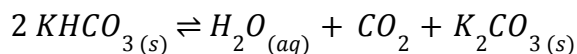


## MEDIUM PACKET 1

## ANSWER KEY

1.  $KHCO_3$  decomposes according to the following equilibrium:



5 g of  $KHCO_3$  were placed into a sealed, 3 L reaction vessel and held at  $90^\circ\text{C}$ . At the point at which no macroscopic change was evident, 4 g of  $KHCO_3$  were present in the vessel. Unreacted  $KHCO_3$  was also present along with gaseous  $H_2O$  and  $CO_2$ . Calculate the unitless equilibrium constant of partial pressures,  $K_p$ , for this reaction at  $90^\circ\text{C}$ . Show all work to support your answer. Given: MW ( $KHCO_3$ ): 84.007 g/mol ; MW ( $K_2CO_3$ ): 105.99 g/mol. Assume all gases are ideal.

$$4g \cdot \frac{1\text{mol}}{105.99} = 0.037739 \text{ moles of } K_2CO_3 = \text{moles } H_2O = \text{moles } CO_2$$

$$PV = nRT \quad P = \frac{nRT}{V} = \frac{0.037739(0.08206)(90+273)}{3}$$

$$P = 0.3747 \text{ atm}$$

$$K_p = (0.3747)^2 = 1.404 \times 10^{-1}$$

$$1.4 * 10^{-1}$$

2. The heat of dissolution of ammonium chloride is  $+14.8 \text{ kJ/mol}$ . How many grams of ammonium chloride must be dissolved to raise 20 mL of water by  $5^\circ\text{C}$ ? The molar mass of ammonium chloride is 53.49 g/mol.

$$\text{Heat required to heat } H_2O \text{ by } 5^\circ\text{C} = (20 \text{ g})(4.184 \frac{\text{J}}{\text{g}^\circ\text{C}})(5) = 418.4 \text{ J} = 0.4184 \text{ kJ}$$

$$\frac{0.4184 \text{ kJ}}{14.8 \text{ k/mol}} = 0.0283 \text{ moles ammonium chloride required}$$

$$0.0283 \text{ moles ammonium chloride} = 0.0283 \text{ mol} * 53.49 \text{ g/mol} = 1.5 \text{ g ammonium chloride}$$

3. 100 mL of a 0.10 M solution of  $NaOH_{(aq)}$  is added to 25 mL of a 0.30 M solution of  $HClO_{3(aq)}$  with the temperature maintained at  $25^\circ\text{C}$ . After the reaction is complete, what is the concentration (in M) of  $OH^-_{(aq)}$  in the solution? What is the pH of this final solution? Is the resulting solution acidic or basic?

$$n(OH^- \text{ added}) = 0.1 \text{ L} \times 0.1 \text{ M} = 0.01 \text{ mol}$$

$$n(H^+ \text{ added}) = 0.025 \text{ L} \times 0.3 \text{ M} = 0.0075 \text{ mol}$$

$$n(OH^- \text{ remaining}) = 0.01 \text{ mol} - 0.0075 \text{ mol} = 0.0025 \text{ mol}$$

$$V = 0.125 \text{ L}$$

$$[OH^-] = \frac{0.0025 \text{ mol}}{0.125 \text{ L}} = 0.02 \text{ M}$$

$$pOH = -\log(0.02) = 1.7$$

$$pH = 14 - 1.7 = 12.3$$

## MEDIUM PACKET 2

## ANSWER KEY

1. In the lab, you need to synthesize a buffer solution with a pH of 9.45. You need to use  $NH_4Cl$ , which has a  $K_a = 5.6 \times 10^{-10}$ . What ratio of conjugate base to conjugate acid will need to be used?

$$pK_a = -\log(K_a) = -\log(5.6 \times 10^{-10}) = 9.2518$$

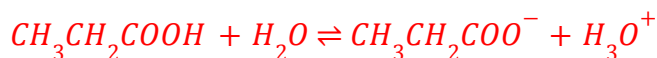
$$pK_a = pH - \log_{10}\left(\frac{[HA]_o}{[A^-]_o}\right)$$

$$9.2518 = 9.45 - \log_{10}\left(\frac{[NH_4^+]_o}{[NH_3]_o}\right)$$

$$\frac{[NH_4^+]_o}{[NH_3]_o} = 1.5783$$

$$\frac{[NH_3]_o}{[NH_4^+]_o} = 0.6336 \quad \text{Ratio of conjugate base } (NH_3) \text{ to conjugate acid } (NH_4^+)$$

2. Propionic acid ( $CH_3CH_2COOH$ ) is a weak acid, with  $K_a = 1.34 \times 10^{-5}$  at  $25^\circ C$ . It reacts with water as follows:  $CH_3CH_2COOH + H_2O \rightleftharpoons CH_3CH_2COO^- + H_3O^+$ .
- a. Calculate the pH at equilibrium of a 0.35 M aqueous solution of propionic acid at  $25^\circ C$ .



I	0.35	0	0
C	-x	+x	+x
E	0.35-x	x	x

$$K_a = \frac{[CH_3CH_2COO^-][H_3O^+]}{[CH_3CH_2COOH]} = \frac{x^2}{0.35-x} = 1.34 \times 10^{-5}$$

Solve by successive approximations

$$\frac{x^2}{0.35} = 1.34 \times 10^{-5}$$

$$x = 2.16 \times 10^{-3} M$$

$$pH = -\log(2.16 \times 10^{-3}) = 2.66$$

- b. Calculate the percent dissociation of propionic acid in this solution.

$$\% \text{ dissociation} = \frac{[H_3O^+]_{eq}}{[CH_3CH_2COOH]_{initial}} \times 100\% = \frac{2.16 \times 10^{-3} M}{0.35 M} \times 100\% = 0.62\%$$

## MEDIUM PACKET 3

## ANSWER KEY

1. A solution of sulfuric acid is prepared by dissolving 0.51 g of 98% (by mass) sulfuric acid in 30 mL of  $H_2O$ . How many grams of  $NaOH$  are required to fully neutralize this solution? The molar mass of sulfuric acid is 98.07 g/mol, and the molar mass of  $NaOH$  is 40.0 g/mol.

$$0.51 \text{ g of 98\% sulfuric acid} = 0.50 \text{ g sulfuric acid} = 0.0051 \text{ moles sulfuric acid}$$
$$2(0.0051 \text{ moles NaOH}) = 2(0.0051 \text{ moles})(40.0 \text{ g/mol}) = 0.408 \text{ g NaOH}$$

2. The energy required to excite thiophene to its first excited state is approximately 5.3 eV. Determine the wavelength (in nm) of the photon required to excite thiophene to its first excited state.

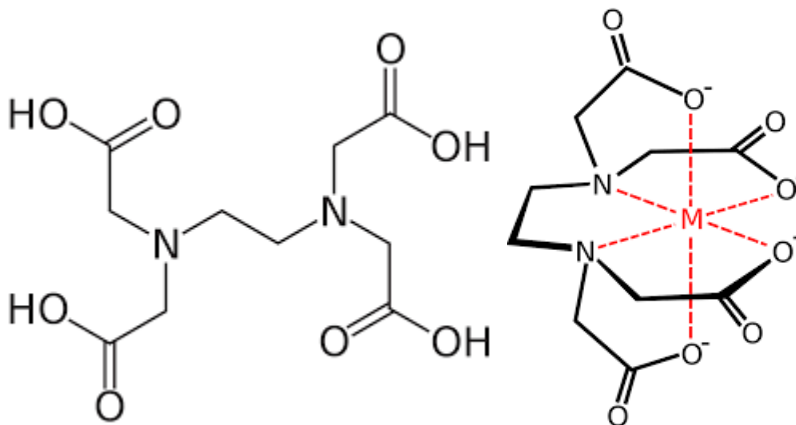
$$5.3 \text{ eV} = 8.49 \times 10^{-19} \text{ J}$$

$$\frac{hc}{\lambda} = 8.49 \times 10^{-19} \text{ J}$$

$$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34})(2.998 \times 10^8)}{8.49 \times 10^{-19}} = 2.34 \times 10^{-7} \text{ m}$$

$$\lambda = 234 \text{ nm}$$

3. EDTA is a commonly used chelator. In which environment do you think it works the best?



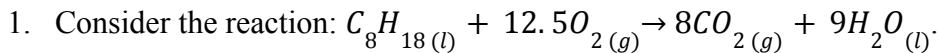
Left: EDTA. Right: EDTA binding to a metal ion.

- Acidic
- Neutral
- Basic

C

# MEDIUM PACKET 4

# ANSWER KEY



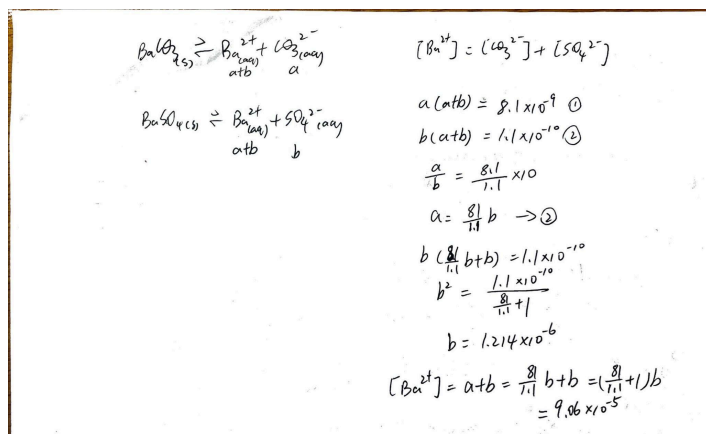
$\Delta H^\circ = -5461 \text{ kJ/mol}$ . Which of the following will make its enthalpy change increase (i.e.  $\Delta H^\circ$  becomes more negative)?

- Replace  $C_8H_{18(l)}$  with  $C_8H_{18(g)}$
- Replace  $H_2O_{(l)}$  with  $H_2O_{(g)}$
- Replace  $C_8H_{18(l)}$  with  $C_8H_{18(s)}$
- Replace  $O_{2(g)}$  with  $O_{2(l)}$

**A**

2. Excess  $BaCO_3$  and  $BaSO_4$  solids are soaked in 1L pure water, and equilibrium is established. Calculate  $[Ba^{2+}]$ . Assume zero volume change, and ignore the effect of any ions on the ionization of water. Given:  $K_{sp}(BaCO_3) = 8.1 \times 10^{-9}$ ;

$$K_{sp}(BaSO_4) = 1.1 \times 10^{-10}$$



**9.06\*10<sup>-5</sup>**

3. If 54 g argon at 400 K is compressed isothermally and reversibly from a pressure of 1.5 atm to 4 atm, calculate the work done on the gas (w) and the heat absorbed by gas (q) in the process.

For an isothermal process,  $\Delta U = 0$ .

$$w = -nRT \ln(V_2/V_1) = -nRT \ln(P_1/P_2)$$

$$w = - (54 \text{ g}) \left( \frac{1 \text{ mol}}{39.95 \text{ g}} \right) (8.314 \frac{\text{J}}{\text{mol K}}) (400 \text{ K}) \left( \ln \frac{1.5 \text{ atm}}{4 \text{ atm}} \right) = 4409 \text{ J}$$

$$0 = q + w$$

$$q_{\text{rev}} = -w_{\text{rev}} = -4409 \text{ J}$$

## MEDIUM PACKET 5

## ANSWER KEY

1. The table below contains weak acid/conjugate base pairs.

a. Fill in the blanks of the table shown below where information is missing.

Acid Name	Acid Formula	$K_a$	$pK_a$	Conjugate Base
Formic acid	$HCOOH$	$1.77 \times 10^{-4}$	3.75	$HCOO^-$
Acetic acid	$CH_3COOH$	$1.76 \times 10^{-5}$	4.75	$CH_3COO^-$
Carbonic acid	$H_2CO_3$	$4.3 \times 10^{-7}$	6.37	$H_2CO_3^-$
Oxalic acid	$H_2C_2O_4$	$5.9 \times 10^{-2}$	1.23	$H_2C_2O_4^-$

b. Choose the most appropriate pair to make a buffer with a desired pH of 3.5.

Need a buffer with a final pH of 3.5, so choose an acid with a  $pK_a$  around that value

To calculate  $pK_a$ :  $pK_a = -\log(K_a)$

Formic acid is the best choice ( $pK_a = 3.75$ )

c. Determine the ratio of acid to conjugate base needed in your buffer.

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

$$3.5 = 3.75 - \log\left(\frac{[HCOOH]}{[HCOO^-]}\right)$$

$$0.25 = \log\left(\frac{[HCOOH]}{[HCOO^-]}\right)$$

$$\left(\frac{[HCOOH]}{[HCOO^-]}\right) = 10^{0.25} = 1.78$$

Need 1.78 times as much  $HCOOH$  as  $HCOO^-$

## MEDIUM PACKET 6

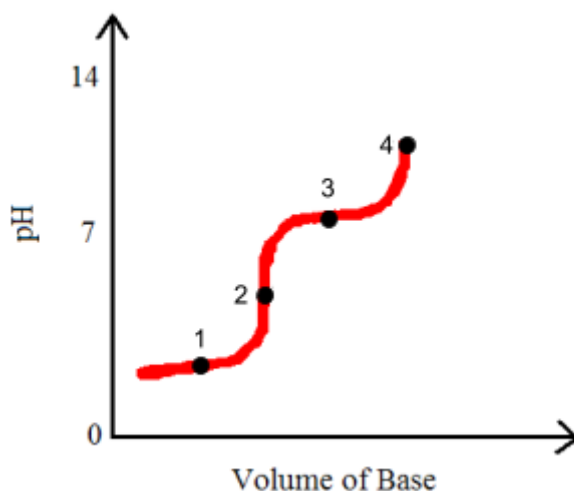
## ANSWER KEY

1. A solution of  $Ba(OH)_2$  is standardized with potassium acid phthalate (abbreviated KHP),  $KHC_8H_8O_4$  (MM = 204). If 1.530 g of KHP is titrated with 34.50 mL of the  $Ba(OH)_2$  solution, what is the molarity of  $Ba(OH)_2$ ?



$$\frac{1.53 \text{ KHP} \times \frac{1 \text{ mol KHP}}{204 \text{ g KHP}} \times \frac{1 \text{ mol Ba(OH)}_2}{2 \text{ mol KHP}}}{34.50 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}} = 0.109 \text{ M Ba(OH)}_2$$

2. A solution of sulfurous acid,  $H_2SO_3$ , is titrated with a solution of sodium hydroxide to produce a curve similar to the one shown.



Give the formulas of the major species present at points 1-4 on the titration curve.

1.  $H_2SO_3$  and  $HSO_3^-$       2.  $HSO_3^-$       3.  $HSO_3^-$  and  $SO_3^{2-}$       4.  $SO_3^{2-}$

3. Solutions of 100 mL of 0.200 M  $NaCl_{(aq)}$  and 75 mL of 0.100 M  $MgCl_{2(aq)}$  are mixed together in a flask. Calculate the molarity of the chloride ion ( $Cl^-$ ) in the final solution.

$$(0.200 \text{ M } Cl^-) * (0.100 \text{ L}) = 0.020 \text{ mol } Cl^-$$

$$(2 * 0.100 \text{ M } Cl^-) * (0.075 \text{ L}) = 0.015 \text{ mol } Cl^-$$

$$0.020 \text{ mol } Cl^- + 0.015 \text{ mol } Cl^- = 0.035 \text{ mol } Cl^-$$

$$100 \text{ mL} + 75 \text{ mL} = 175 \text{ mL} = 0.175 \text{ L}$$

$$0.035 \text{ mol } Cl^- / 0.175 \text{ L} = 0.200 \text{ M}$$

# MEDIUM PACKET 7

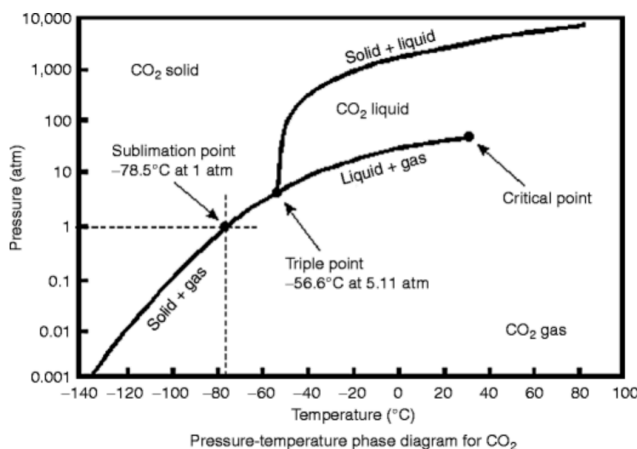
# ANSWER KEY

1. For the following elements, give the orbital from which the second ionization energy will remove the outermost electron from.

Mg: \_\_\_\_\_ Al: \_\_\_\_\_ Na: \_\_\_\_\_ P: \_\_\_\_\_

Mg: 2p Al: 3s Na: 2p P: 3p

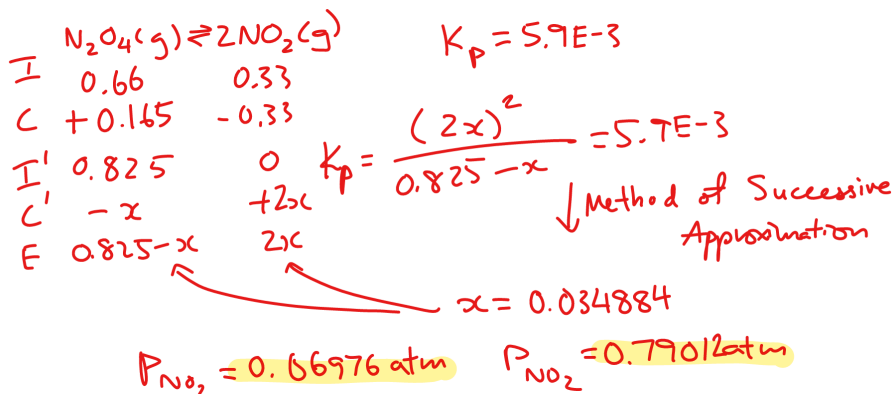
2. Given the phase diagram for  $CO_2$  below, what are the phase changes in order as  $CO_2$  is cooled from  $40^\circ C$  to  $-70^\circ C$ , at 200 atm pressure?



Supercritical fluid  $\rightarrow$  liquid  $\rightarrow$  solid

3. Consider the balanced chemical reaction:  $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

The equilibrium constant,  $K_p$ , for this reaction at 500 K is equal to  $5.9 \times 10^{-3}$ . If 0.660 atm of  $N_2O_4$  and 0.330 atm of  $NO_2$  are sealed in a reaction vessel at 500 K, determine the equilibrium partial pressures (in atm) of the two gases.



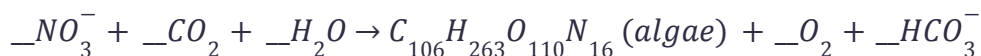
P  $N_2O_4$ : 0.66976 atm

P  $NO_2$ : 0.79012 atm

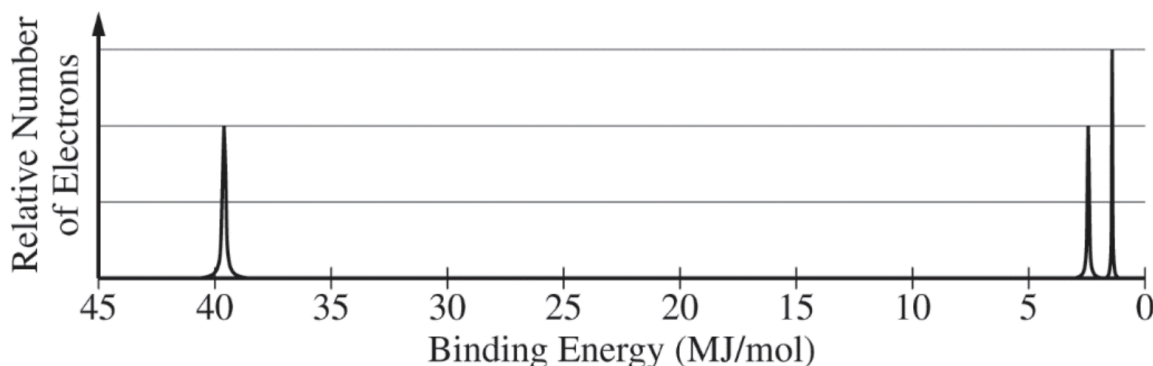
## MEDIUM PACKET 8

## ANSWER KEY

1. American oceanographer Alfred C. Redfield proposed the famous Redfield Ratio, which states that in healthy sea areas, the molar ratio of phytoplanktonic carbon, oxygen, nitrogen, and phosphorus remains relatively constant. This discovery drove the development of ecological stoichiometry. Balance the reaction below describing the phytoplanktonic assimilation of nitrate. Note: you may have decimal coefficients because the coefficient of algae is set to be 1.



2. Consider the photoelectron spectrum of nitrogen below. If a radioactive isotope decays with a half-life of 8.0 minutes, what is the rate constant,  $k$ ?

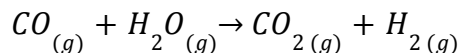


$$t_{1/2} = 0.693 / k$$

$$8 \text{ minutes } (*60 \text{ s} / 1 \text{ min}) = 480 \text{ seconds}$$

$$480 \text{ s} = 0.693 / k \rightarrow k = 0.693 / 480 = 0.0014 \text{ s}^{-1}$$

3. Find the  $\Delta H^\circ$  of the reaction below.



	Bond enthalpy in kJ/mol
C—O in carbon monoxide	+1077
C—O in carbon dioxide	+805
O—H	+464
H—H	+436

$$\Delta H = (\text{bonds broken}) - (\text{bonds formed})$$

$$= (2*464 + 1077) - (2*805 + 436)$$

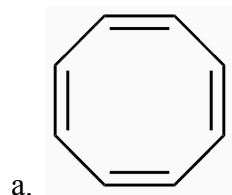
$$= 2005 - 2046 = -41 \text{ kJ/mol}$$



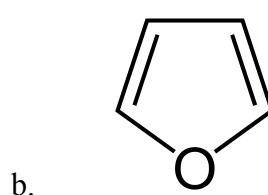
## MEDIUM PACKET 9

## ANSWER KEY

1. Given the following molecules, tell if each of them is aromatic, non-aromatic, or antiaromatic. For the aromatic or antiaromatic compounds, please indicate the number of pi-electrons it has.

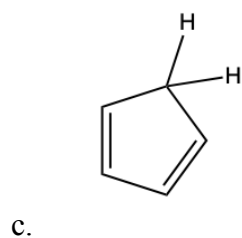


**Key: antiaromatic, 8 pi-electrons**

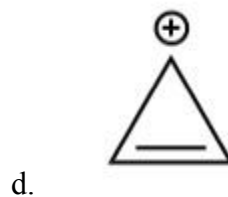


**Key: Aromatic**

**Number of pi-electron: 6**

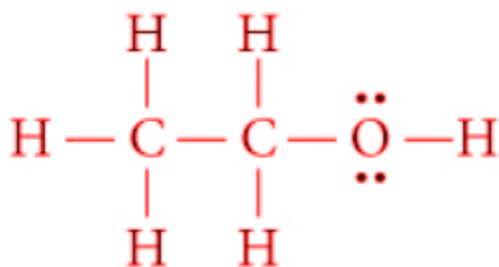


**Key: Non-aromatic**

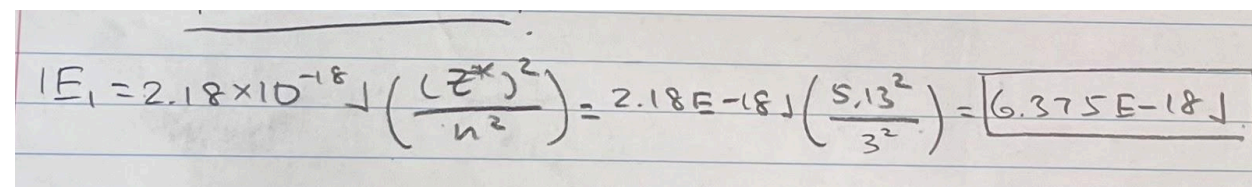


**Key: Aromatic, 2 pi-electrons**

2. Draw out the Lewis-dot structure for  $CH_3CH_2OH$ .



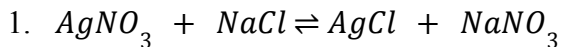
3. Calculate the minimum energy needed to eject a valence electron from a neutral silicon atom in the ground state, given that the  $Z^*$  for its outermost valence electron is 5.13. Show all work to support your circled answer.


$$|E_1| = 2.18 \times 10^{-18} \text{ J} \left( \frac{(Z^*)^2}{n^2} \right) = 2.18 \times 10^{-18} \text{ J} \left( \frac{5.13^2}{3^2} \right) = \boxed{6.375 \times 10^{-18} \text{ J}}$$

**6.37 \* 10<sup>-18</sup> J**

## MEDIUM PACKET 10

## ANSWER KEY



Given that the  $K_{sp}$  of  $AgCl$  is  $1.6 \times 10^{-10}$  at room temperature, and assuming the solution contained 0.4 M of  $Cl^-$  initially, what is the concentration of silver ions dissolved in the water at equilibrium? Express your answer in molarity.

$$K_{sp} = [Ag^+][Cl^-] = 1.6 \times 10^{-10}$$

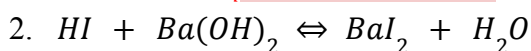


I	Excess	0	0.4M
C	-x	+x	+x
E	Excess	x	0.4+x

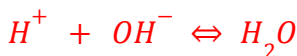
Therefore, the  $K_{sp}$  can be expressed as  $x(0.4+x) = 1.6 \times 10^{-10}$

Solve for x using the quadratic formula

$$x = [Ag^+]_{eq} = 4 \times 10^{-10} M$$



Write up the net ionic equation for this reaction. Assuming at the end of the reaction, the concentration of  $OH^-$  in the solution is  $5.2 \times 10^{-8}$  M. Calculate the pH value for the product mixture.



$$pOH = -\log([OH^-]) = -\log(5.2 \times 10^{-8}) = 7.284$$

$$pH = 14 - pOH = 14 - 7.284 = 6.716$$

3. Calculate the wavelength of light (in nm) required to eject the outermost electron from a Cu atom in its ground state with zero kinetic energy, if that electron has a  $Z^*$  of 16.40. Show all work to support your circled answer.

Handwritten work for problem 3:

$$|E_1| = 2.18 \times 10^{-18} J \left( \frac{Z^{*2}}{n^2} \right) = 2.18 \times 10^{-18} J \left( \frac{16.4^2}{4^2} \right) = 3.665 \times 10^{-17} J$$
$$E_{ph} = |E_1| = \frac{hc}{\lambda}$$
$$\lambda = \frac{hc}{|E_1|} = \frac{(6.626 \times 10^{-34} J \cdot s)(2.998 \times 10^8 m/s)}{3.665 \times 10^{-17} J} = 5.42 \times 10^{-9} m = \underline{5.42 nm}$$

5.42 nm

## MEDIUM PACKET 11

## ANSWER KEY

1. Find the order of  $[S_2O_8^{2-}]$  in the following rate law:

$$\text{Rate} = k [S_2O_8^{2-}]^m [I^-]^n$$

Utilize the following table:

	$[S_2O_8^{2-}]$	$[I^-]$	Rate
Trial 1	$3.657 \times 10^{-2} M$	$4.523 \times 10^{-1} M$	$4.931 \times 10^{-1} \frac{M}{s}$
Trial 2	$7.314 \times 10^{-2} M$	$4.523 \times 10^{-1} M$	$9.861 \times 10^{-1} \frac{M}{s}$

The reaction is **first order** with respect to  $[S_2O_8^{2-}]$ .

$$\frac{\text{Rate 2}}{\text{Rate 1}} = \frac{9.861 \times 10^{-1} \frac{M}{s}}{4.931 \times 10^{-1} \frac{M}{s}} = 1.994$$

$$\frac{[S_2O_8^{2-}]^m}{[S_2O_8^{2-}]^m} = 2^m = 1.994$$

$$m = 0.996 \approx 1$$

2.  $NO_2$  tends to dimerize:  $2NO_2 \rightleftharpoons N_2O_4$ .  $\alpha = [NO_2]/[N_2O_4]$ . Equilibrium is reached in a vessel at some temperature starting with some  $NO_2$ , where the percent concentration of  $NO_2$  is  $\alpha_1$ . If some  $N_2O_4$  is then pumped into this vessel without changing the volume and temperature, after equilibrium is reached again, the percent concentration of  $NO_2$  is  $\alpha_2$ . Which of the following is true?

- A.  $\alpha_1 > \alpha_2$
- B.  $\alpha_1 < \alpha_2$
- C.  $\alpha_1 = \alpha_2$
- D. The relationship of  $\alpha_1$  and  $\alpha_2$  cannot be determined.

**A**

3. Consider a sample of  $CO_2$  gas in a rigid container at 299 K and 0.80 atm that you increase to 414 K. Find the pressure of the gas after the temperature is raised.

$$P_1/T_1 = P_2/T_2$$

$$(0.80 \text{ atm}) / (299 \text{ K}) = (P_2) / (414 \text{ K})$$

$$P_2 = 1.11 \text{ atm}$$

## MEDIUM PACKET 12

## ANSWER KEY

1. An electron is confined to a 3-D box with dimensions  $L_x = 4.0 \text{ \AA}$ ,  $L_y = 2.0 \text{ \AA}$ , and  $L_z = 5.0 \text{ \AA}$ . Using the particle-in-a-box model, answer the following questions. a. Calculate the zero-point energy (in J) for this electron. Show all work to support your circled answer.

$$KE_{111} = \frac{h^2}{8m} \left( \frac{n_x^2}{L_x^2} + \frac{n_y^2}{L_y^2} + \frac{n_z^2}{L_z^2} \right)$$

$$= \frac{(6.626 \times 10^{-34} \text{ s})^2}{8 \cdot 9.11 \times 10^{-31} \text{ kg}} \left( \frac{1}{(4 \times 10^{-10})^2} + \frac{1}{(2 \times 10^{-10})^2} + \frac{1}{(5 \times 10^{-10})^2} \right)$$

$$= \boxed{2.1235 \times 10^{-18} \text{ J}}$$

$2.12 \times 10^{-18} \text{ J}$

2. A 0.34 M aqueous solution of the monoprotic weak acid acrylic acid,  $C_2H_3COOH$ ,  $C_2H_3COOH$  at  $25^\circ\text{C}$  has a percent dissociation of 2.86% after equilibrium is established. Given: 0.34 M is the initial concentration. Using this information, answer the following questions. Determine the pH of the solution after equilibrium is established. Circle your final answer and show all your work.

$$\frac{[A^-]_{eq}}{[HA]_0} = 0.0286$$

$$\frac{[A^-]_{eq}}{0.34} = 0.0286$$

$$[A^-]_{eq} = 9.724 \times 10^{-3} = [H_3O^+]_{eq}$$

$$pH = -\log [H_3O^+]_{eq} = \boxed{2.0122}$$

$2.0122$

3. X has a heat of vaporization of 52.3 kJ/mol at its normal boiling point ( $421^\circ\text{C}$ ). Calculate the  $\Delta G$  (in kJ) of  $X(l) \rightarrow X(g)$  at  $430^\circ\text{C}$  and 1 atm. Assume that the heat of vaporization and the entropy of vaporization are constant. (Round to 3 decimal places).

$$\Delta S_{vap}^\circ = \frac{\Delta H_{vap}^\circ}{T_b^\circ} = \frac{52.3 \times 10^3 \text{ J/mol}}{421 + 273.15 \text{ K}} = 75.34394583 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\Delta G = \Delta H_{vap}^\circ - T \times \Delta S_{vap}^\circ = 52.3 \times 10^3 \text{ J/mol} - 703.15 \text{ K} \times 75.34394583 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\Delta G = -0.678 \text{ kJ}$$

## MEDIUM PACKET 13

## ANSWER KEY

1.  $\text{CH}_3\text{COOH}$  is a monoprotic weak acid with a  $\text{pK}_a$  of 4.76. Calculate the pH of 0.10 M  $\text{CH}_3\text{COOH}$  aqueous solution at  $25^\circ\text{C}$ .



I	0.10	0	0
C	-x	+x	+x
E	0.10-x	x	x

$$x^2/0.10-x = 10^{-4.76}$$

$$x = 0.00130 \text{ M}$$

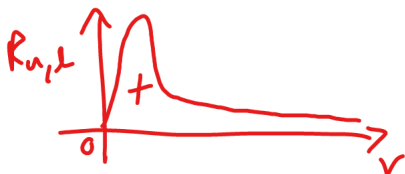
$$\text{pH} = -\log(0.00130) = \mathbf{2.9}$$

2. Consider the following radial wavefunction for the H atom:

$$R_{n, \ell} = \frac{1}{2\sqrt{6}} \left[ \frac{Z}{a_0} \right] \sigma \text{ where } \sigma = \frac{Zr}{a_0}$$

Sketch the following radial wavefunction for the H atom. Be sure to quantitatively identify nodes (if any) on your sketch.

Answer:



3. Calculate the entropy change of 1.5 mol of an ideal gas for the following process.

$$T_i = 81 \text{ K}, V_i = 10 \text{ L}, P_i = 1 \text{ atm}$$

$$T_f = 300 \text{ K}, V_f = 37 \text{ L}, P_f = 1 \text{ atm}$$

$$\Delta S = n c_p \ln\left(\frac{T_2}{T_1}\right) = 1.5 \text{ mol} \left(\frac{5}{2}\right) \left(\frac{8.314 \text{ J}}{\text{mol K}}\right) \ln\left(\frac{300 \text{ K}}{81 \text{ K}}\right) = \mathbf{40.8 \frac{J}{K}}$$

## MEDIUM PACKET 14

## ANSWER KEY

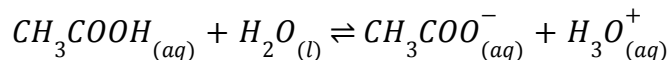
1. What is the mass percent of oxygen in  $Al_2(SO_4)_3 \cdot 18H_2O$ ?

$$30 \text{ O molecules} * 16 \text{ g/mol} = 480 \text{ g/mol}$$

$$480/666.43 = 72.0\%$$

2. Using the thermodynamic data given below:

a. Determine if the reaction is spontaneous in the forward direction at 25°C under standard conditions. Given:  $\Delta G_{rxn}^{\circ} = 27.2 \text{ kJ/mol}$  at 298 K.



	$\Delta H_f^{\circ}$ (kJ/mol)
$H_3O^{+}_{(aq)}$	-285.8
$CH_3COO^{-}_{(aq)}$	-486.1
$CH_3COOH_{(aq)}$	-485.8
$H_2O_{(l)}$	-285.8

No because delta G is greater than zero.

b. Is there a temperature that would make the forward reaction spontaneous? Hint:

calculate  $\Delta S_{rxn}^{\circ}$ .

$$\Delta H_{rxn}^{\circ} = (-486.1 \text{ kJ/mol}) + (-285.8 \text{ kJ/mol}) - (-485.8 \text{ kJ/mol}) - (-285.8 \text{ kJ/mol})$$

$$\Delta H_{rxn}^{\circ} = -0.3 \text{ kJ/mol}$$

$$27.2 \text{ kJ/mol} = -0.3 \text{ kJ/mol} - (298\text{K})\Delta S_{rxn}^{\circ}$$

$$\Delta S_{rxn}^{\circ} = -92.3 \text{ J/mol}$$

$$\Delta G_{rxn}^{\circ} = \Delta H_{rxn}^{\circ} - T\Delta S_{rxn}^{\circ}$$

$$\text{Set } \Delta G_{rxn}^{\circ} = 0$$

$$T = \frac{-0.3 \text{ kJ/mol}}{-92.3 \text{ J/mol}} = 3.25 \text{ K}$$