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Chemistry 1210 Spring 2023 Test 3

Wednesday, March 29, 2023 Time: 1 hour 50 minutes

Name: ANSWERS Student #: _____

*This test consists of **ten** 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 **51** marks (and four bonus marks) available. Good luck!*

1) **[2 marks]** A solution has a pH of 7.1. This solution is:

a) Acidic
b) Neutral
c) Basic
d) There is not enough information to answer this question.

2) **[2 marks]** At 25°C, the pH of a 5×10^{-10} M solution of $Ca(OH)_2$ should be:

a) 4.70 c) 9.00 e) None of these
b) 5.00 d) 9.30

3) **[4 marks]** Calculate the pH (at 25°C) of 15.00 mL of 1.00×10^{-3} M HCl mixed with 25.00 mL of 6.00×10^{-4} M $Mg(OH)_2$.

$[HCl] = \frac{15}{40} \times 1\times10^{-3} = 3.75\times10^{-4}$ M

$[Mg(OH)_2] = \frac{25}{40} \times 6\times10^{-4} = 3.75\times10^{-4}$ M

$HCl \rightarrow H^+ + Cl^-$

3.75×10^{-4} 3.75×10^{-4}

$Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$

3.75×10^{-4} 7.5×10^{-4}

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

3.75×10^{-4} 7.5×10^{-4}

-3.75×10^{-4} -3.75×10^{-4}

0 3.75×10^{-4}

pOH (by DCSC) = 3.426

pH + pOH = 14 $\Rightarrow$ pH = 10.574

4) **[9 marks total]** Calculate the pH (at 25°C) of the following solutions, all made with propionic acid ($HC_3H_5O_2$) and/or its salts. Propionic acid is a weak acid with a $K_a = 1.34 \times 10^{-5}$.

a) **[2 marks]** 0.0746 M propionic acid

$HA \rightleftharpoons H^+ + A^-$

i	0.0746	0	0
c	$-x$	$+x$	$+x$
e	$0.0746-x$	x	x

$$\frac{x^2}{0.0746-x} = 1.34 \times 10^{-5}$$

$$\Rightarrow x = [H^+]_e = 1 \times 10^{-3}$$

$$\boxed{pH = 3.0}$$

b) **[4 marks]** 10.00 mL of 1.00 M propionic acid mixed with 15.00 mL of 0.620 M NaOH

$$[HA] = \frac{10}{25} \times 1 = 0.4\,M$$

$$[NaOH] = \frac{15}{25} \times 0.62 = 0.372\,M$$

$NaOH \rightarrow Na^+ + OH^-$

$0.372 \quad 0.372 \quad 0.372$

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

	0.372	0.4	0
	-0.372	-0.372	$+0.372$
	0	0.028	0.372

$HA \rightleftharpoons H^+ + A^-$

i	0.028	0	0.372
c	$-x$	$+x$	$+x$
e	$0.028-x$	x	$0.372+x$

$$\frac{x(0.372+x)}{0.028-x} = 1.34 \times 10^{-5}$$

$$\Rightarrow x = [H^+]_e = 1.00 \times 10^{-6}$$

$$\boxed{pH = 6.0}$$

c) **[3 marks]** 0.134 M sodium propionate

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

0.134 → 0.134 0.134

$A^- + H_2O \rightleftharpoons HA + OH^-$

	A^-		HA	OH^-
i	0.134		0	0
c	$-x$		$+x$	$+x$
e	$0.134-x$		x	x

$\frac{x^2}{0.134-x} = \frac{1\times10^{-14}}{1.34\times10^{-5}}$

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

$pOH = 5$, so $\boxed{pH = 9.0}$

5) **[8 marks total]** Calculate the pH (at 25°C) of the following solutions, all made with trimethylamine ($(CH_3)_3N$) and/or its salts. Trimethylamine is a weak base with a $K_b = 6.5 \times 10^{-5}$.

a) **[3 marks]** 10 mL of 0.5 M trimethylamine mixed with 15 mL of 0.289 M $HClO_4$

$[B] = \frac{10}{25} \times 0.5 = 0.2M$

$[HClO_4] = \frac{15}{25} \times 0.289 = 0.1734M$

$HClO_4 \rightarrow H^+ + ClO_4^-$

0.1734 → 0.1734 0.1734

$B + H^+ \rightarrow BH^+$

	B	H^+	BH^+
	0.2	0.1734	0
	-0.1734	-0.1734	$+0.1734$
	0.0266	0	0.1734

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

	B		BH^+	OH^-
i	0.0266		0.1734	0
c	$-x$		$+x$	$+x$
e	$0.0266-x$		$0.1734+x$	x

$\frac{x(0.1734+x)}{(0.0266-x)} = 6.5\times10^{-5}$

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

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

b) **[2 marks]** A solution that has [trimethylamine] = 0.215 M and [trimethylammonium perchlorate] = 0.139 M

$BHClO_4 \rightarrow BH^+ + ClO_4^-$

0.139 0.139 0.139

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

i	0.215	0.139	0
c	$-x$	$+x$	$+x$
e	$0.215-x$	$0.139+x$	x

$$\frac{x(0.139+x)}{(0.215-x)} = 6.5\times10^{-5}$$

$\Rightarrow x = [OH^-]_e = 1\times10^{-4}$

$pOH = 4$, $\boxed{pH = 10}$

c) **[3 marks]** A solution that has [trimethylammonium perchlorate] = 0.65 M

$BHClO_4 \rightarrow BH^+ + ClO_4^-$

0.65 0.65 0.65

$BH^+ \rightleftharpoons B + H^+$

i	0.65	0	0
c	$-x$	$+x$	$+x$
e	$0.65-x$	x	x

$$\frac{x^2}{0.65-x} = \frac{1\times10^{-14}}{6.5\times10^{-5}}$$

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

$\boxed{pH = 5.0}$

6) **[6 marks total]** Phosphoric acid (H_3PO_4) is a weak triprotic acid with $pK_{a1} = 2.12$, $pK_{a2} = 7.21$, and $pK_{a3} = 12.32$. Calculate (at 25°C) the pH of the following solutions, all made using phosphoric acid and/or its salts.

a) **[4 marks]** 10 mL of 1 M H_3PO_4 mixed with 15 mL of 1 M KOH

$[H_3A] = \frac{10}{25} \times 1 = 0.4M$

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

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

0.6 → 0.6 0.6

$OH^- + H_3A \longrightarrow H_2O + H_2A^-$

0.6	0.4	0
−0.4	−0.4	+0.4
0.2	0	0.4

Rxn continues...

$OH^- + H_2A^- \rightleftharpoons H_2O + HA^{2-}$

0.2	0.4	0
−0.2	−0.2	+0.2
0	0.2	0.2

$[H_2A^-] = [HA^{2-}]$, so by DCSC **pH = 7.21**

b) **[2 marks]** A solution containing only NaH_2PO_4.

$\frac{1}{2}(pK_{a1} + pK_{a2}) =$ **4.665**

7) **[5 marks total]** A 10-mL aliquot of 1.0×10^{-3} M HCl is titrated with 8.0×10^{-4} M NaOH. An indicator with $pK_{in} = 4.00$ is used.

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

$[HCl] = \frac{10}{10+V} \times 1 \times 10^{-3} = \frac{0.01}{10+V}$ (a)

$[NaOH] = \frac{V}{10+V} \times 8 \times 10^{-4} = \frac{8 \times 10^{-4} V}{10+V}$ (b)

$HCl \rightarrow H^+ + Cl^-$

a

a a

$NaOH \rightarrow Na^+ + OH^-$

b

b b

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

a b

$-b \quad -b$

$a-b$

$a - b = 10^{-4}$

$\left(\frac{0.01 - 8 \times 10^{-4} V}{10+V} = 10^{-4} \right) \times 10^4$

$\frac{100 - 8V}{10+V} = 1$

$100 - 8V = 10 + V$

$90 = 9V$

$\boxed{V = 10 \text{ mL}}$

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

want end point when moles acid = moles base:

$10 \times 10^{-3} = V \times 8 \times 10^{-4}$

$\Rightarrow V = 12.5$ mL

error: $\frac{2.5}{12.5} \times 100 = 20\%$ $\therefore$ **No good!**

8) **[2 marks]** Indicate whether each of the following salts acts as an acid, as a base, or neither in aqueous solution. Circle your choice:

$NaNO_2$	acid	**base**	neither
NH_4Cl	**acid**	base	neither
KF	acid	**base**	neither
KI	acid	base	**neither**

9) **[4 marks]** When 1.63 grams of NaOH (40.0 g/mol) was mixed with 100.0 mL of 0.300 M H_2SO_4 (S = 4.184 J/g·°C, D = 1.00 g/mL) at 22.20°C, the temperature of the resulting solution rose to 29.06°C. Given that the H_2SO_4 was contained in a calorimeter with C = 50 J/°C, calculate ΔH° for the reaction:

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

$q_{soln} + q_{cal} + q_{rxn} = 0$

$(101.63)(4.184)(29.06-22.2) + 50(29.06-22.2) + q_{rxn} = 0$

$\Rightarrow q_{rxn} = -3260\ J$

LR check: $1.63g \times \frac{1\ mol}{40\ g} \times \frac{1\ rxn}{2\ NaOH} = 0.020375\ moles\ rxn$

$100 \times 10^{-3} L \times \frac{0.3\ mol}{1\ L} \times \frac{1\ rxn}{1\ H_2SO_4} = 0.03\ moles\ rxn$

$\therefore \Delta H^\circ = \frac{-3260\ J}{0.020375} = \boxed{-160{,}000\ J \text{ or } -160\ kJ}$

10) **[3 marks total]** Given the following reactions:

$C_2H_2(g) + 2H_2(g) \longrightarrow C_2H_6(g)$	$\Delta H° = -94.5$ kJ
$2H_2O(g) \longrightarrow 2H_2(g) + O_2(g)$	$\Delta H° = 484$ kJ
$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(g)$	$\Delta H° = -3120.8$ kJ

a) **[2 marks]** Calculate $\Delta H°$ for the reaction

$$2CO_2(g) + H_2O(g) \longrightarrow C_2H_2(g) + 2.5O_2(g)$$

2,5

$2CO_2 + H_2O \rightarrow C_2H_6 + 3,5O_2$ $\quad \Delta H° = +1560.4$ kJ

$2H_2 + O_2 \rightarrow 2H_2O$ $\quad \Delta H° = -484$ kJ

$C_2H_6 \rightarrow C_2H_2 + 2H_2$ $\quad \Delta H° = +94.5$ kJ

$2CO_2 + H_2O \rightarrow C_2H_2 + 2.5O_2$ $\quad \Delta H° = 1170.9$ kJ

b) **[1 mark]** What is the enthalpy of formation of $H_2O(g)$? Give your answer in kJ/mol.

$-242 \frac{kJ}{mol}$

11) **[2 marks]** Given the reaction

$$2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(l) \quad \Delta H° = -1453.56$$

And that the molar enthalpies of formation of CO_2 and H_2O are -393.52 kJ and -285.83 kJ respectively, calculate the molar enthalpy of formation of $CH_3OH(l)$.

$2(-393.52) + 4(-285.83) - 2x = -1453.56$

$-1930.36 - 2x = -1453.56$

$\Rightarrow x = -238.4 \frac{kJ}{mol}$

$(32.04\ \frac{g}{mol})$

12) **[4 marks]** When 324.4 mg of $CH_3OH(l)$ is burned in a bomb calorimeter with C = 10.0 kJ/°C, the temperature of the calorimeter increases from 25.0000°C to 25.7346°C. Calculate $\Delta H°$ for the reaction

$$2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(l)$$

$q_{cal} = 10.0(0.7346) = 7.346\ kJ$

$\therefore q_{rxn} = -7.346\ kJ$

$n_{rxn} = 324.4 \times 10^{-3}\ g \times \frac{1\ mol}{32.04\ g} \times \frac{1\ rxn}{2\ CH_3OH} = 5.062\ldots \times 10^{-3}\ mol\ rxn$

$\therefore \Delta E° = \frac{-7.346\ kJ}{5.062\ldots \times 10^{-3}} = -1451.08\ kJ$

$\Delta H° = -1451.08 + (2-3)(8.314 \times 10^{-3})(298.15)$

$= \boxed{-1453.56\ kJ}$

[BONUS – 4 marks] It takes 5.0144 g of FeX_n to lower the freezing point of 100 g of water (K_f = 1.86°C/molal) by 2.3°C. It takes 6.4125 g of RuX_n (same X, same n) to lower the freezing point of 100 g of water by 2.3°C. What are the element X and the value of n? You may assume that both FeX_n and RuX_n ionize completely in water.

$FeX_n \rightarrow Fe^{3+} + nX^-$

$i = 1 + n$

(same for RuX_n)

$2.3 = (n+1)(1.86)\frac{\text{moles}}{0.1\text{ kg}}$

$\Rightarrow \text{moles} = \frac{0.23}{1.86(n+1)}$ for both.

$n+1 = \frac{bc-cf}{ad-ed}$

$= 4$

$n = 3$

So: $\frac{5.0144}{55.845 + nX} = \frac{0.23}{1.86(n+1)}$ (a, b, c, d)

and $\frac{6.4125}{101.07 + nX} = \frac{0.23}{1.86(n+1)}$ (e, f, c, d)

So: $\frac{5.0144}{55.845 + 3X} = 3.09\ldots \times 10^{-2}$ (a, b, c)

$\frac{a}{b+nx} = \frac{c}{d(n+1)}$

$\frac{e}{f+nx} = \frac{c}{d(n+1)}$

$\frac{a}{b+3x} = c$

$a = cb + 3cx$

$a - cb = 3cx$

$x = \frac{a-cb}{3c} = 35.453$

Cl.

$ad(n+1) = bc + cnx$

$ed(n+1) = cf + cnx$

$(ad-ed)(n+1) = bc - cf$

So: $X = Cl$, $n = 3$