WRITE YOUR CENTRE NUMBER, CANDIDATE NUMBER AND NAME ON ALL THE WORK YOU HAND IN.

YOU MAY USE AN HB PENCIL FOR ANY DIAGRAMS OR GRAPHS.

DO NOT USE STAPLES, PAPER CLIPS, GLUE OR CORRECTION FLUID.

DO NOT WRITE IN ANY BARCODES.

SECTION A
Answer all questions.

SECTION B
Answer all questions.

Electronic calculators may be used.
You may lose marks if you do not show your working or if you do not use appropriate units.
A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

This document consists of 19 printed pages and 1 blank page.
1 (a) Calcium has atomic number 20.

Complete the electronic structures for a

calcium atom, \(1s^22s^22p^6\)..........................

calcium ion in the +2 oxidation state. \(1s^22s^22p^6\)..........................  \[1\]

(b) Calcium nitrate, \(\text{Ca(NO}_3\text{)}_2\), is used in fertilisers and can be prepared by an acid-base reaction.

Write an equation for the preparation of calcium nitrate by an acid-base reaction.

..............................................................................................................................................  \[1\]

(c) (i) When anhydrous calcium nitrate is heated strongly, it decomposes to leave a white solid.

Identify this white solid and suggest another observation for this reaction.

..............................................................................................................................................

..............................................................................................................................................  \[1\]

(ii) The ease of thermal decomposition of the Group II nitrates decreases down the group.

Explain this trend.

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..............................................................................................................................................

..............................................................................................................................................  \[2\]
(d) (i) What is meant by the term standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^*$?

...............................................................................................................................................
...............................................................................................................................................
............................................................................................................................................. [2]

(ii) Use the following data to calculate the lattice energy, $\Delta H_{\text{latt}}^*$, of calcium nitrate, Ca(NO$_3$)$_2$(s). You may find it helpful to construct an energy cycle.

<table>
<thead>
<tr>
<th>enthalpy change</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta H_{\text{hyd}}^*$ (Ca$^{2+}$(g))</td>
<td>$-1650 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$\Delta H_{\text{hyd}}^*$ (NO$_3^-$(g))</td>
<td>$-314 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>enthalpy change of solution for Ca(NO$_3$)$_2$(s)</td>
<td>$-19 \text{ kJ mol}^{-1}$</td>
</tr>
</tbody>
</table>

$\Delta H_{\text{latt}}^*$ Ca(NO$_3$)$_2$(s) = ......................... $\text{kJ mol}^{-1}$ [3]

(e) The standard enthalpy change of hydration for Ba$^{2+}$, $\Delta H_{\text{hyd}}^*$ (Ba$^{2+}$(g)), is $-1305 \text{ kJ mol}^{-1}$.

Suggest an explanation for why the $\Delta H_{\text{hyd}}^*$ of the Ba$^{2+}$ ion is less exothermic than the $\Delta H_{\text{hyd}}^*$ of the Ca$^{2+}$ ion.

............................................................................................................................................. [2]

[Total: 12]
2 (a) Complete the table to show the number of unpaired electrons in the outer shell of each of the gaseous atoms, Na to Ar.

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cl</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of unpaired electrons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) (i) Complete the table for the reactions of two Period 3 chlorides with water.

<table>
<thead>
<tr>
<th>Period 3 chloride</th>
<th>observations</th>
<th>pH of solution formed</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiCl₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCl₅</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ii) Write an equation for the reaction between SiCl₄ and H₂O.

........................................................................................................................................................................... [1]
3 The transition element iron is the most abundant element in the Earth’s core.

(a) What is meant by the term *transition element*?

....................................................................................................................................................
.................................................................................................................................................... [1]

(b) In aqueous solution, iron can form complex ions which contain ligands.

(i) Name the *type of bonding* that occurs between a ligand and a transition element.

.................................................................................................................................................... [1]

(ii) Which of the following species can act as a ligand? Complete the table by placing a tick (✓) in the appropriate column to indicate whether the species can act as a ligand or not.

<table>
<thead>
<tr>
<th>species</th>
<th>can act as a ligand</th>
<th>cannot act as a ligand</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3^-$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF$_3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$NCH$_2$CH$_2$NH$_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH$_4^+$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[2]

(c) Manganese ions, Mn$^{2+}$(aq), show some similar chemical properties to those of copper(II) ions, Cu$^{2+}$(aq).

Use this information and the *Data Booklet* to suggest the formula of the manganese species formed in each of the following reactions. State the *type of reaction* taking place in each case.

<table>
<thead>
<tr>
<th>formula of manganese species formed</th>
<th>type of reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn$^{2+}$(aq) + NaOH(aq)</td>
<td></td>
</tr>
<tr>
<td>Mn$^{2+}$(aq) + concentrated HCl</td>
<td></td>
</tr>
<tr>
<td>Mn$^{2+}$(aq) + H$_2$O$_2$(aq)</td>
<td></td>
</tr>
</tbody>
</table>

[5]

[Total: 9]

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In aqueous solution, 2-chloro-2-methylpropane, \((\text{CH}_3)_3\text{CCl}\), reacts with sodium hydroxide, \(\text{NaOH}\). This is a nucleophilic substitution reaction.

\[
(\text{CH}_3)_3\text{CCl}(\text{aq}) + \text{NaOH(}a\text{q}) \rightarrow (\text{CH}_3)_3\text{COH(}a\text{q}) + \text{NaCl}(\text{aq})
\]

(a) Show the mechanism for this reaction. Include all necessary curly arrows, lone pairs and relevant dipoles.

[b] The rate of this reaction was investigated using a large excess of sodium hydroxide.

(b) The graph below shows the results of the experiment.
The reaction is first order with respect to \((\text{CH}_3)_3\text{CCl}\). This can be confirmed from the graph using half-lives.

(i) What is meant by the *half-life* of a reaction?

...........................................................................................................................................

.................................................................................................................................................. [1]

(ii) Calculate the half-life for this reaction. Show all your working and show clearly any construction lines on the graph.

.................................................................................................................................................. [1]

(iii) What would be the effect on the half-life of this reaction if the initial concentration of \((\text{CH}_3)_3\text{CCl}\) was *doubled*?

.................................................................................................................................................. [1]

(c) (i) Use the graph in (b) to determine the rate of reaction at 80 s. Show all your working.

rate = ............................. units ............................. [2]

The rate equation for this reaction is shown.

rate = \(k[(\text{CH}_3)_3\text{CCl}]\)

(ii) Calculate the value of the rate constant, \(k\), for this reaction and give its units.

\(k = .............................\) units ............................. [1]

[Total: 9]
5 \( \text{X} \) is a metallic element.

(a) (i) Draw a fully labelled diagram to show how the standard electrode potential, \( E^\circ \), of \( \text{X}^{2+} \text{(aq)}/\text{X(s)} \) could be measured. 

(ii) What are the conditions needed for the value measured to be a \textbf{standard} electrode potential? 

................................................................................................................................................................. [1]

(iii) State the charge carriers that transfer current through the solutions, .............................................. the wire. ............................................. [1]
(b) An electrochemical cell was set up consisting of an \( \text{X}^{2+}(aq)/\text{X(s)} \) half-cell \((E^\circ = -0.40 \text{ V})\) and an \( \text{Ag}^+(aq)/\text{Ag(s)} \) half-cell \((E^\circ = +0.80 \text{ V})\).

(i) Write an equation for the reaction that would take place if the electrodes of this cell were connected by a wire.

..................................................................................................................................................................................................................................................................................................................................................................................... [1]

When the current was allowed to pass for a period of time,

- the Ag electrode gained 1.30 g in mass,
- the electrode made of metal X lost 0.67 g in mass.

(ii) Calculate the \( A_r \) of metal X; hence suggest an identity for X. Show all your working. Use of the Data Booklet is relevant to this question.

\[ A_r = \text{.........................} \]

X is \text{.........................} \[4\]

[Total: 11]
Boron forms many useful compounds.

(a) The compound diborane, $B_2H_6$, can be used as a rocket fuel. It can be prepared by the reaction of boron trifluoride, $BF_3$, with sodium borohydride, $NaBH_4$.

Balance this equation.

$$\ldots\ldots BF_3 + \ldots\ldots NaBH_4 \rightarrow \ldots\ldots B_2H_6 + \ldots\ldots NaBF_4$$

(b) Primary and secondary alcohols can be formed by the reaction of carbonyl compounds with $NaBH_4$, which is a source of hydride ions, $H^-$. Complete the mechanism for the reaction of butanone with hydride ions, $H^-$, and draw the intermediate in the box. Include all necessary curly arrows and relevant dipoles.

(c) Borane, $BH_3$, is used to synthesise alcohols from alkenes. The reaction occurs in two steps. The $BH_2$ group from $BH_3$ bonds to the least substituted carbon atom of the double bond, and the remaining $H$ from $BH_3$ bonds to the other carbon.

(i) Suggest the type of reaction in step 1.
(ii) The diol $Y$ can be prepared by the same method.

\[ \text{CH}_3 \quad \text{CH}_3 \]
\[ \text{H}_3 \text{C} - \text{CH}_3 \quad \text{OH} \]
\[ \text{OH} \quad \text{CH}_3 \]

$Y$

Draw the structure of the diene which could be used to prepare diol $Y$.

(d) Benzene, $C_6H_6$, and borazine, $B_3N_3H_6$, have planar, cyclic structures.

(i) Describe the structure of and bonding in benzene, $C_6H_6$.

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...............................................................................................................................................
............................................................................................................................................. [3]

(ii) In borazine, $B_3N_3H_6$, the boron and nitrogen atoms alternate around the ring. Each ring atom has a single hydrogen atom bonded to it. All boron-nitrogen bonds in borazine are $0.144 \text{ nm}$ in length, whereas in simple compounds $B-N$ and $B=N$ bond lengths are $0.154 \text{ nm}$ and $0.136 \text{ nm}$ respectively.

Suggest and draw the structure of borazine.

[1]

[Total: 10]
Sunset Yellow is a yellow colouring agent used in food and drinks, which can be made by the following route.

In step 3 of this synthesis, a phenol-like compound, S, reacts with intermediate T made from amine R.
Assume that the $-\text{SO}_3^-\text{Na}^+$ group does not react.

(i) Suggest structures for compounds R, S and T and draw them in the boxes above.  [3]

(ii) Suggest reagents and conditions for

- step 1, .................................................................................................................................
- step 2, .................................................................................................................................  [3]

(iii) What type of organic salt is formed in step 2?
...............................................................................................................................................  [1]
(b) Compound \( W \) has the following structure.

\[
\begin{array}{c}
\text{H}_2\text{N} \quad \text{---} \quad \text{NH}_2
\end{array}
\]

(i) How many \( \sigma \) and \( \pi \) bonds are present in a molecule of \( W \)?

\( \sigma \) bonds .................. \( \pi \) bonds .................. [2]

(ii) The products of the reactions of \( W \) with cold \( \text{HCl} \) and with \( \text{CH}_3\text{CH}_2\text{Br} \) are soluble in water but not in organic solvents.

Complete the table for these reactions of \( W \).

<table>
<thead>
<tr>
<th>reagent</th>
<th>structure of product (molecular formula given)</th>
<th>type of reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{HCl} )</td>
<td>( \text{C}_4\text{H}_9\text{N}_2\text{OC{l}} )</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3\text{CH}_2\text{Br} )</td>
<td>( \text{C}<em>6\text{H}</em>{13}\text{N}_2\text{BrO} )</td>
<td></td>
</tr>
</tbody>
</table>

[Total: 12]
8 (a) The sequence of bases in DNA is a code for the order of amino acids in the primary structure of proteins. The diagram represents the stages involved in the formation of a protein from DNA.

(i) Identify the biochemical structures, A and B₁, B₂ etc.

<table>
<thead>
<tr>
<th>biochemical structure</th>
<th>identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B₁, B₂ etc.</td>
<td></td>
</tr>
</tbody>
</table>

(ii) Name the biochemical processes involved in stages 1 and 3.

<table>
<thead>
<tr>
<th>process</th>
<th>name of biochemical process</th>
</tr>
</thead>
<tbody>
<tr>
<td>stage 1</td>
<td></td>
</tr>
<tr>
<td>stage 3</td>
<td></td>
</tr>
</tbody>
</table>
(b) Adenine is an integral part of DNA.

![Adenine structure](image)

(i) State the molecular formula of adenine.
........................................................................................................................................... [1]

(ii) Identify the three other nitrogenous bases in DNA.
............................................................................. ............................................................................. ............................................................................. [1]

(iii) DNA has a double helical structure that consists of two strands linked together.
What type of bonding exists between the phosphate and sugar groups within a DNA strand, .............................................................................
different bases on the two strands? .................................................................................... [2]

(c) The breakdown of adenosine triphosphate, ATP, provides the energy for many cellular reactions.

\[
\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i
\]

What type of chemical reaction is this?
........................................................................................................................................... [1]

(d) X-ray crystallography can be useful in obtaining information about the structures of large organic molecules, such as ATP. The technique involves X-rays interacting with the electrons within the molecule.

(i) Which element in the molecule of ATP will interact most strongly with the X-ray beam?
........................................................................................................................................... [1]

(ii) Explain why X-ray crystallography will not detect hydrogen atoms.
........................................................................................................................................... [1]

[Total: 10]
9 (a) Some metals are essential to biochemical processes. Complete the following table naming one metal in each case.

<table>
<thead>
<tr>
<th>biochemical process</th>
<th>metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>haemoglobin in oxygen transport</td>
<td></td>
</tr>
<tr>
<td>transmission of nerve impulses</td>
<td></td>
</tr>
<tr>
<td>enzyme cofactor</td>
<td></td>
</tr>
</tbody>
</table>

(b) Enzymes are a special type of protein molecule that catalyse biochemical reactions. Explain briefly the mechanism by which an enzyme breaks down a substrate molecule.

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....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
.................................................................................................................................................... [3]

(c) Disulfide bonds play an important role in the stability of some proteins such as the keratin in human hair. The amino acid involved in the formation of a disulfide bond is cysteine, H₂NCH(CH₂SH)CO₂H.

(i) At which level of protein structure (primary, secondary, tertiary) are disulfide bonds formed? .................................................................................................................................................... [1]

(ii) Use a functional group in cysteine to show how disulfide bonds are formed.

.................................................................................................................................................... [1]

(iii) What type of chemical reaction is this? .................................................................................................................................................... [1]
(d) The NMR spectrum of cysteine, \( \text{H}_2\text{NCH(CH}_2\text{SH})\text{CO}_2\text{H} \), shows five absorptions.

After shaking a solution of cysteine with a few drops of \( \text{D}_2\text{O} \), the NMR spectrum shows only two absorptions, \( \text{E} \) and \( \text{F} \), shown below.

(i) Identify the two types of protons responsible for the absorptions \( \text{E} \) and \( \text{F} \).

\( \text{E} \) ..........................................................................................................................................

\( \text{F} \) ..........................................................................................................................................

(ii) State and explain the splitting patterns of the absorptions \( \text{E} \) and \( \text{F} \).

\( \text{E} \) ..........................................................................................................................................

............................................................................................................................................

\( \text{F} \) ..........................................................................................................................................

...........................................................................................................................................  [2]

[Total: 11]
10 (a) Aspartame is an artificial sweetener that has the structure shown below.

![Aspartame structure]

(i) Draw a circle around each chiral centre in aspartame. [1]

In the stomach, aspartame is hydrolysed by acid to form three organic products.

(ii) On the diagram above, use arrows to indicate the two bonds that would be hydrolysed in the stomach. [2]

(iii) Draw the structures of the three products formed after complete acid hydrolysis of aspartame.

[Diagram representing three organic products]
(b) Aspartame is soluble in water.

By referring to the structure of aspartame, explain why it is soluble in water.

....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................  [2]

(c) Recently, nanotechnology has been involved in the development of a new natural sweetener, Nano Sugar, extracted from sugar cane.

What is the approximate width of a nanoparticle?

....................................................................................................................................................  [1]

[Total: 9]