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!

<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>2.5</td>
</tr>
<tr>
<td>Br</td>
<td>2.8</td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
</tr>
<tr>
<td>I</td>
<td>2.1</td>
</tr>
</tbody>
</table>

All Lewis Structures must include all valence electrons.

I. Nomenclature
1. (4 points each, spelling counts) If the name is given, please give the formula. If the formula is given, please give the name.
   A. Ba(NO₃)₂
   **Barium nitrate**
   B. OF₂
   **Oxygen monofluoride**
   C. K₃PO₄
   **Potassium phosphate**
   D. NiCO₃·6H₂O
   **Nickel (II) carbonate hexahydrate**
   E. C₆H₁₂O₆
   **Copper (II) perchlorate**

II. Multiple Choice (one answer, 4 points each unless otherwise specified)
1) Calculate the molar mass of Ca₃(PO₄)₂.
   A) 87.05 g/mol  
   B) 215.21 g/mol  
   C) 310.18 g/mol  
   D) 279.21 g/mol  
   E) 246.18 g/mol

2) How many liters of a 0.0550 M KCl solution contain 0.153 moles of KCl?
   A) 3.37 L  
   B) 1.48 L  
   C) 0.97 L  
   D) 2.06 L  
   E) 1.4 L

3) A mixture of 0.220 moles CO, 0.350 moles H₂, and 0.640 moles H₂O has a total pressure of 2.95 atm. What is the pressure of H₂?
   A) 1.17 atm  
   B) 0.881 atm  
   C) 1.03 atm  
   D) 0.969 atm  
   E) 0.649 atm

\[ P_{H₂} = \chi_{H₂} \cdot P_{T} = 0.289 \text{ atm} \]
4) Which of the following substances (with specific heat capacity provided) would show the greatest temperature change upon absorbing 100.0 J of heat?
(a) 10.0 g H₂O, C₁₂H₂₂O₁₁ = 4.18 J/g°C
(b) 10.0 g C₂H₅OH, C₁₂H₂₂O₁₁ = 2.42 J/g°C
(c) 10.0 g Cu, C_Au = 0.126 J/g°C
(d) 10.0 g Cu, C_Au = 0.449 J/g°C
(e) 10.0 g Ag, C_Ag = 0.235 J/g°C

5) Calculate the enthalpy change for the reaction
\[ \text{NO}(g) + O(g) \rightarrow \text{NO}_2(g) \]
from the following data: (4 points for circling correct answer, 4 points for answer that justifies correct answer)

\[ \text{NO}(g) + O_2(g) \rightarrow \text{NO}_2(g) + O_2(g) \]
\[ \Delta H_{\text{rxn}} = -198.9 \text{ kJ/mol} \]
\[ \Delta H_{\text{no}} = -142.3 \text{ kJ/mol} \]
\[ \Delta H_{\text{no}} = 495.0 \text{ kJ/mol} \]

\( \text{NO}_2(g) + O_2(g) \rightarrow \text{NO}_2(g) + O_2(g) \)
\( \Delta H_{\text{rxn}} = -198.9 \text{ kJ/mol} \)
\( \frac{1}{2}(2O(g) \rightarrow O_2(g)) \)
\( \Delta H_{\text{rxn}} = \frac{1}{2}(495.0) \)

6) When waves of equal amplitude from two sources are out of phase when they interact, it is called __________.
(A) destructive interference
(B) diffraction
(C) constructive interference
(D) reflection
(E) interference

7) Which of the following statements is TRUE?
(A) We can sometimes know the exact location and speed of an electron at the same time. F
(B) All orbitals in a given atom are roughly the same size. T
(C) Since electrons have mass, we must always consider them to have particle properties and never wave-like properties. F
(D) Atoms are roughly spherical because when all of the different shaped orbitals are overlapped, they take on a spherical shape.
(E) All of the above are true.

8) Place the following elements in order of increasing atomic radius.

\[ \text{P} \quad \text{Ba} \quad \text{Cl} \]
(A) Ba < P < Cl
(B) P < Cl < Ba
(C) Cl < P < Ba
(D) Cl < Ba < P
(E) Ba < Cl < P
9) Identify the compound with the **lowest** magnitude of lattice energy.

A) KCl
B) KF
C) SrF₂
D) CaO

![Image](https://i.imgur.com/5Z5Z5Z5.png)

10) Draw the Lewis structure for CO₃²⁻ including any valid resonance structures. Which one of the following statements is **TRUE**?

A) The CO₃²⁻ ion contains one C-O single bond and two C=O double bonds. 
B) The CO₃²⁻ ion contains two C-O single bonds and one C=O double bond. 
C) The CO₃²⁻ ion contains three C-O double bonds. 
D) The CO₃²⁻ ion contains two C-O single bonds and one C=O triple bond. 
E) None of the above are true.

Almost, I wouldn't ask this one again.

11) A solution is formed at room temperature by vigorously dissolving enough of the solid solute so that some solid remains at the bottom of the solution. Which statement below is **TRUE**?

A) The solution is considered unsaturated.
B) The solution is considered supersaturated.
C) The solution is considered saturated.
D) The solution would be considered unsaturated if it were cooled a bit to increase the solubility of the solid.

12) Choose the aqueous solution below with the **lowest** freezing point.

A) 0.075 M NaI
B) 0.075 M (NH₄)₂PO₄
C) 0.075 M KBrO₃
D) 0.075 M LiCN
E) 0.075 M KNO₂

13) Choose the solvent below that would show the greatest boiling point elevation when used to make a 0.10 M non-electrolyte solution.

A) CCl₄, K_b = 29.9°C/m
B) C₂H₅OH, K_b = 51.2°C/m
C) CH₃CH₂OCH₂CH₃, K_b = 1.79°C/m
D) CH₃OH, K_b = 1.59°C/m
E) CH₃Cl, K_b = 4.70°C/m

14) Use the data given below to construct a Born-Haber cycle to determine the electron affinity of Br⁻. (4 points for circling correct answer, 4 points for answer that justifies correct answer)

<table>
<thead>
<tr>
<th>ΔH°(kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K(s) → K(g)</td>
</tr>
<tr>
<td>K(g) → K⁺(g) + e⁻</td>
</tr>
<tr>
<td>Br(g) → Br⁻(g)</td>
</tr>
<tr>
<td>Br₂(g) → 2 Br(g)</td>
</tr>
<tr>
<td>K₂Br(s) → K⁺(g) + Br⁻(g)</td>
</tr>
<tr>
<td>¹/₂ Br₂(g) → XBr(g)</td>
</tr>
</tbody>
</table>

A) -383 kJ
B) -325 kJ
C) +156 kJ
D) -324 kJ
E) +236 kJ

\[
\begin{align*}
\text{Br}_2(g) + e^- &\rightarrow \text{Br}^-(g) \\
\text{K(s)} + \frac{1}{2} \text{Br}_2(g) &\rightarrow \text{KBr}(s) \\
\text{K}^+(g) + \text{Br}^-(g) &\rightarrow \text{KBr}(s) \\
\text{K}(s) + \frac{1}{2} \text{Br}_2(g) &\rightarrow \text{KBr}(s)
\end{align*}
\]

\[
\begin{align*}
89 + 419 + \frac{1}{2} (193) + x - 674 = -394 \\
x - 69.5 = -394
\end{align*}
\]

\[
x = 283
\]
III. Free Response

If you've ever seen the movie "My Big Fat Greek Wedding," then you know that Windex is a miracle solution capable of curing anything from "psoriasis to poison ivy." Windex is a solution with ammonia, NH₃, dissolved in water.

1. (12 points) When Windex and bleach are added together, toxic fumes of chloramine gas, NH₂Cl, can be formed. The reaction for this process can be approximated as:

\[ 10.0\text{mL} \quad 3.23\text{M} \]
\[ \text{NH}_3(aq) + \text{NaOCl}(aq) \rightarrow \text{NH}_2\text{Cl}(g) + \text{NaOH}(aq) \]

\[ \text{2.78M} \quad 0.887\text{M} \]

Windex is a 3.23 M solution of ammonia, NH₃. Bleach is a 0.887 M solution of NaOCl. If 10.0 mL of Windex are mixed with 35.0 mL of bleach, what volume of chloramine can be produced at 755 mm Hg and 33.0°C? \( P = nRT \)

\[
\frac{0.0100\text{L}}{1\text{L soln}} \quad 3.23\text{mol NH}_3 \quad 1\text{mol NH}_2\text{Cl} = 0.0323\text{mol NH}_2\text{Cl}
\]

\[
\frac{0.0350\text{L}}{1\text{L soln}} \quad 0.887\text{mol NaOCl} \quad 1\text{mol NH}_2\text{Cl} = \frac{0.0310\text{mol NH}_2\text{Cl}}{n}
\]

\[
\frac{PV = nRT}{P} = \frac{(0.0310\text{mol})(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}})(306\text{K})}{0.993\text{atm}}
\]

\[ V = 0.784 \text{ L of NH}_2\text{Cl gas} \]

2. (10 points) Windex is a 3.23 M solution of ammonia, NH₃. What is the concentration of sulfuric acid if it takes 12.45 mL of Windex to titrate 25.00 mL of the unknown H₂SO₄?

\[ 2\text{NH}_3(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow (\text{NH}_4)_2\text{SO}_4(aq) \]

\[
\frac{0.01245\text{L}}{1\text{L soln}} \quad 3.23\text{mol NH}_3 \quad 1\text{mol H}_2\text{SO}_4 = 0.0201\text{mol H}_2\text{SO}_4
\]

\[
\left[ \text{H}_2\text{SO}_4 \right] = \frac{0.0201\text{mol H}_2\text{SO}_4}{0.02500\text{L}} = 0.804\text{M H}_2\text{SO}_4
\]

For titration problems, you are determining the "initial" concentration of H₂SO₄ before mixing/reacting with NH₃. Therefore, use the initial volume of H₂SO₄ here.
3. (8 points) As I've mentioned above, Windex is a solution in which ammonia is dissolved in water. Draw one molecule of ammonia, and then draw as many hydrogen bonds as possible between the ammonia molecule and water molecules.

\[
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{N} \quad \text{H} \\
\text{H} & \quad \text{O} \\
\text{H} & \quad \text{O} \\
\end{align*}
\]

4. (14 points) Calculate the change in the enthalpy of reaction, \( \Delta H_{\text{rxn}} \), for the following reaction in two ways:

\[2 \text{ NH}_3(g) \rightarrow \text{ N}_2(g) + 3 \text{ H}_2(g)\]

\( \Delta H_{\text{rxn}} = -46.9 \text{ kJ/mol} \)

A. From \( \Delta H_f \) values.

\[\Delta H_{\text{rxn}} = 0 + 3 \times 0 - [2 \times (-46.9)] = 91.8 \text{ kJ/mol}\]

B. From Bond Dissociation Energies. Draw the Lewis structure of each reactant and product as part of your answer.

\[2 \text{ H} \quad \text{N} \quad \text{H} \quad \rightarrow \quad \text{N}=\text{N} : + 3 \text{ H} \quad \text{H} \]

\[-946 \quad 3 \times 436 \]

\[\Delta H_{\text{rxn}} = 80 \text{ kJ/mol} \]

(not too shallow)
5. (6 points) For ammonia,
   A. What is its H-N-H bond angle? 
   \[ \angle \text{H-N-H} = 109.5^\circ \]
   B. What is the hybridization on N?
   \[ \text{sp}^3 \]

6. (6 points) Which is larger, an atom of carbon or an atom of nitrogen? Explain why (based on what we talked about in class for trends in sizes of atoms).

Carbon is larger. Both carbon and nitrogen have their valence electron in the n=2 principal energy level. However, nitrogen has an additional proton which pulls the electron in the n=2 level closer to the nucleus and causes N to be smaller than C.
7. (10 points) The boiling point of ammonia is -33.3°C. The freezing point of ammonia is -77.7°C.

The following values are the specific heat capacities of each phase and the change in enthalpy for each phase change:

- **Gaseous** \( C_v \approx 2.06 \text{ J/g \degree C} 
- **Liquid** \( C_v \approx 4.74 \text{ J/g \degree C} 
- **Solid** \( C_v \approx 2.10 \text{ J/g \degree C} 
- \Delta H_{\text{fus}} = -23.35 \text{ kJ/mol} 
- \Delta H_{\text{vap}} = 5.65 \text{ kJ/mol} 

A. Draw a heating curve for \( \text{NH}_3 \) from solid to gas phases. Label each axis, each phase, and each phase change with its proper label. Also label the freezing and boiling point on the y-axis.

B. Calculate the energy in Joules necessary to change 10.0 g of \( \text{NH}_3(g) \) at 100°C to \( \text{NH}_3(s) \) at -50°C.

1. \( q_{\text{fus}} = (10.0 \text{ g}) \times (2.06 \text{ J/g \degree C}) \times (33.3 - (100 \degree C)) = -2746 \text{ J} \)

2. \( q_{\text{cond}} = (-23.35 \text{ kJ/mol}) \times (0.587 \text{ mol}) \)

\[ \frac{10.0 \text{ g} \text{NH}_3}{14.0 \text{ g} \text{NH}_3} = -13.7 \text{ kJ} \]

3. \( q_{\text{liq}} = (10.0 \text{ g}) \times (4.74 \text{ J/g \degree C}) \times (50.0 - (-33.3)) = -792 \text{ J} \)

\[ q_1 + q_2 + q_3 = -17238 \text{ J} = -17.2 \text{ kJ} \]
8. The bond energy of the N-H bond is 389 kJ/mol.
   A. (3 points) Calculate the energy of a single N-H bond in J/bond.

\[
\frac{389 \text{ kJ}}{\text{mol}} \cdot \frac{1000 \text{ J}}{1 \text{ kJ}} \cdot \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ bonds}} = 6.46 \times 10^{-19} \text{ J/bond}
\]

B. (6 points) Based upon your answer in A, calculate the wavelength and frequency of a photon that has just enough energy to break the N-H bond. If you are unable to get what you think is the correct answer for A, use 9.17 \times 10^{19} \text{ J/bond} to answer part B (it's not the correct answer, but it will allow you to work this problem).

\[
E = \frac{hc}{\lambda} \quad \lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34} \text{ J s})(3.00 \times 10^8 \text{ m/s})}{6.46 \times 10^{-19} \text{ J}}
\]

\[
\lambda = 3.08 \times 10^{-7} \text{ m} \quad \nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{3.08 \times 10^{-7} \text{ m}} = 9.74 \times 10^{14} \text{ s}^{-1}
\]

9. (4 points) Write a full electron configuration (no noble gas core) for the Ni atom in the ground state.

Ni atom: 28e^- 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8

10. (4 points) Write an abbreviated electron configuration (using a noble gas core) for the Ag⁺ ion in its ground state.

Ag⁺ ion: [Kr] 4d^10

11. (6 points) Draw a Maxwell-Boltzmann Distribution (fraction of molecules with a given Kinetic Energy on the y-axis, Kinetic Energy on the x-axis) for ammonia at 300 K and 600 K. Label each curve with its temperature.
A. (4 points) For NH₃ and H₂O, what can we say about their dispersion forces? Does one of these two molecules have a lot more dispersion forces or are the dispersion forces about the same?

The LDF are about the same because their molar masses are about the same.

B. (4 points) Which one of these two has the stronger hydrogen bonding? How do you know?

H₂O because its boiling pt. is so much higher (T_b of NH₃ is -33.3°C - see problem 7). Larger IMF = higher T_b. Hydrogen Bond.

13. (4 points) In a closed bottle of Win-dex at 25°C, the total pressure is 782 mm Hg. Win-dex is a solution of ammonia in water, so the NH₃(g) is effectively collected over water. What is the partial pressure of the ammonia?

\[ P_t = P_{NH_3} + P_{H_2O} \]
\[ 782 \text{ mm Hg} = P_{NH_3} + 23.78 \text{ mm Hg} \]
\[ P_{NH_3} = 758 \text{ mm Hg} \]

14. (4 points) What are the oxidation numbers of nitrogen and hydrogen in ammonia?

N/H₃
\[ ON = -3 \]
\[ H = +1 \]

15. (4 points) Draw ammonia in its proper electron geometry.

16. (6 points) The concentration of hydroxide ions in Win-dex is \( 7.62 \times 10^{-2} \) M OH⁻. What is the pH of Win-dex?

\[ pOH = -\log (7.62 \times 10^{-2}) = 2.12 \]
\[ pH = 14 - pOH = 11.88 \]
17. (10 points) Determine what type of electrolyte each substance below is. Then, list the total molarity of particles in 1.00 M solutions each of the following solutions:

A. NH₄Cl  strong electrolyte
   2.0 M particles

B. NH₃  weak electrolyte
   a little more than 1.00 M

C. NH₃  nonelectrolyte
   1.00 M

D. C₁₂H₂₅OH  non electrolyte
   1.00 M
18. This question is about the bonding of NH₃.
A. (8 points) Draw the orbital overlap diagram for NH₃. Label each bond with the type of atomic orbital (s, p, sp, sp², sp³, sp⁴, sp⁵) and whether it's a sigma or pi bond.

B. (6 points) Draw the electrons in the orbitals for the unhybridized nitrogen atom (before bonding) and the hybridized atom once bonded.

C. The Molecular Orbital Energy diagram of ammonia, a molecule with 4 atoms, is pretty similar to the Molecular Orbital Energy diagram of a molecule with only two atoms because there are only two types of atoms, nitrogen and hydrogen.

A. (8 points) Fill in the dotted box below and then all of the electrons for the NH₃ molecule.