Read the Following Carefully

1. This exam has 14 pages. Question are on pages 2 through 13 and a periodic table is on page 14. Ensure that all pages for the examination paper are present.

2. A sheet containing the periodic table, physical constants and some equations which may be useful to you are provided. The periodic table sheet is the last page of the exam paper and should be detached for easier use.

3. Read each question carefully and answer each question in the space provided.

4. Show all relevant calculations.

5. Numerical answers should be reported to the appropriate number of significant digits and MUST include the correct units.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Points</th>
<th>Grade</th>
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<tbody>
<tr>
<td>1-2</td>
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1. The figure below shows a vessel in which three chambers all have equal volumes and all are at the same temperature. Each chamber contains an ideal gas with molar amounts proportional to the number of atoms or molecules.

![Diagram of three connected vessels with chambers A, B, and C]

a) Which one has the highest pressure? Explain your answer in terms of the kinetic molecular theory! (1 mark)

b) If the pressure of container B is 1.50 bar, what is the pressure in container C? (2 marks)

c) If the pressure of container B is 1.50 bar, what is the total pressure in the containers if the stopcocks separating each of the containers is opened so that the gases mix. (2 marks)

2. Calcium carbide (CaC₂) is used in many industrial applications such as the production of acetylene, fertilizer, and steel. It is formed along with CO, a poisonous gaseous by-product, in an electric arc furnace according to the following reaction:

\[
\text{CaO}(s) + 3 \text{C}(s) \rightarrow \text{CaC}_2(s) + \text{CO}(g)
\]

If 100.0 g of solid carbon is reacted with an unlimited supply of CaO, what volume of CO is formed at 298 K and 1.02 bar pressure? (4 marks)
3. Charles’s Law states that the volume of a gas is proportional to the temperature of the gas. Explain Charles’s Law in terms of the kinetic molecular theory. (2 marks)

4. Below is a plot showing the distribution of molecular speeds for N₂ at 300 K.

![Graph showing the distribution of molecular speeds for N₂ at 300 K.]

On this plot, sketch the distribution for Cl₂ at 300 K and the one for N₂ at 500 K. (2 marks)

5. A 29.8 g steel spoon at 18.5 °C is dipped into 180. g of hot coffee at 90.3 °C. Assuming that coffee has the same heat capacity as water and the heat capacity of steel is 0.420 J g⁻¹ °C⁻¹ what is the final temperature of the spoon and coffee? (4 marks)
6. Palmitic acid is the main component of body fat and burns according to the following balanced chemical reaction.

\[
\text{C}_{16}\text{H}_{32}\text{O}_2(s) + 23 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 16 \text{H}_2\text{O}(l)
\]

In a bomb calorimetry experiment 0.7081 g of palmitic acid (molar mass = 256.42 g mol\(^{-1}\)) was combusted in a bomb calorimeter with a heat capacity of 10.26 kJ °C\(^{-1}\). The temperature of the calorimeter was observed to rise by 2.599 °C. Determine the \(\Delta_r U^o\) and \(\Delta_r H^o\) (at 298 K) for the combustion of palmitic acid. (**5 marks**)

7. The heats of formation for the reactants and products in the combustion of palmitic acid are provided below.

\[
\text{C}_{16}\text{H}_{32}\text{O}_2(s) + 23 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 16 \text{H}_2\text{O}(l)
\]

\[
\Delta_r H^o / \text{kJ mol}^{-1} = \begin{cases} -892 & \text{for } \text{C}_{16}\text{H}_{32}\text{O}_2(s) \\ -393.5 & \text{for } 23 \text{O}_2(g) \\ -285.8 & \text{for } 16 \text{H}_2\text{O}(l) \end{cases}
\]

Compute \(\Delta_r H^o\) for the combustion of palmitic acid. (**3 marks**)
The structures of the reactants and products for the combustion of butanoic acid are provided below the equation.

\[
\text{C}_4\text{H}_8\text{O}_2(\text{s}) + 5 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{l})
\]

Use the bond energies below to estimate \(\Delta H^\circ\). (3 marks)
9. State whether you think each of the following processes are exothermic or endothermic. (4 marks)

\[ 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(s) + 6 \text{O}_2(g) \]

\[ \text{Cu}(s) \rightarrow \text{Cu}(l) \]

\[ \text{Cl}(g) + e^- \rightarrow \text{Cl}^-(g) \]

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

\[ 2 \text{F}(g) \rightarrow \text{F}_2(g) \]

\[ \text{O}^-(g) + e^- \rightarrow \text{O}^{2-}(g) \]

\[ \text{O}(g) \rightarrow \text{O}^+(g) + e^- \]

\[ \text{K}^-(g) + \text{Cl}^-(g) \rightarrow \text{KCl}(s) \]

10. Below is a plot of the total radial probability diagram for a 1s orbital.

   a) On the same plot, sketch the total radial probabilities for the 2s and the 2p orbitals (2 marks).

   ![Graph of total radial probability diagram for a 1s orbital]

   b) Explain briefly why the 2s orbital is lower in energy than the 2p orbital. For example, why is the electron configuration of \( \text{Li} \) 1s\(^2\)2s\(^1\) rather than 1s\(^2\)2p\(^1\)? (1 mark)

11. Write the condensed ground state electron configurations for the following. (6 marks)

   S : 
   Cu : 
   Zn\(^{2+}\) : 
   Br : 
   Bi (element 83) : 
   Sb\(^{3+}\) :
12. How many electrons have the following sets of quantum numbers: \(2\) marks
   a) \(n = 3\) __________
   b) \(n = 3, \ell = 1\) __________
   c) \(n = 3, \ell = 1, m_\ell = 1\) __________
   d) \(n = 3, \ell = 1, m_\ell = 1, m_s = \frac{1}{2}\) __________

13. a) Circle the largest atom in the following pairs: \(1\) mark
     Na or S
     Mg or Ca

b) In the following pairs, circle the atom with largest first ionization energy \(1\) mark
     Na or Mg
     Mg or Ca

c) In the following pairs, circle the ionic compound with the highest melting point. \(1\) mark
     NaCl or MgCl\(_2\)
     NaCl or NaBr

14. Below are the reactions of two different alkali metal with water:
   \[
   \begin{align*}
   2 \text{Li}(s) + 2 \text{H}_2\text{O}(l) & \rightarrow 2 \text{LiOH}(aq) + \text{H}_2(g) \\
   2 \text{K}(s) + 2 \text{H}_2\text{O}(l) & \rightarrow 2 \text{KOH}(aq) + \text{H}_2(g)
   \end{align*}
   \]

   The reaction with potassium (K) is significantly more vigorous than the reaction with lithium (Li).
   Using periodic trends, explain this observation. \(2\) marks

15. The first ionization energy of nitrogen (N) is 1402 kJ mol\(^{-1}\) and that of oxygen (O) is 1319 kJ mol\(^{-1}\) despite the general trend for ionization energies to increase going from left to right across the periodic table. Use the electron configurations for N and O to explain why O has the lower ionization energy. \(2\) marks

16. Will the ionization energy of a hydrogen atom where the electron is in the \(n=2\) excited state be greater or less than the ionization energy from the ground state? Use diagrams or equations to support your answer. \(2\) marks
17. a) Below is the skeletal structure for proline, C₅H₈NO₂, one of the 20 proteinogenic amino acids. Complete the Lewis structure for proline by placing lone pairs and multiple bonds where required. (2 marks)

b) For the N atom in proline, what is the electron group geometry, shape, and hybridization? (1.5 marks)

  electron group geometry_______________________
  shape __________________________
  hybridization ________________________

c) For the C atom that is attached to two oxygen atoms in proline, what is the electron group geometry, shape, and hybridization? (1.5 marks)

  electron group geometry_______________________
  shape __________________________
  hybridization ________________________

18. a) Draw the Lewis structure for XeF₄. (2 marks) b) Draw and name the shape of XeF₄. (2 mark)

b) State whether XeF₄ is polar or non-polar and state the dominant intermolecular forces between molecules of XeF₄. (2 marks)
19. To the right is a Lewis structure for fluoroethene. Use Valence Bond and Orbital Hybridization Theories to describe the bonding in fluoroethene. Your answer should show the following steps. (5 marks)

i) Using the Lewis structure of fluoroethene and VSEPR theory, predict the shape around each of the C atoms.

ii) What is the hybridization of each C?

iii) Provide a sketch, illustrating and labelling the types of all the bonds in the molecule, sigma (σ) or pi (π), and the atomic and/or hybrid orbitals that overlap to form these bonds.

20. a) Draw the molecular orbital diagram for the H₂ molecule. Don’t forget to label the atomic and molecular orbitals and populate the MOs with the correct number of electrons. (2 marks)

b) What is the bond order for H₂? (1 mark) ______________

c) What is the bond order for H₂⁺? (1 mark) ______________
21. a) Define the term “excited state.” (1 mark)

b) Draw the molecular orbital diagram for an excited state of H₂ and determine the bond order. (1 mark)

22. Sketch and correctly label the orbitals indicated below showing the phases (+ or -) and the position of the nucleus (or nuclei).

a) any d orbital (1 mark).

b) the \( \sigma_{2p} \) and \( \sigma_{2p}^{*} \) molecular orbitals (2 marks)

![Diagram of \( \sigma_{2p} \) and \( \sigma_{2p}^{*} \) molecular orbitals]


c) the \( \pi_{2p} \) and \( \pi_{2p}^{*} \) molecular orbitals (2 marks)

![Diagram of \( \pi_{2p} \) and \( \pi_{2p}^{*} \) molecular orbitals]
23. For the following pairs of compounds, circle the one with the highest boiling point. Briefly explain your choice. (5 marks)

a) CH₃─SH or CH₃─SeH

b) CH₃─CH₂─CH₂─CH₂―CH₃ or CH₃―CH―CH₃

c) H₂C=C=O or CH₃―O―CH₃

d) CH₃―CH₂―NH₂ or CH₃―N―CH₃

e) HCl or NaCl

24. The heats of vaporization and fusion for water are 40.7 and 6.02 kJ mol⁻¹. Briefly explain why the heat of vaporization is so much higher than the heat of fusion of a substance. (2 marks)

25. Which of the following solutes (propanol) CH₃CH₂CH₂OH or pentanol (CH₃CH₂CH₂CH₂CH₂OH) would you expect to be more soluble in water? Explain your answer in terms of intermolecular forces within the pure solutes and within pure water, as well as between the solutes and water in the mixture. (2 marks)
26. In an experiment designed to determine the heat of vaporization of carbon tetrachloride (CCl₄), the vapour pressure of CCl₄ was found to be 213 Torr at 40.1 °C and its normal boiling point (at 760 Torr) was found to be 76.7 °C. Calculate \( \Delta_{vap} H^0 \). (4 marks)

27. a) The vapour pressure of water at 70.0 °C is 31.2 kPa. What is the vapour pressure of a solution containing 200 g of water and 25 g of urea (\( \text{CH}_4\text{N}_2\text{O}_2 \), MM = 60.06 g mol\(^{-1}\)?) (3 marks)

b) How would the vapour pressure change if, instead of urea, the same number of moles of CaCl₂ were added to the same amount of water in part a)? Be specific and provide a brief explanation of your answer. (2 marks)
28. Hemoglobin is a globular iron containing protein responsible for the transport of oxygen in the body. In an experiment, 0.5515 g of hemoglobin was dissolved in 100.00 mL of solution at 25.0 °C. The osmotic pressure was measured to be 1.985 x 10^{-3} bar. Determine the molar mass of hemoglobin. (3 marks)
**PERIODIC TABLE OF THE ELEMENTS**

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<th>Element</th>
<th>Atomic Number</th>
<th>Atomic Mass</th>
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<tr>
<td><strong>2</strong> He</td>
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### Some Useful Constants

<table>
<thead>
<tr>
<th>Quantity and Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>( \Delta H_{\text{f, liquid}} )</td>
<td>( \text{H}_2\text{O(s)} \text{ at } 273 \text{ K} ) ( 6.01 \text{ kJ mol}^{-1} )</td>
</tr>
<tr>
<td>( \Delta H_{\text{vap, liquid}} )</td>
<td>( \text{H}_2\text{O(l)} \text{ at } 373 \text{ K} ) ( 40.7 \text{ kJ mol}^{-1} )</td>
</tr>
<tr>
<td>Specific Heat Capacity of ( \text{H}_2\text{O(l)} ) at 0°C</td>
<td>4.184 J g(^{-1}) K(^{-1})</td>
</tr>
<tr>
<td>Specific Heat Capacity of ( \text{H}_2\text{O(s)} ) at 0°C</td>
<td>4.184 J g(^{-1}) K(^{-1})</td>
</tr>
<tr>
<td>Avogadro Constant, ( N_A )</td>
<td>( 6.022 \times 10^{23} \text{ mol}^{-1} )</td>
</tr>
<tr>
<td>Ideal Gas Constant, ( R )</td>
<td>8.314 L kPa mol(^{-1}) K(^{-1})</td>
</tr>
</tbody>
</table>

### Conversion Factors

- 1 bar = 100 kPa = 101.325 kPa = 101.325 N m\(^{-2}\) = 101.325 dyn cm\(^{-2}\) = 101.325 Pa = 100000 dyne cm\(^{-2}\) = 100000 Pascal = 101.325 hectopascals
- 1 cal = 4.184 J = 1000 ergs
- 1 L = 1 dm\(^3\) (exactly) = 1000 cm\(^3\)
- 1 bar = 10 mmHg = 10 torr = 0.9869 atm
- 1 kg = 1000 g

### Some Useful Formulas

\[
\nu_{\text{rms}} = \sqrt{\frac{3RT}{M}} \quad \text{and} \quad \nu_{\text{rms}} = \sqrt[3]{\frac{3RT}{\text{mol}}}
\]

\[
E_n = -2.179 \times 10^{-18} \frac{Z^2}{n^2}
\]

\[
r_n = \frac{n^2 a_o}{Z^2}
\]

\[
PV = nRT \quad e_n = \frac{1}{2} \text{mv}^2 \quad \lambda \nu = c \quad C = k_i P_{\text{gas}} \text{ or } k_T P_{\text{gas}}
\]

\[
\lambda = \frac{h}{m v} \quad \Delta E(J) = -Z^2 \times 2.179 \times 10^{-18} \left( \frac{1}{n^2} - \frac{1}{n^2} \right)
\]

\[
\Delta U = q + w \quad \pi = iCRT \text{ or } iMRT
\]

\[
\Delta H = \Delta U + RT \Delta n_{\text{gases}} \quad \Delta T_r = iK_m \quad \Delta T_b = iK_f m \quad P_a = x_a P_{\text{gas}}^a
\]

\[
\Delta H^0 = \sum v_i \lambda_i H^0 \text{ (products)} - \sum v_i \lambda_i H^0 \text{ (reactants)} \quad P_{\text{tot}} = x_a P_{\text{gas}}^a + x_b P_{\text{gas}}^b \text{ (mixture of volatile liquids)}
\]