This exam has 200 points in total.

Part I. Short Answer. Answer 12 of the next 13 questions. You MUST cross out the one you wish not to be graded. 5 points each.

You must do both parts a and b of each problem.

<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen trifluoride</td>
<td>NF$_3$</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>CaCO$_3$</td>
</tr>
<tr>
<td>Ammonium bromide</td>
<td>NH$_4$Br</td>
</tr>
<tr>
<td>Magnesium sulfate heptahydrate</td>
<td>MgSO$_4$·7H$_2$O</td>
</tr>
</tbody>
</table>

3. Magnesium has 3 stable isotopes. What is the isotopic abundance of $^{24}$Mg?

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass</th>
<th>Isotopic Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{24}$Mg</td>
<td>23.98504 amu</td>
<td>?</td>
</tr>
<tr>
<td>$^{25}$Mg</td>
<td>24.98583 amu</td>
<td>10.00%</td>
</tr>
<tr>
<td>$^{26}$Mg</td>
<td>25.98259 amu</td>
<td>11.01%</td>
</tr>
</tbody>
</table>

\[
(23.98504 \cdot 0.7899 + 24.98583 \cdot 0.1 + \ldots + 25.98259 \cdot 1.1101) = 24.305049255
\]

2. \(78.99\%\)

4 sig figs \(\rightarrow 24.31\)

What is the atomic weight of Magnesium (show your work)?

3. \(24.31\) g/mol

(Any indication that they multiplied the % by the masses is fine)

4. How many moles of PbO are produced from the reaction of 5.0 mol of PbS and 6.0 mol of O$_2$?

\[
2 \text{ PbS (s) + 3 O}_2 \ (g) \rightarrow 2 \text{ PbO (s) + 2 SO}_2
\]

5. \(4.0\) moles PbO

\[
\begin{align*}
5.0 \text{ mol PbS} & \cdot \frac{2 \text{ PbO}}{2 \text{ PbS}} = 5.0 \text{ mol PbO} \\
6.0 \text{ mol O}_2 & \cdot \frac{2 \text{ PbO}}{3 \text{ O}_2} = 4.0 \text{ mol O}_2 \ (\text{Limiting Reactant})
\end{align*}
\]
5. What is the oxidation number of each element in NaBiO₃?

\[
\begin{align*}
\text{Na:} & \quad +1 \\
\text{Bi:} & \quad +5 \\
\text{O:} & \quad -2 \\
\end{align*}
\]

6. True or False:
A. When chemical bonds are broken, energy is released.
   - F

B. The phase change of liquid to solid, commonly called freezing, is exothermic.
   - T

C. The electrons in a molecule can be in an excited state if it absorbs a photon.
   - T

D. If a substance absorbs red photons, it will appear red.
   - F

E. Heat (q) and work (w) are two examples of state functions.
   - F

7. Rank the following atoms or ions:

   A. Increasing ATOMIC radius: O, F, Ga, Br
   - F < O < Br < Ga

   B. Increasing IONIC radius: Ti⁴⁺, V⁵⁺, Cl⁻
   - V⁵⁺ < Ti⁴⁺ < Cl⁻

   C. Increasing Second Ionization Energy: K, Ca, Sc
   - Ca < Sc < K

8. Which of the following molecules would exhibit dipole-dipole interactions as an intermolecular force? Circle all correct answers.

A) ICl₄⁻
B) PCl₅
C) ClF₃
D) SO₂
E) None of the above
9. Which of the following molecules would have the molecular geometry known as T-Shaped? Circle all correct answers.

(A) ClO$_3^-$
(B) ClF$_3$
(C) NF$_3$
(D) IF$_3$
(E) None of the above

10. How many total, angular, and radial nodes does a 4d orbital have?

Total Nodes: $\frac{3}{2}$  Angular nodes: $\frac{2}{2}$  Radial Nodes: $\frac{1}{1}$

11. Which atom or ion has exactly 3 unpaired electrons? Circle all correct answers.

(A) Cr$^{3+}$
(B) P$^+$
(C) Sc
(D) V$^{2+}$

12. Adding the following compounds to water will increase the boiling point and decrease the freezing point. Assuming one mole of each is added to water. Rank the compounds in terms of boiling point elevation (1 = highest to 3 = lowest)

$\underline{2}$ NaCl, $\underline{1}$ MgCl$_2$, $\underline{3}$ CH$_3$CH$_2$OH

13. Indicate if the following combinations will form a stable solution. Fill in the blank with the appropriate key term: soluble, insoluble, miscible, or immiscible.

(1) Soluble Pb(NO$_3$)$_2$ (s) in H$_2$O (l)

(2) Miscible CH$_3$OH (l) in NH$_3$ (l)

(2) Insoluble NaCl (s) in CO$_2$ (l)
Part II. Problems. Answer 6 of the next 7 questions. You MUST cross out the one you wish not to be graded. 12 points each.

14. What is the wavelength of a photon that can excite an electron in a hydrogen atom from the 1s orbital to a 3d orbital? Report your answer in nanometers and with three significant digits.

\[
\Delta E_n = -2.0178 \times 10^{-18} \text{ J} \left( \frac{1}{3^2} - \frac{1}{1^2} \right) = 1.936 \times 10^{-18} \text{ J}
\]

\[
E = \frac{n^2}{\lambda} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{2.998 \times 10^8 \text{ m/s}} = 1.936 \times 10^{-18} \text{ J}
\]

\[
\lambda = \frac{1.0261 \times 10^{-7} \text{ m}}{103 \text{ nm}}
\]

15. A. What are the partial pressures of all gases when a 1.7 L ridged container of N₂O₅ at 0°C and 1.00 atm pressure decomposes completely into NO₂ (g) and O₂ (g)?

Unbalanced Reaction: \( \text{N}_2\text{O}_5 (g) \rightarrow 2\text{NO}_2 (g) + \frac{1}{2}\text{O}_2(g) \)

\[
\eta_{\text{NO}_2} = \eta_{\text{N}_2\text{O}_5} \cdot \frac{2 \eta_{\text{O}_2}}{1 \eta_{\text{N}_2\text{O}_5}} \quad P_{\text{NO}_2} = \frac{\eta_{\text{N}_2\text{O}_5} \cdot R \cdot T}{V} = \frac{\eta_{\text{N}_2\text{O}_5} \cdot \frac{1}{2} \eta_{\text{O}_2}}{V} \quad \frac{2 \eta_{\text{O}_2}}{1 \eta_{\text{N}_2\text{O}_5}} = 1 \times 2
\]

\[
P_{\text{N}_2\text{O}_5} \quad 0 \text{ atm}
\]

\[
P_{\text{NO}_2} \quad 2.00 \text{ atm}
\]

\[
P_{\text{O}_2} \quad 0.50 \text{ atm}
\]

16. In each list:
A. Circle which molecule will have the highest boiling point. Why?

\[ \text{F}_2 \quad \text{Br}_2 \quad \text{Cl}_2 \]

Why? \( \text{Br}_2 \) has the highest molecular weight and is the most polarizable. London Dispersion will be strongest.

B. Circle which molecule that will have the highest vapor pressure.

\[ \text{CH}_3\text{CH}_2\text{OH} \quad \text{CH}_3\text{COCH}_3 \quad \text{CH}_3\text{CH}_2\text{CH}_3 \]

Why? Propene has only L-O-D, and therefore the weakest IMF’s.

C. Circle which atom or molecule will be diamagnetic.

\[ \text{N}_2 \quad \text{O}_2 \quad \text{Al} \]

Why? In the class demo, it did not stick to the magnet. Also, the MO diagram has no unpaired electrons.
17. An unknown compound contains only carbon, nitrogen, and hydrogen (and no oxygen). When the unknown is combusted completely with excess oxygen it produces 55.0 g of CO₂, 15.8 g of H₂O, and 23.0 g of NO₂. What is the empirical formula of the compound?

\[
\begin{align*}
\text{C:} & \quad 55.0 \text{ g CO}_2 \quad \frac{1 \text{ mol CO}_2}{44 \text{ g}} = \frac{1.25}{5} = 2.5 \times 2 = 5 \\
\text{H:} & \quad 15.8 \text{ g H}_2\text{O} \quad \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 1.75 \quad \frac{1.75}{5} = 3.5 \times 2 = 7 \\
\text{N:} & \quad 23.0 \text{ g NO}_2 \quad \frac{1 \text{ mol NO}_2}{46.01 \text{ g}} \quad \frac{1 \text{ mol N}}{1 \text{ mol NO}_2} = \frac{0.50}{5} = 1 \times 2 = 2
\end{align*}
\]

18. When the following solutions are mixed together, what precipitate (if any) will form? If no precipitate forms, indicate that fact.

A. Al(NO₃)₃ (aq) + Ba(OH)₂ (aq) → \[\text{Al(OH)}_3 (s) \text{ precipitates}\]

Balanced reaction: \[2 \text{Al(OH)}_3 (aq) + 3 \text{Ba(OH)}_2 (aq) \rightarrow 2 \text{Al(OH)}_3 (s) + 3 \text{Ba(NO}_3)_2 (aq)\]

B. Na₂SO₄ (aq) + Pb(NO₃)₂ (aq) → \[\text{PbSO}_4 (s) \text{ precipitates}\]

\[\text{Na}_2 \text{SO}_4 (aq) + \text{Pb(NO}_3)_2 (aq) \rightarrow \text{PbSO}_4 (s) + 2 \text{NaNO}_3 (aq)\]

C. KCl (aq) + NH₄Br (aq) → \[\text{No Precipitate}\]

\[\text{KCl (aq) + NH}_4 \text{Br (aq) \rightarrow KBr (aq) + NH}_4 \text{Cl (aq)}\]

19. What is the mass of Ca(OH)₂ (s) required to neutralize 12.0 ml of 3.50 M HClO₄ (aq)?

Balanced reaction: \[\text{Ca(OH)}_2 + 2 \text{HClO}_4 \rightarrow 2 \text{H}_2 \text{O (l)} + \text{Ca(ClO}_4)_2 \text{ (aq)}\]

\[\begin{align*}
\text{Moles HClO}_4 : \quad 0.12 \text{ L} \times 3.5 \text{ M} = 0.42 \text{ moles HClO}_4 \\
\text{Moles Ca(OH)}_2 : \quad 0.42 \text{ moles HClO}_4 \cdot \frac{1 \text{ Ca(OH)}_2}{2 \text{ HClO}_4} = 0.21 \text{ moles Ca(OH)}_2 \\
\text{Mass Ca(OH)}_2 : \quad 0.21 \text{ moles Ca(OH)}_2 \cdot 74.098 \text{ g/mole} = 15.16 \text{ g Ca(OH)}_2
\end{align*}\]

20. Given the following reactions,

\[\text{Fe}_2\text{O}_3 (s) + 3\text{CO (s) \rightarrow 2Fe (s) + 3CO}_2 (g) \quad \Delta H = -28.0 \text{ kJ}\]

\[3\text{Fe (s) + 4CO}_2 (s) \rightarrow 4\text{CO (g) + Fe}_3\text{O}_4 (s) \quad \Delta H = +12.5 \text{ kJ}\]

What is the enthalpy of the reaction of Fe₂O₃ with CO?

\[3 \cdot (-28.0 \text{ kJ}) + 2 \cdot (12.5 \text{ kJ}) = -59.6 \text{ kJ}\]
Part III. Problems. Answer 4 of the next 5 questions. You MUST cross out the one you wish not to be graded. 17 points each.

22. A. Using Lewis structures and resonance structures, which molecule has a higher bond order, NO₂⁻ or NO₃⁻?

\[
\begin{align*}
\text{NO}_2^- & \text{ has a higher Bond Order} \\
\text{B. O. for N-O} & = 1.5
\end{align*}
\]

B. Using a molecular orbital diagram, which molecule has a higher bond order, NO or NO⁻?

\[
\begin{align*}
\text{NO:} & \quad \text{NO}^- \\
\begin{array}{c}
\uparrow
\end{array} & \quad \begin{array}{c}
\downarrow
\end{array} \\
\text{B. O.} & = 2.5
\end{align*}
\]

C. Using molecular orbital theory, decide if OF is more likely to form an OF⁺ ion or an OF⁻ ion.

\[
\begin{align*}
\text{OF}^+ & \quad \text{OF}^- \\
\begin{array}{c}
\uparrow
\end{array} & \quad \begin{array}{c}
\downarrow
\end{array} \\
\text{B. O.} & = 2
\end{align*}
\]
21. A. How much heat (in kJ) is required to convert a 100. cm\(^3\) block of ice that has an initial temperature of -40.\(^\circ\)C into liquid water at 0.0 \(^\circ\)C? (Data: \(\Delta H_{\text{fus}} = 6.01 \text{ kJ/mole, density (ice)} = 0.9340 \text{ g/cm}^3, C_p (\text{ice}) = 2.1 \text{ J/g \(\cdot\) \(\circ\)C, C_p (water) = 4.2 \text{ J/g \(\cdot\) \(\circ\)C})

\[
q_{\text{melt}} = n \cdot \Delta H = \frac{100. \text{ cm}^3 \cdot 0.9340 \text{ g/cm}^3}{18.02 \text{ g/mol}} \cdot 6.01 \text{ kJ/mol} = 31.18 \text{ kJ} \]

\[
q_{\text{melt}} = 31.18 \text{ kJ} + 7.845 \text{ kJ} = 39.025 \text{ kJ}
\]

B. Using enthalpies of formation, would the combustion of 1.07 L of methane (g) at 1.00 atm of pressure and 25 \(^\circ\)C provide enough heat to melt the 100. cm\(^3\) block of ice? Show all work.

<table>
<thead>
<tr>
<th>Substance</th>
<th>(\Delta H_f^\circ (\text{kJ/mol}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH(_4) (g)</td>
<td>-75.0</td>
</tr>
<tr>
<td>H(_2)O (g)</td>
<td>-242</td>
</tr>
<tr>
<td>CO(_2) (g)</td>
<td>-393.5</td>
</tr>
</tbody>
</table>

\[
q = n \Delta H_r = \frac{PV}{RT} \cdot \Delta H = \frac{(1.0 \text{ atm} \cdot 1.07 L \cdot 0.08206 \text{ atmL/mol \cdot K} \cdot 298.15 \text{ K}}{1.0 \text{ atm} \cdot 1.0 \text{ L}} = -802.5 \text{ kJ} = -35.1 \text{ kJ}
\]

No, there is not enough energy to warm the ice and melt the ice.

35.1 kJ < 39 kJ

C. Using bond enthalpies, would the combustion of 1.0 g of acetylene (HCCH) provide enough heat to melt the 100. cm\(^3\) block of ice? Show your work.

Hint: Acetylene is a linear molecule with one hydrogen attached to each carbon.

<table>
<thead>
<tr>
<th>Bond Type</th>
<th>C-H</th>
<th>C-C</th>
<th>O-H</th>
<th>C=O</th>
<th>C=C Double bond</th>
<th>C=C Triple bond</th>
<th>O=O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Enthalpy (kJ/mol)</td>
<td>413</td>
<td>348</td>
<td>463</td>
<td>799</td>
<td>614</td>
<td>839</td>
<td>495</td>
</tr>
</tbody>
</table>

\[
\Delta H_{\text{m}} = 2(C-H) + (C=C) + \frac{5}{2}(O=O) - \left(4(C=O) + 2(0-H)\right)
\]

\[
\Delta H_{\text{m}} = 2(413) + 839 + \frac{5}{2} \cdot 495 - \left(4(799) + 2(463)\right)
\]

\[
\Delta H_{\text{m}} = -1219.5 \text{ kJ}
\]

\[
q = n \Delta H = \frac{1.0 \text{ g C}_2 \text{H}_2 \cdot \text{mol}}{26.049 \text{ g C}_2 \text{H}_2} \cdot 1 \text{ mol} = -1219.5 \text{ kJ} = -46.8 \text{ kJ}
\]

Yes, there is enough energy to warm the ice and melt the ice.
23. Below is the phase diagram for N$_2$. The gray solid line at 1.0 atm is given to help guide your eye.

A. Label the following 6 points on the graph. Label each region as either solid, liquid, gas, or super critical fluid. Label the triple point and the critical point.

B. What is the phase transition that happens at 1 atm of pressure as the temperature increases from -200 °C to 25 °C? **Evaporation**

C. What is the minimum pressure necessary to create liquid N$_2$? **0.12 atm**

D. At 2 atm of pressure, which value is closest to the freezing temperature of N$_2$? Circle the best answer:

   a) -211 °C  
   b) -209 °C  
   c) -192 °C  
   d) -200 °C  
   e) -140 °C

E. Label the phase diagram with at star (*) at the pressure and temperature conditions of this room. Define the P and T at this point.

\[ P = 1.00 \text{ atm} \]
\[ T = 25^\circ \text{C} \]
24. Balance the following redox reaction using the methods of half reactions. Show your work.

A. \( \text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + \text{H}_2\text{O}(g) \)

\[
\begin{align*}
\text{NH}_3 + \text{H}_2\text{O} & \rightarrow \text{NO} + 5\text{H}^+ + 5\text{e}^- \\
4\text{e}^- + 4\text{H}^+ + \text{O}_2 & \rightarrow 2\text{H}_2\text{O}
\end{align*}
\]

\[
\begin{align*}
4 \text{NH}_3 + 4\text{H}_2\text{O} & \rightarrow 4\text{NO} + 20\text{H}^+ + 20\text{e}^- \\
20\text{e}^- + 20\text{H}^+ + \text{SO}_2 & \rightarrow 10\text{H}_2\text{O}
\end{align*}
\]

\[
\begin{align*}
4 \text{NH}_3 + 5\text{SO}_2 & \rightarrow 6\text{H}_2\text{O} + 4\text{NO}
\end{align*}
\]

B. Which reactant has been oxidized? 
\( \text{NH}_3 \)

C. Which reactant has been reduced? 
\( \text{O}_2 \)

D.(b) If 3.49 g of ammonia and 2.16 g oxygen are allowed to react, what volume of nitric oxide is evolved at 273.2K and 1.00 atm?

\[
\begin{align*}
\text{NH}_3 & : 3.49 \text{ g} \text{ NH}_3 \cdot \frac{\text{1 mol}}{17.03 \text{ g}} = 0.205 \text{ mol} \\
\text{O}_2 & : 2.16 \text{ g} \text{ O}_2 \cdot \frac{\text{1 mol}}{32 \text{ g}} = 0.0675 \text{ mol}
\end{align*}
\]

\( \text{O}_2 \) is the limiting reactant.

\[
\begin{align*}
\text{NO} & : 0.054 \\
\text{V} & = \frac{nRT}{P} = \frac{0.054 \text{ mol} \cdot 0.08206 \text{ L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1} \cdot 273.2 \text{ K}}{1.00 \text{ atm}} \approx 1.21 \text{ L}
\end{align*}
\]

25. A solution of 5.00 g of lauril alcohol in 0.100 kg of benzene freezes at 4.1°C. Calculate the molar mass of lauril alcohol. \( K_f \) for benzene is 5.12 °C kg/mol and the normal freezing point of benzene is 5.5°C. Show all work.

\[
\begin{align*}
\Delta T_f & = -K_f \cdot M = -K_f \cdot \frac{\text{mass}(g)}{\text{MW}(g)} \\
\Delta T_f & = -5.12 \text{ °C Kg} \cdot \frac{\text{S. 00 g}}{\text{MW(g) Lauril alcohol}} \\
-1.4 & = 0.100 \text{ Kg} \\
-5.12 & = \frac{1 \text{ mol}}{\text{MW(g) Lauril alcohol}} \\
\text{or MW} & = \frac{-5.12 \text{ °C Kg} \cdot 5.00 \text{ g}}{1 \text{ mol}} \\
\text{MW} & = 183 \frac{3}{\text{mol}} \rightarrow \frac{180.5}{\text{mol}} \text{ (2 sig)}
\end{align*}
\]

Part I: 60 pts 
Part II: 72 pts 
Part III: 68 pts