INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer one question from Section B. Write your answers on answer sheets. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet and indicate the number of sheets used in the appropriate box on your cover sheet.
SECTION A

Answer all the questions in the spaces provided.

1. The data below is from an experiment used to measure the enthalpy change for the combustion of 1 mole of sucrose (common table sugar), C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}(s). The time-temperature data was taken from a data-logging software programme.

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Mass of sample of sucrose, $m = 0.4385$ g

Heat capacity of the system, $C_{\text{system}} = 10.114$ kJ K\textsuperscript{-1}

(a) Calculate $\Delta T$, for the water, surrounding the chamber in the calorimeter. [1]

(b) Determine the amount, in moles, of sucrose. [1]

(This question continues on the following page)
(Question 1 continued)

(c)  

(i) Calculate the enthalpy change for the combustion of 1 mole of sucrose.  

(ii) Using Table 12 of the Data Booklet, calculate the percentage experimental error based on the data used in this experiment.  

(d) A hypothesis is suggested that TNT, 2-methyl-1,3,5-trinitrobenzene, is a powerful explosive because it has:

- a large enthalpy of combustion
- a high reaction rate
- a large volume of gas generated upon combustion

Use your answer in part (c)(i) and the following data to evaluate this hypothesis:

<table>
<thead>
<tr>
<th></th>
<th>Equation for combustion</th>
<th>Relative rate of combustion</th>
<th>Enthalpy of combustion / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>C₁₂H₂₂O₁₁(s) + 12O₂(g) → 12CO₂(g) + 11H₂O(g)</td>
<td>Low</td>
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<tr>
<td>TNT</td>
<td>2C₃H₆N₆O₆(s) → 7CO(g) + 7C(s) + 5H₂O(g) + 3N₂(g)</td>
<td>High</td>
<td>3406</td>
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</tbody>
</table>
2. (a) List the following types of electromagnetic radiation in order of increasing wavelength (shortest first). \[1\]

I. Yellow light
II. Red light
III. Infrared radiation
IV. Ultraviolet radiation

(b) Distinguish between a continuous spectrum and a line spectrum. \[1\]

(c) The thinning of the ozone layer increases the amount of UV-B radiation that reaches the Earth’s surface.

<table>
<thead>
<tr>
<th>Type of Radiation</th>
<th>Wavelength / nm</th>
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</thead>
<tbody>
<tr>
<td>UV-A</td>
<td>320 – 380</td>
</tr>
<tr>
<td>UV-B</td>
<td>290 – 320</td>
</tr>
</tbody>
</table>

Based on the information in the table above explain why UV-B rays are more dangerous than UV-A. \[3\]
3. (a) Define the term *average bond enthalpy*.

(b) Use the information from Table 10 of the Data Booklet to calculate the enthalpy change for the complete combustion of but-1-ene, according to the following equation.

\[
C_4H_8(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)
\]
4. 0.600 mol of aluminium hydroxide is mixed with 0.600 mol of sulfuric acid, and the following reaction occurs:

\[ 2\text{Al(OH)}_3(s) + 3\text{H}_2\text{SO}_4(aq) \rightarrow \text{Al}_2(\text{SO}_4)_3(aq) + 6\text{H}_2\text{O}(l) \]

(a) Determine the limiting reactant.  

(b) Calculate the mass of \( \text{Al}_2(\text{SO}_4)_3 \) produced.  

(c) Determine the amount (in mol) of excess reactant that remains.  

(d) Define a Brønsted-Lowry acid and a Lewis base.

Bronsted-Lowry acid  

Lewis base  

(e) \( \text{H}_2\text{SO}_4(aq) \) is a strong acid. State the name and the formula of any weak acid.
5. (a) List two characteristics of a homologous series. [1]

(b) Ethanol and ethanoic acid can be distinguished by their melting points. State and explain which of the two compounds will have a higher melting point. [2]

(c) Draw the three isomers containing the alcohol functional group of formula C₄H₉OH. [2]
SECTION B

Answer one question. Write your answers on the answer sheets provided. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.

6. (a) (i) Outline the principles of the valence shell electron pair repulsion (VSEPR) theory. [3]

(ii) Use the VSEPR theory to deduce the shape of \( \text{H}_2\text{O}^+ \) and \( \text{C}_2\text{H}_4 \). For each species, draw the Lewis structure, name the shape, and state the value of the bond angle(s). [6]

(iii) Predict and explain whether each species is polar. [2]

(iv) Using Table 7 of the Data Booklet, predict and explain which of the bonds O-H, O-N or N-H would be most polar. [2]

(b) Predict and explain which of the following compounds consist of molecules:
\[ \text{NaCl, BF}_3, \text{CaCl}_2, \text{N}_2\text{O, P}_4\text{O}_6, \text{FeS and CBr}_4. \] [2]

(c) Diamond, graphite and \( C_{60} \) fullerene are three allotropes of carbon.

(i) Describe the structure of each allotrope. [3]

(ii) Compare the bonding in diamond and graphite. [2]
7. (a) The diagrams below represent equilibrium mixtures for the reaction \( Y + X_2 \rightleftharpoons XY + X \) at 350 K and 550 K respectively. Deduce and explain whether the reaction is exothermic or endothermic. [2]

![Diagram](image)

\[ X = \quad \text{350 K} \]
\[ Y = \quad \text{550 K} \]

(b) The equation for the main reaction in the Haber process is:

\[
N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H \text{ is negative}
\]

(i) Determine the equilibrium constant expression for this reaction. [1]

(ii) State and explain the effect on the equilibrium yield of ammonia with increasing the pressure and the temperature. [4]

(iii) In practice, typical conditions used in the Haber process involve a temperature of 500 °C and a pressure of 200 atm. Explain why these conditions are used rather than those that give the highest yield. [2]

(iv) At a certain temperature and pressure, 1.1 dm\(^3\) of \(N_2(g)\) reacts with 3.3 dm\(^3\) of \(H_2(g)\). Calculate the volume of \(NH_3(g)\), that will be produced. [1]

(v) Suggest why this reaction is important for humanity. [1]

(vi) A chemist claims to have developed a new catalyst for the Haber process, which increases the yield of ammonia. State the catalyst normally used for the Haber process, and comment on the claim made by this chemist. [2]

(This question continues on the following page)
(c) State **two** physical properties associated with metals and explain them at the atomic level. [4]

(d) Describe the acid-base character of the oxides of the period 3 elements Na to Ar. For sodium oxide and sulfur trioxide, write balanced equations to illustrate their acid-base character. [3]
8. (a) The following is a computer-generated representation of the molecule, methyl 2-hydroxy benzoate, better known as oil of wintergreen.

(i) Deduce the empirical formula of methyl 2-hydroxy benzoate and draw the full structural formula, including any multiple bonds that may be present. The computer-generated representation shown does not distinguish between single and multiple bonds. [2]

(ii) In this representation, two of the carbon-oxygen bond lengths shown are 0.1424 nm and 0.1373 nm. Explain why these are different and predict the carbon-oxygen bond length in carbon dioxide. [2]

(iii) Name all the functional groups present in the molecule. [2]

(b) (i) State and explain the trend in the boiling points of the first six alkanes involving straight-chains. [2]

(ii) Write an equation for the reaction between methane and chlorine to form chloromethane. Explain this reaction in terms of a free-radical mechanism. [5]

(This question continues on the following page)
(c) (i) Identify the formulas of the organic products, A–E, formed in the reactions, I–IV:

I. \( \text{CH}_3(\text{CH}_2)_n\text{OH} + \text{K}_2\text{Cr}_2\text{O}_7 \rightarrow \text{H}^+ \rightarrow \text{A} \rightarrow \text{H}^+ \rightarrow \text{B} \)

II. \( (\text{CH}_3)_2\text{CBr} + \text{NaOH} \rightarrow \text{C} \)

III. \( (\text{CH}_3)_2\text{CHOH} + \text{K}_2\text{Cr}_2\text{O}_7 \rightarrow \text{H}^+ \rightarrow \text{D} \)

IV. \( \text{H}_2\text{C} = \text{CH}_2 + \text{Br}_2 \rightarrow \text{E} \)

(ii) \( \text{H}_2\text{C}=\text{CH}_2 \) can react to form a polymer. Name this type of polymer and draw the structural formula of a section of this polymer consisting of three repeating units.
SECTION A

1.  (a)  \( \Delta T = 23.70 - 23.03 = 0.67 \, ^\circ \text{C/K}; \)

(b)  \( n = \left( \frac{0.4385 \, \text{g}}{342.34 \, \text{g mol}^{-1}} \right) = 1.281 \times 10^{-3} \, \text{mol}; \)

(c)  \( \Delta H_c = (C \Delta T) / n = \frac{-[(10.114 \, \text{kJ K}^{-1})(0.67 \, \text{K}]}{(1.281 \times 10^{-3} \, \text{mol})} = -5.3 \times 10^3 \, \text{kJ mol}^{-1}; \)

Use ECF for values of \( \Delta T \) and \( n. \)

(ii)  \( \text{Percentage experimental error} = \frac{(-5.3 \times 10^3) + (5.6 \times 10^3)}{(-5.6 \times 10^3)} \times 100 = 5.4 \% ; \)

Use ECF for values of \( \Delta H_c. \)

(d)  enthalpy change of combustion of sucrose > TNT, and therefore not important;

rate of reaction for TNT is greater than that of sucrose, so this is valid;

amount of gas generated (in mol) for sucrose > than that of TNT (according to the given equation), so this is not important;  

2.  (a)  IV < I < II < III /ultra violet radiation < yellow light < red light < infrared radiation;

(b)  A continuous spectrum has all colours/wavelengths/frequencies whereas a line spectrum has only (lines of) sharp/discrete/specific colours/ wavelengths/ frequencies;

(c)  UV-B radiation has shorter wavelength;

hence, has higher energy;

increases risk of damage to skin cells / OWTTE / causes cancer;

3.  (a)  The amount of energy needed to break 1 mole of (covalent) bonds;

in the gaseous state;

average calculated from a range of compounds; 

Award \([1]\) each for any two points above.

(b)  Bonds broken

\( (612) + (2 \times 348) + (8 \times 412) + (6 \times 496) / 7580 \, \text{(kJ mol}^{-1}) ; \)

Bonds made

\( (8 \times 743) + (8 \times 463) / 9648 \, \text{(kJ mol}^{-1}) ; \)

\( \Delta H = -2068 \, \text{(kJ mol}^{-1}) ; \)

Award \([3]\) for the correct answer.

Award full ECF.

Allow kj but no other incorrect units.

Even if the first two marks are lost, the candidate can score \([1]\) for a clear correct subtraction for \( \Delta H. \)
4. (a) \(0.600 \text{ mol } \text{Al(OH)}_3 \equiv (1.5)(0.600) \text{ mol } \text{H}_2\text{SO}_4\) / \(0.900 \text{ mol } \text{H}_2\text{SO}_4\) needed, but only
0.600 mol \(\text{H}_2\text{SO}_4\) used;
\(\text{H}_2\text{SO}_4\) limiting reactant; \[2\]
*Some working must be shown in order to score the second point.*

(b) \(0.200 \text{ mol } \text{Al}_2(\text{SO}_4)_3\);
68.4 (g);
Penalize incorrect units. \[2\]

(c) \(0.200 \text{ mol};\)
*Use ECF from (a).* \[1\]

(d) A Brønsted Lowry acid is a proton/\(\text{H}^+\) donor;
A Lewis base is an electron-pair donor; \[2\]

(e) \(\text{H}_2\text{CO}_3\) and carbonic acid / \(\text{CH}_3\text{COOH}\) and ethanoic acid;
*Accept any other weak acid and correct formula.* \[1\]
5. (a) one general formula / same general formula;
   differ by CH₃;
   similar chemical properties;
   gradual change in physical properties;
   Award [1] for any two of the above characteristics. [1 max]

(b) ethanol lower / ethanoic acid higher;
   due to larger mass of ethanoic acid / stronger
   van der Waals' / London / dispersion forces;
   due to stronger hydrogen bonding / 2 hydrogen
   bonds per molecule;
   Accept either answer for second mark. [2 max]

(c)

\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{CH}_3 \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad \text{H}_2\text{C} & \quad \text{C} & \quad \text{OH} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{CH}_3 \\
\text{H} & \quad \text{H} & \quad \text{OH} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\]

Allow condensed structural formulas such as CH₃CH₂CH₂CH₂OH.
SECTION B

6.  (a)  (i)  Find number of electron pairs/charge centres in (valence shell of) central atom; electron pairs/charge centres (in valence shell) of central atom repel each other;

   *Any one of the following:*
   - to positions of minimum energy/repulsion / maximum stability;
   - pairs forming a double or triple bond act as a single bond;
   - non-bonding pairs repel more than bonding pairs / OWTTE;
   - *Do not accept repulsion between bonds or atoms.*
   *[3 max]*

   (ii)

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<tr>
<th>Species</th>
<th>Lewis (electron-dot) structure</th>
<th>Shape</th>
<th>Bond angle(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_2O^+</td>
<td>![Lewis structure of H_2O^+]</td>
<td>Trigonal/triangular pyramidal;</td>
<td>Allow values in the range 106° to 109.5°;</td>
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<tr>
<td>C_2H_4</td>
<td>![Lewis structure of C_2H_4]</td>
<td>Trigonal/triangular planar;</td>
<td>Allow values of approximately 120°;</td>
</tr>
</tbody>
</table>

*Accept crosses and dots for electrons in Lewis structures also.
As the Lewis structures were asked for, and not 3D representations, do not penalize incorrectly drawn geometries.
Do not accept structure of hydronium cation without lone pair on oxygen.
No penalty for missing charge.*

   (iii)  H_2O^+: is polar and explanation either using a diagram or in words, involving the net dipole moment;
   - e.g. the three individual O-H bond dipole moments add as vectors to give a net dipole moment.

   C_2H_4: is non polar and explanation either using a diagram or in words, involving no net dipole moment;
   - e.g. the vector sum of the individual bond dipole moments is zero.

   For simple answers such as bond polarities do not cancel for H_2O^+ and do cancel for C_2H_4. Award [1], only for the last two marking points.

   (iv)  O-H is most polar;
   - O-H has greatest difference between electro negativities / calculation showing values of 1.4, 0.5 and 0.9 respectively;

   (b)  BF_3, N_2O, P_4O_6 and CBr_4;
   - Non-metals only / small difference in electronegativity values of the elements;
### Table: Allotrope Structures

<table>
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<tr>
<th>Allotrope</th>
<th>Structure</th>
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<tbody>
<tr>
<td>Diamond</td>
<td>3D array/network involving tetrahedral carbons / each carbon atom joined to four others;</td>
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<tr>
<td>Graphite</td>
<td>layer structure involving trigonal (triangular) planar carbons / with each carbon atom joined to three others / with hexagonal (six-membered) rings of carbon atoms;</td>
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</tbody>
</table>
| $C_{60}$ fullerene | truncated icosahedrons;  
**Accept carbon atoms form a ‘ball’ with 32 faces, of which 12 are pentagons and 20 are hexagons, exactly like a soccer ball.**  
**Do not accept soccer ball alone.** |

(ii) Diamond: covalent bonds (only);  
Graphite: covalent bonds **and** the separated layers held together by (weak) London / van der Waals / dispersion forces;  

[3]  

[2]
7. (a) less product is present at higher temperatures; Therefore the forward reaction is exothermic; [2]

(b) (i) \( K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]} \) (ignore units); [1]

(ii) Increasing the pressure:
Yield increases / equilibrium moves to the right / more ammonia;
4 gas molecules \( \rightarrow \) 2 / decrease in volume / fewer gas molecules on right hand side;

Increasing the temperature:
Yield decreases / equilibrium moves to the left / less ammonia;
Exothermic reaction / OWTTE; [4]

(iii) Higher temperature increases rate;
Lower pressure is less expensive / lower cost of operating at low pressure /
reinforced pipes not needed;
Do not award a mark just for the word “compromise”.

(iv) 2.2 (dm³);
Penalize incorrect units. [1]

(v) Fertilizers / increasing crop yields;
Production of explosives for mining; [1 max]

(vi) Fe/iron;
Allow magnetite/iron oxide.
Claim is not valid since catalysts do not alter the yield/position of equilibrium /
only increase the rate of reaction; [2]

(c) Electrical conductivity:
Bonding electrons are delocalised;
Current flow occurs without displacement of atoms within the metal / able to flow within the metal;

Malleability:
Can be hammered into thin sheets;
atoms capable of slipping with respect to one another; [4]

(d) Oxides of: Na and Mg are basic;
Al is amphoteric;
Si to Cl are acidic;
Ar has no oxide;
All four correct award [2], two or three correct award [1].
\( \text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH} \) and \( \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \);

Must be balanced for mark.
Award marks for alternative correct equations such as \( \text{SO}_3 \) with \( \text{NaOH} \). [3]
8. (a) (i) (Empirical formula =) C₆H₄O₅;

Allow double bonds on arene in alternate positions, or allow delocalized representation (of pi electrons).

(ii) the bond at 0.1373 nm is a double bond and the bond at 0.1424 nm is a single bond; in CO₂ (g) both bonds are double bonds and would have a value around 0.137 nm;

(iii) Ester;
Arene / benzene ring;
Alcohol;
Do not accept alkane as a type of functional group in this molecule.

(b) (i) boiling point increases as the number of carbons increases / OWTTE;
Greater Mₘ and hence greater van der Waals'/London/Dispersion forces present;

(ii) \( \text{CH}_4 + \text{Cl}_2 \xrightarrow{\text{hv/UV light}} \text{CH}_3\text{Cl} + \text{HCl} \);
Do not award mark if hv/uv light is not given.

Initiation step:
\( \text{Cl}_2 \xrightarrow{\text{hv/UV light}} 2\text{Cl}^- \);
Do not award mark if hv/uv light is not given.
Penalize once only.

Propagation step:
\( \text{CH}_4 + \text{Cl}^- \rightarrow \text{CH}_3^- + \text{HCl} \);
\( \text{CH}_3^- + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}^- \);

Termination step:
\( \text{Cl}^- + \text{Cl}^- \rightarrow \text{Cl}_2 \) or \( \text{Cl}^- + \text{CH}_3^- \rightarrow \text{CH}_3\text{Cl} \) or \( \text{CH}_3^- + \text{CH}_3^- \rightarrow \text{CH}_3\text{CH}_3 \);
Allow fish-hook half-arrow representations i.e. use of \( \sim \).
Penalize use of full curly arrows once only.
Penalize missing dots on radicals once only.
(c) (i)

A. $= \text{CH}_3(\text{CH}_2)_2\text{CHO}$;
B. $= \text{CH}_3(\text{CH}_2)_2\text{COOH} / \text{CH}_3(\text{CH}_2)_2\text{CO}_2\text{H}$;
C. $= (\text{CH}_3)_2\text{COH}$;
D. $= (\text{CH}_3)_2\text{CO}$;
E. $= \text{BrCH}_2\text{CH}_2\text{Br}$;

Allow correct structural formulas.

(ii) addition;

\[
\begin{array}{ccccccc}
\text{C} & - & \text{C} & - & \text{C} & - & \text{C} \\
\text{H} & | & \text{H} & | & \text{H} & | & \text{H} \\
\text{H} & | & \text{H} & | & \text{H} & | & \text{H} \\
\end{array}
\]

\[
/ (\text{CH}_2\cdot\text{CH}_2)_3 \ - / \ (\text{CH}_2)_6 \ - \\
\text{H} & | & \text{H} & | & \text{H} & | & \text{H} & | & \text{H} \\
\text{H} & | & \text{H} & | & \text{H} & | & \text{H} & | & \text{H} \\
\]

[5]