reaction — open vs closed system considerations.

**STEP 2**
- Temperature is reduced — Le Chatelier’s considerations to drive the exothermic reaction in a forward direction.
- High pressure — Le Chatelier’s consideration to reduce the pressure (3 mol → 2 mol) drives the reaction in the forward direction.
- Lower temperature suggests that no large activation energy barrier is present in the mechanism.
- Removal of NO₂ drives the reaction in the forward direction.

**STEP 3**
- Fine spray system — effectively increases the contact area of H₂O to increase contact of collisions between H₂O and reactants.
- H₂O also acts as a cooling method to remove heat and drive the equilibrium in the forward direction.