AP CHEMISTRY

TOPIC 7: ACIDS & BASES, PART D

Day 81:

- Polyprotic acids
- Amphoteric substance
- Acid-Base salts

---

1. Write out the stepwise dissociation reactions and the K_a expressions for the diprotic acid H_2SO_3 .

$$H_2SO_3 \leftrightarrow HSO_3^{-1} + H^{+1} \qquad \frac{\left[\ HSO_3^{-1}\ \right]\left[\ H^{+1}\ \right]}{\left[\ H_2SO_3\ \right]}$$

$$HSO_3^{-1} \leftrightarrow SO_3^{-2} + H^{+1} \qquad \frac{\left[\ SO_3^{-2}\ \right]\left[\ H^{+1}\ \right]}{\left[\ HSO_3^{-1}\ \right]}$$

2. Calculate the pH of a 0.10 M H_2CO_3 ($K_{a_1} = 4.3 \times 10^{-7}$, $K_{a_2} = 4.3 \times 10^{-11}$).

	$[H_2CO_3]$	+	$[H_2O]$	$\leftrightarrow$	$[HCO_3^{-1}]$	+	$[H_3O^{+1}]$
I	0.10 M		-		0		0
C	$-x$		-		$+x$		$+x$
E	0.10 $M - x$		-		x		x

$$K_{a_1} = 4.3\times10^{-7} = \frac{\left[\ HCO_3^{-1}\ \right]\left[\ H_3O^{+1}\ \right]}{\left[\ H_2CO_3\ \right]} = \frac{x^2}{0.10-x} = \frac{x^2}{0.10}$$

$$x^2 = (\ 0.10\ )(\ 4.3\times10^{-7}\ ), \qquad x = \sqrt{\ 4.3\times10^{-8}} = 2.07\times10^{-4}$$

$$[\ H_3O^{+1}\ ] = 2.1 \times 10^{-4}\ M.$$

$$\textbf{pH} = -\log(\ 2.1 \times 10^{-4}\ ) = \textbf{3.68}$$

There is no need to do a second ICE chart since the pH will not change by significant amount… If you do a second ICE chart, the concentration of the [H^{+1}] = 4.30 x 10^{-11} *M*. This concentration is so small it will NOT affect the pH.

3. Given that the K_a value for acetic acid is 1.8 x 10^{-5} and the K_a value for hypochlorous acid is 3.5 x 10^{-8}, which is the stronger base, OCl^{-1} or $C_2H_3O_2^{-1}$? Explain why.

From the K_a values, acetic acid is a stronger acid than hypochlorous acid. Conversely, the conjugate base of acetic acid, $C_2H_3O_2^{-1}$, will be a weaker base than the conjugate base of hypochlorous acid, OCl^{-1}, Thus, the hypochlorite ion, OCl^{-1}, is a stronger base than the acetate ion, $C_2H_3O_2^{-1}$, ***In general, the stronger acid, the weaker the conjugate base.*** *This statement comes from the relationship $K_w = K_a \times K_b$ which holds true for all conjugate acid-base pairs.*

Also, you could calculate the K_b for each the of bases… A higher K_b equals the stronger base…

$$C_2H_3O_2^{-1} : \ K_b = \frac{K_w}{K_a} = \frac{1.00\times10^{-14}}{1.8\times10^{-5}} = 5.56\times10^{-10} \quad ; \quad OCl^{-1} : \ K_b = \frac{K_w}{K_a} = \frac{1.00\times10^{-14}}{3.5\times10^{-8}} = 2.86\times10^{-7}$$

4. Calculate the pH for 0.10 *M* CH_3NH_3Cl, $K_b = 4.38 \text{ x } 10^{-4}$ for CH_3NH_2.

$$CH_3NH_3Cl \rightarrow CH_3NH_3^{+1} + Cl^{-1}$$

($CH_3NH_3^{+1}$, conjugate acid of a weak base, Cl^{-1}, conjugate base of a strong acid)

The chlorine ion, Cl^{-1}, has no effect on the solution to make it basic or acidic.

$$K_a = \frac{K_w}{K_b} = \frac{1.00\times10^{-14}}{4.38\times10^{-4}} = 2.28\times10^{-11}$$

	[$CH_3NH_3^{+1}$]	+	[H_2O]	$\rightleftharpoons$	[CH_3NH_2]	+	[H_3O^{+1}]
I	0.10 *M*		-		0		0
C	- *x*		-		+ *x*		+ *x*
E	0.10 *M* - *x*		-		*x*		*x*

$$K_a = 2.28\times10^{-11} = \frac{\left[\ CH_3NH_2\ \right]\left[\ H_3O^{+1}\ \right]}{\left[\ CH_3NH_3^{+1}\ \right]} = \frac{x^2}{0.10-x} = \frac{x^2}{0.10}$$

$$x^2 = (\ 0.10\ )\left(\ 2.28\times10^{-11}\ \right), \qquad x = \sqrt{\ 2.28\times10^{-12}} = 1.51\times10^{-6}$$

$$[\ H_3O^{+1}\ ] = 1.51 \text{ x } 10^{-6}\ M$$

pH = - log (1.51 x 10^{-6}) = **5.82**

5. Calculate the pH for 0.050 *M* NaCN, $K_a = 6.2 \text{ x } 10^{-10}$ for HCN.

$$NaCN \rightarrow Na^{+1} + CN^{-1}$$

(Na^{+1}, conjugate acid of a strong base, CN^{-1}, conjugate base of a weak acid)

The sodium ion, Na^{+1}, has no effect on the solution to make it basic or acidic.

$$K_b = \frac{K_w}{K_a} = \frac{1.00\times10^{-14}}{6.2\times10^{-10}} = 1.61\times10^{-5}$$

	[CN^{-1}]	+	[H_2O]	$\rightleftharpoons$	[HCN]	+	[OH^{-1}]
I	0.050 *M*		-		0		0
C	- *x*		-		+ *x*		+ *x*
E	0.050 *M* - *x*		-		*x*		*x*

$$K_b = 1.61\times10^{-5} = \frac{\left[\ HCN\ \right]\left[\ OH^{-1}\ \right]}{\left[\ CN^{-1}\ \right]} = \frac{x^2}{0.050-x} = \frac{x^2}{0.050}$$

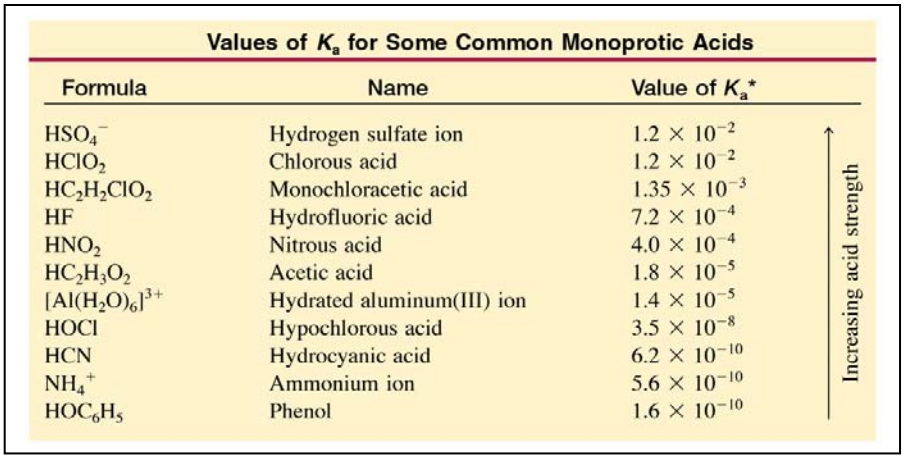
$$x^2 = (\ 0.050\ )\left(\ 1.61\times10^{-5}\ \right), \qquad x = \sqrt{\ 8.06\times10^{-7}} = 8.98\times10^{-4}$$

$$[\ OH^{-1}\ ] = 8.98 \text{ x } 10^{-4}\ M$$

pOH = - log (8.98 x 10^{-4}) = 3.05

pH = 14 - 3.05 = **10.95**

6. An unknown salt is either NaCN, $NaC_2H_3O_2$, NaF, NaCl, $NaNO_2$, or NaOCl. When 0.100 mol of the salt is dissolved in 1.00 liter of water, the pH of the solution is 8.07. What is the identity of this salt? (use the chart below)



Values of K_a for Some Common Monoprotic Acids

Formula	Name	Value of K_a*
HSO_4^-	Hydrogen sulfate ion	1.2×10^{-2}
$HClO_2$	Chlorous acid	1.2×10^{-2}
$HC_2H_2ClO_2$	Monochloracetic acid	1.35×10^{-3}
HF	Hydrofluoric acid	7.2×10^{-4}
HNO_2	Nitrous acid	4.0×10^{-4}
$HC_2H_3O_2$	Acetic acid	1.8×10^{-5}
$[Al(H_2O)_6]^{3+}$	Hydrated aluminum(III) ion	1.4×10^{-5}
HOCl	Hypochlorous acid	3.5×10^{-8}
HCN	Hydrocyanic acid	6.2×10^{-10}
NH_4^+	Ammonium ion	5.6×10^{-10}
HOC_6H_5	Phenol	1.6×10^{-10}

Answers:

All these salts contain Na $^{+1}$ which has no acidic / basic properties and a conjugate base of a weak acid (except for NaCl where Cl $^{-1}$ is a neutral species.) All conjugates bases of weak acids are weak bases since K_b for these species are between K_w and one (1). To identify the species, we will use the data given (in the chart above) to determine the K_b value for the weak conjugate base. From the K_b value and the data above, we can identify the conjugate base present by calculating K_a value for the weak acid.

	$[A^{-1}]$	+	$[H_2O]$	$\rightleftharpoons$	[HA]	+	$[OH^{-1}]$
I	0.100 *M*		-		0		0
C	$-x$		-		$+x$		$+x$
E	0.100 *M* - x		-		x		x

$$K_b = \frac{[\;HA\;]\,[\;OH^{-1}\;]}{[\;A^{-1}\;]} = \frac{x^2}{(0.100-x)}$$

pH = 8.07 (given from question)

pOH = 14.00 - 8.07 = 5.93

$[\,OH^{-1}\,] = x = \text{antilog}\;(-5.93) = 1.17 \times 10^{-6}\,M$

$$K_b = \frac{(\;1.17\times10^{-6}\;)^2}{(0.100\;-\;1.17\times10^{-6}\;)} = 1.38\times10^{-11} = \text{For “Unknown Salt”}$$

Since we are NOT given K_b values for the Salts, we must find the K_a for the conjugate acid.

$$K_a = \frac{K_w}{K_b} = \frac{1.00\times10^{-14}}{1.38\times10^{-11}} = 7.24\times10^{-4}$$

from the table above, this K_a value is closest to HF, Therefore the unknown salt is NaF.