Chemistry 1A, Fall 2011

Midterm Exam #2
October 18, 2011
(90 min, closed book)

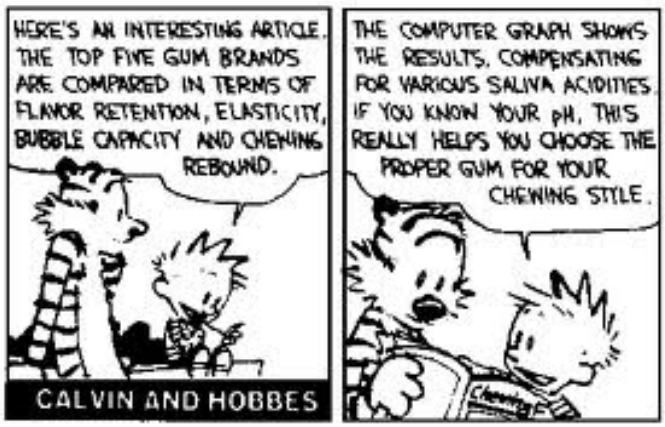
Name:_____

SID:_____

GSI Name:_____

- The test consists of 4 short answer questions and 23 multiple choice questions.
- Put your written answers in the boxes provided. Answers outside the boxes will NOT be considered in grading.
- Write your name on every page of the exam.

Question	Page	Points	Score
Multiple Choice	2-8	76	
Cabbage juice	2	6	
Kitty Litter	3	6	
Nicotine	6	4	
Caffeine	8	8	
Total		100	



Useful Equations and Constants:

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

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$

$R = 0.0821$ L atm mol^{-1} K^{-1}
$T\,(K) = T\,(°C) + 273$

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}

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CABBAGE JUICE INDICATOR

Cabbage juice indicator contains two weak acids: anthocyanin, HA, and anthoxanthin, HB. Data on red cabbage juice are given in the tables below.

Anthocyanin: $HA\ (aq) \leftrightarrows H^+\ (aq) + A^-\ (aq)$
red blue

Anthoxanthin: $HB\ (aq) \leftrightarrows H^+\ (aq) + B^-\ (aq)$
colorless yellow

Red cabbage pH indicator colors

pH	2	4	6	8	10	12
color	red	red-purple	purple	blue	blue- green	green

1. Use the data to estimate K_a for anthocyanin.

   A) 10^7 B) 10^{-2} C) 10^{-6} [2] D) 10^{-11}

2. The major species in a cabbage juice solution at pH = 2 are:

   A) HA, A^-, HB B) A^-, HB C) A^-, B^- D) HA, HB [4]

3. Suppose you have a purple solution of cabbage juice. What happens to the color if you add water?

   A) Nothing B) Turns a lighter shade of purple [2] C) Turns more blue [4] D) Turns more red [2]

SHORT ANSWER: At pH > 12 the red cabbage juice solution is green. Over time, the solution turns yellow. Present a hypothesis as to why this happens.

Above pH 12 the major species present are A_- (blue) and B^-(yellow) which gives a green solution. Since the solution turns yellow over time the A^- must decompose.
(2 points)

Use this hypothesis to predict what you would observe if you added acid to the yellow solution to neutralize it.

If you add acid to a solution of A^- and B^-, the pH should drop forming more HA and HB, which would turn the solution from yellow to green to blue (and maybe even purple if you add enough acid). But if A^- has decomposed HA won't form so the solution would probably just turn from yellow (B^-) to colorless (HB).
(4 points)

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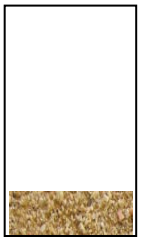
KITTY LITTER

Cat urine has a strong, unpleasant odor due to ammonia, NH_3. Fortunately, kitty litter not only absorbs moisture, but it also absorbs much of the odor. Many kitty litters are made of clay, which absorbs water and ammonia.

A certain brand of kitty litter was tested for its ability to absorb NH_3 (g). The kitty litter and NH_3 are in a closed 10 L container at 25°C.



$$NH_3\ (g) \leftrightarrows NH_3\ (clay)$$

# of moles of NH_3 absorbed	Mass of clay	Partial pressure of NH_3
2.7 moles	0.1 kg	0.10 atm

4. Use the test results to determine if there is more NH_3 in the clay or in the gas phase. Which of the following statements is true?

   A) Most of the NH_3 is absorbed in the clay. [2]

   B) Most of the NH_3 remains as a gas.

   C) NH_3 (g) is in equilibrium with NH_3 (clay), so both are present in equal amounts.

5. In the test described above, what happens if the volume of the container is decreased to 5 L with the same total # of moles of NH_3 at 25°C?

   A) The partial pressure of NH_3 is 0.20 atm.

   B) The # of moles of NH_3 absorbed in the clay increases. [2]

   C) There is no change because the equilibrium constant does not depend on pressure.

6. The kitty litter is exposed to other gases. Which gas requires the smallest partial pressure to result in absorption of 1 mole of gas per 0.10 kg of clay?

   A) O_2 B) He C) CO_2[2] D) H_2S [4]

SHORT ANSWER: Vinegar (acetic acid) can also be used to reduce the odor of cat urine. Write the reaction between vinegar (CH_3COOH) and ammonia (NH_3).

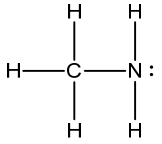
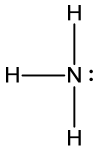
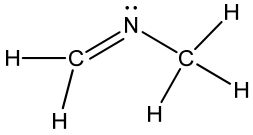
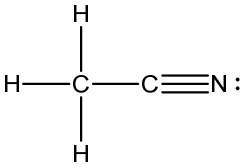
$CH_3COOH + NH_3 \rightarrow CH_3COO^-NH_4^+$
(2 points)

Explain why this reaction reduces the odor.

The product, ammonium acetate ($CH_3COO^-NH_4^+$) is ionic and will likely not be able to go into the gas phase. It will either be an ionic solid or remain aqueous if there is enough liquid present.
(4 points)

ORGANIC BASES

Nucleic acids, proteins, neurotransmitters, and stimulants are all organic bases that contain nitrogen atoms. Use the data below to answer the questions about organic bases.

Name	Formula	Lewis Structure	K_b	pK_b
methylamine	CH_5N		4.4×10^{-4}	3.4
ammonia	NH_3		2×10^{-5}	4.7
methylene methanamine	C_2H_5N		10^{-7}	7
acetonitrile	C_2H_3N		10^{-24}	24

7. Which solution is the most basic?

A) 0.10 M CH_5N [3] B) 0.10 M NH_3 C) 0.10 M C_2H_5N

8. What is the pH of a 0.10 M solution of methylamine (CH_5N)?

A) 2 B) 5 C) 9 D) 12 [4]

9. What is the pK_a for the conjugate acid of methylamine?

A) 2.3×10^{-11} B) 10.6 [2] C) 4.4×10^{-4} D) 3.4

10. The best explanation for the trends in K_b is

A) Changes in hydrogen bonding

B) Changes in molar mass

C) Changes in the hybridization around the N atom [3]

D) Changes in the number of H atoms attached to the C atoms

E) Changes in the electron density around the N atom [4]

11. Which species below is the strongest acid?

A) NH_4^+ [3] B) NH_3 C) CH_5NH^+ [1] D) CH_5N

12. Which statement is correct about the difference in pK_b between methylamine, CH_5N, and ammonia, NH_3?

A) Methylamine is **more** basic because the CH_3 group shifts electron density **towards** the N atom. [3]

B) Methylamine is **more** basic because the CH_3 group shifts electron density **away from** the N atom.

C) Methylamine is **more** basic because electron density shifts **away from** the N atom due to resonance structures.

13. Ammonium chloride, NH_4Cl, produces acidic solutions. When cobalt ions, Co^{2+}, are added to NH_4Cl (aq), the complex cation, $Co(NH_3)_6^{2+}$ forms. What happens to the pH of the solution?

A) The pH **decreases** because NH_3 is removed and more NH_4^+ dissociates. [3]

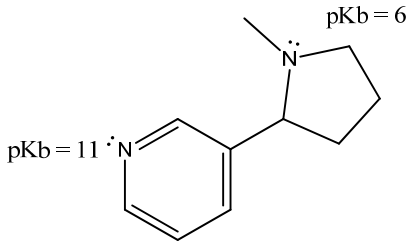
B) The pH **decreases** because Cl- is a weak conjugate base.

C) The pH **increases** because Co^{2+} is a strong acid.

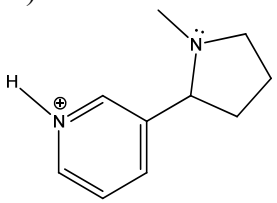
D) The pH **stays the same** because NH_4Cl (aq) is a buffer. [1]

Name_____GSI_____

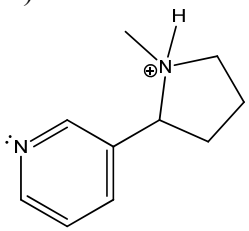
14. The nicotine molecule is shown below along with pK_b for each N atom. What is the predominant form of nicotine present in the blood at pH = 7.2?



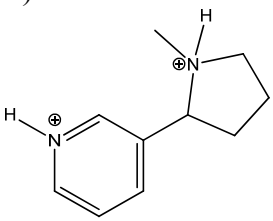
A)



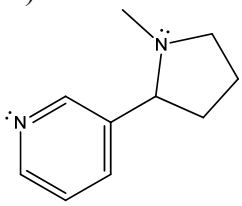
B)



C)



D)



[2] [4]

15. A sample of nicotine is titrated with 0.10 M HCl solution. Which graph below best represents the titration curve? (Note. The dotted line corresponds to pH 7.)

pH

A)	B) [1]	C)	D) [4]
41	195	54	920

Volume HCl added

SHORT ANSWER: Nicotine is highly toxic. About 60 mg can be a lethal dosage for an adult human. One cigar contains about 120 mg of nicotine. Nicotine in the gas phase can enter the bloodstream. Why doesn't smoking a cigar kill the smoker instantly? Describe a partition equilibrium in your answer.

There are several possible pathways the nicotine could enter the bloodstream from a cigar and each has a possible equilibrium or partitioning. Any one of the examples below is acceptable.
From the smoke:
Nicotine (s) ⇆ Nicotine (g)
Nicotine (g) ⇆ Nicotine (blood)

From chewing on the cigar:
Nicotine (s) ⇆ Nicotine (aq) in saliva
Nicotine (aq) ⇆ Nicotine (blood)

Since the nicotine is in equilibrium between two phases (s,g, aq, blood) not all the nicotine present in a cigar will transfer over to the bloodstream. In fact the K_{eq} must be small, much less than 1 since smoking a cigar doesn't kill you.

Some may mention that a good fraction of nicotine gets combusted before it can participate in these equilibria.
(4 points)

HEAT AND TEMPERATURE

16. You mix 300 mL of water at 60˚C with 100 mL of water at 20˚C. What is the final temperature of the mixture?

    A) 30°C B) 40°C C) 50°C [3]

17. Why do farmers spray water on oranges to protect them from freezing on a cold night?

    A) When water freezes, heat is transferred to the oranges.

    B) The temperature of the oranges will stay at 0°C until all the water freezes. [3]

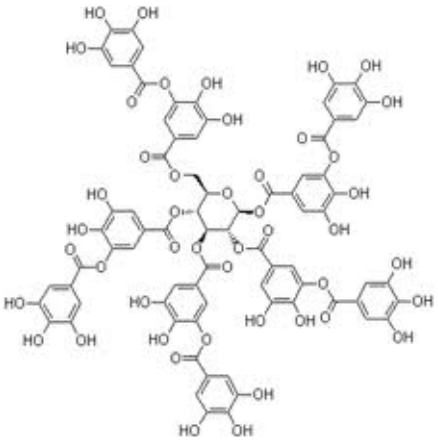
    C) Solid water provides an insulating layer because ice has a high heat capacity

    D) All of the above [1]

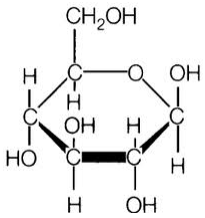
EXTRACTION OF CAFFEINE

When tea leaves are soaked in boiling water, several compounds dissolve in the water. Three compounds in high concentration are tannic acid (HT), glucose ($C_6H_{12}O_6$) and caffeine ($C_8H_{10}N_4O_2$). Use the data below to answer questions about a tea solution.

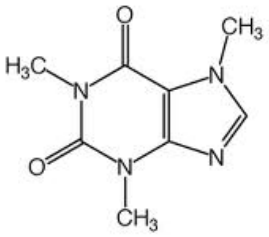
Name_____GSI_____



tannic acid, HT



glucose, $C_6H_{12}O_6$



caffeine, $C_8H_{10}N_4O_2$

[Note: Tannic acid is abbreviated as HT.]

K_a (tannic acid) ~ 10^{-6}
K_a (glucose) ~ 10^{-12}
K_b (caffeine) = 4.2×10^{-4}

Solubility caffeine in water = 22 mg/ml at 25°C; 180 mg/mL at 80°C
Solubility of caffeine in CH_2Cl_2 = 140 mg/ml at 25°C
Solubility of glucose in CH_2Cl_2 = insoluble

18. A solution of caffeine is prepared at 80°C by dissolving 10 g caffeine in 100 mL of water. The solution is cooled to 25°C. What is the concentration of the caffeine in that solution?

A) 180 mg/mL B) 100 mg/mL C) 78 mg/mL D) 22 mg/mL
[1] [3]

19. What is the pH of a 10^{-10} M aqueous solution of tannic acid?

A) 7 [3] B) 8 [1] C) 9 D) 10

20. A 1.0 L solution is made by mixing 0.010 mole of tannic acid, 0.0005 mole of caffeine and 0.010 mole of glucose with water. Which ion forms when you add NaOH to the solution?

A) T^- [4] B) $C_6H_{11}O_6^-$ C) $C_8H_{11}N_4O_2^+$

21. You add 0.005 mole of NaOH to the solution above. The pH of the solution is

A) pH ~ 11 because caffeine is the strongest base

B) pH ~ 6 because there is a HT/T^- buffer [4]

C) pH ~ 3 because tannic acid is the strongest acid

D) pH ~ 2 because glucose is present in the highest concentration

22. When $CaCl_2$ is added to a solution of tannic acid, CaT_2 precipitates. What happens to the pH?

A) increases B) decreases C) stays the same
[4]

23. The K_{sp} for CaT_2 (s) is 2×10^{-12}. How much (M) CaT_2 dissolves in water?

A) 8×10^{-5} [4] B) 1.4×10^{-6} [2] C) 2×10^{-12} D) 1.6×10^{-4}

SHORT ANSWER: Calcium hydroxide, $Ca(OH)_2$, is added to a tea solution containing tannic acid, glucose, and caffeine. A precipitate forms and the pH increases to 8. Write a balanced chemical equation(s) for the reaction.

$2\ HT\ (aq) + Ca(OH)_2\ (aq) \leftrightarrows CaT_2\ (s) + 2\ H_2O\ (l)$
(4 points)

Next, methylene chloride, CH_2Cl_2, is added. Two liquid layers are observed at 25°C because CH_2Cl_2 is not miscible with water. Where are most of the caffeine molecules? Explain your thinking.

Caffeine molecules are both in the aqueous and in the methylene chloride phase. However, judging from a higher solubility of caffeine in methylene chloride than in water, most of the caffeine molecules will be in the methylene chloride phase.
(4 points)