Please answer each of the following questions to the best of your ability. If you wish to receive partial credit, please show your work. For multiple choice, there is no partial credit (unless otherwise noted) and there is only one correct answer. For multiple choice, please clearly mark the correct answer. For all ionic species, please show the charge on each ion to receive full credit.

<table>
<thead>
<tr>
<th>Element</th>
<th>Electronegativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>4.0</td>
</tr>
<tr>
<td>O</td>
<td>3.5</td>
</tr>
<tr>
<td>Cl</td>
<td>3.0</td>
</tr>
<tr>
<td>N</td>
<td>3.0</td>
</tr>
<tr>
<td>S</td>
<td>2.8</td>
</tr>
<tr>
<td>Br</td>
<td>2.8</td>
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<tr>
<td>C</td>
<td>2.5</td>
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<tr>
<td>H</td>
<td>2.1</td>
</tr>
</tbody>
</table>

1. Multiple choice are four points each unless otherwise noted.

1. Which of the following reactions is a crystal lattice energy reaction for magnesium chloride, MgCl₂?
   A. Mg(s) + Cl₂(g) → MgCl₂(s)
   B. Mg(g) + 2 Cl(g) → MgCl₂(g)
   C. Mg²⁺(g) + 2 Cl⁻(g) → MgCl₂(s)
   D. Mg(g) + 2 e⁻ → Mg²⁺(g)

2. Place the following in order of increasing magnitude of lattice energy.

A. LiBr < NaBr < CaO
   B. CaO < NaBr < LiBr
   C. NaBr < LiBr < CaO
   D. CaO < LiBr < NaBr
   E. LiBr < CaO < NaBr
   F. NaBr < CaO < LiBr

3. Determine the electron geometry of XeO₃.
   A. Linear
   B. Trigonal planar
   C. Tetrahedral
   D. Trigonal bipyramidal
   E. Octahedral

4. Of the following bonds between the same two atoms, a _____ bond is the longest and a _____ bond is the strongest.
   A. triple, triple
   B. triple, single
   C. single, single
   D. double, triple

5. Which one of the following statements is FALSE?
   A. A covalent bond involves the transfer of one or more electrons from one atom to another.
   B. A dipole is a partial permanent separation of charge.
   C. A CF₄ molecule is a nonpolar molecule made from polar bonds.
   D. A helium atom is nonpolar.
6. How many of the following elements can form compounds with an expanded octet?

   A. 0  ✓   O  X  Cl   ✓  Xe  ✓
   B. 1
   C. 2
   D. 3
   E. 4

7. Describe a pi bond.
   A. side by side overlap of p orbitals above and below the line connecting the two nuclei
   B. end to end overlap of p orbitals along the axis connecting the two nuclei
   C. s orbital overlapping with the end of a p orbital along the axis connecting the two nuclei
   D. overlap of two s orbitals along the axis connecting the two nuclei

8. A molecule containing a central atom with sp\(^3\)d hybridization has a(n) _______ electron geometry.
   A. linear
   B. trigonal bipyramidal
   C. octahedral
   D. tetrahedral
   E. bent

II. Free Response
1. (20 points) For each of the following pairs of molecules, list the dominant IMF for each molecule (2 points each) and circle the molecule with the higher boiling point (1 point each, only awarded if your answer is correct and both dominant IMFs are correct):

   A. \( \text{Cl}_2 \)
   LDF
   B. \( \text{Br}_2 \)
   LDF
   C. \( \text{CH}_4 \)
   LDF
   D. \( \text{NH}_3 \)
   LDF
   E. \( \text{HF} \)
   LDF
   F. \( \text{PF}_3 \)
   LDF
   G. \( \text{BrF}_3 \)
   LDF
   H. \( \text{F}_2 \)
   LDF
   I. \( \text{F}_2 \)
   LDF
   J. \( \text{F}_2 \)
   LDF
   K. \( \text{F}_2 \)
   LDF
   L. \( \text{F}_2 \)
   LDF
   M. \( \text{F}_2 \)
   LDF
   N. \( \text{F}_2 \)
   LDF
   O. \( \text{F}_2 \)
   LDF
   P. \( \text{F}_2 \)
   LDF
   Q. \( \text{F}_2 \)
   LDF

   32 poin.
   354
2. The two molecules below are structural isomers, meaning that they have the same chemical formula but different arrangement (different bonding) of atoms.

A. (10 points) Calculate $\Delta H_{\text{rxn}}$ for this reaction using bond dissociation energies.

\[
\begin{align*}
\text{Reactants:} & \\
\text{H}_3C\text{C}_2\text{O}_\text{CH}_3 & \rightarrow \\
\text{H}_3C\text{C}_3\text{O}_\text{H} \\
\text{8 C-H} & = 8 \times 414 \\
\text{1 C-C} & = 1 \times 347 \\
\text{2 C-O} & = 2 \times 360 \\
\text{Total} & = 4379 \\
\text{Products:} & \\
\text{H}_3C\text{C}_3\text{O}_\text{H} & \\
\text{7 C-H} & = 7 \times (-414) \\
\text{2 C-C} & = 2 \times (-347) \\
\text{1 C-O} & = 1 \times (-360) \\
\text{1 O-H} & = 1 \times (-464) \\
\text{Total} & = -4416 \\
\end{align*}
\]

\[\Delta H_{\text{rxn}} = \text{Energy to break reactant bonds} + \text{Energy to make product bonds} = 4379 + (-4416) = -37 \text{ kJ/mol}\]

B. (6 points) Complete the Reaction Energy Diagram for the reaction in A by adding the reactants, products, and $\Delta H_{\text{rxn}}$.

\[\text{Potential Energy} \quad \Delta H_{\text{rxn}} = -37 \text{ kJ/mol} \quad \text{Reaction Progress}\]
3. Provide the listed information for each molecule or ion. Remember, Lewis structures must show all atoms, all bonds, and all nonbonding electron pairs. When you draw the shape, you don’t have to draw all nonbonding electron pairs.

A. \( \text{O}_3 \) –1e⁻

i. (6 points) Best Lewis Structure (label each atom with a nonzero formal charge)

\[ \text{O} = \text{O} - \text{O} \]

ii. (2 points) Electron geometry

trigonal planar

iii. (4 points) Draw one resonance structure that is different than your answer to i above

\[ \text{O} = \text{O} - \text{O} \]

B. \( \text{SO}_4^{2-} \) (sulfate ion)

i. (6 points) Best Lewis Structure (label each atom with a nonzero formal charge)

\[
\text{S} \quad \text{O} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{S} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{O} \
\]

ii. (2 points) Hybridization of central sulfur

tetrahedral

iii. (4 points) Draw the correct shape

\[
\text{S} \quad \text{O} \\
\text{O} \\
\text{O} \\
\text{O}
\]
4. For water:
   A. (8 points) Draw a heating curve for water with "Heat Added" on the x-axis and "Temperature" on the y-axis. Label the regions according to their phases (solid, liquid, and gas) and phase transitions (solid to liquid and liquid to gas).

   B. (10 points) How much energy is released when 37.7 g H₂O(g) are cooled from 110°C to a liquid at 42.0°C? (10 points)

   \[ q_1 = m \cdot C_p \cdot \Delta T = (37.7 \text{ g} \text{ H}_2\text{O})(2.03 \text{ J/g} \cdot \text{°C})(100 \text{ °C} - 110 \text{ °C}) = -765 \text{ J} \]

   \[ q_2 = -\Delta H_{vap} \text{ (mol)} = (-40,700 \text{ J/mol}) (2.09 \text{ mol H}_2\text{O}) = -85,063 \text{ J} \]

   \[ q_3 = m \cdot C_p \cdot \Delta T = (37.7 \text{ g} \text{ H}_2\text{O})(4.184 \text{ J/g} \cdot \text{°C})(42 - 100 \text{ °C}) = -9149 \text{ J} \]

   \[ q_1 + q_2 + q_3 = -94977 \text{ J} = -9.50 \times 10^4 \text{ J} = -95.0 \text{ kJ} \]

   \[ \frac{37.7 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = \frac{18.02 \text{ g H}_2\text{O}}{2.09 \text{ mol H}_2\text{O}} = 2.09 \text{ mol H}_2\text{O} \]
5. The molecular orbital energy diagram for the valence orbitals of the NO molecule and the NO⁻ ion is shown below. Use this diagram to answer the following questions.

A. (6 points) Fill in all of the electrons for the NO molecule in the diagram below.

B. (3 points) What is the bond order in NO?

\[ BO = \frac{8 - 3}{2} = 2.5 \]

C. (3 points) What is the bond order in NO⁻?

\[ BO = \frac{8 - 4}{2} = 2 \]

D. (3 points) Is NO⁻ diamagnetic, or is it paramagnetic?

Paramagnetic w/ 2 unpaired e⁻

E. (3 points) Which has the larger bond distance, NO or NO⁻?

Smaller BO = NO⁻
6. Shown below is a graph of Boiling Point Vs. Molar Mass for four covalently-bonded compounds in which the central atom is in the same group of the periodic table.

A. (4 points) Suggest a reason involving intermolecular forces why the boiling point of H$_2$O is so much higher than the boiling point of the other three compounds.

H$_2$O has hydrogen bonding as its dominant IMF.
The others have dipole-dipole as their dominant IMF.

B. (4 points) From H$_2$S to H$_2$Se to H$_2$Te, would you expect the dipole-dipole forces to increase or decrease? Why?

H$_2$S Based on the difference in EN being larger for H$_2$S 2.1 2.8 than H$_2$Se and H$_2$Te, I would expect the dipole-dipole forces to decrease. H$_2$Te has the most molar mass.

C. (4 points) From H$_2$S to H$_2$Se to H$_2$Te, would you expect the dispersion forces to increase or decrease? Why?

7. (8 points) The standard state of phosphorus at 25°C is P$_4$. This molecule has 4 equivalent P atoms, no double or triple bonds, and no expanded octets. Draw its Lewis Structure. Label any atoms with nonzero formal charge. (Partial credit will be given for Lewis Structures that obey the octet rule but are not the correct answer.)

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\[
\begin{align*}
\text{P} & \quad \text{P} \\
\text{P} & \quad \text{P}
\end{align*}
\]
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