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>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
</tr>
<tr>
<td>H</td>
<td>2.1</td>
</tr>
</tbody>
</table>

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

1) Which of the following statements is TRUE?
   A) Vapor pressure increases with temperature.
   B) Hydrogen bonds are stronger than covalent bonds.
   C) Intermolecular forces hold the atoms in molecules together.
   D) Dispersion forces are generally stronger than dipole-dipole forces.

2) In liquid propanol, CH₃CH₂CH₂OH, which intermolecular forces are present?
   A) Dispersion, hydrogen bonding and dipole-dipole forces are present.
   B) Only dipole-dipole and ion-dipole forces are present.
   C) Only dispersion and dipole-dipole forces are present.
   D) Only hydrogen bonding forces are present.
   
3) Determine the electron geometry and of NCl₃.
   A) tetrahedral
   B) linear
   C) trigonal planar
   D) linear
   E) tetrahedral

4) Which one of the following statements is FALSE?
   A) The most stable Lewis structure has the least amount of formal charge possible.
   B) If there is a negative formal charge, it is most stable on the most electronegative atom
   C) An expanded octet can be used to minimize the formal charge for oxygen.
   D) The formal charge on carbon in CH₄ is zero.

5. Which of the Lewis structures has the longest carbon-oxygen bond?
   A) \( :\overset{\cdot}{C}=\overset{\cdot}{O} : \)
   B) \( \overset{\cdot}{O}=C=\overset{\cdot}{O} : \)
   C) \( \left[ \begin{array}{c} \overset{\cdot}{O} \\ \overset{\cdot}{O} \end{array} \right] _{2^-} \)
   D) \( \overset{\cdot}{O}-C-OH \)
6. Which of the following statements concerning the molecular orbital energy level diagrams for first and second period homonuclear diatomic molecules is FALSE?
   A) The two \( \pi_{2p} \) orbitals have the same energy.
   B) The two \( \pi^*_{2p} \) orbitals have the same energy.
   C) The diagram for \( \text{Be}_2, \text{B}_2, \text{C}_2 \), and \( \text{N}_2 \) molecules has the two \( \pi_{2p} \) orbitals at a lower energy than the \( \sigma_{2p} \) orbital.
   D) The diagram for \( \text{O}_2, \text{F}_2 \), and \( \text{Ne}_2 \) molecules has the \( \sigma^*_{2p} \) orbital at a lower energy than the two \( \pi^*_{2p} \) orbitals.
   E) The bonding orbitals always have lower energy than the antibonding orbitals formed from the same set of atomic orbitals.

7. Electronegativity is a measure of
   A) the charge on an electron.
   B) a molecule’s polarity.
   C) the charge on an atom.
   D) the number of extra electrons on an anion.
   E) an atom’s ability to attract bonding electrons to itself.

8. The lattice energy for ionic crystals increases as the product of the charges on the ions ______________ and the size of the ions ______________.
   A) increases, increases
   B) increases, decreases
   C) decreases, increases
   D) decreases, decreases
   E) none of these is generally correct

II. Drawing Section
1. (12 points) Draw the best Lewis Structure for \( \text{CH}_2\text{F}_2 \). Note any atoms with nonzero formal charges.

   \[
   \begin{array}{c}
   \text{H} \quad \text{F} - \text{C} - \text{F} \\
   \text{H}
   \end{array}
   \]

   B. Draw the correct geometry for \( \text{CH}_2\text{F}_2 \). Also draw dipole arrows for any dipoles in the molecule.

   \[
   \begin{array}{c}
   \text{H} \\
   \text{F} - \text{C} - \text{F} \\
   \text{H}
   \end{array}
   \]

   C. What is the hybridization of carbon in \( \text{CH}_2\text{F}_2 \)?

   \[
   \text{sp}^3
   \]
2. (14 points) Draw the best Lewis Structure for SO$_3^{2-}$. Note any atoms with nonzero formal charges.

\[
\begin{array}{c}
\text{O} \quad \text{S} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O}
\end{array}
\]

B. Draw all resonance structures for SO$_3^{2-}$:

\[
\begin{array}{c}
\text{O} \quad \text{S} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O}
\end{array} \leftrightarrow \begin{array}{c}
\text{O} \quad \text{S} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O}
\end{array} \leftrightarrow \begin{array}{c}
\text{O} \quad \text{S} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O}
\end{array}
\]

C. What is the bond angle between O-S-O atoms in SO$_3^{2-}$?

\[\angle 109.5^\circ\]

3. (10 points) According to molecular orbital theory when two atoms come together to form a diatomic molecule, the molecular orbitals from due to the constructive interference (bonding) and destructive interference (antibonding) of the atomic orbitals.

Draw the $\sigma_\text{xy}$ bonding molecular orbital and one of the $\pi_{2p}$ bonding molecular orbitals for C$_2$. Just to be clear, I am NOT asking for a molecular orbital energy diagram (with the arrow for energy). Make sure that your picture labels where the nuclei are for each orbital that you draw.
4. (8 points) Below is methyl methacrylate. Draw as many hydrogen bonds as possible that this molecule can have with water.

III. Free Response
1. (18 points) The following is a Born-Haber cycle for Na₂O. Please fill in all of the blank areas as appropriate. Then determine the value of the crystal lattice energy for Na₂O.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔH value (kJ/mol)</th>
<th>Name of Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(s) → Na(g)</td>
<td>109</td>
<td>Sublimation of sodium</td>
</tr>
<tr>
<td>Na(g) → Na⁺(g) + e⁻</td>
<td>495</td>
<td>1st IE of Na⁺</td>
</tr>
<tr>
<td>O₂(g) → 2 O(g)</td>
<td>498</td>
<td>Bond Dissociation of O₂</td>
</tr>
<tr>
<td>O(g) + e⁻ → O⁺(g)</td>
<td>-141</td>
<td>Electron Affinity 1 of Oxygen</td>
</tr>
<tr>
<td>O⁺(g) + e⁻ → O²⁻(g)</td>
<td>770</td>
<td>Electron Affinity 2 of Oxygen</td>
</tr>
<tr>
<td>2Na⁺(g) + O²⁻(g) → Na₂O(s)</td>
<td>-2502</td>
<td>Crystal Lattice Energy of Na₂O</td>
</tr>
<tr>
<td>2 Na(s) + ½ O₂(g) → Na₂O(s)</td>
<td>-416</td>
<td>Standard Enthalpy of formation of Na₂O(s)</td>
</tr>
</tbody>
</table>

\[ 2 \times (109) + 2 \times (495) + \frac{1}{2} \times (498) + (-141) + 770 + x = -416 \]
\[ 2086 + x = -416 \]
\[ x = -2502 \]
2. (20 points) For each of the following pairs of molecules, list the dominant IMF for each molecule (2 point each) and circle the one with the higher boiling point (1 point each, only awarded if your answer is correct and both dominant IMFs are correct):

A. (H₂O) Kr
   hydrogen LDF

B. CH₄ CF₄ (because of higher molar mass)
   LDF LDF

C. (NaCl) HCl
   ion-ion dipole-dipole

D. hydrogen
   H-C-C-O-H H-C-O-C-H
dipole-dipole

3. (4 points) Explain why the lattice energy of MgS is approximately 4 times as large as that of NaCl. Use at least two numbers in your answer.

MgS has a product charge of 4, whereas NaCl only has a product charge of 1. Therefore, the lattice energy of MgS will be 4 times as large as NaCl's lattice energy.
4. (12 points) How much energy is required to heat 87.1 g acetone (molar mass=58.08 g/mol) from a solid at -154.0°C to a liquid at -42.0°C? The following physical data may be useful. (10 points)

\[ \Delta H_{\text{fus}} = 7.27 \text{ kJ/mol} \]
\[ C_{\text{liq}} = 2.16 \text{ J/(g°C)} \]
\[ C_{\text{gas}} = 1.29 \text{ J/(g°C)} \]
\[ C_{\text{sol}} = 1.65 \text{ J/(g°C)} \]
\[ T_{\text{melting}} = -95.0°C \]

![Diagram showing the phase transitions and temperature changes](image)

\[ q_{\text{sol}} = m C_{\text{sol}} \Delta T \]
\[ q_{\text{fus}} = \Delta H_{\text{fus}} (\text{mol}) \]
\[ q_{\text{1, q}} = m C_{\text{liq}} \Delta T \]

\[ q_{\text{sol}} = 87.1 \text{ g acetone} \cdot 1.65 \text{ J/(g°C)} \cdot [-95.0°C - (-154.0°C)] = 8479 \text{ J} = 8.48 \text{ kJ} \]

\[ q_{\text{fus}} = 7.27 \text{ kJ/mol} \cdot 1.50 \text{ mol} = 10.9 \text{ kJ} \]

\[ q_{\text{1, q}} = 87.1 \text{ g acetone} \cdot 2.16 \text{ J/(g°C)} \cdot [-93.0°C - (-95.0°C)] = 9971 \text{ J} = 9.97 \text{ kJ} \]

Total energy: \[ 8.48 \text{ kJ} + 10.9 \text{ kJ} + 9.97 \text{ kJ} = 29.4 \text{ kJ} \]
5. To answer the following questions, refer to the figure.

A. (4 points) Which of the substances in the figure has the highest intermolecular forces? Explain your choice. (8 points)

Ethylene glycol. Vapor pressure decreases as INE increases. At any given temperature, ethylene glycol has the lowest vapor pressure.

B. (4 points) Mt. McKinley in Alaska is 20,320 feet tall at its summit. The atmospheric pressure is 450 mm Hg at this height. What is the boiling point of ethanol at this elevation?

6. (12 points) Draw Lewis structures of each of the following reactants and products. Then, use the bond energies provided to estimate $\Delta H^{\circ}_{\text{rxn}}$ for the reaction below.

$$\text{PCl}_3(g) + \text{Cl}_2(g) \rightarrow \text{PCl}_5(l) \quad \Delta H^{\circ}_{\text{rxn}} = ?$$

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl-Cl</td>
<td>243</td>
</tr>
<tr>
<td>P-Cl</td>
<td>331</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
3 \times (243) & \quad + \quad 1 \times (243) \\
943 & \quad \rightarrow \quad 5 \times (-331) \\
943 & \quad + \quad 243 & \quad - \quad 1655 = -419 \text{ kJ/mol}
\end{align*}
\]