Scientific instruments play an important role in research. (0 pts) Which instrument is pictured above?

Atomic Force Microscope  Barometer  Coulometer  Diode Laser  Electrochemical Cell

Test-taking strategy: PLEASE READ THIS FIRST!
Write your name on all 14 pages. This test consists of two parts: multiple choice (answers to be circled and entered on the Scantron sheet) and short answer. In order to maximize your score on the exam:

- Do the questions you know how to do first, then, go back and answer the questions you skipped.
- Budget your time carefully -- don't spend too much time on any one problem.
- Show all work for which you want credit and don't forget to include units.
- The "tear off" back page has some useful data and equations.
Section 1: Multiple Choice. 20 questions, 6 points each.

Instructions: For the following questions, circle the answer on the exam sheet and bubble in the correct answer on your Scantron sheet. Unless you are specifically told that there might be more than one answer to a problem, assume that only one answer is correct.

1.) You are taking test version C. Please fill in bubble “C” on the Scantron sheet.

2.) Which of the following has the smallest atomic radius?

A) S^2-    B) Cl^-   C) Ar   D) K^+   E) Ca^{2+}

3.) Which of the following might be the pH of a 0.1 M weak base at 25 °C?

A) 1       B) 4       C) 6       D) 9       E) 13

4.) A solution of 0.01 M Ba(NO_3)_2 and 0.01 M Pb(NO_3)_2 (both of which dissociate completely in water) is titrated with SO_4^{2-}. At the point when PbSO_4(s) first begins to precipitate, what will be the concentration of Ba^{2+} in the solution? Assume a negligible change in volume.
K_{sp}(BaSO_4) = 1 \times 10^{-10}; K_{sp}(PbSO_4) = 1 \times 10^{-8}.

A) 1 \times 10^{-10} M B) 1 \times 10^{-8} M C) 1 \times 10^{-6} M D) 1 \times 10^{-4} M E) 1 \times 10^{-2} M

5.) Under what conditions would the following exothermic reaction be spontaneous?

Fe(s) + CO(g) \rightarrow FeO(s) + C(s)

A) At all T     B) At no T     C) At high T     D) At low T     E) At 100 °C

6.) Which of the following compounds is chiral?

A) \begin{array}{c}
\text{H} \\
\text{Cl}
\end{array} \begin{array}{c}
\text{H} \\
\text{Cl}
\end{array} \begin{array}{c}
\text{H} \\
\text{Cl}
\end{array} \begin{array}{c}
\text{H}
\end{array}

B) \begin{array}{c}
\text{H} \\
\text{F}
\end{array} \begin{array}{c}
\text{C} \\
\text{Cl}
\end{array} \begin{array}{c}
\text{H}
\end{array}

C) \begin{array}{c}
\text{H} \\
\text{H}
\end{array} \begin{array}{c}
\text{C} \\
\text{H}
\end{array} \begin{array}{c}
\text{OH}
\end{array}

D) \begin{array}{c}
\text{CH}_3 \\
\text{C} \\
\text{CH}_3
\end{array} \begin{array}{c}
\text{C} \\
\text{H}_3
\end{array} \begin{array}{c}
\text{Br}
\end{array}

E) \begin{array}{c}
\text{F}
\end{array} \begin{array}{c}
\text{C} \\
\text{C}
\end{array} \begin{array}{c}
\text{CH}_3
\end{array}

7.) Which of the following can have the electron configuration 1s^22s^22p^63s^23p^64s^23d^{10}4p^6s^1?

A) Ba^+     B) Cs^-     C) Sr     D) Rb     E) Kr

8.) For the reaction carried out at 100 °C and 1 atm: CH_4(g) + CCl_4(g) \rightarrow 2 CH_2Cl_2(g), which of the following must be true?

A) \Delta P > 0     B) \Delta H > 0     C) \Delta S > 0     D) \Delta G > 0     E) \Delta E > 0
In the following 3 problems, choose the one answer that best describes “X” in the given figures.

9.) For the endothermic reaction, SiO$_2$(s) $\leftrightarrow$ Si(s) + O$_2$(g), X=?

A) P  B) mass of SiO$_2$(s)  C) K
D) Q  E) total mass

10.) For 1 mole of an ideal gas at constant pressure, X=?

A) P/V  B) urms  C) 1/V
D) R  E) V

11.) For the titration curve, X=?

A) 1.0 M HCl  B) 0.01 M NaOH  C) 0.1 M NaOH
D) 0.1 M NH$_3$  E) 0.01 M NH$_3$

12.) A steel cylinder containing He(g) is fitted with a pressure release valve designed to open if the pressure exceeds 30 atm. If the helium has an initial pressure of 12 atm at 25 °C, to what temperature would you have to heat the gas to cause the valve to open?

A) 10 °C  B) 63 °C  C) 149 °C  D) 400 °C  E) 472 °C

13.) A mass of 2.875 g of a compound consisting of only nitrogen and oxygen is vaporized in a 1.0 L flask at 100 °C. The pressure in the flask is found to be 2.0 atm. What is the compound?

A) NO  B) NO$_2$  C) N$_2$O  D) N$_2$O$_4$  E) N$_2$O$_5$

14.) Which of the following has the lowest ionization energy?

A) S$^{2-}$  B) Cl$^{-}$  C) Ar  D) K$^+$  E) Ca$^{2+}$
15.) For an isothermal (ΔT = 0) expansion of a monatomic ideal gas against a constant external pressure of 0.5 atm in which 4.0 L·atm of heat is absorbed by the system, what is the change in volume, ΔV?
   A) -4 L  B) -2 L  C) 4 L  D) 8 L  E) Can't determine.

16.) Which of the following is the correct emission spectrum for the energy level diagram pictured to the left?
   A) \[ \text{Energy Levels} \]
   B) \[ \text{Energy Levels} \]
   C) \[ \text{Energy Levels} \]
   D) \[ \text{Energy Levels} \]
   E) \[ \text{Energy Levels} \]

17.) What is the approximate ΔH° for the following reaction? Hint: there are two ways to solve this problem.
   \[ 4 \text{ C-C} + 3 \text{ H-H} + 0.5 \text{ O=O} \rightarrow 2 \text{ C-O} + 6 \text{ C-H} \]
   A) -1200 kJ  B) -900 kJ  C) -300 kJ  D) -200 kJ  E) 900 kJ

18.) For the reaction: \[ \text{CO}_2(g) \rightarrow \text{C(s)} + \text{O}_2(g) \] at equilibrium, what happens to the reaction quotient, Q, relative to the equilibrium constant, K, if the volume is suddenly doubled without changing the temperature?
   A) Q < K  B) Q = K  C) Q > K  D) \[ Q = \frac{1}{K} \]  E) Can't determine.

19.) Pictured to the left is the Lewis electron dot structure for sulfur trioxide.
   What is the formal charge on the sulfur atom?
   A) 2-  B) 1-  C) 0  D) 1+  E) 2+

20.) How many photons of yellow light (λ = 600 nm) would it take to stop a 2.0 gram bullet traveling at 55 m·sec⁻¹ (λ = 6x10⁻²⁴ nm)?
   A) 10⁻²²  B) 10⁴  C) 10²²  D) 10²⁴  E) 10²⁶

21.) When mixed with excess acetic acid in a model air bag, 1.0 gram of which of the following carbonates should produce the most CO₂(g)?
   A) BeCO₃  B) MgCO₃  C) Na₂CO₃  D) CaCO₃  E) K₂CO₃
Section 2: Short Answer. 10 questions, 20 points each.

Answer the following four short answer questions. Partial credit will be given, so show your work whenever possible. Your final answers (including units where applicable) must be written in the boxes when provided.

1a.) (8 Points) Draw the Lewis electron dot structure for the sulfur tetrafluoride anion, $SF_4^2-$:

**Lewis Dot Structure:**

b.) (4 Points) What is the steric number (number of atoms and lone pairs) for the sulfur atom in $SF_4^2-$?

**Steric Number =**

c.) (8 Points) Draw and name the molecular structure (i.e. the geometric arrangement of the atoms) of $SF_4^2-$:

**Molecular Structure:**

Name:
2.) Silicon nitride (Si₃N₄) is an extremely hard ceramic which has been suggested as a possible material for building a non-metal engine. Si₃N₄ can be made by reacting silicon tetrachloride (SiCl₄) with ammonia (NH₃).

a.) (5 points) Balance the equation for the formation of Si₃N₄.

\[ \text{____ SiCl}_4 (g) + \text{____ NH}_3 (g) \rightarrow \text{____ Si}_3 \text{N}_4 (s) + \text{____ HCl (g)} \]

b.) (8 points) 10.0 grams of NH₃ are reacted with 10.0 grams of SiCl₄. Which of these reagents will be used up first?

Limiting Reagent =


c.) (7 points) If the reaction from part b.) is run to completion, how many moles of Si₃N₄ will be produced?

Moles of Si₃N₄ =

3.) Sulfur dioxide reacts with oxygen in the presence of a platinum catalyst to form sulfur trioxide:

\[ \text{2 SO}_2(g) + \text{ O}_2(g) \rightarrow \text{ 2 SO}_3(g) \]

a.) (8 Points) 4.0 moles of SO₂(g) and 2.0 moles of O₂(g) are placed in a 24.5 L sealed vessel without the catalyst (i.e. no reaction occurs) at 25 °C. What is the total pressure?

Total Pressure =

b.) (5 Points) What is the partial pressure of SO₂(g) in the vessel before any reaction?

Partial Pressure =

c.) (7 Points) The platinum catalyst is added to the vessel and the reaction proceeds to completion without any change in temperature. What is the final pressure? Assume the platinum does not affect the volume.

Final Pressure =
4a.) (10 Points) Determine $\Delta H_f^0$ in kJ·mol$^{-1}$ for HCl and HF which are formed via the following exothermic reaction in which $X = \text{Cl}$ or $X = \text{F}$.

$$\text{H}_2(\text{g}) + \text{X}_2(\text{g}) \longrightarrow 2 \text{HX(}\text{g})$$

\[
\begin{align*}
\Delta H_f^0(\text{HCl}) &= \\
\Delta H_f^0(\text{HF}) &=
\end{align*}
\]

b.) (10 Points) Which bond, H-Cl or H-F, is more polar? In 20 words or less, explain your choice in light of the enthalpies of formation you found in part a.).

Answer and Explanation:

5.) CN$^-$ is the conjugate base to the weak acid HCN, with $K_a = 6.0 \times 10^{-10}$, $pK_a = 9.22$.

a.) (4 Points) What is $K_b$ for CN$^-$?

$$K_b =$$

b.) (8 Points) What is the pH of 50 mL of a 0.1 M solution of NaCN (which dissociates completely to Na$^+$ and CN$^-$)?

$$\text{pH} =$$

c.) (8 Points) How many mL of 1.0 M HCl should be added to the solution in b.) in order to bring the pH to 9.22?

$$\text{mL of 1.0 M HCl} =$$
6a.) (7 Points) The maximum wavelength of light which can eject electrons from a tungsten surface is 250 nm. What is the work function, \( \Phi \), for tungsten?

\[ \Phi = \]

b.) (7 Points) What would be the ratio of kinetic energies of electrons ejected from a tungsten surface using 200 nm light to electrons ejected from a tungsten surface using 150 nm light?

\[ \frac{E_{200\ nm}}{E_{150\ nm}} = \]

c.) (6 Points) If a photon with \( \lambda = 250\ nm \) can eject one electron from a tungsten surface, how many electrons will a photon with \( \lambda = 125\ nm \) eject?

\[ \#\ of\ electrons = \]

7.) The dissolution of \( \text{NH}_4\text{NO}_3(s) \) in water is an endothermic process, making it an ideal candidate for use with water in cold packs.

a.) (6 Points) What is \( \Delta H^\circ \) for the dissolution of \( \text{NH}_4\text{NO}_3(s) \)?

\[ \Delta H^\circ = \]

b.) (7 Points) If 0.50 moles of \( \text{NH}_4\text{NO}_3(s) \) are dissolved in 100 mL of \( \text{H}_2\text{O} \), what is the total amount of heat absorbed from the water?

\[ q = \]

c.) (7 Points) If the water is initially at 25 °C, what will be the final temperature of the water?

\[ T = \]
8.) The famous 589 nm ($h\nu = 205 \text{ kJ/mol}^{-1}$) yellow line in sodium arises from an electron initially in an excited state of sodium ([Ne]3p$^1$) falling into the ground state ([Ne]3s$^1$).

a.) (8 Points) If the ionization energy of a sodium atom in the ground state is 494 kJ mol$^{-1}$, what is the ionization energy of an electron in the [Ne]3p$^1$ excited state?

\[
IE_{[Ne]3p^1} =
\]

b.) (6 Points) Would you expect the effective nuclear charge, $Z_{eff}$, that is felt by an electron in a 3s orbital to be higher, lower, or the same as the $Z_{eff}$ felt by an electron in a 3p orbital? Circle your answer.

- Higher
- Same
- Lower

c.) (6 Points) If sodium were ionized such that it had only one electron (Na$^{10+}$), what would be $\Delta E$ for the 3p$^1$ $\rightarrow$ 3s$^1$ transition?

\[
\Delta E =
\]

9.) At 100 °C, H$_2$O(ℓ) is in equilibrium with 1.0 atm of H$_2$O(g).

a.) (6 Points) $\Delta H^\circ$ for the vaporization of water is +44.0 kJ mol$^{-1}$. What is $\Delta S^\circ$ for the vaporization of water at 100 °C? You will receive partial credit for the correct sign.

\[
\Delta S^\circ =
\]

b.) (7 Points) What is $\Delta G^\circ$ for the vaporization of H$_2$O(ℓ) at 25 °C? You will receive partial credit for the correct sign.

\[
\Delta G^\circ =
\]

c.) (7 Points) What is the equilibrium partial pressure of H$_2$O(g) at 25 °C?

\[
\text{Pressure} =
\]
10.) A student uses the method we used in the spectroscopy lab to determine that the masses of chlorophyll A and B in a 1.25 mg sample of lettuce are 6.5x10^{-3} mg and 3.0x10^{-3} mg, respectively.

<table>
<thead>
<tr>
<th>Species</th>
<th>Specific absorbance (L·cm·mg^{-1}) at 425 nm in ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll A</td>
<td>81</td>
</tr>
<tr>
<td>Chlorophyll B</td>
<td>55</td>
</tr>
<tr>
<td>Carotene</td>
<td>60</td>
</tr>
</tbody>
</table>

a.) (8 Points) If the 1.25 mg of lettuce is dissolved in 1.0 L of ethanol, what would be the individual absorbances of chlorophyll A and B in the sample at 425 nm? The path length is 1.0 cm.

\[
A_{\text{chlorophyll A}} = \]

\[
A_{\text{chlorophyll B}} = \]

b.) (4 Points) When the absorbance of the 1.25 mg sample of lettuce in 1.0 L of ethanol is measured, the value of 0.825 suggests that a third compound is contributing to the total absorbance. If this is true, what is the absorbance of the third compound at 425 nm?

\[
A_{\text{3rd component}} = \]

c.) (8 Points) The assumption is made that the mystery third component of the absorbance is carotene, whose specific absorbance is given in the table above. If this assumption is correct, what would be the weight percent of carotene in lettuce? The path length is 1.0 cm.

\[
\text{Weight Percent} = \]
Section 3: Finish the Picture. 8 questions, 10 points each.

For each question in this section, provide the sketch required on the same graph and, if you wish, explain your answer in 20 words or less in the box provided. Your explanation might allow partial credit to be assigned, but may also cost you points if it is incorrect.

1.) Shown below is a plot of $\Delta G$ as a function of the reaction quotient, $Q$, for a process in which the equilibrium constant, $K$, is equal to 3.0. Draw a plot of $\Delta G$ versus $Q$ for a process in which $K = 5.0$.

![Graph of $\Delta G$ versus reaction quotient $Q$.]

**Explanation:**

2.) Shown below is a plot of the partial pressure of $N_2O_4$ versus the partial pressure of $NO_2$ for the following exothermic process at equilibrium with the temperature held at 25 °C:

$$2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$$

Draw a plot of $P_{N_2O_4}$ versus $P_{NO_2}$ at equilibrium at a higher temperature.

![Graph of $P_{N_2O_4}$ versus $P_{NO_2}$.]

**Explanation:**
3. Shown below is a plot of $KE_{\text{electron}}$ versus $\lambda^{-1}$ (where $\lambda$ is the wavelength of the light) for an electron which can be ejected by blue light but not by green light ($\lambda = 500$ nm). Draw a plot of $KE_{\text{electron}}$ versus $\lambda^{-1}$ for an electron which can be ejected by green light, but not red light.

4. Fill in the electron dots for the Lewis electron dot structure of phosphorus trifluoride, PF$_3$.

5. Shown below is chromatogram of a compound with an $R_f$ value of 0.5. Draw a spot at the correct location for a compound with an $R_f = 0.3$. 

**Explanation:**
6.) Shown below is a plot of the distribution of speeds of the molecules in an ideal gas at 25 °C. Draw a plot showing the distribution of speeds of the molecules for the same gas at a temperature lower than 25°C.

7.) Shown below is the interference pattern created when red light is diffracted through two slits. Sketch an interference pattern for green light diffracted through the same two slits.

8.) Shown below is a plot of [Ag⁺] as a function of the moles of AgX(s) added to 1.0 L of water where X = Br⁻. Draw a plot of [Ag⁺] versus AgX(s) added when X = Cl⁻. Note: the K_{sp} for AgCl is 1.6x10^{-10} and the K_{sp} for AgBr is 7.7x10^{-13}.
Ideal Gas:

\[ PV = nRT \]

\[ R = 8.3145 \text{ J/mol} \cdot \text{K}^{-1} \]

\[ R = 0.08206 \text{ L-atm/mol} \cdot \text{K}^{-1} \]

\[ E = \frac{3}{2} nRT \]

\[ u_{\text{rms}} = \sqrt[3]{\frac{RT}{M}} \]

Acids and Bases:

\[ K_w = [H_2O^+][OH^-] = K_aK_b \]

\[ K_w = 1.0 \times 10^{-14} \text{ at } 25 ^\circ \text{C} \]

\[ pK_w = -\log[H_2O^+] \]

\[ pH = pK_a - \log \left( \frac{[HA]}{[A^-]} \right) \]

\[ \Delta H^o = \sum \Delta H^o_{\text{prod}} - \sum \Delta H^o_{\text{react}} \]

\[ \Delta G^o = \sum \Delta G^o_{\text{prod}} - \sum \Delta G^o_{\text{react}} \]

Thermodynamics:

\[ \Delta E_{\text{sys}} = q + w \]

\[ w = -P_{\text{ext}} \Delta V \]

\[ \Delta E_{\text{univ}} = 0 \]

\[ \Delta S_{\text{univ}} \geq 0 \]

\[ \Delta G^o = \Delta H^o - T\Delta S^o \]

\[ \Delta G^o = -RT \ln K \]

\[ \Delta G = \Delta G^o + RT \ln Q \]

\[ \ln K = -\frac{\Delta H^o}{R} \left( \frac{1}{T} \right) + \frac{\Delta S^o}{R} \]

Quantum:

\[ E_{\text{photon}} = h\nu = \frac{hc}{\lambda} \]

\[ h = 6.626 \times 10^{-34} \text{ J-s} \]

\[ m = p = \frac{h}{\lambda} \]

\[ c = 3.00 \times 10^8 \text{ m-s}^{-1} \]

\[ E_n = -\frac{Z^2}{n^2} R_Y \]

\[ R_Y = 1312 \text{ kJ-mol}^{-1} \]

\[ K_{E_{\text{electron}}} = h\nu - \Phi \]

\[ \Delta E_n = -Z^2 \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) R_Y \]

\[ IE = \frac{Z_{\text{eff}}^2}{n^2} R_Y \]

\[ 1 \text{ nm} = 1 \times 10^{-9} \text{ m} \]

\[ A = \varepsilon bc \]

Standard Thermodynamic Parameters (25 °C):

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta H^o ) (kJ·mol(^{-1}))</th>
<th>( S^o ) (J·K(^{-1})·mol(^{-1}))</th>
<th>( \Delta G^o ) (kJ·mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_2\text{O (l)} )</td>
<td>-286</td>
<td></td>
<td>-237</td>
</tr>
<tr>
<td>( \text{H}_2\text{O (g)} )</td>
<td>-242</td>
<td></td>
<td>-228</td>
</tr>
<tr>
<td>( \text{NH}_4\text{NO}_3(s) )</td>
<td>-366</td>
<td>151</td>
<td>-184</td>
</tr>
<tr>
<td>( \text{NH}_4^+(aq) )</td>
<td>-133</td>
<td>113</td>
<td>-79</td>
</tr>
<tr>
<td>( \text{NO}_3^- (aq) )</td>
<td>-205</td>
<td>146</td>
<td>-109</td>
</tr>
<tr>
<td>( \text{C}_2\text{H}_6(g) )</td>
<td>-85</td>
<td>229</td>
<td>-33</td>
</tr>
<tr>
<td>( \text{CH}_3\text{OCH}_3(g) )</td>
<td>-184</td>
<td>266</td>
<td>-113</td>
</tr>
<tr>
<td>( \text{C}_2\text{H}_5\text{OH (l)} )</td>
<td>-278</td>
<td>161</td>
<td>-175</td>
</tr>
</tbody>
</table>

Bond Enthalpies (25 °C):

<table>
<thead>
<tr>
<th>Bond</th>
<th>BE (kJ·mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-C</td>
<td>350</td>
</tr>
<tr>
<td>C-O</td>
<td>350</td>
</tr>
<tr>
<td>O-O</td>
<td>140</td>
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<tr>
<td>H-H</td>
<td>450</td>
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<td>C-H</td>
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<td>O=O</td>
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<tr>
<td>H-Cl</td>
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<tr>
<td>Cl-Cl</td>
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<tr>
<td>F-F</td>
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