READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
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.

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.
1 (a) Complete the table to show the composition and identity of some atoms and ions.

<table>
<thead>
<tr>
<th>name of element</th>
<th>nucleon number</th>
<th>atomic number</th>
<th>number of protons</th>
<th>number of neutrons</th>
<th>number of electrons</th>
<th>overall charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>boron</td>
<td>10</td>
<td>5</td>
<td>..................</td>
<td>..................</td>
<td>..................</td>
<td>0</td>
</tr>
<tr>
<td>nitrogen</td>
<td>..................</td>
<td>..................</td>
<td>8</td>
<td>10</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>..................</td>
<td>208</td>
<td>82</td>
<td>82</td>
<td>80</td>
<td>..................</td>
<td></td>
</tr>
<tr>
<td>..................</td>
<td>..................</td>
<td>3</td>
<td>3</td>
<td>80</td>
<td>+1</td>
<td></td>
</tr>
</tbody>
</table>

(b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are not the actual symbols of the elements.

<table>
<thead>
<tr>
<th>ionisation energies, kJ mol⁻¹</th>
<th>fifth</th>
<th>sixth</th>
<th>seventh</th>
<th>eighth</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>7012</td>
<td>8496</td>
<td>27107</td>
<td>31671</td>
</tr>
<tr>
<td>Y</td>
<td>6542</td>
<td>9362</td>
<td>11018</td>
<td>33606</td>
</tr>
<tr>
<td>Z</td>
<td>7238</td>
<td>8781</td>
<td>11996</td>
<td>13842</td>
</tr>
</tbody>
</table>

(i) State and explain the group number of element Y.

<table>
<thead>
<tr>
<th>group number</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>....................................</td>
<td>..................</td>
</tr>
<tr>
<td>....................................</td>
<td>..................</td>
</tr>
<tr>
<td>....................................</td>
<td>..................</td>
</tr>
</tbody>
</table>

(ii) State and explain the general trend in first ionisation energies across the third period.

| .................................... | ................................. |
| .................................... | ................................. |
| .................................... | ................................. |

(iii) Complete the electronic configuration of element X.

| 1s² | .................................... |
|     | .................................... |
(c) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table.

<table>
<thead>
<tr>
<th>mass number</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>abundance</td>
<td>99.76%</td>
<td>0.04%</td>
</tr>
</tbody>
</table>

(i) Calculate the abundance of the third isotope.

\[
\text{abundance} = \ldots \% \quad [1]
\]

(ii) The relative atomic mass of this sample of oxygen is 16.0044.

Calculate the mass number of the third isotope. You must show your working.

\[
\text{mass number} = \ldots \quad [2]
\]

[Total: 11]
The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

<table>
<thead>
<tr>
<th>element</th>
<th>bond energy /kJ mol⁻¹</th>
<th>standard enthalpy change of atomisation, ( \Delta H_{\text{at}}^\circ /kJ\text{ mol}^{-1} )</th>
<th>boiling point of element /K</th>
<th>boiling point of hydrogen halide /K</th>
</tr>
</thead>
<tbody>
<tr>
<td>fluorine, F−F</td>
<td>158</td>
<td>79</td>
<td>85</td>
<td>293</td>
</tr>
<tr>
<td>chlorine, Cl−Cl</td>
<td>242</td>
<td>121</td>
<td>238</td>
<td>188</td>
</tr>
<tr>
<td>bromine, Br−Br</td>
<td>193</td>
<td>112</td>
<td>332</td>
<td>206</td>
</tr>
<tr>
<td>iodine, I−I</td>
<td>151</td>
<td>107</td>
<td>457</td>
<td>238</td>
</tr>
</tbody>
</table>

(a) (i) Explain the meaning of the term *standard enthalpy change of atomisation*.

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

(ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

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

(iii) The standard enthalpy of formation of iodine monochloride, ICl, is −24.0 kJ mol⁻¹.

Use this information and the bond energies of iodine and chlorine to calculate the I−Cl bond energy.

\[
\text{I−Cl bond energy} = \text{.................. kJ mol}^{-1} \quad [2]
\]
(b) (i) Explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.
.............................................................................................................................................
.............................................................................................................................................
............................................................................................................................................. [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl, HBr and HI.
.............................................................................................................................................
.............................................................................................................................................
............................................................................................................................................. [2]

(c) In an experiment, two of the halogens are represented as \( \text{P}_2 \) and \( \text{Q}_2 \).

\( \text{P}_2 \) combines with hydrogen on heating to form HP, which can be easily broken down into its elements. A solution of HP in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

\( \text{Q}_2 \) combines explosively with hydrogen in sunlight to form HQ, which is stable to heat. A solution of HQ in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

(i) Identify the halogens \( \text{P}_2 \) and \( \text{Q}_2 \).

\( \text{P}_2 = \) ............................................................... \( \text{Q}_2 = \) ............................................................... [1]

(ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.
.............................................................................................................................................
.............................................................................................................................................
............................................................................................................................................. [2]

(iii) Write an equation for the thermal decomposition of HP.
............................................................................................................................................. [1]
(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous H₂Q,

2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

(d) Chlorine reacts directly with many elements to form chlorides. Three such compounds are MgCl₂, AlCl₃ and SiCl₄.

(i) State and explain the pattern shown by the formulae of these three chlorides.

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

MgCl₂ .......................................................... 
AlCl₃ .......................................................... 
SiCl₄ .......................................................... 

[Total: 21]
Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $\text{H}_2\text{C}_2\text{O}_4$.

The relevant half-equations are shown.

\[
\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}
\]

\[
\text{H}_2\text{C}_2\text{O}_4 \rightarrow 2\text{CO}_2 + 2\text{H}^+ + 2\text{e}^-
\]

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

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

(b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $\text{H}_2\text{C}_2\text{O}_4 \cdot x\text{H}_2\text{O}$, was reacted with a 0.0200 mol dm$^{-3}$ solution of acidified potassium dichromate(VI).

32.0 cm$^3$ of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

(i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

\[
\text{amount} = \text{......................... mol} \quad [1]
\]

(ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

\[
\text{amount} = \text{......................... mol} \quad [1]
\]

(iii) Calculate the relative molecular mass, $M_r$, of the hydrated ethanedioic acid.

\[
M_r = \text{.........................} \quad [1]
\]

(iv) Calculate the value of $x$ in $\text{H}_2\text{C}_2\text{O}_4 \cdot x\text{H}_2\text{O}$.

\[
x = \text{.........................} \quad [1]
\]

[Total: 6]
This question is about molecules with molecular formula \( \text{C}_4\text{H}_8\text{O}_2 \).

(a) Give the structural formulae of the pair of **chain** isomers with the formula \( \text{C}_4\text{H}_8\text{O}_2 \) that are carboxylic acids.

(b) (i) Give the structural formulae of a pair of **positional** isomers with the formula \( \text{C}_4\text{H}_8\text{O}_2 \) that are esters.

(ii) Give the reagents and conditions needed to produce one of your esters in (i).

\[ \text{...} \] [2]
(c) The infra-red spectra of one of the esters and of another isomer, X, are shown.

X decolourises bromine water and is not an ester or an acid.

Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm⁻¹.

..............................................................
..............................................................
..............................................................
..............................................................
..............................................................
[3]
[Total: 9]
A reaction sequence based on propan-1-ol is shown.

(a) Reactions 1 and 2 can both be carried out using the same reagents.
(i) Identify suitable reagents for reactions 1 and 2.
...............................................................................................................................................
............................................................................................................................................. [1]
(ii) State and explain how the reaction should be carried out to ensure that reaction 2 rather than reaction 1 occurs.
...............................................................................................................................................
...............................................................................................................................................
...............................................................................................................................................
............................................................................................................................................. [2]

(b) Identify the necessary reagents and conditions for each of reactions 3 and 4.
reaction 3 .................................................................................................................................
.............................................................................................................................................
reaction 4 .................................................................................................................................
............................................................................................................................................. [2]
(c) (i) Complete the reaction mechanism for reaction 5. Include all relevant lone pairs, curly arrows, charges and partial charges.

\[ \text{CH}_3\text{CH}_2\text{C} = \text{O} \quad \text{→} \quad \text{CH}_3\text{CH}_2\text{C-OH} \quad \text{→} \quad \text{CH}_3\text{CH}_2\text{C-CN} \]

The product of reaction 5 exhibits stereoisomerism.

(ii) Draw the two stereoisomers in the conventional way.

(iii) Suggest why a mixture of the two stereoisomers is formed by reaction 5.

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

[Total: 13]