

# *Chemistry 1A, Fall 2006*

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## Final Exam, Version B

Dec 12, 2006

(180 min, closed book)

Name: \_\_\_\_\_

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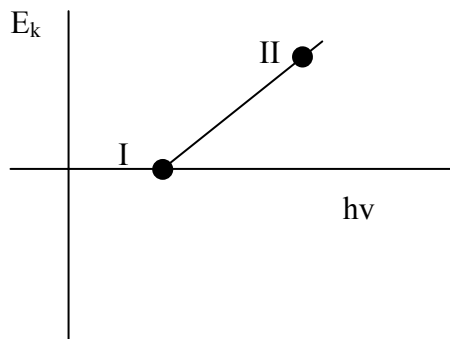
- There are 60 Multiple choice questions worth 4.34 points each.
- There are 13 short answer questions.
- For the multiple choice section, fill in the Scantron form AND circle your answer on the exam.
- Put your final answers in the boxes provided. Answers outside the boxes may not be considered in grading.
- The homework and chemquizzes that each question is based upon is listed after the question e.g. [HW 1.13, CQ 7.3]

Question	Page	Points	Score
Question 61 - 63	14	22	
Question 64 - 67	15	28	
Question 69 – 69	16	12	
Question 70-72	17	12	
Question 72 – 73	18	16	
Total		90	

1.) Which is a possible electronic configuration for  $O^+$ ?

- A)  $1s^2 2s^2 2p^4$
- B)  $1s^2 2s^2 2p^2 3s^1$
- C)  $1s^2 2s^2 2p^6 3s^1$
- D)  $1s^2 2s^2 2p^5$
- E) None of these

2.) The following is a plot of electron kinetic energy vs. photon energy for the interaction of photons and oxygen atoms. What does point 'I' represent?



- A) electronegativity of O
- B) electron affinity of O
- C)  $1s^2 2s^2 2p^2 3s^1$
- D) atomic radius of O
- E) photons emitted by O

3.) In a one mole sample of carbon atoms, how many protons are in each nucleus?

- A) 5    **B) 6**    C) 7    D) 8    E) cannot be determined

4.) In a one mole sample of carbon atoms, how many neutrons are in each nucleus?

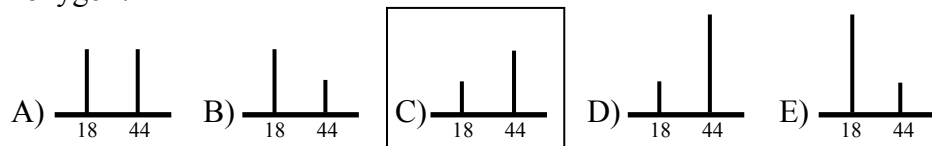
- A) 5    B) 6    C) 7    D) 8    **E) cannot be determined**

5.) What is the minimum energy (J) required to eject an electron from chromium metal?  
The work function for chromium metal is  $7.00 \times 10^{-19}$  J. [HW 1.14]

- A)  $7.00 \times 10^{-19}$
- B)  $1.41 \times 10^{-18}$
- C)  $2.11 \times 10^{-12}$
- D)  $4.45 \times 10^{-23}$
- E)  $8.11 \times 10^{-18}$

- 6.) What wavelength radiation (nm) must be used to eject electrons from chromium metal with a velocity of  $1.50 \times 10^6$  m/s? The work function for chromium metal is  $7.00 \times 10^{-19}$  J. [HW 1.14]
- A) 4.67  
 B) 23.4  
 C) 101  
 D) 512  
 E)  115
- 7.) What energy (in Rydbergs) is required to excite an  $\text{He}^{+1}$  ion from its ground state to its first excited state? [HW 1.23, 1.25]
- A) 14  
 B) 25  
 C) 101  
 D)  3  
 E) 87
- 8.) How many electrons in an atom can have the quantum numbers  $n=5, l=2$ ? [HW 1.53]
- A) 1                      B) 2                      C) 6                       D) 10                      E) 32
- 9.) Which statement is true for many electron atoms? [HW 1.59, discussion]
- A)  's' electrons shield more efficiently than 'p' electrons.  
 B) The effective nuclear charge is independent of the number of electrons in an atom.  
 C) Electrons with  $l=2$  are better at shielding than those with  $l=1$ .  
 D) Electrons may share the same set of quantum numbers for short times.  
 E) Electrons cannot share orbitals.
- 10.) Which neutral element would have the ground state electronic configuration  $[\text{Ne}]3s^23p^5$ ? [HW 1.67]
- A) O                       B) Cl                      C) Ar                      D) P                      E) Al
- 11.) What is the arrangement of the following atoms in order of *decreasing* atomic radius? Sulfur (S), Chlorine (Cl), Silicon (Si) [HW 1.82]
- A) S, Cl, Si  
 B) Si, Cl, S  
 C) Cl, S, Si  
 D)  
 E) S, Si, Cl

12.) Which would be the mass spectrum of the products when acetylene ( $C_2H_2$ ) is burned in oxygen?



13.) What is the formal charge on the oxygen atom in the ONF molecule? [HW 2.33, 2.43]

- A) -2      B) -1      **C) 0**      D) +1      E) +2

14.) What is the shape of the ONF molecule? [HW 2.33, 3.7]

- A) Linear  
 B) **Bent**  
 C) Trigonal planar  
 D) Trigonal pyramid  
 E) Tetrahedral

15.) Which intermolecular forces are important in liquid ONF? [HW 5.1]

- I: Dispersion / VanderWaals forces  
 II: Dipole-dipole forces  
 III: Hydrogen bonding

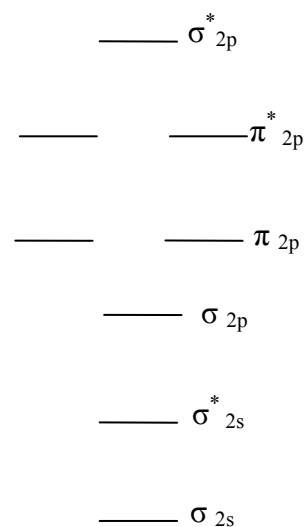
- A) I only      B) II only      C) III only      **D) I and II**      E) I, II and III

16.) What is the I-I-I bond angle in  $I_3^-$ ? [HW 3.9]

- A) 60      B) 90      C) 109      D) 120      **E) 180**

17.) Which of the following is most paramagnetic? [HW 3.47]

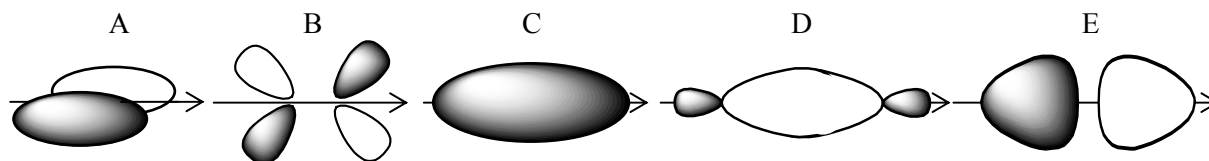
- A)  $F_2$   
 B)  $F_2^-$   
 C)  **$F_2^{+2}$**   
 D)  $F_2^+$   
 E)  $F_2^{-2}$



18.) What is the hybridization of sulfur in SF<sub>4</sub>? [HW 3.33]

- A) sp
- B) sp<sup>2</sup>
- C) sp<sup>3</sup>
- D)  dsp<sup>3</sup>
- E) d<sup>2</sup>sp<sup>3</sup>

Use the table of molecular orbitals for a diatomic molecule to answer questions 19 – 22  
The arrow indicate the internuclear axis.



19.) Which antibonding orbital would form between atomic s orbitals?

- A) A
- B) B
- C) C
- D) D
- E)  E

20.) Which sigma bonding orbital would form between atomic p orbitals?

- A) A
- B) B
- C) C
- D)  D
- E) E

21.) Which is a  $\pi$  molecular bonding orbital?

- A)  A
- B) B
- C) C
- D) D
- E) E

22.) Which is the highest energy orbital?

- A) A
- B)  B
- C) C
- D) D
- E) E

For questions 23 – 27, consider a mixture of four gases, Kr, He, Ne, and Ar in a closed 10 L container. There are 10 grams of each gas present.

23.) Which gas has the highest partial pressure?

- A) Kr
- B) Ne
- C)  He
- D) Ar
- E) all are equal

24.) Which particles have the highest rms velocity?

- A) Kr
- B) Ne
- C)  He
- D) Ar
- E) all are equal

25.) Which particles have the highest average kinetic energy?

- A) Kr
- B) Ne
- C) He
- D) Ar
- E)  all are equal

26.) If the partial pressure of He is 2.0 atm, what is the temperature of the system?

- A)  98K
- B)  270K
- C)  323K
- D)  440K
- E)  60K

27.) If the temperature is doubled which is true of the energy of the system?

- A)  The energy doubles.
- B)  The energy increases by a factor of  $2^{1/2}$ .
- C)  The energy decreases by a factor of 2.
- D)  The energy increases but the factor cannot be determined.
- E)  The energy decreases but the factor cannot be determined.

Continue with the next question:

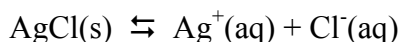
28.) What is the change in internal energy of a gas undergoing the following process? A gas sample is heated in a cylinder by supplying 524 J of heat while a piston compresses the gas by doing 313 J of work. [HW 6.5]

- A)  +211 J
- B)  -211 J
- C)  +837 J
- D)  -837 J
- E)  0 J

29.) Estimate the boiling point of dimethyl ether using Trouton's rule which states that the entropy of vaporization of most liquids is about 90 J/K mol. The enthalpy of vaporization of dimethyl ether is 21.51 kJ/mol. [HW 7.16]

- A)  273K
- B)  425K
- C)  239K
- D)  310K
- E)  70K

30.) Which of the following will result in a change in the solubility of AgCl for the reaction shown (assume  $K_{sp}$  for AgCl is  $\sim 10^{-8}$ )?



- A)  Addition of NaCl
- B)  Heating the reaction vessel
- C)  Addition of AgCl
- D)  A & B but not C
- E)  A, B, & C

For questions 31-36, consider the reaction  $C(s, \text{graphite}) \rightleftharpoons C(s, \text{diamond})$ . Solid graphite is the standard state of carbon.  $\Delta G^\circ_f$  for  $C(s, \text{diamond})$  is +2.90 kJ/mol. The standard molar entropy for graphite is 5.70 J/K mol, and for diamond is 2.38 J/K mol. All values are for 298K.

31.) What is  $\Delta G^\circ$  (kJ/mol) for the reaction?

- A)  +2.90 *All answers were accepted on all versions due to the typo.*
- B)  -2.38
- A)  +5.70
- B)  +3.32
- C)  -3.32

32.) What is the equilibrium constant for the reaction at 298K?

- A)  43
- B)   $1.1 \times 10^5$
- C)   $3.1 \times 10^{-1}$
- D)  2.3
- E)   $9.7 \times 10^{-3}$

33.) Which is thermodynamically more stable and why?

- A)  Graphite, because it has a higher molar entropy.
- B)  Graphite, because it has a lower free energy of formation.
- C)  Graphite, because it has a negative enthalpy of formation.
- D)  Diamond because it has a positive free energy of formation.
- E)  Diamond because it has a lower molar enthalpy.

34.) What explains the well known longevity of diamond (with respect to graphite)?

- A)  Diamond is thermodynamically more stable than graphite.
- B)  Graphite spontaneously changes to diamond under standard conditions.
- C)  The conversion of graphite to diamond displays first order kinetics.
- D)  Diamond is kinetically stable with respect to graphite (a high activation energy)
- E)  The rate of graphite conversion to diamond is fast.

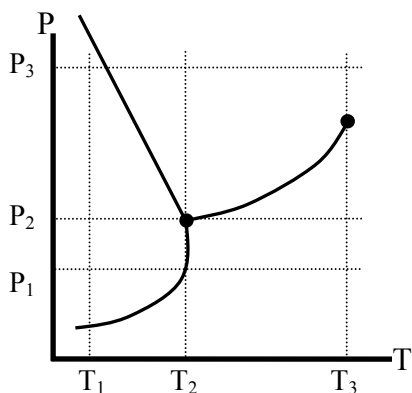
35.) Which is true of the standard enthalpy of the reaction at 298K?

- A)   $\Delta H^\circ > 0$
- B)   $\Delta H^\circ = 0$
- C)   $\Delta H^\circ < 0$
- D)  Cannot be determined from the information given.

36.) A 10.0 gram sample of a compound (MM=156 g/mol) decomposes in aqueous solution in a perfect calorimeter (zero heat capacity) containing 100.0 ml of water. The temperature is observed to change from 25°C to 35°C. What is the enthalpy of decomposition for this compound (kJ/mol)?

- A) -65.2      B) -41.8      C) 0      D) 23.4      E) 99.1

37.) What will occur with an increase in temperature at constant pressure when starting from the point (T<sub>1</sub>, P<sub>1</sub>) on the following phase diagram [HW 8.18, 8.19]?



- A) Solid to gas phase change.  
 B) Solid to liquid phase change.  
 C) Liquid to gas phase change.  
 D) Liquid to solid phase change  
 E) The system is a solid for all temperatures.
- 38.) Which is true about reactions and equilibrium? [HW 9.1]
- A) The reaction stops when equilibrium is reached.  
 B) An equilibrium reaction is not affected by increasing the concentration of reactants.  
 C) The higher the initial pressure of a reactant, the larger the equilibrium constant achieved.  
 D) Equilibrium reactions favor products.  
 E) Equilibrium can be reached starting from any mixture of products and reactants.



For questions 39 – 44, consider the gas phase reaction  $\text{N}_2 + 3 \text{H}_2 \rightleftharpoons 2 \text{NH}_3$  with equilibrium constant  $K = 0.278$  at 800 K. At 800K, the molar entropy of  $\text{H}_2$  (g) is 131 J/K mol, of  $\text{N}_2$  is 192 J/K mol, and of  $\text{NH}_3$  (g) is 192 J/K mol.

39.) What is the standard entropy change associated with this reaction at 800K (J/mol)?

- A)  -201
- B) -41.5
- C) -0.451
- D) 238
- E) 444

40.) From bond enthalpies listed on your periodic table handout, which is the best estimate of the enthalpy of formation of ammonia (kJ/ mol  $\text{NH}_3$ )?

- A) -99
- B) 71
- C)  -41.5
- D) -0.45
- E) 499

41.) Analysis of a reaction mixture at 800K yielded the following partial pressures:  $\text{N}_2 = 0.417$  atm,  $\text{H}_2 = 0.524$  atm and  $\text{NH}_3 = 0.122$  atm. What is the reaction quotient for the reaction?

- A) 0.116
- B)  0.248
- C) 2.90
- D) 1.91
- E) 0.881

42.) Which best describes the condition of the reaction mixture in question 41?

- A) The reaction mixture is at equilibrium.
- B)  The reaction mixture is not at equilibrium.
- C) can't tell.

43.) What best describes how a reaction mixture like that in question 41 will proceed?

- A)  Toward products.
- B) Toward reactants.
- C) No change.

44.) Which best describes how the reaction mixture will proceed when equilibrium is reached for this reaction, and the volume of the container is then reduced by a factor of two?

- A)  Toward products.
- B) Toward reactants.
- C) No change.

Questions 45 – 56 refer to the sugar glucose ( $C_6H_{12}O_6$ ).

45.) Solid glucose dissolves in water without dissociation. How would you write the equilibrium expression for this dissolution ( $K_{sp}$ )?

- A)  $[C_6H_{12}O_6]$
- B)  $1/[C_6H_{12}O_6]$
- C)  $[C_6H_{12}O_6]/[H_2O]$
- D)  $[C_6H_{12}O_6]^2$
- E)  $[C_6H_{12}O_6]/[H_2O]^2$

46.) Solid glucose dissolves in water without dissociation. A concentration of dissolved glucose of 1.5M is found in equilibrium with the solid at a certain temperature. What is the equilibrium constant for dissolution ( $K_{sp}$ ) at that temperature?

- A)  $2.25 \times 10^{-5}$
- B)  $1.5$
- C)  $3.56 \times 10^3$
- D) 150
- E) 2.3

For questions 47 – 57, consider these three acids in answering the following questions.

formic acid ( $\text{HCOOH}$ , $\text{pK}_a = 3.75$ )
acetic acid ( $\text{CH}_3\text{COOH}$ , $\text{pK}_a = 4.75$ )
Hydrochloric acid ( $\text{HCl}$ )

47.) Which is the arrangement of the acids from strongest to weakest?

- A) formic > acetic > hydrochloric
- B)  hydrochloric > formic > acetic
- C) acetic > formic > hydrochloric
- D) formic > hydrochloric > acetic
- E) hydrochloric > acetic > formic

48.) What is the pH of 0.1 M HCl?

- A) -1      B) 0       C) 1      D) 2      E) 3

49.) Which is the reaction of acetic acid with water described by its  $\text{pK}_a$ ?

- A)  $\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{OH}^-$
- B)  $\text{CH}_3\text{COOH} + \text{H}_3\text{O}^+ \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_2\text{O}$
- C)  $\text{CH}_3\text{COOH} + \text{OH}^- \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_2\text{O}$
- D)   $\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+$
- E)  $\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COOH}_2^+ + \text{OH}^-$

50.) What is the equilibrium constant for the reaction of acetic acid with water described by its  $\text{pK}_a$ ?

- A)   $1.78 \times 10^{-5}$
- B)  $8.99 \times 10^{-3}$
- C)  $4.03 \times 10^{-8}$
- D)  $9.88 \times 10^{-10}$
- E) 4.75

51.) What is the pH of 0.25 M formic acid?

- A) 2.18      B) 2.98      C) 3.75      D) 4.75      E) 5.05

52.) What is the pH of a solution of 0.25 M acetic acid when titrated to  $\frac{1}{2}$  equivalence point with NaOH?

- A) 2.18      B) 2.88      C) 3.75      **D) 4.75**      E) 5.05

53.) What arrangement represents the relative base strengths?

- A)  $\text{Cl}^- > \text{HCOO}^- > \text{CH}_3\text{COO}^-$   
B)  **$\text{CH}_3\text{COO}^- > \text{HCOO}^- > \text{Cl}^-$**   
C)  $\text{HCOO}^- > \text{Cl}^- > \text{CH}_3\text{COO}^-$   
D)  $\text{Cl}^- > \text{CH}_3\text{COO}^- > \text{HCOO}^-$   
E)  $\text{CH}_3\text{COO}^- > \text{Cl}^- > \text{HCOO}^-$

54.) What is the equilibrium constant for the reaction  $\text{HCOOH} + \text{CH}_3\text{COO}^- \rightleftharpoons \text{HCOO}^- + \text{CH}_3\text{COOH}$ ?

- A)  **$\frac{K_a(\text{formic})}{K_a(\text{acetic})}$**   
B)  $\frac{K_a(\text{acetic})}{K_a(\text{formic})}$   
C)  $K_a(\text{formic}) \times K_a(\text{acetic})$   
D)  $K_a(\text{acetic}) \times K_a(\text{formic})$   
E)  $\frac{K_a(\text{formic})^2}{K_a(\text{acetic})}$

55.) Which side is favored at equilibrium for the reaction  $\text{HCOOH} + \text{CH}_3\text{COO}^- \rightleftharpoons \text{HCOO}^- + \text{CH}_3\text{COOH}$ ?

- A) **products**  
B) reactants  
C) can't tell

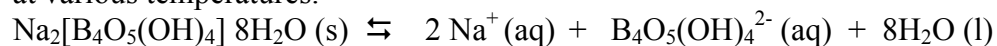
56.) What is the pH buffer region for formic acid?

- A) 5.75 – 6.75  
B) **2.75 – 4.75**  
C) 1.67 – 2.88  
D) 0.00 – 14.00  
E) 4.56 – 5.55

57.) At pH 6.5, which species is present in highest concentration in a 0.1 M solution of formic acid?

- A)  $\text{OH}^-$       B)  $\text{H}_3\text{O}^+$       C)  $\text{HCOOH}$       **D)  $\text{HCOO}^-$**       E)  $\text{Cl}^-$

58.) In lab you explored the dissolution of borax in water by titrating saturated solutions at various temperatures.

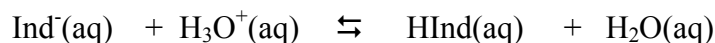


The class data indicated that the thermodynamic parameters  $\Delta H^\circ$ ,  $\Delta S^\circ$ , and  $\Delta G^\circ$  for the reaction at  $25^\circ\text{C}$  are all positive numbers.

Which of the following is *false* for this reaction *at equilibrium*?

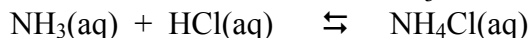
- A) While the reaction is in equilibrium, both products and reactants are always present.
- B) If all species are at 1 M concentration, the forward reaction is spontaneous.
- C) The value of  $\Delta G$  is zero.
- D) The reaction will tend to favor products as temperature increases.
- E) Adding more solid will not cause any more borax to dissolve.

59.) A solution of an indicator is blue. In excess acid, the indicator turns yellow. Which statement is true when the solution is green?



- A) The water produced dilutes the blue color and makes it appear green.
- B) Both  $\text{Ind}^-$  and  $\text{HInd}$  are present in solution.
- C) The  $\text{H}_3\text{O}^+$  is the green species.
- D) All the reactants have formed products.
- E) The endpoint was missed in the titration.

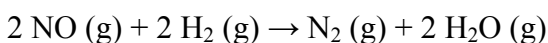
60.) Consider the aqueous reaction of the weak base  $\text{NH}_3$  with the strong acid  $\text{HCl}$ :



Which of the following statements is true at the equivalence point for this general acid-base reaction?

- A) The pH is equal to 7 since salt and water are the main products
- B) The pH is equal to 7 because the acid is neutralized
- C) The pH is less than 7 because  $\text{NH}_4^+$  is a weak acid
- D) The pH is greater than 7 because  $\text{Cl}^-$  is a weak base

For question 61 - 63, consider the following reaction which is first order in H<sub>2</sub> and third order in NO for the following questions.



61.) (4 pt) Write an expression for the rate of the reaction.

$$\text{rate} = k [\text{H}_2]^1 [\text{NO}]^3$$

62.) (8 pt) The rate constant for the reaction is  $3.0 \times 10^2 \text{ M}^{-2}\text{s}^{-1}$ . What is the rate when the  $[\text{H}_2] = 0.2 \text{ M}$  and  $[\text{NO}] = 0.4 \text{ M}$

$$\begin{aligned} \text{rate} &= k [\text{H}_2]^1 [\text{NO}]^3 \\ &= (3.0 \times 10^2 \text{ M}^{-2}\text{s}^{-1})(0.2 \text{ M})(0.4 \text{ M})^3 \\ &= 3.84 \text{ M}^2/\text{s} \end{aligned}$$

63.) (10 pt) Starting with equal concentrations of H<sub>2</sub> and NO, by what factor does the rate decrease when two thirds of the H<sub>2</sub> is consumed?

**since the reactants in the balanced equation are in a 2:2 ratio**

$$\text{rate}_1 = k [\text{x}]^1 [\text{x}]^3 = kx^4$$

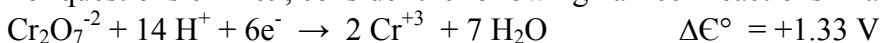
**when 2/3 of the H<sub>2</sub> reacts, there is 1/3 left of both H<sub>2</sub> and NO**

$$\text{rate}_2 = k [1/3 \text{ x}]^1 [1/3 \text{ x}]^3 = k(1/81)x^4$$

**1/81 is 1.23%**

**This makes sense that the rate of the reaction would slow down dramatically because if less molecules are present, there won't be as many collisions and therefore not as many reactions**

For questions 64 – 69, consider the following half cell reactions in aqueous solution:



64.) (10 pt) Write and balance the reaction between  $\text{Cr}_2\text{O}_7^{-2}$  and  $\text{Mn}^{+2}$  in aqueous acidic solution.

**Using these half reactions, the first thing you need to do is to determine which reaction is the reduction and which is the oxidation. Since  $\Delta\mathcal{E}^\circ$  is a greater positive number for the Mn half reaction, that reaction goes forward and the Cr half reaction goes backward. Then, make sure the electrons balance.**



65.) (6 pt) Identify the element that is oxidized in the reaction in question 64 and indicate the whether the oxidation number increases or decreases and by what amount.

Element: **Cr**

change in oxidation number:  
**increases by 3**

66.) (6 pt) Identify the element that is reduced in the reaction in question 64 and indicate the whether the oxidation number increases or decreases and by what amount.

Element: **Mn**

change in oxidation number:  
**decreases by 5**

67.) (6 pt) Is the reaction in question 64 spontaneous from the standard state? Explain in 20 words or less.

Explanation:

**As written, the reaction is spontaneous because  $\Delta\mathcal{E}^\circ$  is + which means  $\Delta G$  is -.**

68.) ( 6 pt) What is the pH of the reaction in the standard state? How would increasing the pH shift the reaction at equilibrium?

pH: **0**

Shift in equilibrium: **shift to the right**

69.) ( 6 pt) What is the voltage of a galvanic cell created using the half cell reactions given? Indicate how an increase in pH will effect the voltage of the galvanic cell and explain your reasoning?

Voltage:  
 $\Delta E^\circ = + 0.22V$

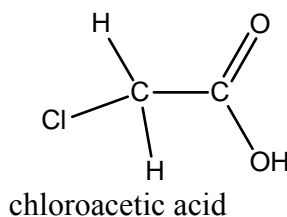
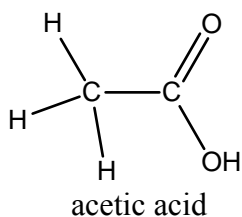
Effect of voltage (increase, decrease or stay the same): **increase**

Explain:

**Increasing the pH would remove the product  $H^+$ . The system would shift to form more products which would increase the electrical work it does.**



For questions 70 – 73, consider the weak acids acetic acid and chloroacetic acid whose structures are shown below for the following questions.

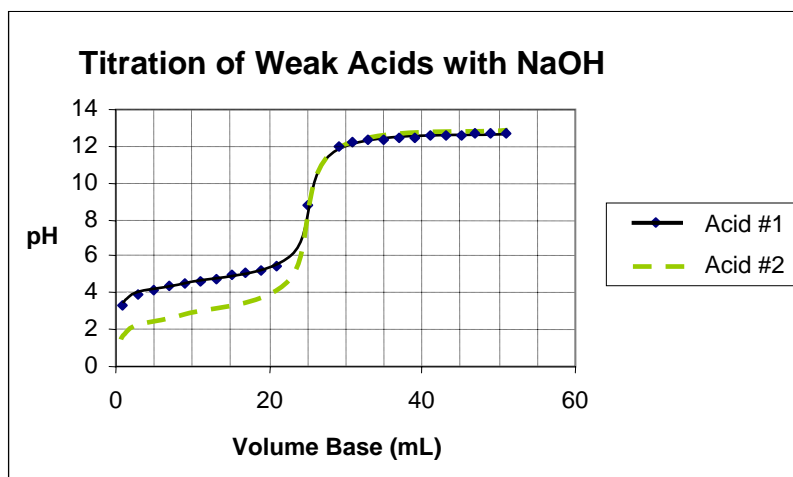


- 70.) (6 pt) Given the structures of acetic acid and chloroacetic acid above, explain the relationship of functional groups to acid strength. (Hint: the acids are identical except for one atom. How does this affect the tendency of the acid to lose a proton?)

Explanation: **either explanation is acceptable**

- 1) **electron withdrawing groups like Cl will weaken or polarize the OH bond, making the acid more likely to lose a H<sup>+</sup>**
- 2) **electron withdrawing groups like Cl will help to stabilize the extra electron of the conjugate base**

- 71.) (6 pt) The graph below shows the titration of two weak acids of equal concentration with the strong base, NaOH. Based on the titration curve data, determine which acid is acetic acid and which acid is chloroacetic acid.  $M_{\text{base}} = 0.150 \text{ M NaOH}$ ,  $V_{\text{acid}} = 15.00 \text{ mL}$



Acid #1 is (circle one)

acetic acid

chloroacetic acid

Acid #2 is (circle one)

acetic acid

chloroacetic acid

72.) ( 8 pt) Explain your choice of acids for the previous question based on the data available in the graphs.

Explanation:  
**the initial pH of the stronger acid will be lower than the initial pH of the weaker acid**

73.) (8 pt) Given the graph and data above, what is the concentration of both of the weak acids?

[Acetic Acid]:

**0.25M**

[Chloroacetic Acid]:

**0.25M**

**acids are equal concentrations**

**$M_A V_A = M_B V_B$  at the equivalence point**

**from the graph, the equivalence point is at 25mL**

**$M_A = (0.150M)(25mL)/(15mL) = 0.25M$**

## Quantum:

$$E = h\nu$$

$$\lambda\nu = c$$

$$\lambda_{\text{deBroglie}} = h / p = h / mv$$

$$E_{\text{kin}}(e^-) = h\nu - \Phi = h\nu - h\nu_0$$

$$E_n = -\frac{Z^2}{n^2} R_\infty$$

$$\Delta x \Delta p \sim h$$

$$p = mv$$

Particle in a box (1-D Quantum):

$$E_n = h^2 n^2 / 8mL^2; n = 1, 2, 3...$$

Vibrational:

$$E_v = (v + 1/2) hA / 2\pi; A = (k/m)^{1/2}$$

Rotational:

$$E_n = n(n + 1) hB; B = h / 8\pi^2 I; I = 2mr^2$$

$$m = m_A m_B / (m_A + m_B)$$

## Ideal Gas:

$$PV = nRT$$

$$E_{\text{kin}} = \frac{3}{2} RT$$

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

## Constants:

$$N_0 = 6.02214 \times 10^{23} \text{ mol}^{-1}$$

$$R_\infty = 2.179874 \times 10^{-18} \text{ J}$$

$$R_\infty = 3.28984 \times 10^{15} \text{ Hz}$$

$$k = 1.38066 \times 10^{-23} \text{ J K}^{-1}$$

$$h = 6.62608 \times 10^{-34} \text{ J s}$$

$$m_e = 9.101939 \times 10^{-31} \text{ kg}$$

$$c = 2.99792 \times 10^8 \text{ m s}^{-1}$$

$$T(\text{K}) = T(\text{C}) + 273.15$$

$$F = 96,485 \text{ C / mol}$$

$$1 \text{ V} = 1 \text{ J / C}$$

Gas Constant:

$$R = 8.31451 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$R = 8.20578 \times 10^{-2} \text{ L atm K}^{-1} \text{ mol}^{-1}$$

$$1 \text{ nm} = 10^{-9} \text{ m}$$

$$1 \text{ kJ} = 1000 \text{ J}$$

$$1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr} \approx 1 \text{ bar}$$

$$1 \text{ L atm} \approx 100 \text{ J}$$

## Thermodynamics:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta H^\circ = \sum \Delta H^\circ_f(\text{products}) - \sum \Delta H^\circ_f(\text{reactants})$$

$$\Delta S^\circ = \sum S^\circ(\text{products}) - \sum S^\circ(\text{reactants})$$

$$\Delta G^\circ = \sum \Delta G^\circ_f(\text{products}) - \sum \Delta G^\circ_f(\text{reactants})$$

$$S = k_B \ln W$$

$$\Delta S = q_{\text{rev}} / T$$

$$\Delta E = q + w$$

$$w = -P_{\text{ext}} \Delta V$$

for  $aA + bB \rightleftharpoons cC + dD$

$$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b} \quad \text{At equilibrium, } Q = K$$

$$\Delta G = \Delta G^\circ + RT \ln Q$$

$$G = G^\circ + RT \ln(a); a = \text{activity} = \gamma P / P^\circ \text{ or } \gamma[A] / [A]^\circ$$

$$\Delta G^\circ = -RT \ln K$$

$$\Delta G^\circ = -nF\Delta E^\circ$$

$$\Delta E = \Delta E^\circ - (RT/nF) \ln Q$$

$$\ln K = -\frac{\Delta H^\circ}{R} \frac{1}{T} + \frac{\Delta S^\circ}{R}$$

$$\Delta T = ik_{b,f} m$$

$$\Pi = iMRT$$

$$P_{\text{total}} = P_A + P_B = X_A P_A^\circ + X_B P_B^\circ$$

## Acid Base:

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\text{pX} = -\log X$$

$$\text{pH} = \text{p}K_a + \log \frac{[A^-]}{[HA]}$$

## Kinetics:

$$[A]_t = [A]_0 e^{-kt}$$

$$\ln[A]_t = \ln[A]_0 - kt$$

$$t_{1/2} = \ln 2 / k$$

$$1/[A]_t = 1/[A]_0 + kt$$

$$k = A e^{(-E_a/RT)}$$

$$\ln(k_1/k_2) = E_a/R (1/T_2 - 1/T_1)$$

$$t_{1/2} = 1/[A]_0 k$$

$$t_{1/2} = [A]_0 / kt$$