CHEM*1040 Midterm Examination Grading Key, Fall 2007

PART A: Multiple Choice Section [2 points each]

For each question, circle the letter of the one correct answer and enter the answer on the Test Scoring Sheet **in pencil only**. The Test Scoring Answer Sheet will be considered final. There is no penalty for incorrect answers. Answers must be transferred to the Test Scoring Answer Sheet **within** the time given for the examination.

1. In humans, vitamin C is a highly effective antioxidant. Combustion analysis of a 25.0-mg sample of vitamin C produced 10.2 mg of water. What is the percent hydrogen in vitamin C?

A) 2.29%
[✓ B)] 4.57%
C) 8.87%
D) 40.8%

Answer:
10.2 mg H_2O *× 1 mmol* H_2O*/18.02 mg* H_2O *× 2 mmol H/1mmol* H_2O *= 1.13 mmol H*
1.13 mmol H × 1.01 mg H/1 mmol H = 1.14 mg H
% H in vitamin C = 1.14 mg/25.0 mg ***sample*** *× 100% = 4.57%*

2. Trisodium phosphate (TSP), available at most hardware stores, is a cleaning agent, stain remover and degreaser, commonly used to prepare surfaces for painting. How many moles of Na^+ ions are present in 0.625 moles of TSP?

A) 0.625
[✓ B)] 1.88
C) $3.76×10^{23}$
D) $1.13×10^{24}$

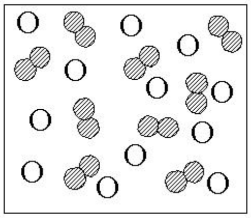
Answer:
$Na_3PO_4 \rightarrow 3Na^+ + PO_4^{3-}$
0.625 mol *3 × 0.625 mol = 1.88 moles* Na^+ *ions*

3. How many mL of 0.200 M HCl(aq) are neutralised by 85.7 mL of 1.00 M $Mg(OH)_{2(aq)}$?

A) 214 mL
B) 429 mL
[✓ C)] 857 mL
D) 1710 mL

Answer: $2HCl_{(aq)} + Mg(OH)_{2(aq)} \rightarrow MgCl_{2(aq)} + 2H2O_{(l)}$
1.00mmol/mL × 85.7mL = 85.7 mmol $Mg(OH)_2$
85.7 mmol $Mg(OH)_2$ *× 2 mmol HCl/1 mmol* $Mg(OH)_2$ *= 171.4 mmol*
171.4 mmol HCl × 1 mL/0.200 mmol = 857 mL

4. Consider the reaction: $2P_{(s)} + 5Cl_{2(g)} \rightarrow 2PCl_{5(s)}$.
The diagram to the right shows a mixture of $P_{(s)}$ and $Cl_{2(g)}$, where each symbol represents 1 mole of the species. How many moles of excess reactant are left over after the reaction is complete?



A) 3.0 moles
B) 3.6 moles
C) 4.2 moles
D) 8.0 moles
[✓ E)] 8.4 moles

Answer: *From diagram - 12 P atoms & 9* Cl_2 *molecules*
12 P atoms/2 P atoms per reaction = 6 reactions
9 Cl_2 *molecules /5* Cl_2 *per rxn = 1.8 rxns ∴ limiting reagent*
If rxn proceeds 1.8 times, (1.8× 2 =) 3.6 moles of P will be used
∴12 – 3.6 = 8.4 moles of P remain.

5. Consider the following reaction: $WO_{3(s)} + 3H_{2(g)} \rightarrow W_{(s)} + 3H_2O_{(g)}$
When 1.00 g of hydrogen gas react with excess WO_3(s), 15.5 grams of W(s) are produced. What is the percent yield? (The molar mass of W is 183.84 g/mol.)

[✓ A)] 51.1%
B) 25.5%
C) 17.0%
D) 8.52%

Answer: *Actual yield = 15.5 g ∴ need to find theoretical yield*
1.00g H_2 *× 1 mol* H_2*/2.02g* H_2 *× 1 mol W/3 mol* H_2 *× 183.84 g W/1 mol W =* 30.3_4 *g W*
% yield = actual yield/theoretical yield × 100% = 15.5/30.3 × 100% = 51.1%

6. Acid rain is produced by the following sequence of reactions:

$$4FeS_{2(s)} + 11O_{2(g)} \rightarrow 2Fe_2O_{3(s)} + 8SO_{2(g)}$$

$$2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$$

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(l)}$$

Calculate the moles of FeS_2 that would be needed to produce 9.0 moles of H_2SO_4.

A) 36 moles
B) 18 moles
[✓ C)] 4.5 moles
D) 2.2 moles

<u>Answer</u>: $9.0 \text{ moles } H_2SO_4 \times 1 \text{ mol } SO_3/1 \text{ mol } H_2SO_4 = 9.0 \text{ mol } SO_3$
$9.0 \text{ mol } SO_3 \times 2 \text{ mol } SO_2/2 \text{ mol } SO_3 = 9.0 \text{ mol } SO_2$
$9.0 \text{ mol } SO_2 \times 4 \text{ molFeS}_2/8 \text{ mol } SO_2 = 4.5 \text{ mol } SO_2$

7. A solid sample consists of <u>one or more</u> of the following salts: NH_4Br, Na_2CO_3, $CaCl_2$. The solid sample dissolves completely in water and when dilute $HCl_{(aq)}$ is added to this solution, effervescence (bubbles) is seen. For which salt is there not enough information to determine whether it is present or absent.

[✓ A)] NH_4Br
B) Na_2CO_3
C) $CaCl_2$
D) None of the above

<u>Answer</u>: NH_4Br, Na_2CO_3 *and* $CaCl_2$ *are all soluble.*
$Na_2CO_{3(aq)} + CaCl_{2(aq)} \rightarrow CaCO_{3(s)} + NaCl_{(aq)}$ $\therefore$ *one of these can't be present*
$Na_2CO_{3(aq)} + HCl_{(aq)} \rightarrow H_2CO_{3(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)}$
$\therefore$ Na_2CO_3 *must be present,* $CaCl_2$ *can't be present and* NH_4Br *is indeterminate.*

8. If the equilibrium constant for: $4NH_{3(g)} + 5O_{2(g)} \leftrightarrow 4NO_{(g)} + 6H_2O_{(g)}$ is K, determine the equilibrium constant for: $2NO_{(g)} + 3H_2O_{(g)} \leftrightarrow 2NH_{3(g)} + 5/2O_{2(g)}$

A) –2K
B) K^{-1}
C) –K
D) –0.5K
[✓ E)] $K^{-½}$

<u>Answer</u>: Equation is flipped and multiplied by ½, therefore, invert K and take square root.

9. The equilibrium constant for the reaction $2NOBr_{(g)} \leftrightarrow 2NO_{(g)} + Br_{2(g)}$ is 0.37 at a certain temperature. If 0.10 moles of NOBr, NO and Br_2 are mixed in a 1.00 L container at this temperature, which one of the following is true?

A) The system is at equilibrium and therefore no net change occurs.
B) [NOBr] = [NO] = [Br_2] at equilibrium
C) NOBr(g) will be formed until equilibrium is reached
[✓ D)] NO(g) and Br_2(g) will be formed until equilibrium is reached

<u>Answer</u>: $Q = (NO)^2(Br_2)/(NOBr)^2$
$Q = (0.10)^2(0.10)/(0.10)^2$
$Q = 0.10 << K$
$\therefore$ *b/c too few product, rxn will move from left to right (form products)*

10. The pH of a 0.0050 M aqueous solution of calcium hydroxide is

A) 2.00
B) 11.40
C) 11.70
[✓ D)] 12.00
E) 12.70

<u>Answer</u>: $Ca(OH)_{2(aq)} \rightarrow Ca^{2+}_{(aq)} + 2OH^-_{(aq)}$

I	0.0050	0	0
C	<u>–0.0050</u>	<u>+ 0.0050</u>	<u>+ 2× 0.0050</u>
E	0	0.0050	0.010

$pOH = -\log(0.010)$
$pOH = 2.00$
$pH = 14.00 - pOH = 12.00$

11. The conjugate base of ammonia is

A) NH_4^+

B) NH_3

C) OH^-

[✓ D)] NH_2^-

Answer: ammonia ≡ NH_3

A conjugate base has one less H^+ : $NH_3 - H^+ = NH_2^-$

12. Which of the following produces the strongest conjugate acid?

A) ammonia ($pK_b = 4.74$) $pK_a = 14.00 - 4.74 = 9.26$ *As* pK_a *gets smaller, the acid gets stronger.*

[✓ B)] aniline ($pK_b = 9.13$) $pK_a = 14.00 - 9.13 = 4.87$ *∴ strongest conjugate acid*

C) pyridine ($pK_b = 8.85$) $pK_a = 14.00 - 8.85 = 5.15$

D) trimethylamine ($pK_b = 4.19$) $pK_a = 14.00 - 4.19 = 9.81$

13. The pK_a for hypobromous acid, HBrO, is 8.55. This statement matches which of the following reactions?

A) $BrO^-(aq) + H_2O(l) \leftrightarrow HBrO(aq) + OH^-(aq)$

B) $HBrO(aq) + OH^-(aq) \leftrightarrow BrO^-(aq) + H_2O(l)$

[✓ C)] $HBrO(aq) + H_2O(l) \leftrightarrow BrO^-(aq) + H_3O^+(aq)$

D) $BrO^-(aq) + H_3O^+(aq) \leftrightarrow HBrO(aq) + H_2O(l)$

Answer: By definition, pK_a *(or* K_a*) is a weak acid + water reacting to produce a conjugate base and hydronium ions.*

14. A 0.10M solution of a weak acid, HA, is found to be 15% ionised.
What is the value of the ionisation constant, K_a, for this acid?

A) 1.5

B) 0.15

[✓ C)] 2.6×10^{-3}

D) 2.2×10^{-3}

Answer: $HA(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + A^-(aq)$; $15\% = [H_3O^+]/[HA] \times 100\%$

$[H_3O^+] = 0.10 \times 15/100 = 0.015$

$K_a = ([H_3O^+]\times[A^-])/[HA] = (0.015)^2/(0.10 - 0.015) = 2.6\times10^{-3}$

15. A weak base with $K_b = 1.8\times10^{-4}$ is 4.2% protonated in a 0.10 M solution.
In a 1.0 M solution, the percent protonation would be,

A) 0%.

[✓ B)] less than 4.2%.

C) 4.2%.

D) greater than 4.2%.

Answer: Ionisation increases with dilution, therefore if the solution is more concentrated, the percent protonation would decrease.

i.e., $HA(aq) + H_2O(l) \leftarrow H_3O^+(aq) + A^-(aq)$

16. A water soluble salt composed of the cation of a weak base and the anion of a strong acid is dissolved in pure water. What is the pH of the resulting solution?

[✓ A)] The pH is less than 7.00.

B) The pH is 7.00.

C) The pH is greater than 7.00.

D) Too little information is provided to make any conclusion.

Answer: Cation of a weak base, i.e., NH_4^+

Anion of a strong acid, i.e, Cl^-

End solution would be acidic.

17. Which of the following properly arranges 0.10 M solutions of KCN, $HCOOH$, NH_2OH and $(CH_3)_3NHBr$ in order of **increasing** pH? *basic salt; weak acid; weak base and acidic salt*

A) $KCN_{(aq)} < NH_2OH_{(aq)} < (CH_3)_3NHBr_{(aq)} < HCOOH_{(aq)}$ *$K_b(CN^-) = K_W/K_a(HCN) = 2.0\times10^{-5}$*

B) $KCN_{(aq)} < (CH_3)_3NHBr_{(aq)} < NH_2OH_{(aq)} < HCOOH_{(aq)}$ *$K_a(HCOOH) = 1.8\times10^{-4}$ stronger WA*

C) $HCOOH < (CH_3)_3NHBr_{(aq)} < KCN_{(aq)} < NH_2OH_{(aq)}$ *$K_b(NH_2OH) = 1.1\times10^{-8}$ weaker WB*

[✓ D)] $HCOOH_{(aq)} < (CH_3)_3NHBr_{(aq)} < NH_2OH_{(aq)} < KCN_{(aq)}$ *$K_a((CH_3)_3NH^+) = K_W/K_b(CH_3)_3NH)$*

stronger WA < weaker weak acid(WA) < weaker WB < stronger weak base (WB) *$= 1.5\times10^{-10}$*

18. Which of the following pairs of ions **can** exist in large concentrations **simultaneously** in aqueous solution?

[✓ A)] $H_3O^+_{(aq)}$ and $I^-_{(aq)}$ *strong acid + neutral = **no reaction** ∴ **can** exist together*

B) $CH_3NH_3^+_{(aq)}$ and $OH^-_{(aq)}$ *weak acid + strong base = reaction*

C) $H_3O^+_{(aq)}$ and $F^-_{(aq)}$ *strong acid + weak base = reaction*

D) $NH_4^+_{(aq)}$ and $OH^-_{(aq)}$ *weak acid + strong base = reaction*

19. Which one of the following salts gives a basic aqueous solution?

A) $CsNO_3$ *neutral salt – formed from strong base ($CsOH$) + strong acid (HNO_3)*

B) $CrCl_3$ *acidic salt – Cr^{3+} forms a complex w/ water & reacts with water to form H_3O^+*

[✓ C)] $NaClO$ *basic salt – formed from a strong base ($NaOH$) + weak acid ($HClO$)*

D) $(CH_3)_2NH_2Br$ *acidic salt – formed from a weak base + strong acid (HBr)*

E) $KHSO_4$ *acidic salt – formed from sulphuric acid + KOH; HSO_4^- is still acidic*

20. Solutions are made by combining equal volumes of the following solutions. Which is a buffer?

A) 0.10 M HCN and 0.10 M $NaOH$ *no HCN left (total neutralisation)*

[✓ B)] 0.10 M $NaCN$ and 0.050 M HCN *both conjugates present within 2:1 ratio, ∴ a buffer!*

C) 0.10 M $HClO_4$ and 0.10 M $NaClO_4$ *strong acid + its neutral salt doesn't form a buffer*

D) 0.10 M $HClO_4$ and 0.050 M $NaClO_4$ *strong acid + its neutral salt doesn't form a buffer*

21. Which pair of solutions would most likely be used to produce a buffer solution with a pH close to 6?

A) 0.10 M H_3BO_3 and 0.10 M NaH_2BO_3 $K_a(H_3BO_3) = 5.8\times10^{-10}$ *$pK_a = 9.24$*

B) 0.10 M CH_3NH_2 and 0.10 M CH_3NH_3Cl $K_b(CH_3NH_2) = 4.4\times10^{-4}$ *$pK_a = 14.00 - pK_b = 10.64$*

C) 0.10 M HNO_2 and 0.10 M $LiNO_2$ $K_a(HNO_2) = 4.5\times10^{-4}$ *$pK_a = 3.35$*

[✓ D)] 0.10 M NH_2OH and 0.10 M NH_3OHBr $K_b(NH_2OH) = 1.1\times10^{-8}$ *$pK_a = 14.00 - pK_b = 6.04$*

Effective buffer range = $pK_a \pm 1$

Part B. [Total of 18 points]

WRITTEN GRADING KEY

[6 marks]

1. Aqueous hydrochloric acid reacts with aluminum metal to form aluminium chloride and hydrogen gas.

(i) Write a balanced equation for this reaction.

$6HCl_{(aq)} + 2Al_{(s)} \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)}$ *(–1 for each mistake)*

/2

If excess hydrochloric acid reacts with 0.0753 moles of aluminum, how many litres of hydrogen gas are produced at 100.0°C and 761 Torr? *(ratio used __must__ match above equation)*

 # moles of H_2 = 0.0753 moles Al × 3 moles H_2/2 moles Al = 0.113_0 (1 pt for mole conversion using ratio)

100.0°C = 373.15 K *(1 pt for converting T)*

761 Torr = 1.00_1 atm = $101._4$ kPa *(1 pt for converting P)*

/4

$$V = \frac{(0.113_0\ \text{mol})(\mathbf{0.0821\ atm \cdot L/mol \cdot K})(373.15\ \text{K})}{1.00_1\ \text{atm}}$$

$$V = 3.46\text{L}$$

OR

$$V = \frac{(0.113_0\ \text{mol})(\mathbf{8.314\ kPa \cdot L/mol \cdot K})(373.15\ \text{K})}{101._4\ \text{kPa}}$$

$$V = 3.46\ \text{L}$$

(1 pt for choosing correct R & substituting numbers into equation properly)

[8 marks]

2. A buffer solution was prepared by mixing 0.0596 M acetic acid, CH_3COOH, and 0.0425 M potassium acetate, CH_3COOK. To 1.00 L of this buffer solution, 0.0150 moles of hydrochloric acid is added. Write the net ionic equation for the reaction and calculate the final solution pH, assuming no volume change.

NIE: $H^+_{(aq)} + CH_3COO^-_{(aq)} \leftrightarrow CH_3COOH_{(aq)}$ ***OR***

(2 pts for NIE) $H_3O^+_{(aq)} + CH_3COO^-_{(aq)} \leftrightarrow CH_3COOH_{(aq)} + H_2O_{(l)}$ *(-1 for each mistake)*

(1 pt)	*I:*	*0.0150 mol*	*0.0425 mol*	*0.0596 mol*	
	C:	*– 0.0150*	*– 0.0150*	*+ 0.0150*	$K_a = 1.8\times10^{-5}$
	E:	*0*	*0.0275 (1 pt)*	*0.0746 (1 pt)*	$pK_a = 4.74$

/8

$$pH = pK_a + \log (CH_3COO^-/CH_3COOH)$$

$$= 4.74 + \log (0.0275/0.0746)$$ *(2 pts – proper substitution of pK_a & base over acid))*

$$= 4.74 - 0.433 = 4.31$$ *(1 point for final answer)*

If final answer is 4.60, then didn't react strong acid with weak base (i.e., starting pH): 2/6 + NIE grade

[4 marks]

3. i) Write the net ionic equation for the reaction that occurs when a small amount of KOH is added to a buffer solution containing CH_3NH_2 and CH_3NH_3Cl.

$CH_3NH_3^+{}_{(aq)} + OH^-_{(aq)} \leftrightarrow CH_3NH_{2(aq)} + H_2O_{(l)}$ *(–1 for each mistake)*

(i.e., charges, elements, subscripts, correct species)

/2

ii) Calculate the value of the equilibrium constant for the above reaction.

$K_{eq} = 1/K_b\ (CH_3NH_2)$ *(K_{eq} needs to match above equation.)*

$= 1/3.6\times10^{-4}$ *1 pt*

$= 2.8\times10^{+3}$ *OR 2800* *1 pt*

/2

PAGE TOTAL

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DATA SHEET

(Any work on the page will **NOT** be graded.)

Gas constant, $R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$

$R = 8.314\ \text{kPa L mol}^{-1}\ \text{K}^{-1}$

$R = 0.0821\ \text{atm L mol}^{-1}\ \text{K}^{-1}$

Avogadro's Number $= 6.022 \times 10^{23}\ \text{mol}^{-1}$

1 atm = 101.3 kPa = 760 Torr

0°C = 273.15 K

$K_w = 1.0 \times 10^{-14}$

Acidity and Basicity Constants

Acid	**K_a**	**Base**	**K_b**
HNO_2	4.3×10^{-4}	$(C_2H_5)_3N$	1.0×10^{-3}
HF	3.5×10^{-4}	$(CH_3)_2NH$	5.4×10^{-4}
HCOOH	1.8×10^{-4}	CH_3NH_2	3.6×10^{-4}
CH_3COOH	1.8×10^{-5}	$(CH_3)_3N$	6.5×10^{-5}
H_2CO_3	4.3×10^{-7} (K_{a1})	NH_3	1.8×10^{-5}
HClO	3.5×10^{-8}	NH_2OH	1.1×10^{-8}
HBrO	2.0×10^{-9}	C_5H_5N (pyridine)	1.8×10^{-9}
HCN	4.9×10^{-10}	$C_6H_5NH_2$ (aniline)	4.3×10^{-10}

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H**																	2 **He**
2	3 **Li**	4 **Be**											5 **B**	6 **C**	7 **N**	8 **O**	9 **F**	10 **Ne**
3	11 **Na**	12 **Mg**											13 **Al**	14 **Si**	15 **P**	16 **S**	17 **Cl**	18 **Ar**
4	19 **K**	20 **Ca**	21 **Sc**	22 **Ti**	23 **V**	24 **Cr**	25 **Mn**	26 **Fe**	27 **Co**	28 **Ni**	29 **Cu**	30 **Zn**	31 **Ga**	32 **Ge**	33 **As**	34 **Se**	35 **Br**	36 **Kr**
5	37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 **Xe**
6	55 **Cs**	56 **Ba**	57 **La**	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl**	82 **Pb**	83 **Bi**	84 **Po**	85 **At**	86 **Rn**
7	87 **Fr**	88 **Ra**	89 **Ac**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Ds**								

Molar Masses (g/mol)

H	1.01	Al	26.98
C	12.01	Ar	39.95
N	14.01	P	30.97
O	16.00	S	32.06
F	19.00	Cl	35.45
Na	22.99	Cu	63.54
Ca	40.08	Ba	137.33