Chemistry 1A, Fall 2010

Midterm Exam #2
October 13, 2010
(90 min, closed book)

Name:________**KEY**___________

SID:____________________________________

GSI Name:_________________

- The test consists of 4 short answer questions and 21 multiple choice questions.
- Put your written answers in the boxes provided. Answers outside the boxes may not be considered in grading.
- Write your name on every page of the exam.

Question	Page	Points	Score
Multiple Choice	2-8	75	
Partitioning-molecular view	5	5	
Partitioning-predict	6	5	
Hydrangea Color	7	10	
Autodissociation	8	5	
Total		100	

Useful Equations and Constants:

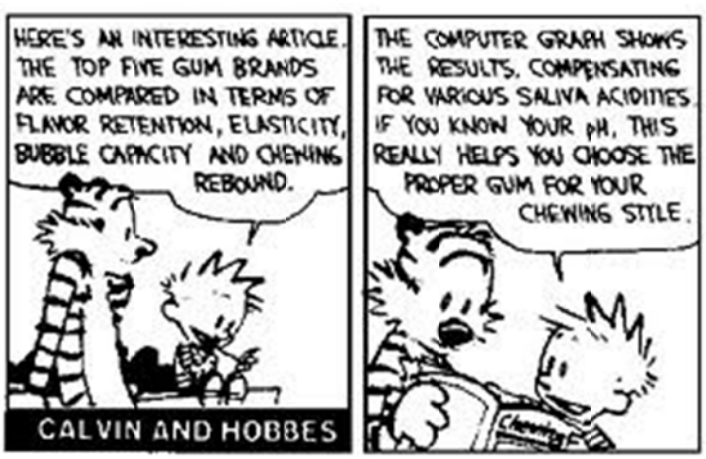
$pH = -\log[H^+]$
$pX = -\log X$
$X = 10^{-pX}$
$K_w = 1\times10^{-14}$ at 25°C

Strong acids and bases:

HCl	$LiOH$
HNO_3	$NaOH$
H_2SO_4	KOH
$HClO_4$	
HBr	
HI	

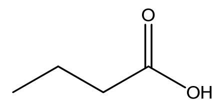
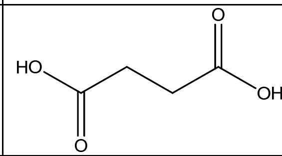
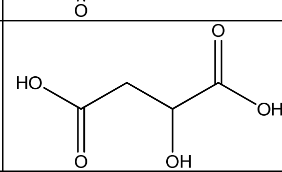
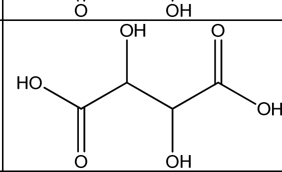
Acid dissociation constants (Ka)

CH_3COOH	1.75×10^{-5}
NH_4^+	5.70×10^{-10}
HCN	6.2×10^{-10}
$CH_3NH_3^+$	2.3×10^{-11}
H_2CO_3	4.45×10^{-7}
$(CH_3)_3NH^+$	1.58×10^{-10}



ACIDS FOUND IN FOOD

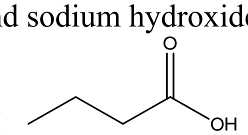
Four acids found in foods are shown in the table.

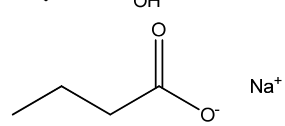
Acid	Formula	Structure	K_{a1}	K_{a2}
butyric acid $C_4H_8O_2$	$CH_3{-}CH_2{-}CH_2{-}COOH$		1.5×10^{-5}	
succinic acid $C_4H_6O_4$	$HOOC{-}CH_2{-}CH_2{-}COOH$		6.9×10^{-5}	2.5×10^{-6}
malic acid $C_4H_6O_5$	$HOOC{-}CH_2{-}CH(OH){-}COOH$		4.0×10^{-4}	7.8×10^{-6}
tartaric acid $C_4H_6O_6$	$HOOC{-}CH(OH){-}CH(OH){-}COOH$		1.0×10^{-3}	4.5×10^{-5}

1. What is the pH of a 0.0050 M solution of butyric acid?
   A) 2.3 (1) B) 3.6 (3) C) 4.1 D) 4.8

2. It takes 56 mL of 0.012 M NaOH to titrate 50 mL of succinic acid to the second equivalence point. What is the concentration of succinic acid?
   A) 0.0022 M B) 0.0067 M (3) C) 0.013 M (1) D) 0.026 M

3. Which of the molecules or ions listed below is present in the largest concentration when equal number of moles of butyric acid and sodium hydroxide are mixed?

   A) Butyric acid, $CH_3CH_2CH_2COOH$ 

   B) Sodium butyrate, $CH_3CH_2CH_2COONa$  (3)

   C) OH^-

   D) Sodium butyrate and OH^- are present in roughly equal concentrations

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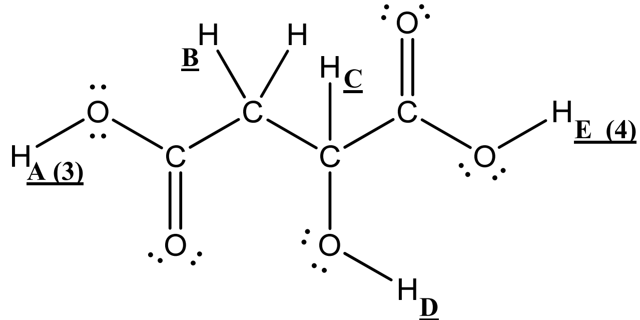
4. Sourness is directly related to acid strength. Solid malic acid is used to coat candy to make it taste extremely sour. What could you do to make the candy taste less sour?
   A) Use sodium hydrogen malate, $C_4H_5O_5Na$ (3)
   B) Use solid succinic acid, $C_4H_6O_4$ (3)
   C) Use solid tartaric acid, $C_4H_6O_6$
   D) Both A and B (4)
   E) Both B and C

5. Which H atom is the first to dissociate from malic acid?



6. A solution of succinic acid is titrated with sodium hydroxide. During the titration, 15 mL of a 0.100M NaOH solution was added to 10mL of a 0.100M succinic acid solution.

   What is the pH of the resulting solution?
   A) 3.2
   B) 4.1
   C) 5.6 (4)
   D) 7.0
   E) 12.2 (2)

7. Which indicator would you choose to detect the equivalence point of a titration of sodium butyrate, $C_4H_7O_2Na$, with hydrochloric acid, HCl?
   A) methyl orange, pK_a = 3.8 (4)
   B) methyl red, pK_a = 5.0 (3)
   C) bromothymol blue, pK_a = 7.3
   D) phenol red, pK_a = 8.0
   E) phenolphthalein, pK_a = 9.5

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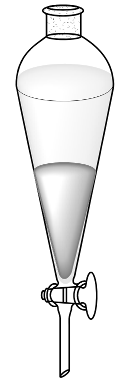
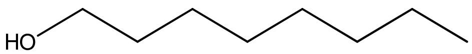
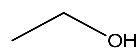
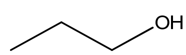
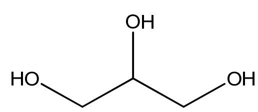
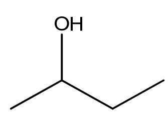
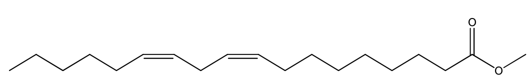
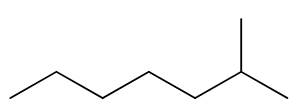
PARTITIONING AND THE ENVIRONMENT



Environmental scientists use the octanol-water partition coefficient, K_{OW}, to predict where a compound will remain if released into the environment. If a chemical is more soluble in the octanol, it tends to accumulate in the tissues of animals. If the chemical is more soluble in water, it tends to be easily flushed as waste by the animals. The equilibrium constant expresses the relative amounts dissolved in the two solvents.

Solute (aq) ⇆ Solute (octanol) $\quad K_{OW} = \frac{[\text{Solute}]\text{octanol}}{[\text{Solute}]\text{water}}$

Octanol, 

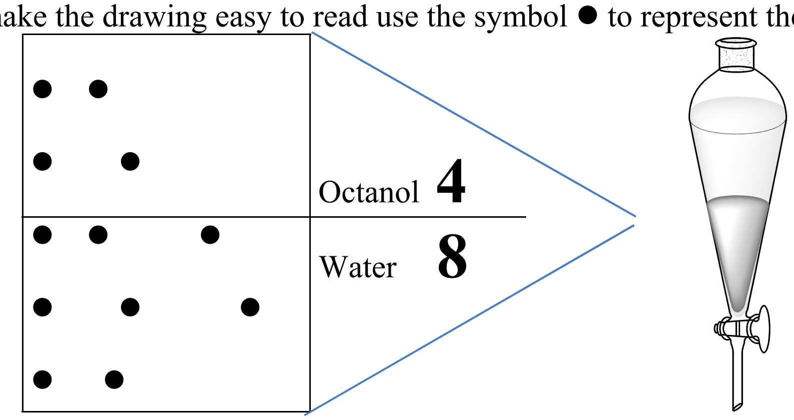
Fuel	Structure	$\log K_{OW}$	K_{OW}
Methanol	$H_3C—OH$	-0.74	0.18
Ethanol		-0.30	0.50
1-Propanol		0.25	1.78
Glycerol		-1.76	0.02
2-Butanol		0.65	4.47
Biodiesel (Methyl Linoleate)		6.82	6.61×10^6
Gasoline (isooctane)		5.83	6.76×10^5

8. Based on the data, which compounds are more soluble in octanol (fat) than water?
   A) Ethanol (2)
   B) Glycerol
   C) Methanol
   D) 2-Butanol (3)

9. Examine the data for ethanol. A 25 gram sample of ethanol was mixed with a two-phase mixture of 1L of water and 1L of ~~ethanol~~ octanol. What is the concentration (mol/L) of ethanol in the water ?
   A) 0.18 (2) B) 0.50 C) 0.54 D) 0.36 (3)

Note: all answers were accepted due to the typo in the question.

The boxes below show the interface between the octanol and water. Draw in 12 molecules of ethanol, showing their distribution in the two solvents.
To make the drawing easy to read use the symbol ● to represent the ethanol.



10. How would the concentration of ethanol in the octanol change if the 25 grams of ethanol was added to 1L of water and only 500 mL of octanol?

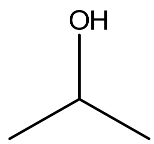
A	B	C
concentration would increase (3)	concentration would decrease	concentration would stay the same (1)

Note: A is correct. We did accept both A and C for 3 points.

11. How would the number of moles of ethanol in the octanol change if the 25 grams of ethanol was added to 1L of water and only 500 mL of octanol?

A	B	C
Number of moles would increase	Number of moles would decrease (3)	Number of moles would stay the same

12. Estimate the equilibrium constant, K_{OW}, for 2-propanol (shown below).



A 0.75 (4) B 1.25 (4) C 1.78 D 2.0 (3)

Explain your reasoning.
The 2-propanol should have a similar K_{OW} to 1-propanol, but not identical because the structures are different. The 1-propanol is linear but 2-propanol is branched. The overall dipole moment of the 2-propanol will be slightly higher than then 1-proponal. The 1-popanol and 1-octanol molecules both have similar shapes (sausage-like) and will have greater London Forces with each other than the 2-propanol. All of these reasons mean that 2-propanol would be more attracted to the water phase which would give a slightly smaller K_{OW}.

13. Formic acid (HCOOH) is a weak acid with a K_a of 1.8×10^{-4} and a K_{OW} of 0.88.

$$HCOOH\ (aq) \leftrightarrows HCOOH\ (octanol)$$

Which of the following scenarios would cause the concentration of formic acid in octanol to decrease?
A) Buffer the water at a pH of 2
B) Buffer the water at a pH of 3 (3)
C) Buffer the water at a pH of 5 (4)
D) Adding more octanol (4)

FLOWER COLOR AND SOIL

The acidity of soil is thought to play an important role in determining the color of the flowers on certain plants. Gardeners control the acid base properties of the soil by the addition of metal salts, such as aluminum compounds.

Name	**Formula**	K_{sp}	**solubility**
Aluminum hydroxide	$Al(OH)_3$	4.6×10^{-33}	3.4×10^{-9} M
Aluminum phosphate	$Al(PO_4)$	6.3×10^{-19}	7.9×10^{-10} M
Aluminum sulfate	$Al_2(SO_4)_3$	1.1×10^{2}	1.0 M

14. Which aluminum compound is the least soluble?
    A) Aluminum hydroxide, $Al(OH)_3$ (1)
    B) Aluminum phosphate, $Al(PO_4)$ (3)
    C) Aluminum sulfate, $Al_2(SO_4)_3$

15. Why does aluminum hydroxide, $Al(OH)_3$, have a smaller K_{sp}, but a larger solubility compared with aluminum phosphate, $Al(PO_4)$?
    A) Aluminum hydroxide, $Al(OH)_3$, is a strong base, and therefore, it dissociates completely. So it is more soluble. (1)
    B) The relationship between solubility and K_{sp} is different for the two salts because of the different charges on the anions. (3)
    C) Phosphate, PO_4^{3-}, is a weak base, and therefore, forms a buffer. The PO_4^{3-} equilibrates with HPO_4^{2-}, thereby decreasing it solubility.

Hydrangeas are popular summer flowers. The color of the large blooms depends on the concentration of the Al^{3+} in the soil. The Al^{3+} binds to a dye molecule in the flowers, Dye^-, according to the equilibrium given below. When the Al^{3+} is bound to the dye the color of the flower is blue.

$$\underset{\text{blue}}{[\text{Al-Dye}]^{2+}} \leftrightarrows Al^{3+} + \underset{\text{pink}}{Dye^-}$$

Suppose you add aluminum hydroxide, $Al(OH)_3$ (s), and sulfuric acid, H_2SO_4 (aq) to the soil. Complete the chemical equation for the reaction that occurs when aluminum hydroxide and sulfuric acid are mixed. Be sure to balance the equation.

$\mathbf{4}Al(OH)_3\ (s) + \mathbf{6}H_2SO_4\ (aq) \rightarrow \mathbf{2}Al_2(SO_4)_3\ (aq) + \mathbf{12}H_2O\ (l)$ (5 points)

Explain how adding both $Al(OH)_3$ and H_2SO_4 to the soil helps to make the flowers turn blue.

For full credit, students need to address both solubility and favoring reactants (5 points)
Dissolving Al^{3+}
$Al(OH)_3$ is not very soluble, and therefore the plants do not get Al^{3+} ions. The addition of H_2SO_4 to $Al(OH)_3$ forms $Al_2(SO_4)_3$, which is very soluble.

Favoring the formation of Al^{3+}-Dye
An increase in the concentration of Al^{3+} shifts the equilibrium in favor of the blue Al^{3+}-dye.

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AUTODISSOCIATION IN LIQUIDS

K_W for water at 100°C is 5.13×10^{-13}. Use this information to answer the next 3 questions.

16. What is the pH of pure water at 100°C?
    A) 6.1 (4) B) 7.0 C) 7.9 D) 12.3

17. What is the pOH of pure water at 100°C?
    A) 6.1 (4) B) 7.0 C) 7.9 (3) D) 12.3

18. What is the acid-base character of pure water at 100°C
    A) acidic (3) B) neutral (4) C) basic

If the temperature is below -60°C, it is possible to use liquid hydrogen sulfide, $H_2S(l)$, as a solvent. The questions below ask you to consider how the solvent properties of H_2S (l) differ from H_2O (l).

19. Which equation represents the autodissociation reaction in pure H_2S (l).
    A) $2H_2S\,(l) \leftrightarrows H_3S^+$ (solvated) + HS^- (solvated) (4)
    B) $2H_2S\,(l) \leftrightarrows HS^-\,(aq) + HS^{2-}\,(aq)$
    C) $H_2S\,(l) \leftrightarrows H_2S\,(g)$

    Do you expect that there is more or less dissociation of H_2S (l) compared with H_2O (l)?

Explain your reasoning. **There are many valid explanations and any logical reasoning should get 5 points.**
1) The H-S bond is weaker than the H-O bond
O attracts H^+ more strongly than S because O is more electronegative (or because the water molecule is more polar, or because O forms hydrogen bonds and S does not)
2) The weaker H-S bond means a stronger acid, but the weak attraction of H^+ by S indicates a weaker acid.
3) Students can conclude either that the weak H-S bond is more important and hence H_2S is more dissociated, or they can conclude that the weak attraction dominates and hence H_2O is more dissociated. (I believe the correct answer is that H_2O is more dissociated, but we are more interested in student's considering competing factors.)

20. Will small amounts of H_2O (s) dissolved in H_2S (l) increase or decrease the acidity of liquid hydrogen sulfide at -60°C?
    A) Increase the acidity
    B) Decrease the acidity
    C) Have no effect on the acidity (4)

Note: all answers for Q20 were accepted because there is a good argument for each one.

21. Which reaction best describes what happens when you mix pure H_2S (g) with pure NH_3 (g) at 25°C in a sealed container?
    A) $H_2S\,(g) + NH_3\,(g) \leftrightarrows NH_4^+\,(aq) + HS^-\,(aq)$ (2)
    B) $H_2S\,(g) + NH_3\,(g) \leftrightarrows H_3S^+\,(aq) + NH_2^-\,(aq)$
    C) $H_2S\,(g) + NH_3\,(g) \leftrightarrows NH_4SH\,(s)$ (4)
    D) $H_2S\,(g) + NH_3\,(g) \leftrightarrows NH_4SH\,(g)$ (4)