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Chemistry 1154 R25 Fall 2023 Test 3

Friday, November 24, 2023 Time: 1 hour 50 minutes

Name: ANSWERS Student #: _____

*This test consists of **eleven** pages of questions, the formula sheet, and a periodic table. Please ensure that you have a complete test and, if you do not, obtain one from me **immediately**. There are **45** marks (and three bonus marks) available. Good luck!*

1) **[13 marks total]** Calculate the pH (at 25°C) of the following solutions. Trimethylamine ($(CH_3)_3N$) is a weak base with $K_b = 6.3 \times 10^{-5}$.

a) **[3 marks]** 1.59 M $(CH_3)_3N$

↕ B

$B + H_2O \rightleftharpoons BH^+ + OH^-$

i	1.59	0	0
c	$-x$	$+x$	$+x$
e	$1.59-x$	x	x

$$\frac{x^2}{1.59-x} = 6.3 \times 10^{-5}$$

$\Rightarrow x = [OH^-]_e = 0.010\ldots$ M

$pOH = 2$, $\boxed{pH = 12}$

b) **[3 marks]** 10 mL of 3.975 M $(CH_3)_3N$ mixed with 15 mL of 1.67 M $(CH_3)_3NHBr$

B BHBr

$[B] = \frac{10}{25} \times 3.975 = 1.59\ M$

$[BHBr] = \frac{15}{25} \times 1.67 = 1.002\ M$

$BHBr \rightarrow BH^+ + Br^-$

1.002 1.002 1.002

	$B + H_2O \rightleftharpoons$	$BH^+ +$	OH^-
i	1.59	1.002	0
c	$-x$	$+x$	$+x$
e	$1.59-x$	$1.002+x$	x

$\frac{x(1.002+x)}{1.59-x} = 6.3\times10^{-5}$

$x = [OH^-]_e = 9.997\times10^{-5}$

$pOH = 4.0$

$\boxed{pH = 10}$

c) **[4 marks]** 10 mL of 2.5 M $(CH_3)_3N$ mixed with 15 mL of 1.0 M HBr

B

$[B] = \frac{10}{25} \times 2.5 = 1M$

$[HBr] = \frac{15}{25} \times 1 = 0.6M$

$HBr \rightarrow H^+ + Br^-$

0.6 0.6 0.6

	$B + H^+ \rightarrow$	BH^+
I	0.6	0
C	-0.6	$+0.6$
E	0.4	0.6

	$B + H_2O \rightleftharpoons$	$BH^+ +$	OH^-
i	0.4	0.6	0
c	$-x$	$+x$	$+x$
e	$0.4-x$	$0.6+x$	x

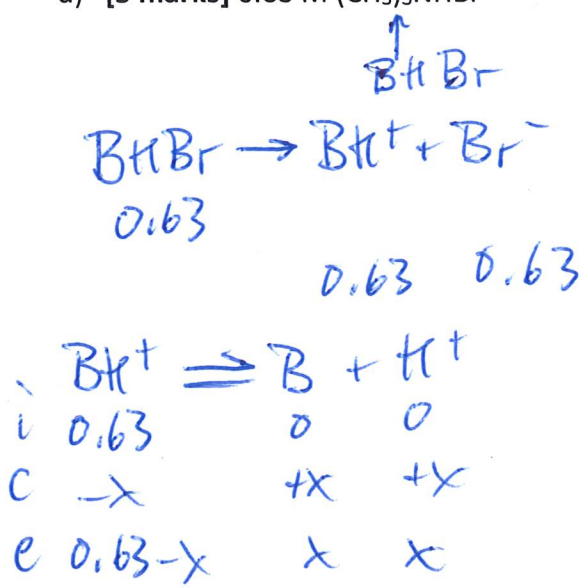
$\frac{x(0.6+x)}{(0.4-x)} = 6.3\times10^{-5}$

$x = [OH^-]_e = 4.2\times10^{-5}$

$pOH = 4.377$

$\boxed{pH = 9.623}$

d) **[3 marks]** 0.63 M $(CH_3)_3NHBr$



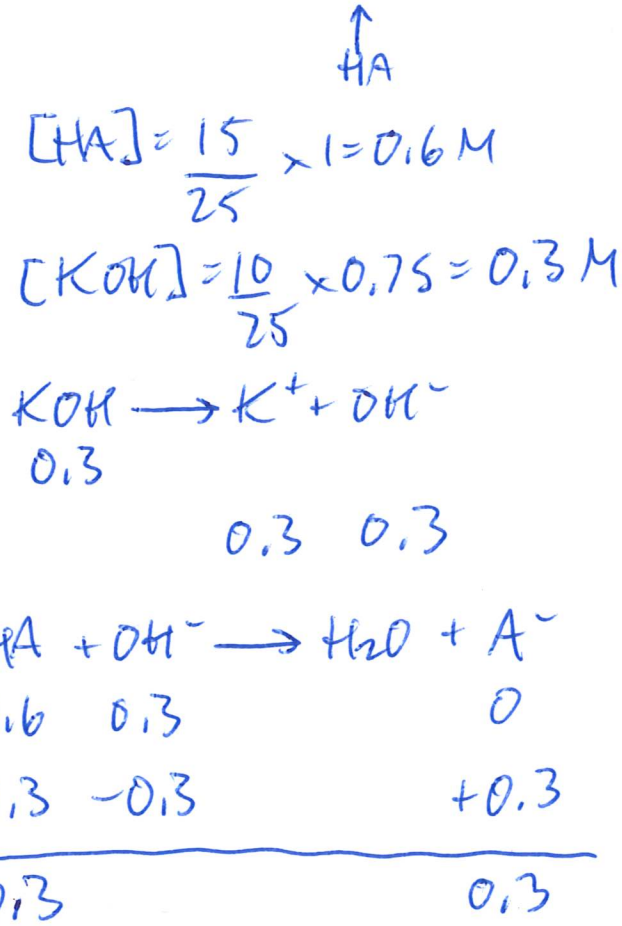
$$\frac{x^2}{0.63} = \frac{1\times10^{-14}}{6.3\times10^{-5}}$$

$$\Rightarrow x = [H^+]_e = 1\times10^{-5}$$

pH = 5

2) **[6 marks]** Calculate the pH (at 25°C) of the following solutions. Benzoic acid ($HC_6H_5CO_2$) is a weak acid with $K_a = 6.3 \times 10^{-5}$.

a) 15 mL of 1.0 M $HC_6H_5CO_2$ mixed with 10 mL of 0.75 M KOH



[HA] = [A⁻], so

By DCSC **pH = pKa = 4.20**

b) 0.63 M $NaC_6H_5CO_2$

↑
NaA

$NaA \rightarrow Na^+ + A^-$

0.63

0.63 0.63

	A^-	+ H_2O ⇌	HA	+ OH^-
i	0.63		0	0
c	−x		+x	+x
e	0.63−x		x	x

$\frac{x^2}{0.63-x} = \frac{1\times10^{-14}}{6.3\times10^{-5}}$

$x = [OH^-]_e = 1\times10^{-5}$

$pOH = 5$, $\boxed{pH = 9}$

3) **[9 marks total]** Calculate the pH (at 25°C) of the following solutions. Fumeric acid ($H_2C_4H_2O_4$) is a polyprotic acid with $K_{a1} = 0.015$ and $K_{a2} = 2.6 \times 10^{-7}$.

a) **[2 marks]** 2.00 M $KHC_4H_2O_4$

↑
KHA

$pK_{a_1} = 1.8239...$

$pK_{a_2} = 6.585...$

$pH = \frac{1}{2}(pK_{a_1} + pK_{a_2}) = \boxed{4.204}$

b) **[3 marks]** 10 mL of 2.00 M $H_2C_4H_2O_4$ mixed with 20 mL of 1.50 M KOH

↑
H_2A

$[H_2A] = \frac{10}{30} \times 2 = \frac{2}{3}$ M

$[KOH] = \frac{20}{30} \times 1.5 = 1$ M

$KOH \rightarrow K^+ + OH^-$

1 1 1

$H_2A + OH^- \rightarrow H_2O + HA^-$

$\frac{2}{3}$	1		0
$-\frac{2}{3}$	$-\frac{2}{3}$		$+\frac{2}{3}$
0	$\frac{1}{3}$		$\frac{2}{3}$

$HA^- + OH^- \rightarrow H_2O + A^{2-}$

$\frac{2}{3}$	$\frac{1}{3}$		0
$-\frac{1}{3}$	$-\frac{1}{3}$		$+\frac{1}{3}$
$\frac{1}{3}$	0		$\frac{1}{3}$

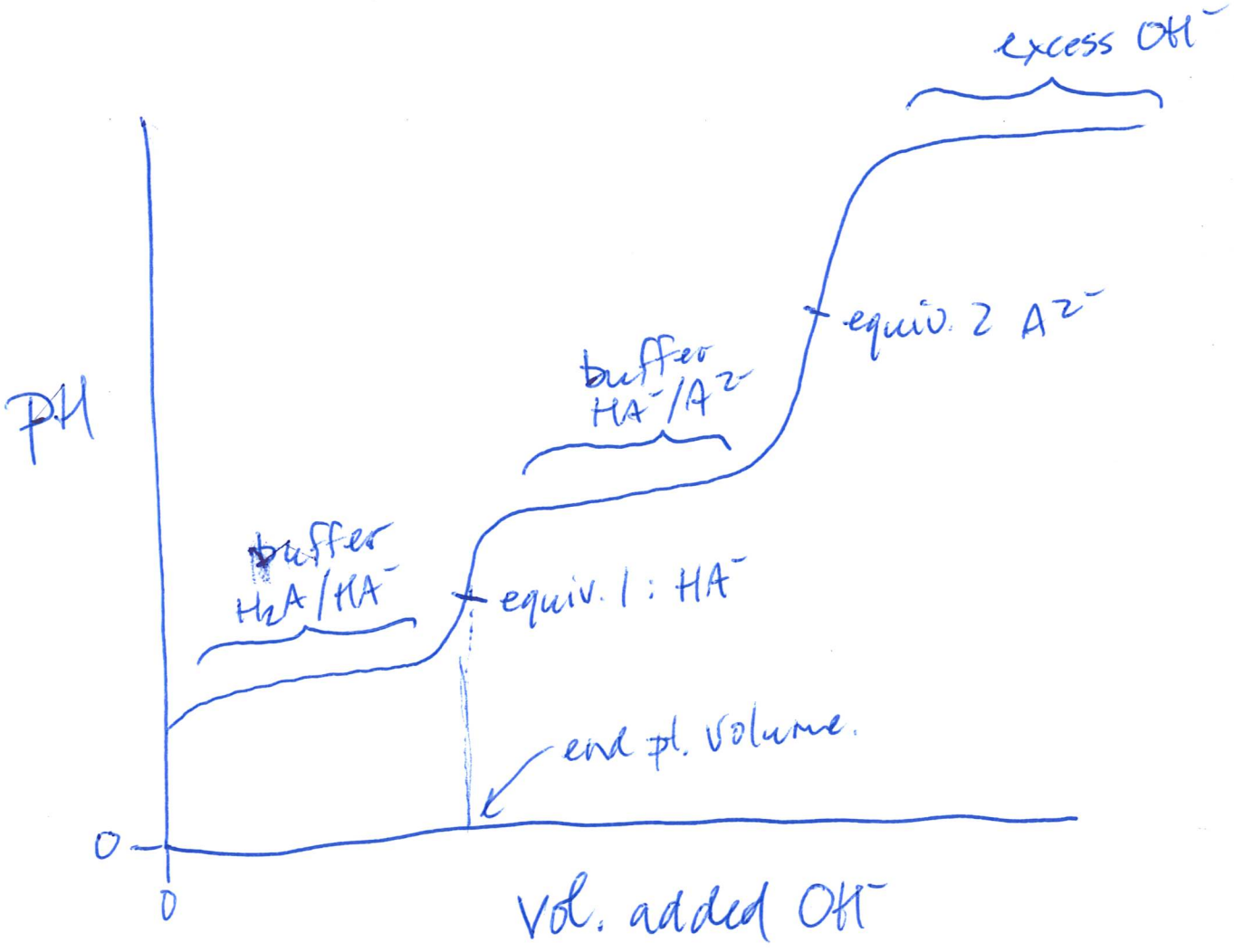
$[HA^-] = [A^{2-}]$, so

by DCSC $pH = pK_{a2}$

$= \boxed{6.585}$

c) **[4 marks]** Sketch (not necessarily to scale) the complete titration curve you would expect to see for Fumeric acid when titrated with a strong base. On your sketch, indicate:

i) Any buffer regions and the acid species present there
ii) Any equivalence points and the acid species present there
iii) Where the pH is controlled by excess base
iv) Where the end point of the titration would be observed. Assume you are using an indicator with a pK_a of 4



4) **[5 marks total]** A 10 mL aliquot of 0.012 M HNO_3 is titrated with 0.01 M KOH. An indicator with a $pK_a = 3.00$ is used for the titration.

a) **[4 marks]** At what added volume of KOH will the end point be reached?

- use V mL of KOH
- excess acid @ endpoint.

$[HNO_3] = \frac{10}{10+V} \times 0.012 = \frac{0.12}{10+V} \equiv a$

$[KOH] = \frac{V}{10+V} \times 0.01 = \frac{0.01V}{10+V} \equiv b$

$HNO_3 \rightarrow H^+ + NO_3^-$

a

a a

$KOH \rightarrow K^+ + OH^-$

b

b b

$OH^- + H^+ \rightarrow H_2O$

b a

-b -b

a-b

$a - b = 10^{-3}$

$\frac{0.12 - 0.01V}{10+V} = 10^{-3}$

$0.12 - 0.01V = 0.01 + 10^{-3}V$

$0.011V = 0.11$

$V = 10\,mL$

b) **[1 mark]** Is the indicator a suitable one for the titration? How do you know? (No marks for guessing. 😊)

$10(0.012) = Z(0.01)$

$Z = 12\,mL$

No. error $\frac{2\,mL}{12\,mL} \times 100\% = 16.6\%$

5) **[2 marks]** Complete the following table:

Acid	Conjugate Base
HPO_4^{2-}	PO_4^{3-}
H_2O	OH^-
NH_2^-	NH^{2-}
CH_4	CH_3^-

6) **[4 marks]** When 1.99 g of NaOH (40.0 g/mol) is mixed with 100.0 mL of 0.500 M H_2SO_4 (S = 4.184 J/g·°C, D = 1.00 g/mL) at 22.68°C, the temperature of the resulting solution increases to 32.01°C. Calculate ΔH for the reaction:

$2NaOH(s) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

Give your answer in kJ.

$q_{sol'n} = (100\ mL \times 1.00\frac{g}{mL} + 1.99g) \times 4.184\frac{J}{g\cdot°C} \times (32.01 - 22.68)°C$

$= 3981.3\ldots J$

$\therefore q_{rxn} = -3981.3\ldots J$

LR check:

$1.99g\ NaOH \times \frac{1\ mol}{40.0g} \times \frac{1\ rxn}{2\ NaOH} = 0.024875\ mol\ rxn$

$100\times10^{-3}L \times 0.5\frac{moles\ H_2SO_4}{L} \times \frac{1\ rxn}{1\ H_2SO_4} = 0.05\ moles\ rxn$

$\therefore 0.024875\ mol\ rxn = -3981.3\ldots J$

or

$1\ mol\ rxn = -160,054\ldots J$

$-160,054\ J \times \frac{1\ kJ}{1000\ J} = \boxed{-160.05\ kJ}$

7) **[3 marks]** Given the following reactions:

$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(l)$ $\quad \Delta H° = -2599.1$ kJ
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$ $\quad \Delta H° = -571.6$ kJ
$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(l)$ $\quad \Delta H° = -3120.8$ kJ

Calculate $\Delta H°$ for the reaction

$C_2H_2(g) + 2H_2(g) \longrightarrow C_2H_6(g)$

$C_2H_2 + 2.5O_2 \rightarrow 2CO_2 + H_2O \quad \Delta H° = -1299.55$ kJ

$2H_2 + O_2 \rightarrow 2H_2O \quad \Delta H° = -571.6$ kJ

$2CO_2 + 3H_2O \rightarrow C_2H_6 + 3.5O_2 \quad \Delta H° = -1560.4$ kJ

$C_2H_2 + 2H_2 \rightarrow C_2H_6 \quad \Delta H° = -310.75$ kJ

8) **[1 mark]** Write the thermochemical equation for the formation of $C_2H_6(g)$, for which $\Delta H°_f = -84$ kJ/mol.

$2C(s, \text{graphite}) + 3H_2(g) \rightarrow C_2H_6(g) \quad \Delta H° = -84$ kJ

9) **[2 marks]** Given that the enthalpy of formation of $CO_2(g)$ is -393.5 kJ/mol, and of $H_2O(l)$ is -285.8 kJ/mol, and given the reaction

$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(l)$ $\quad \Delta H° = -2599.1$ kJ

calculate $\Delta H°_f$ for $C_2H_2(g)$. Give your answer in kJ/mol

$2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$

$2x \quad 5(0) \qquad 4(-393.5) \quad 2(-285.8)$

$2x \qquad\qquad -2145.6$

$-2145.6 - 2x = -2599.1$

$\Rightarrow x =$ **226.75 kJ/mol**

[BONUS – 3 marks]

The first ionization of H_2SO_4 is complete, and $K_{a2} = 0.011$. Calculate the pH of a 0.01 M solution of H_2SO_4.

$$H_2SO_4 \longrightarrow HSO_4^- + H^+$$

$$0.01 \qquad 0.01 \quad 0.01$$

$$HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$$

	HSO_4^-	H^+	SO_4^{2-}
i	0.01	0.01	0
c	$-x$	$+x$	$+x$
e	$0.01-x$	$0.01+x$	x

$$\frac{x(0.01+x)}{0.01-x} = 0.011$$

$$0.01x + x^2 = 1.1\times10^{-4} - 0.011x$$

$$x^2 + 0.021x - 1.1\times10^{-4} = 0$$

$$x = \frac{-0.021 + \sqrt{(0.021)^2 + 4(1)(1.1\times10^{-4})}}{2(1)}$$

$$= 4.3\times10^{-3}$$

$$[H^+]_e = 0.01 + 4.3\times10^{-3} = 0.0143\ldots M \Rightarrow \boxed{pH = 1.843}$$