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 one correct answer. Good luck and good skill!

1. Multiple choice are three points.
   1) How many moles of C$_3$H$_8$ contain 9.25 x 10$^{24}$ molecules of C$_3$H$_8$?
      A) 65.1 moles C$_3$H$_8$
      B) 28.6 moles C$_3$H$_8$
      C) 34.9 moles C$_3$H$_8$
      D) 46.2 moles C$_3$H$_8$
      E) 15.4 moles C$_3$H$_8$

   \[
   \frac{9.25 \times 10^{24} \text{ molecules C}_3\text{H}_8}{6.022 \times 10^{23} \text{ molecules}} = 1.52 \text{ mol C}_3\text{H}_8
   \]

2) Determine the empirical formula for a compound that contains C, H and O. It contains 52.14% C and 34.73% O by mass. + 13.12% H
   A) C$_2$H$_6$O
   B) CHO
   C) C$_4$H$_3$O$_2$
   D) CH$_4$O$_3$
   E) CH$_3$O

   \[
   \begin{align*}
   &52.14\% \text{C} \div 12.01\text{gC} = 4.34 \text{ mol C} \\
   &34.73\% \text{O} \div 16.00\text{gO} = 2.17 \text{ mol O} \\
   &13.12\% \text{H} \div 1.008\text{gH} = 13.02 \text{ mol H}
   \end{align*}
   \]

   \[\text{EF} = \text{C}_2\text{O}_4\text{H}_6\]

3) Determine the concentration of a solution prepared by diluting 20.0 mL of a 0.200 M NaCl to 250.0 mL.
   A) 0.160 M
   B) 0.0320 M
   C) 2.50 M
   D) 0.00800 M
   E) 0.0160 M

   \[
   \frac{(20)(0.2)}{250} = 0.250x
   \]

4) Assuming that all of these substances do dissolve in water, which of the following solutions will have the highest concentration of particles?
   A) 0.045 M Al$_2$(SO$_4$)$_3$
   B) 0.050 M (NH$_4$)$_2$CO$_3$
   C) 0.05 M LiBr
   D) 0.067 M NaI
   E) 0.10 M KF

   \[2(0.045) = 0.090 \\ 3(0.050) = 0.150 \\ 2(0.05) = 0.10 \\ 1(0.067) = 0.067 \\ 2(0.10) = 0.20 \]

5) The pressure of a gas is doubled and the temperature of the gas is halved. If the amount of gas is constant, what happens to the volume of the gas?
   A) It stays the same.
   B) It doubles.
   C) It increases by a factor of 4.
   D) It halves.
   E) It decreases by a factor of 4.

   \[
   \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \\
   \frac{P_1}{P_2} = \frac{V_2}{V_1} \frac{T_1}{T_2} \\
   \frac{1}{4} = \frac{2}{1} \frac{1}{x}
   \]

   \[15 \text{ points} \]

   \[3690 \]
6) A mixture of 1.0 mol He and 1.0 mol Ne are at 1.00 atm and 0°C in a rigid container. Which one of the following statements is TRUE?

A) Both gases have the same average kinetic energy.

B) Both gases contribute equally to the density of the mixture under these conditions.

C) Both gases have the same molecular speed.

D) The mixture has a volume of 22.4 L.

E) All of the above are TRUE.

7) Choose the reaction that illustrates ΔH for Ca(NO₃)₂(s).

A) Ca(s) + N₂(g) + 3O₂(g) → Ca(NO₃)₂(s)

B) Ca²⁺(aq) + 2 NO₃⁻(aq) → Ca(NO₃)₂(aq)

C) Ca(s) + 2 N(g) + 6 O(g) → Ca(NO₃)₂(s)

D) Ca(NO₃)₂(aq) → Ca²⁺(aq) + 2 NO₃⁻(aq)

E) Ca(NO₃)₂(s) → Ca(s) + N₂(g) + 3 O₂(g)

8) In which orbital below would an electron (on average) be farthest from the nucleus?

A) 1s

B) 4s

C) 3s

D) 3d

E) 2p

9) In which pair do both compounds exhibit predominantly ionic bonding?

A) SO₂ and HCl

B) KNO₃ and CH₄

C) KF and CuO

D) KCl and CO₂

E) Barry Allen and Iris West

10) According to the Kinetic Molecular Theory:

A) Gas molecules are in continuous, random motion and collisions are perfectly elastic.

B) The absolute temperature of a gas depends on its molar mass.

C) Gas particles travel in straight or curved paths.

D) All gas particles are diatomic.

11) Dynamic equilibrium for the reaction that establishes the vapor pressure of a gas in contact with its liquid can be defined as:

A) rate of dissolution = rate of precipitation

B) rate of dissolution < rate of precipitation

C) rate of dissolution > rate of precipitation

D) rate of bubbling > rate of dissolving

E) rate of evaporating > rate of condensing

F) rate of evaporating = rate of condensing

G) rate of studying > rate of sleeping

12) Use the molecular orbital diagram shown to determine which of the following is most stable.

A) C₂²⁻

B) N₂²⁻

C) B₂

D) B₂⁻

E) B₂²⁻
13) Which of the statements concerning the phase diagram below is/are CORRECT?
1. Only the solid phase exists at point A. \( A \)
2. At point C, the solid and liquid phases are in equilibrium. \( C \)
3. At point D, the critical point, the substance exists as a supercritical fluid. \( S \)

\[ \text{Options: A) 1 only  B) 2 only  C) 3 only  D) 1 and 3  E) 1, 2, and 3} \]

14) How many sigma and pi bonds are in the molecule pictured below?

- A) thirteen sigma bonds and one pi bond
- B) eleven sigma bonds and two pi bonds
- C) thirteen sigma bonds and two pi bonds
- D) eleven sigma bonds and five pi bonds
- E) five sigma bonds and eleven pi bonds

15) Which of the following sets of quantum numbers is allowed?
- A) \( n = 2, l = 1, m_l = +1/2, m_s = -1/2 \)
- B) \( n = 3, l = 2, m_l = +1, m_s = +1 \)
- C) \( n = 4, l = 1, m_l = 0, m_s = -1/2 \)
- D) \( n = 4, l = 2, m_l = -1, m_s = 0 \)
- E) \( n = 5, l = 2, m_l = +2, m_s = +1 \)

16) Using the following thermochemical data:

\[ \frac{1}{2} \left( 2\text{H}_2\text{O}(s) + 6\text{HF}(g) \rightarrow 2\text{HoF}_3(s) + 3\text{H}_2\text{O}(g) \right) \quad \Delta H_{\text{rxn}} = -1787.4 \text{ kJ/mol-rxn} \]
\[ \frac{1}{2} \left( 2\text{H}_2\text{O}(s) + 6\text{HCl}(g) \rightarrow 2\text{HoCl}_3(s) + 3\text{H}_2\text{O}(g) \right) \quad \Delta H_{\text{rxn}} = -1457.0 \text{ kJ/mol-rxn} \]

Calculate \( \Delta H_{\text{rxn}} \) for the following reaction:

\[ \text{HoF}_3(s) + 3\text{HCl}(g) \rightarrow \text{HoCl}_3(s) + 3\text{HF}(g) \]

- A) \(-3244.4 \text{ kJ/mol-rxn}\)
- B) \(330.4 \text{ kJ/mol-rxn}\)
- C) \(165.2 \text{ kJ/mol-rxn}\)
- D) \(660.8 \text{ kJ/mol-rxn}\)
- E) \(-1622.2 \text{ kJ/mol-rxn}\)

[12 points]
17) The picture below shows the combining of two atomic orbitals on the left to create one molecular orbital on the right. What kind of molecular orbital is shown in the right portion of the picture?

\[ \begin{align*}
&\text{A) } \sigma_{2s} \\
&\text{B) } \sigma^*_{2s} \\
&\text{C) } \pi_{2s} \\
&\text{D) } \pi^*_{2s} \\
&\text{E) } \sigma_{2p}
\end{align*} \]

18) How many protons, neutrons, and electrons are in a neutral atom of \(^{56}\)Fe?

- A) 26 protons, 29 neutrons, 55 electrons
- B) 26 protons, 29 neutrons, 29 electrons
- C) 26 protons, 29 neutrons, 26 electrons
- D) 55 protons, 26 neutrons, 55 electrons
- E) 26 protons, 29 neutrons, 26 electrons

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

A. benzene

\[ \text{C}_6\text{H}_6 \]

C. sodium perchlorate

\[ \text{NaClO}_4 \]

E. Fe(CH\(_3\)COO)\(_2\)

\[ \text{iron (II) acetate} \]

B. \(\text{S}_2\text{O}_3\)

\[ \text{trisulfur tetroxide} \]

D. CuSO\(_4\)·H\(_2\)O

\[ \text{Copper (II) sulfate monohydrate} \]

F. potassium oxide

\[ \text{K}_2\text{O} \]
III. Free Response

1) When 0.529 g of magnesium are placed in 250.0 mL of 0.100 M HCl, a single replacement redox reaction occurs:

\[
\text{Mg(s)} + 2 \text{HCl(aq)} \rightarrow \text{H}_2(\text{g}) + \text{MgCl}_2(\text{aq})
\]

\[
\begin{array}{c|c|c|c|c|c}
\text{O} & \text{N} & 0 & \text{H} & 0 & \text{Mg}
\end{array}
\]

\[
\begin{array}{c|c|c|c|c|c}
\text{0} & \text{1} & -1 & 0 & \text{2} & -2
\end{array}
\]

A. Determine the oxidation number of each element in each formula. (6 points)

B. \underline{Mg} was oxidized. (2 points)

C. Write the total ionic equation (TIE) and the net ionic equation (NIE) for this reaction. (6 points)

TIE: \[
\text{Mg(s)} + 2\text{H}^+(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})
\]

NIE: \[
\text{Mg(s)} + 2\text{H}^+(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{Mg}^{2+}(\text{aq})
\]

D. How many liters of hydrogen gas can be collected over water at 25.0°C and an atmospheric pressure of 744 mm Hg? (10 points)

\[
\text{P}_{\text{atm}} = \text{P}_{\text{H}_2} + \text{P}_{\text{H}_2\text{O}}
\]

\[
744\text{mmHg} = \text{P}_{\text{H}_2} + 23.76\text{mmHg}
\]

\[
\text{P}_{\text{H}_2} = 720.22\text{mmHg}
\]

\[
\text{V} = 0.323\text{L}\text{H}_2(\text{g})
\]

\[
\frac{0.529\text{g Mg}}{1\text{mol Mg}} \cdot \frac{1\text{mol H}_2}{24.30\text{g}} = 0.0218\text{mol H}_2
\]

\[
0.250\text{L} \cdot \frac{0.1\text{mol HCl}}{1\text{L soln}} \cdot \frac{1\text{mol H}_2}{2\text{mol HCl}} = 0.0125\text{mol H}_2
\]

24 points
2) Consider the following compounds: 
$\text{H}_2\text{CO}_3$, $\text{Fe}((\text{CH}_3\text{COO})_2$, $\text{HCN}$, $\text{PhO}$, $(\text{NH}_4)_2\text{SO}_4$, $\text{HNO}_3$, $\text{C}_2\text{H}_5\text{OH}$, $\text{CaCO}_3$, $\text{NaF}$, $\text{Fe}_2\text{S}_3$, $\text{HCl}$, $\text{H}_2\text{PO}_4$. 
For this question, full points will be awarded for listing only those that are correct (no more no less). Each wrong answer (either omitted or listed) will subtract one point. You also can’t get less than zero points.
A. List the ionic compounds that are insoluble in water. (4 points)
- $\text{CaCO}_3$
- $\text{Fe}_2\text{S}_3$
- $\text{PbO}$

B. List the ones that are strong acids. (4 points)
- $\text{HNO}_3$
- $\text{HCl}$

3) When I was growing up, I always thought that the reason my parents put salt on their food was to cool it down because the food was always too hot for me when they put the salt on it. Does putting salt on food cool it down? Let’s calculate it!
A. What is the change in enthalpy of reaction for the dissolving of salt? (6 points)

$$\text{NaCl(s)} \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq)$$

$$\Delta H = [-240.34 + -110.1] - [-411.2] = \underline{\text{377.4 kJ/mol}}$$

B. Is this process endothermic or exothermic? (4 points)
- endo

4) Draw a picture of the results on the screens of the single and double slit experiments for electrons. (8 points)

- Single slit:
  - Electron shooter
  - Stream of electrons
  - Single slit
  - Screen

- Double slit:
  - Electron shooter
  - Stream of electrons
  - Double slit
  - Screen
5) Two calculations:
A. Calculate the wavelength of the electron in a hydrogen atom. The electron is traveling at $2.2 \times 10^6$ m/s. (6 points)

$$\lambda = \frac{n}{mv} = \frac{6.626 \times 10^{-34}}{(2.2 \times 10^6)(9.1 \times 10^{-28})} = 3.3 \times 10^{-10} \text{ m}$$

B. What is the wavelength of electromagnetic radiation necessary to move an electron in helium from the $n=1$ principal energy level to the $n=2$? (6 points)

$$E = -2.19 \times 10^{-18}(2)^2\left(\frac{1}{\infty} - \frac{1}{1}\right)$$

$$= -2.19 \times 10^{-18}(4)(-1)$$

$$= 8.76 \times 10^{-18} \text{ J}$$

$$E = \frac{hc}{\lambda}$$

$$8.76 \times 10^{-18} = \frac{6.6 \times 2.6 \times 10^{-24}}{\lambda}$$

$$\lambda = 23 \text{ nm}$$

6) Draw the orbital energy diagram (hint: with boxes and arrows) for a zinc atom. The orbital energy diagram must show the correct electrons in each orbital and the correct order of the energy of the sublevels. You can use a noble gas core to represent the core electrons. (6 points)

Zn: [Ar] 4s$^2$ 3d$^{10}$

Energy

4s

3d

[Ar]
7) Consider the carbonate ion, $CO_3^{2-}$.
A. Draw all of the resonance structures for carbonate. (8 points)

\[
\begin{align*}
\begin{array}{c}
\text{\[} \begin{array}{c}
\text{[O=C=O]}^{2-} \text{[O=C=O]}^{2-} \text{[O=C=O]}^{2-}
\text{\]}
\text{\[} \begin{array}{c}
\text{[O=C=O]}^{2-} \text{[O=C=O]}^{2-} \text{[O=C=O]}^{2-}
\text{\]}
\end{array}
\end{array}
\end{align*}
\]

B. For carbonate, what is the true nature of the carbon-oxygen bond? (6 points)

The true bond is a 4/3 bond. Stronger than a single bond, but weaker than a double bond. It is shorter than a single, but longer than a double.

8) For each of the molecules in the list below, give the following information:

<table>
<thead>
<tr>
<th>A. SO$_3$</th>
<th>B. NH$_4^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Best Lewis Structure. Note any nonzero formal charges. (4 points)</td>
<td>i. Best Lewis Structure. Note any nonzero formal charges. (4 points)</td>
</tr>
<tr>
<td>![Lewis Structure of SO$_3$]</td>
<td>![Lewis Structure of NH$_4^+$]</td>
</tr>
<tr>
<td>ii. Hybridization on the S atom (2 points)</td>
<td>ii. Hybridization on the N atom (2 points)</td>
</tr>
<tr>
<td>$sp^2$</td>
<td>$sp^3$</td>
</tr>
<tr>
<td>iii. Electron geometry on the S atom (2 points)</td>
<td>iii. Electron geometry on the N atom (2 points)</td>
</tr>
<tr>
<td>trigonal planar</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>iv. Approximate bond angles about the S atom (2 points)</td>
<td>iv. Approximate bond angles around the N atom (2 points)</td>
</tr>
<tr>
<td>120°</td>
<td>109.5°</td>
</tr>
<tr>
<td>v. Draw the shape and dipole arrows around the S atom. (4 points)</td>
<td>v. Draw the shape with in and out wedges and dipole arrows around the N atom. (4 points)</td>
</tr>
<tr>
<td>![Shape of SO$_3$]</td>
<td>![Shape of NH$_4^+$]</td>
</tr>
<tr>
<td>vi. Is the molecule polar or nonpolar? (2 points)</td>
<td>nonpolar</td>
</tr>
</tbody>
</table>

376 points
9) Draw skeletal structures of two molecules with the same molar mass (± 2 g) that have different IMF. Then explain why one of them has a higher boiling point than the other. (10 points)

(a) 

(b) 

Both have LDF, but (a) has more area of interaction.

10) What is the pH of a solution in which 32.3 mL of 0.200 M NaOH have been added to 25.00 mL of 0.100 M HCl? (12 points)

\[ \text{HCl (aq) + NaOH (aq) } \rightarrow \text{ NaCl (aq) + H}_2\text{O (l)} \]

\[
\begin{align*}
0.0323 \text{L NaOH} & \quad 0.200 \text{ mol} = 0.00646 \text{ mol NaOH} \\
0.0250 \text{L HCl} & \quad 0.100 \text{ mol} = 0.00250 \text{ mol HCl}
\end{align*}
\]

\[
M = \frac{0.00394 \text{ mol NaOH}}{0.0573 \text{L soln}} = 0.0691 \text{ M}
\]

\[
\text{pOH} = -\log [\text{OH}^-] = -\log [0.0691] = 1.14
\]

\[
\text{pH} = 12.84
\]

\[22 \text{ points} \]

\[377\]
11) 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): (20 points)

A. \[ \text{LDF} \]

B. \[ \text{dipole-dipole} \]

C. \[ \text{N}_2 \]

D. \[ \text{MgO} \]

\[ \text{ion-ion bonding} \]

\[ \text{LDF} \]

\[ \text{P}_2 \]

\[ \text{LDF} \]

\[ \text{NaF} \]

\[ \text{ion-ion bonding} \]
12) Dry ice is CO$_2$(s). Its sublimation point is $-78^\circ$C, in which it goes straight from the solid phase to the gas phase. For CO$_2$(s), the heat capacity is 1.06 J/g$^\circ$C. For CO$_2$(g), its heat capacity is 0.839 J/g$^\circ$C. The standard enthalpy of sublimation of CO$_2$(s) is 33.9 kJ/mol.

A. Draw a heating curve for carbon dioxide. Label the axes, the phases, phase change, and sublimation temperature on the drawing. (8 points)

B. If 10.0 g of CO$_2$(s) at $-100^\circ$C are placed in a sealed container with 50.0 g of water at 100$^\circ$C, what is the final temperature of the mixture. (Hint: the fact that everything is in a sealed container is only so that any CO$_2$(g) won't escape.) (10 points)

\[
q = \text{mol} \Delta H_{\text{sub}}, \quad q = n \cdot \Delta H
\]

\[
-78 \degree \text{C} \quad s \rightarrow g
\]

\[
(0.393 \text{kJ}) (10 \text{ g CO}_2)(T_f + 78) = (150 \text{g H}_2\text{O})(4.184 \text{J/g}^\circ\text{C})(T_f - 100)
\]

1) \( q = (10 \text{g})(1.0 \text{J/g}^\circ\text{C})(22^\circ \text{C}) \)

\( q = 233.2 \text{J} \)

2) \( q = (10 \cdot 237 \text{mol CO}_2)(33,900 \text{J/mol}) \)

\( q = 770,208 \text{J} \)

\( 1003.4 \text{J} + (0.839 \text{J/g}^\circ\text{C})(10 \text{g CO}_2)(T_f + 78^\circ\text{C}) = -209.2T_f + 20920 \)

\( 1003.4 \text{J} + 8.39 T_f + 1514.42 = -209.2 T_f + 20920 \)

\( 8.39 T_f = -209.2 T_f + 19242.18 \)

\( 217.59 T_f = 19242.18 \)

\( T_f = 86.5^\circ\text{C} \)

C. 4 points Extra Credit (you can do it on the back or ask for scratch paper) I would like to know the ratio of dry ice at $-10^\circ$C to water at 25$^\circ$C that will get the water to 1$^\circ$C. Of course, the dry ice will sublime and not dilute my "water".

See instructor