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 all ionic species, please show the charge on each ion to receive full credit. Good luck!

All Lewis Structures must include all valence electrons.

Background information from Wikipedia on the chemicals in the Final Exam (interesting but NOT actually useful for the exam):

**Caffeine** is a bitter, white crystalline xanthine alkaloid and a stimulant drug. Caffeine is found in varying quantities in the seeds, leaves, and fruit of some plants, where it acts as a natural pesticide that paralyzes and kills certain insects feeding on the plants, as well as enhancing the reward memory of pollinators. It is most commonly consumed by humans in infusions extracted from the seed of the coffee plant and the leaves of the tea bush, as well as from various foods and drinks containing products derived from the kola nut. Other sources include yerba maté, guarana berries, guayusa, and the yaupon holly.

**Theobromine**, formerly known as xanthine, is a bitter alkaloid of the cacao plant. It is found in chocolate, as well as in a number of other foods, including the leaves of the tea plant, and the kola (or cola) nut. It is in the methylxanthine class of chemical compounds, which also includes the similar compounds theophylline and caffeine. It does NOT contain any bromine.

**Adenosine** acts as an inhibitory neurotransmitter that suppresses activity in the central nervous system. "Largely as a consequence of its blockade of adenosine receptors, caffeine also has profound effects on most of the other major neurotransmitters, including dopamine, acetylcholine, serotonin, and, in high doses, on norepinephrine", and to a small extent epinephrine, glutamate, and cortisol.

I. Nomenclature

1. If the name is given, please give the formula. If the formula is given, please give the name. (4 points each, spelling counts)

   A. CH₃CH₂CH₃
      \text{Propane}

   B. NaCH₃COO
      \text{Sodium Acetate}

   C. CuSO₄·5H₂O
      \text{Copper (II) Sulfate Pentahydrate}

   D. H₂SO₄
      \text{Sulfuric Acid}
II. Free Response

1. Caffeine can break down in the body to form theobromine. One possible reaction for this process is pictured below.

\[
\text{caffeine} + O_2(g) \rightarrow \text{theobromine} + CO_2(g) + H_2(g)
\]

A. Can a molecule of caffeine hydrogen bond with another caffeine molecule? If so, draw two caffeine molecules with at least one hydrogen bond between them. If not, then explain why not. (6 points)

A caffeine molecule cannot hydrogen bond with another caffeine molecule because there is no O-H, F-H, or N-H bond within the molecule.

B. Can a molecule of theobromine hydrogen bond with a water molecule? If so, draw one molecule of theobromine with at least one hydrogen bond to a water molecule. If not, then explain why not. (6 points)
D. For the combustion of caffeine, calculate the change in the enthalpy of reaction, $\Delta H_{\text{rxn}}$. (16 points)

\[
\text{caffeine, } \text{C}_g\text{H}_{10}\text{N}_4\text{O}_2
\]

\[
\begin{align*}
\text{H} & - \ddot{\text{O}} - \text{H} \\
+ 9.5 \text{ O}_2(g) & \rightarrow 8 \text{ CO}_2(g) + 5 \text{ H}_2\text{O}(g) + 2 \text{ N}_2(g) \\
\end{align*}
\]

\[
\begin{align*}
\ddot{\text{O}} &= \ddot{\text{O}} \\
\ddot{\text{O}} &= \text{C} = \ddot{\text{O}} \\
\end{align*}
\]

**Bonds broken:**
- C-H (10) 414
- C-C (1) 347
- C=C (1) 611
- C-N (10) 305
- C=N (1) 615
- C=O (2) 736
- O=O (9.5) 493

**Bonds formed:**
- C=O (16) (-799)
- O-H (10) (-464)
- N=N (2) (-940)

\[
\Delta H_{\text{rxn}} = (10)(414) + 347 + 611 + (10) 305 + 615 + (2)(736) + 9.5 (493) + (16)(-799) + (10)(-464) + (2)(-940)
\]

\[
\Delta H_{\text{rxn}} = -4342 \text{ kJ/mol}
\]
2. Consider the molecule NF, which can serve as a ligand for transition metal complexes.
   A. Draw the best Lewis structure for NF. If there are any atoms with nonzero formal charges, please note these on your best Lewis structure. (6 points)

\[
\begin{array}{c}
\begin{tikzpicture}
  \node (N) at (0,0) {N};
  \node (F) at (1,1) {F};
  \draw (N) -- (F);
\end{tikzpicture}
\end{array}
\]

B. Draw an orbital overlap diagram for NF. For an orbital overlap diagram, draw and label each of the atomic orbitals (1s, 2s, 2p, etc.) involved in bonding and then label each bond as a sigma or pi bond. (8 points)

C. Draw the Molecular Orbital Energy Diagram for NF. Use the MO Energy Levels for \( \text{N}_2 \), which is pictured on one of your conversion and equation sheets. (6 points)
3. When 22.3 mL of 1.00 M AgNO₃ is mixed with 21.7 mL of 1.50 M NaCl, the temperature of the mixture rises from 21.6°C to 29.7°C. The mass of the mixture is 45.9 grams, and its specific heat is 3.94 J/g·°C.

\[
\text{AgNO}_3(\text{aq}) + \text{NaCl}(\text{aq}) \rightarrow \text{AgCl(s)} + \text{NaNO}_3(\text{aq})
\]

A. Determine the oxidation numbers of each element in each compound. Then list any elements (if any) that have been oxidized or reduced. (13 points)

<table>
<thead>
<tr>
<th>Reactant side ON:</th>
<th>Product side ON:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag: +1 Na: +1</td>
<td>Ag: +1 Na: -1</td>
</tr>
<tr>
<td>N: +5 Cl: -1</td>
<td>N: +5 Cl: -2</td>
</tr>
<tr>
<td>O: -2</td>
<td>O: -2</td>
</tr>
</tbody>
</table>

B. Calculate ΔH_rxn for the above reaction using the data in the problem statement. Show your work to receive credit. (12 points)

\[
\begin{align*}
\Delta H_{\text{rxn}} &= \Delta H_{\text{f(products)}} - \Delta H_{\text{f(reactants)}} \\
\Delta H_{\text{f(AgNO}_3)} &= \frac{1 \text{ mol}}{0.0223 \text{ L}} = 45.4 \text{ J} \\
\Delta H_{\text{f(NaCl)}} &= \frac{1 \text{ mol}}{0.0217 \text{ L}} = -1464.85 \text{ J} \\
\Delta H_{\text{rxn}} (0.0223 \text{ mol}) &= -1464.85 \text{ J} \\
\Delta H_{\text{rxn}} &= \frac{-65.7 \text{ kJ/mol}}{1 \text{ mol}}
\end{align*}
\]
4. What is the pH of a 0.0155 M solution of HCl? (4 points)

\[
pH = -\log (0.0155) = 1.81
\]

5. The laser in most red laser pointers has a wavelength of 633 nm. What are the frequency, and energy (in J/photon and kJ/mol of photons) of photons with this wavelength? (8 points)

\[
\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{633 \times 10^{-9} \text{ m}} = 4.74 \times 10^{14} \text{ s}^{-1}
\]

\[
E = h\nu = (6.626 \times 10^{-34} \text{ J s}) (4.74 \times 10^{14} \text{ s}^{-1}) = 3.14 \times 10^{-9} \text{ J/photons}
\]

\[
\frac{3.14 \times 10^{-9} \text{ J}}{6.022 \times 10^{23} \text{ photons}} = \frac{1.89 \times 10^{-19} \text{ J/photons}}{1 \text{ mol photons}} = 1.89 \times 10^{-2} \text{ kJ/mol}
\]

6. List the electron configuration using a noble gas core for the Ag^{+} ion. (6 points)

\[[\text{Kr}] 4d^{10}\]

7. Draw the distribution of kinetic energy values for a gas such as nitrogen at 300 K and 600 K. Label both axes and label each temperature. (8 points)
8. For NO$_3^-$, give the following information:

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>i. Best Lewis Structure including all bonds and lone pairs. Please note any nonzero formal charges on the Lewis structure. (6 points)</td>
<td>ii. Draw the shape of the electron geometry. <strong>Draw all dipoles.</strong> (4 points)</td>
</tr>
<tr>
<td><img src="image" alt="Lewis Structure" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td>iii. Hybridization on the N atom (2 points)</td>
<td>iv. Approximate bond angles about the N atom. Your answer must include a $&lt;$, $&gt;$, or $=$ symbol because I want you to include the effect of any electron pairs on the central atom if they are present. (2 points)</td>
</tr>
<tr>
<td>$sp^2$</td>
<td>$120^\circ$</td>
</tr>
</tbody>
</table>

9. 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):

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td><img src="image" alt="Molecule A" /> dipole-dipole</td>
<td><img src="image" alt="Molecule B" /> L.D.F.</td>
</tr>
<tr>
<td>B. MgO ion-ion forces</td>
<td>NaCl ion-ion forces</td>
</tr>
</tbody>
</table>

24 points
10. This question is about the thiocyanate ion, SCN⁻.

A. Draw two valid Lewis structures for SCN⁻ (carbon is the central atom in both structures). Explain why one of the two is better than the other. (8 points)

This structure is better because the is assigned to the more electronegative element.

B. What is the true nature of the sulfur-carbon bond and the carbon-nitrogen bond in SCN⁻? (4 points)