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Chemistry 1210 Spring 2024 Test 3

Wednesday, March 27, 2024

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 **43** marks available. Good luck!*

1) **[11 marks total]** A battery was constructed using the following half-reactions:

$Mg^{2+}(aq, 0.10\ M) + 2e^{-1} \rightleftharpoons Mg(s)$ $\quad \varepsilon° = -2.36\ V$

$Cl_2(g, 0.010\ bar) + 2e^{-1} \rightleftharpoons 2Cl^{-1}(aq, 10\ M)$ $\quad \varepsilon° = 1.36\ V$

Platinum electrodes were available where necessary, and 3 litres of solution were used in each half cell. The battery was run at 25°C.

a) **[1 mark]** Write the overall reaction occurring in the battery.

$Mg \rightleftharpoons Mg^{2+} + 2e^-$ $\quad \varepsilon° = +2.36V$

$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ $\quad \varepsilon° = +1.36V$

$Mg + Cl_2 \rightleftharpoons Mg^{2+} + 2Cl^-$

b) **[1 mark]** Calculate ε° for the battery.

$2.36 + 1.36 = 3.72V$

c) **[2 marks]** Calculate K for the battery.

$\varepsilon° = \frac{0.059159}{2} \log K$

$\Rightarrow \log K = 125.762\ldots$

So $K = 5.79 \times 10^{125}$

d) **[2 marks]** What voltage will the battery generate under the conditions given?

$$E = 3.72 - \frac{0.059159}{2} \log\left(\frac{0.1 \times 10^2}{0.01}\right)$$

$$= \boxed{3.631\ V}$$

e) **[1 mark]** Give the cell notation for the battery.

$$Mg(s) \mid Mg^{2+}(aq, 0.1\ M) \mid\mid Cl_2(g, 0.01\ bar) \mid Cl^-(aq, 10\ M) \mid Pt(s)$$

f) **[3 marks]** A current of 2.0 amperes was drawn from the battery for 16 hours, 4 minutes, and 51.2 seconds. What was the $[Mg^{2+}]$ after that time?

16×3600

4×60

51.2

$57891.2\ s$

$$57891.2\ s \times \frac{2\ coul}{s} \times \frac{1\ mol\ e^-}{96{,}485.33212\ coul} \times \frac{1\ Mg^{2+}}{2e^-}$$

$$= 0.6\ moles\ Mg^{2+}\ \underline{created}$$

$$So\ [Mg^{2+}] = \frac{0.1\ \frac{moles}{L} \times 3L + 0.6\ moles}{3L}$$

$$= \boxed{0.3\ M}$$

g) **[1 mark]** This battery cannot be recharged successfully. Why? (No marks for guessing. 😊)

Water will both oxidize before Cl^- and reduce befor Mg^{2+} (more positive E°s for it).

2) **[4 marks]** A concentration cell was set up using the half-reaction:

$2H^+(aq) + 2e^{-1} \rightleftharpoons H_2(g)$

Both half-cells had the pressure of H_2 set to 0.20 bar. In one of the half cells the $[H^+]$ was 0.10 M, and in the other the H^+ was generated by a 0.035 M solution of a weak acid. The concentration cell was run at 10.06°C. If the battery so constructed generated 46.3 mV, what was the K_a of the weak acid?

$H_2(0.2) \rightleftharpoons 2H^+(xM) + 2e^-$

$2H^+(0.1\,M) + 2e^- \rightleftharpoons H_2(0.2)$

overall: $2H^+(0.1\,M) \rightleftharpoons 2H^+(xM)$ $\mathcal{E}^\circ = 0$

$46.3 \times 10^{-3} = 0 - \frac{(8.314462618)(283.21)}{2 \cdot 96{,}485.33212} \ln Q$

$\Rightarrow Q = 0.022499\ldots$

$= \frac{x^2}{0.1^2} \Rightarrow x = 0.015\ M\ H^+$

It all came from HA...

	$HA \rightleftharpoons$	H^+	$+ A^-$
i	0.035	0	0
c	$-y$	$+y$	$+y$
e	$0.035-y$	y	y

$K_a = \frac{(0.015)^2}{(0.02)} = \boxed{0.01125}$

3) **[1 mark]** Which of the following species is most likely to be amphiprotic?

a) NH_3 b) H_3PO_4 c) $C_2H_3O_2^{-1}$ d) $H_2AsO_4^{-1}$

4) **[2 marks]** When $K_w = 1.0 \times 10^{-13}$, the pH of a 3×10^{-10} M solution of $Mg(OH)_2$ is closest to:

a) 3.48
b) 3.78
c) 6.50
d) 9.22
e) 9.52
f) None of these

5) **[11 marks total]** Calculate the pH of the following solutions, all made at 25°C:

a) **[3 marks]** 10.0 mL of 1.0×10^{-3} M HBr mixed with 15.0 mL of 5.0×10^{-4} M KOH.

$[HBr] = \frac{10}{25} \times 1 \times 10^{-3} = 4 \times 10^{-4}\ M$

$[KOH] = \frac{15}{25} \times 5 \times 10^{-4} = 3 \times 10^{-4}\ M$

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

4×10^{-4}

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

3×10^{-4}

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

4×10^{-4} 3×10^{-4}

-3×10^{-4} -3×10^{-4}

1×10^{-4}

$pH\ (by\ DCSC) = -\log(1 \times 10^{-4})$

$= \boxed{4.0}$

b) **[3 marks]** 10.0 mL of a solution that has [HA] = 0.20 M and [NaA] = 0.10 M mixed with 15.0 mL of 0.05 M NaOH. HA is a weak acid with a $K_a = 1.40 \times 10^{-4}$

$[HA] = \frac{10}{25} \times 0.2 = 0.08M$

$[NaA] = \frac{10}{25} = 0.1 = 0.04M$

$[NaOH] = \frac{15}{25} \times 0.05 = 0.03M$

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

	0.03	0.08	0.04
	−0.03	−0.03	+0.03
	0	0.05	0.07

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

0.04

0.04

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

0.03

0.03

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

i	0.05	0	0.07
c	−x	+x	+x
e	0.05−x	x	0.07+x

$\frac{x(0.07+x)}{(0.05-x)} = 1.4 \times 10^{-4}$

$x = [H^+]_e = 1 \times 10^{-4}$

$pH = 4.0$

c) **[3 marks]** 0.014 M NaA (same weak acid as in (b)).

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

0.014

0.014

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

i	0.014	0	0
c	−x	+x	+x
e	0.014−x	x	x

$\frac{x^2}{0.014-x} = \frac{1 \times 10^{-14}}{1.4 \times 10^{-4}}$

$\Rightarrow x = [OH^-]_e = 1 \times 10^{-6}$

$pOH = 6, \quad pH = pK_w - pOH = 8$

d) **[2 marks]** 10.0 mL of 0.20 M NH_3 (K_b = 1.74 x 10^{-5}) mixed with 15.0 mL of 0.1335 M HI.

$[NH_3] = \frac{10}{25} \times 0.2 = 0.08\,M$

$[HI] = \frac{15}{25} \times 0.1335 = 0.0801\,M$

$HI \rightarrow H^+ + I^-$

0.0801

0.0801

$NH_3 + H^+ \longrightarrow NH_4^+$

	0.08	0.0801	
	−0.08	−0.08	+0.08
	0	1×10^{-4}	0.08

By DCSC, $[H^+]_e = 1 \times 10^{-4}$

$\boxed{pH = 4.0}$

6) **[14 marks total]** H_2A is a weak acid with $K_{a1} = 2.5 \times 10^{-4}$ and $K_{a2} = 4.0 \times 10^{-9}$. Calculate the pH of the following solutions made using H_2A and/or its salts at 25°C.

a) **[3 marks]** 10.0 mL of 0.18 M H_2A mixed with 15.0 mL of 0.30 M NaHA.

$[H_2A] = \frac{10}{25} \times 0.18 = 0.072\ M$

$[NaHA] = \frac{15}{25} \times 0.3 = 0.18\ M$

$NaHA \rightarrow Na^+ + HA^-$

0.18 0.18

$H_2A \rightleftharpoons HA^- + H^+$

	H_2A	HA^-	H^+
i	0.072	0.18	0
c	$-x$	$+x$	$+x$
e	$0.072-x$	$0.18+x$	x

$\frac{(0.18+x)(x)}{0.072-x} = 2.5 \times 10^{-4}$

$\Rightarrow x = [H^+]_e = 1 \times 10^{-4}$; **pH = 4.0**

b) **[2 marks]** 15.0 mL of 0.30 M NaHA

$pH = \frac{1}{2}(pK_{a_1} + pK_{a_2}) =$ **6**

c) **[4 marks]** 10.0 mL of 0.21 M H_2A mixed with 15.0 mL of 0.18 M NaOH

$[H_3A] = \frac{10}{25} \times 0.21 = 0.084\ M$

$[NaOH] = \frac{15}{25} \times 0.18 = 0.108\ M$

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

0.108 0.108

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

0.108	0.084	0
−0.084	−0.084	+0.084
0.024	0	0.084

rxn continues...

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

i 0.024	0.084	0
−0.024	−0.024	+0.024
0	0.06	0.024

$HA^- \rightleftharpoons H^+ + A^{2-}$

i	0.06	0	0.024
c	−x	+x	+x
e	0.06−x	x	0.024+x

$\frac{x(0.024+x)}{(0.06-x)} = 4.0 \times 10^{-9}$

$x = [H^+]_e = 1 \times 10^{-8}$

pH = 8.0

d) **[1 mark]** What would be the pK_a for an indicator that you would use for the titration of H_2A? How do you know? (No marks for guessing. 😊)

Pick an indicator whose colour changes at the 1ST equiv. point, for which the pH=6. ∴ pK_a for indicator should be 6.

e) **[4 marks]** Sketch the titration curve you would expect to see for H_2A being titrated by NaOH. On your graph, indicate:

i) The equivalence point or points
ii) The buffer region or regions
iii) The region or regions on the graph where the pH is controlled by OH^-
iv) The point or points on the graph where the pH is controlled by one amphiprotic species.