16.3 Acid and Base Strength

Acid and Base Strength

Acid Ionization

See Class Web Site.

Acid:

- ◉ H_3PO_4
- ○ CH_3CO_2H
- ○ H_2CO_3
- ○ HCl
- ○ HNO_3
- ○ $HClO_4$

Ionize

6 Strong Acids:

HCl	HNO_3
HBr	H_2SO_4
HI	$HClO_4$

6 Strong Bases:

LiOH	$Ca(OH)_2$
NaOH	$Ba(OH)_2$
KOH	$Sr(OH)_2$

Ionized acid is indicated by red in the above diagram

16.3 Acid and Base Strength

Acid and Base Hydrolysis Equilibria, Ka, and Kb

Weak Acids:

$$HA_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+ + A^-$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

Weak Bases:

$$B_{(aq)} + H_2O_{(l)} \rightleftharpoons BH^+ + OH^-$$

$$K_b = \frac{[BH^+][OH^-]}{[B]}$$

16.3 Acid and Base Strength

Acid and Base Hydrolysis Equilibria, Ka, and Kb

K_a Values			K_a Values		
Name of Acid	**Acid**	**K_a**	**Name of Acid**	**Acid**	**K_a**
Sulfuric acid	H_2SO_4	large	Hexaaquaaluminum ion	$Al(H_2O)_6^{3+}$	7.9×10^{-6}
Hydrochloric acid	HCl	large	Carbonic acid	H_2CO_3	4.2×10^{-7}
Nitric acid	HNO_3	large	Hydrogen sulfide	H_2S	1×10^{-7}
Hydronium ion	H_3O^+	1.0	Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	Hypochlorous acid	$HClO$	3.5×10^{-8}
Phosphoric acid	H_3PO_4	7.5×10^{-3}	Ammonium ion	NH_4^+	5.6×10^{-10}
Hexaaquairon(III) ion	$Fe(H_2O)_6^{3+}$	6.3×10^{-3}	Hydrocyanic acid	HCN	4.0×10^{-10}
Hydrofluoric acid	HF	7.4×10^{-4}	Hexaaquairon(II) ion	$Fe(H_2O)_6^{2+}$	3.2×10^{-10}
Formic acid	HCO_2H	1.8×10^{-4}	Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}
Acetic acid	CH_3CO_2H	1.8×10^{-5}	Water	H_2O	1.0×10^{-14}
			Hydrogen sulfide ion	HS^-	1×10^{-19}

The larger the Ka, the stronger the acid.

16.3 Acid and Base Strength

Relationship Between Ka and Kb – Conjugate Acid-Base Pair

Acid : HA — $-H^+$ — Conjugate Base : A^-

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+ + A^- \qquad K = K_a$$

$$*\ A^- + H_2O(l) \rightleftharpoons HA(aq) + OH^- \qquad K = K_b$$

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+ + OH^- \qquad K = K_aK_b$$

$K \rightarrow K_w$

$K_aK_b = K_w$ for a conjugate acid-base pair.

* An anion acting as a base?
We will address this in more detail shortly.

16.4 Estimating the pH of Acid and Base Solutions

Strong Acid and Strong Base Solutions

What is the **pH** of an aqueous solution of 1.15×10^{-2} M hydrobromic acid?

	HBr	+	$H_2O(l)$	=	H_3O^+	+	Br^-
I	1.15×10^{-2}				0		0
C	$- 1.15 \times 10^{-2}$				1.15×10^{-2}		1.15×10^{-2}
E	0				1.15×10^{-2}		1.15×10^{-2}

HBr : Strong acid ... 100%

I : Initial concentrations
C : Change in concentrations
E : Equilibrium concentrations

$[H_3O^+] = 1.15 \times 10^{-2}$

$pH = -\log_{10}(1.15 \times 10^{-2})$
$= 1.94$

16.4 Estimating the pH of Acid and Base Solutions

Strong Acid and Strong Base Solutions

What is the **pH** of an aqueous solution of 1.0×10^{-5} M sodium hydroxide?

pH = ?.0

a) 5
b) 6
c) 7
d) 8
e) 9

	NaOH	+	~~$H_2O(l)$~~	=	Na^+	+	OH^-
I	1.0×10^{-5}				0		0
C	-1.0×10^{-5}				1.0×10^{-5}		1.0×10^{-5}
E	0				1.0×10^{-5}		1.0×10^{-5}

NaOH : Strong Base → 100%

$[OH^-] = 1.0 \times 10^{-5}$

$pOH = -\log_{10}(1.0 \times 10^{-5})$

$= 5$

$pH + pOH = 14$ @ 25°C

$pH + 5 = 14$

$pH = 9$

16.4 Estimating the pH of Acid and Base Solutions

pH of a Weak Acid – Quadratic Equation

Calculate the **pH** of a 0.372 M aqueous solution of hypochlorous acid ($HClO$, $K_a = 3.5 \times 10^{-8}$).

	$HClO$	+ $H_2O(l)$	⇌ H_3O^+	+ ClO^-
I	0.372		0	0
C	$-x$		x	x
E	$0.372 - x$		x	x

$$K_a = \frac{[H_3O^+][ClO^-]}{[HClO]}$$

$$3.5 \times 10^{-8} = \frac{(x)(x)}{(0.372 - x)}$$

$$3.5 \times 10^{-8}(0.372 - x) = x^2$$

$$x^2 + 3.5 \times 10^{-8} x - 1.302 \times 10^{-8} = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad a = 1,\; b = 3.58 \times 10^{-8},\; c = -1.302 \times 10^{-8}$$

$x = 1.141 \times 10^{-4}$, -1.141×10^{-4}

↳ Disregard as this solution makes no chemical sense!

$$x = 1.141 \times 10^{-4} = [H_3O^+]$$

$$pH = -\log_{10}(1.141 \times 10^{-4}) = 3.94$$

While this method is the most accurate, solving a quadriatic equation can be problematic on "bad math days!" ☺ ... as in on exam days!!

16.4 Estimating the pH of Acid and Base Solutions

pH of a Weak Acid – Approx Method

Calculate the **pH** of a 0.372 M aqueous solution of hypochlorous acid ($HClO$, $K_a = 3.5 \times 10^{-8}$).

	$HClO$	+	$H_2O(l)$	=	H_3O^+	+	ClO^-
I	0.372				0		0
C	$-x$				x		x
E	$0.372 - x$				x		x

If $[HA]_i > 100 K_a$ then :- $[HA]_i - x \approx [HA]_i$

$0.372 > 100(3.5 \times 10^{-8})$

then $0.372 - x \approx 0.372$

$$K_a = \frac{[H_3O^+][ClO^-]}{[HClO]}$$

$$3.5 \times 10^{-8} = \frac{x \cdot x}{0.372}$$

$$x^2 = 0.372(3.5 \times 10^{-8})$$

$$x = \sqrt{0.372(3.5 \times 10^{-8})}$$

$$= 1.141 \times 10^{-4} = [H_3O^+]$$

$$pH = -\log_{10}(1.141 \times 10^{-4}) = 3.94$$

After you have done some of these you will notice :-

That as long as $[HA]_i > 100 K_a$

$$x = \sqrt{[HA]_i K_a}$$