#89 Notes **<u>Unit 11: Acids & Bases and Radiochemistry</u>**

<u>Ch. Acids, Bases, and Radioactivity</u>

Common Strong Acids		Common Strong Bases
HCl	hydrochloric acid	Group #1 + OH
HNO_3	nitric acid	NaOH, KOH etc.
H_2SO_4	sulfuric acid	$Ca(OH)_2$
$HClO_4$	perchloric acid	$Ba(OH)_2$
If #O - #H $\geq$ 2, then strong acid.		$Sr(OH)_2$

Common Weak Acids		Common Weak Bases	
H_3PO_4	phosphoric acid	NH_3	ammonia
HNO_2	nitrous acid	CH_3NH_2	methyl amine
H_2CO_3	carbonic acid	$C_2H_5NH_2$	ethyl amine
$HC_2H_3O_2 = CH_3CO_2H$		** $\underline{H_2}NOH$	hydroxyl amine
	(acetic acid)	** $\underline{H_2}NNH_2$	hydrazine

** Acids: start with "H" or end in $-CO_2H$ (-COOH) and have a sour taste.
** Bases: end in –OH (positive ion in front) or end in –NH, $-NH_2$, NH_3
They have a bitter taste and feel slippery.

* <u>3 Acid/Base Theories</u>

I. <u>Arrhenius Theory</u>

a) <u>Acids produce H^+</u> in a water solution

$$H_2O + HCl_{(g)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)} \ (+ H_2O)$$

b) <u>Bases produce OH^-</u> in a water solution

$$H_2O + NaOH_{(s)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)} \ (+ H_2O)$$

Acids, Bases and Salts are Electrolytes (Ion forming in water).

II. Brønsted-Lowry Theory

a) Acids donate protons (H^+) ← lose $1e^-$, 1 p left, 0 neutrons

$HCl_{(g)} + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$ H_3O^+ = hydronium ion

↑ conjugate acid (acid always has "H^+") -protonated base

↑ conjugate base - deprotonated acid

b) Bases accept protons

$NH_{3(g)} + H_2O \rightarrow NH_4^+_{(aq)} + OH^-_{(aq)}$

conj. acid (has "H^+") conj. base

III. Lewis Theory

a) Acids are e^- pair acceptors.

b) Bases are e^- pair donors.

$:NH_3 + H_2O \rightarrow H:NH_3^+ + OH^-$

* Bases have extra electrons.

* Strong acids/bases completely ionize (fall apart).

* Weak acids/bases only partially ionize (equilibriums).

$HF_{(g)} + H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + F^-_{(aq)}$ $K_a = 7.2 \text{ X}10^{-4}$

$$K_a = \frac{[H_3O^+]\,[F^-]}{[HF]}$$

The larger the K_a, the more H_3O^+, the stronger the acid.
(The larger the K_b, the more OH^-, the stronger the base.)

Ex. 1) List the following in order of increasing acid strength: H_2O, HCl, & HF.
**$K_w = 1 \text{ X}10^{-14}$

H_2O ($K = 1 \text{ X}10^{-14}$) < HF ($K = 7.2 \text{ X}10^{-4}$) < HCl (no K, so strong acid)
smallest K, so weakest

#90 Notes IV. pH scale

- is a measure of the acidity(H_3O^+ or H^+)

← 0 – 7 – 14 →
acid base

* **$pH = -\log[H_3O^+]$** * **$pOH = -\log[OH^-]$**

** **$H_3O^+ = H^+$**

$H_2O_{(l)} + H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + OH^-_{(aq)}$

* **$K_w = 1 \times 10^{-14} = [H_3O^+][OH^-]$**
-log ( )
* **$14 = pH + pOH$**

Ex. 1) Find $[H_3O^+]$, $[OH^-]$, pH, & pOH for a **strong acid**:

a) 0.213 M HNO_3 (no K so strong acid)

$HNO_3 + H_2O \rightarrow$		H_3O^+ +	NO_3^-	
0.213 M		0	0	(<u>I</u>nitial)
- 0.213 M	→	+ 0.213 M	+ 0.213 M	(<u>C</u>hange)
0		0.213 M	0.213 M	(<u>F</u>inal)

$H_3O^+ = 0.213$ M

pH = $-\log(H_3O^+) = -\log(0.213\text{ M}) = -(-0.672) =$ **0.672**

$K_w = [H_3O^+][OH^-]$
$1 \times 10^{-14} = (0.213\text{ M})(OH^-)$
4.69×10^{-14} M = $[OH^-]$ pOH = $-\log(OH^-) = -\log(4.69 \times 10^{-14}\text{ M})$
$= -(-13.329) =$ **13.329**

**The whole number is the power and is not significant!

<u>OR</u>

From pH = **0.672** pH + pOH = 14
0.672 + pOH = 14
pOH = **13.328**

pOH = $-\log(OH^-)$
13.328 = $-\log(OH^-)$
-13.328 = $\log(OH^-)$ move (-) before 10^x
$4.70 \times 10^{-14} = [OH^-]$

Ex. 2) Calculate $[H_3O^+]$ and $[OH^-]$ from:

a) pH = 4.90 ← pH < 7 so acidic

$pH = -\log [H_3O^+]$

$4.90 = -\log [H_3O^+]$

$-4.90 = \log [H_3O^+]$ **move (-) before 10x

10^x $(-4.90 = \log [H_3O^+])$

$\mathbf{1.3 \times 10^{-5}\ M = [H_3O^+]}$

$K_w = 1 \times 10^{-14} = (1.3 \times 10^{-5}\ M)(OH^-)$

$\mathbf{7.7 \times 10^{-10}\ M = [OH^-]}$

b) pOH = 5.80

$pOH = -\log [OH^-]$

$5.80 = -\log [OH^-]$

10^x $(-5.80 = \log [OH^-])$

$\mathbf{1.6 \times 10^{-6}\ M = [OH^-]}$

$K_w = 1 \times 10^{-14} = (H_3O^+)(1.6 \times 10^{-6}\ M)$

$\mathbf{6.3 \times 10^{-9}\ M = [H_3O^+]}$

Is this acidic or basic? $pH = -\log [H_3O^+] = -\log 6.3 \times 10^{-9}\ M =$ **8.20 (pH > 7 so, basic)**

<u>Or</u> look at $[H_3O^+]$ and $[OH^-]$:

if $[H_3O^+]$ is larger, it is acidic,

if $[OH^-]$ is larger, it is basic.

**** $H_3O^+ = H^+$**

#91 Notes V. Weak Acids/ Bases

-only partially ionize (equilibrium)

Ex. 1) What is the pH of a 0.200 M solution of acetic acid ($CH_3COOH = HC_2H_3O_2$)?

(**weak acid**) What are the major species present? $K = 1.8 \times 10^{-5}$

$$
\begin{array}{llll}
HC_2H_3O_2 + H_2O_{(l)} & \leftrightarrow H_3O^+ & + C_2H_3O_2^- & \\
0.200\ M & & & (\text{Initial}) \\
\underline{\quad - x \quad} & \underline{+x} & \underline{+x} & (\text{Change}) \\
0.200\ M - x & x & x & (\text{Equilibrium})
\end{array}
$$

$$K_a = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$$

no liquids: $H_2O_{(l)}$

$$1.8 \times 10^{-5} = \frac{(x)(x)}{0.200\ M - x}$$

(2.00×10^{-1})

If K_a is smaller than the Concentration by **10^{3} or more**, assume x is small. (0.200 M – x would equal just 0.200 M)

$$1.8 \times 10^{-5} = \frac{x^2}{0.200\ M}$$

1.9×10^{-3} M = x = $[H_3O^+] = [C_2H_3O_2^-]$

pH = -log(1.9×10^{-3}) = 2.72

$[HC_2H_3O_2]$ = 0.200 M – x = 0.198 M

Ex. 2) What is the pH of a 0.520 M solution of ethyl amine, $C_2H_5NH_2$?

(**weak base**) $K = 5.6 \times 10^{-4}$

$$
\begin{array}{lll}
C_2H_5NH_2 + H_2O \leftrightarrow & C_2H_5NH_3^+ & + OH^- \\
0.520\ M & & \\
\underline{\ -x\ } & \underline{+x} & \underline{+x} \\
0.520 - x & x & x
\end{array}
$$

$$K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]}$$

$$5.6 \times 10^{-4} = \frac{(x)(x)}{(0.520 - x)}$$

x is small

(5.20×10^{-1})

$$5.6 \times 10^{-4} = \frac{x^2}{(0.520)}$$

$1.71 \times 10^{-2} = x = OH^-$

pOH = - log $[OH^-]$ or $K_w = [H_3O^+][OH^-]$

pOH = 1.77 14 = pH + pOH

14 - 1.77= **12.23 = pH**

Ex. 3) What is the pH of a 0.340 M solution of $HClO_2$ (chlorous acid)

K of $HClO_2$ = 1.2 $X10^{-2}$

$HClO_2 + H_2O \leftrightarrow H_3O^+ + ClO_2^-$

0.340 M		
-x	+x	+x
0.340 – x	x	x

$$K_a = \frac{[H_3O^+]\,[ClO_2^-]}{[HClO_2]}$$

$$1.2\ X10^{-2} = \frac{(x)\,(x)}{(0.340 - x)}$$ x is **not** small

(3.40 $X10^{-1}$)

$0.012\,(0.340 - x) = x^2$

$0.00408 - 0.012x - x^2 = 0$

a = -1

b = -0.012

c = 0.00408

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{-(-0.012) \pm \sqrt{(-0.012)^2 - 4(-1)\,(0.00408)}}{2\,(-1)}$$

$$\frac{0.012 \pm \sqrt{0.000144 + 0.01632}}{-2}$$

$$\frac{0.012 \pm \sqrt{0.016464}}{-2}$$

$$\frac{0.012 \pm 0.1283}{-2} = \frac{0.1403}{-2} \text{ or } \frac{-0.1163}{-2}$$

x = -0.070 or **0.058**

negative concentrations are impossible!

$[H_3O^+]$ = x = 0.058 M, **pH =** -log $[H_3O^+]$ **= 1.24**

check: $K_a = \frac{(0.058)\,(0.058)}{(0.340 - 0.058)} = 1.19\ X10^{-2} \approx 1.2\ X10^{-2}$

Ex.4) Find pH of 0.10 M $Sr(OH)_2$. **Strong Bases, like strong acids completely fall apart.

Strong Base: $Sr(OH)_2 + H_2O \rightarrow Sr^{2+}_{(aq)} + 2\ OH^-_{(aq)}$

	0.10 M		
	<u>-0.10 M</u>	<u>+0.10 M</u>	<u>+ 2(0.10M)</u>
	0	0.10 M	0.20 M

$[OH^-] = 0.20$ M   pOH = - log $[OH^-] = 0.70$ 14 – pOH = **pH = 13.30**

#92 Notes Ch. Aqueous Equilibria

I. Buffered Solutions

-resist changes in pH.

A buffered solution may contain a weak acid with its salt (CB) or
a weak base with its salt (CA).

Acids: $HNO_2 + H_2O \leftrightarrow H_3O^+ + NO_2^-$

CA CB + (Na^+ or K^+)

$NaNO_2$ or KNO_2 = salts of HNO_2

Bases: $C_6H_5NH_2 + H_2O \leftrightarrow C_6H_5NH_3^+ + OH^-$

CA + (Cl^- or Br^-) CB

$C_6H_5NH_3Cl$ or $C_6H_5NH_3Br$ = salts of $C_6H_5NH_2$

Ex.1) What is the pH of a 0.300 M solution of HClO buffered with 0.0400 M NaClO?
K of HClO = 3.5×10^{-8}

$HClO + H_2O \leftrightarrow$	H_3O^+	$+ ClO^-$	
0.300 M		0.0400 M	$\leftarrow$ from 0.0400 M Na^+ClO^-
-x	+x	+x	
0.300 –x	x	0.0400 + x	

$$3.5 \times 10^{-8} = \frac{(x)(0.0400 + x)}{(0.300 - x)}$$ x is small

$$3.5 \times 10^{-8} = \frac{(x)(0.0400)}{(0.300)}$$

$2.6 \times 10^{-7} = x = [H_3O^+]$ **pH** = **-** log $[H_3O^+]$ = **6.58**

Ex. 2) What is the pH of a solution containing 0.450 M H_2NNH_2 and 0.250 M H_2NNH_3Cl.
K of H_2NNH_2 = 3.0 X10^{-6}

$H_2NNH_2 + H_2O \leftrightarrow H_2NNH_3^+ + OH^-$

0.450 M	0.250 M		← from 0.250 M $H_2NNH_3^+Cl^-$
-x	+x	+x	
0.450 – x	0.250 + x	x	

$$3.0 \times 10^{-6} = \frac{(0.250 + x)(x)}{(0.450 - x)}$$ x is small

$$3.0 \times 10^{-6} = \frac{(0.250)(x)}{(0.450)}$$

5.4 X10^{-6} = x = $[OH^-]$
pOH = - log $[OH^-]$ = 5.27
pH = 14 - pOH **= 8.73**

#93 Notes   II. Solubility Equilibria

- describes the amount of solid that dissolves in a saturated solution (no more solid will dissolve).

Ex. 1) Calculate the solubility of Ag_2CO_3 in mols per liter. $K_{sp} = 8.1 \times 10^{-12}$

$Ag_2CO_{3(s)} \leftrightarrow 2\ Ag^+_{(aq)} + CO_3^{2-}{}_{(aq)}$

-x   +2x   +x

$K_{sp} = [Ag^+]^2 [CO_3^{2-}]^1$

$K_{sp} = (2x)^2 (x)^1$

$K_{sp} = 4x^3$

$8.1 \times 10^{-12} = 4x^3$

1.3×10^{-4} M = x   **1.3×10^{-4} mol/L**

Ex. 2) Calculate the K_{sp} of CaF_2, if its solubility is 2.15×10^{-4} mol/L.

$CaF_{2(s)} \leftrightarrow Ca^{2+}{}_{(aq)} + 2\ F^-{}_{(aq)}$

-x   x   2 x $x = 2.15 \times 10^{-4}$ mol/L

$K_{sp} = [Ca^{2+}]^1 [F^-]^2$

$K_{sp} = (x)^1 (2x)^2$

$K_{sp} = 4x^3$

$K_{sp} = 4\ (2.15 \times 10^{-4}\ \text{mol/L})^3 =$ **3.97×10^{-11}**

Ex. 3) Calculate the solubility of $Cu_3(PO_4)_2$ in mol/L. $K_{sp} = 8.4 \times 10^{-15}$

$Cu_3(PO_4)_{2(s)} \leftrightarrow 3\ Cu^{2+}{}_{(aq)} + 2\ PO_4^{3-}{}_{(aq)}$

-x   +3x   +2x

$K_{sp} = [Cu^{2+}]^3 [PO_4^{3-}]^2$

$K_{sp} = (3x)^3 (2x)^2$

$K_{sp} = (27\ x^3)(4\ x^2)$

$K_{sp} = 108\ x^5$

$8.4 \times 10^{-15} = 108\ x^5$

$7.8 \times 10^{-17} = x^5$

6.0×10^{-4} mol/L = x

III. Precipitation Reactions

Ex.1) Will a precipitate form, if 25 ml of 0.100 M $AgNO_3$ is added to 105 ml of 0.200 M Na_2CO_3?

$AgNO_{3(aq)} + Na_2CO_{3(aq)} \rightarrow Ag_2CO_3 + NaNO_3$

Ag^+ NO_3^- Na^+ CO_3^{2-} ↑ ↑

$K_{sp} = 8.1 \times 10^{-12}$ no K_{sp}

a) Find concentration of ions in new volume: 25 ml + 105 ml = 130 ml (new solution)

ML = ML

(0.100 M $AgNO_3$) (25 ml) = M (130 ml)

0.0192 mol/L = M_{AgNO3}

$\underline{X1Ag^+}$ $\underline{X1\ NO_3^-}$

0.0192 M Ag^+ **0.0192 M NO_3^-**

(0.200 M Na_2CO_3) (105 ml) = M (130 ml)

0.162 mol/L = $M_{\mathbf{Na2CO3}}$

$\underline{X2Na^+}$ $\underline{X1CO_3^{2-}}$

0.324 M Na^+ **0.162 M CO_3^{2-}**

b) Put concentrations into K_{sp} equation:

$Ag_2CO_{3(s)} \leftrightarrow 2\ Ag^+_{(aq)} + CO_3^{2-}{}_{(aq)}$

$K_{sp} = [Ag^+]^2\ [CO_3^{2-}]^1 = (0.0192\ M\ Ag^+)^2\ (0.162\ M\ CO_3^{2-})^1 = 5.97 \times 10^{-5}$

K_{sp} calculated = 5.97×10^{-5} >>> Real K_{sp} from book = 8.1×10^{-12}
for a saturated solution
since Ksp is <u>more than</u> saturated, solid forms (precipitate)

If the K_{sp} calculated is less than the real K_{sp},
it is less than saturated (not full), so no solid forms.

#95 Notes Ch. Radiochemistry

The “attractive” nuclear force between protons and neutrons is usually stronger than the repulsion energy of the protons. But some isotopes have too many protons and not enough neutrons, so there is too much repulsion. These atoms are unstable (radioactive).
Atoms with more than 83 protons are always unstable (atomic #’s > 83).

I. Nuclear Decay Reactions (to become stable)

alpha (α) particle $_{2}^{4}He$ -barely passes through paper

beta (β) particle $_{-1}^{0}e$ - stopped by 3 mm Al or 10 mm wood

gamma (γ) is electromagnetic energy - stopped by 60 cm Al or 7cm Pb

positron particle $_{+1}^{0}e$

emission (given off), so put particle on product side
capture (taken in), so put particle on the reactant side

Ex. 1) ^{265}Bh decays by α-emission.

$$\mathbf{_{107}^{265}Bh \rightarrow {}_{2}^{4}He + {}_{105}^{261}Db}$$

Ex. 2) ^{99}Mo decays by β-emission (β-).

$$\mathbf{_{42}^{99}Mo \rightarrow {}_{-1}^{0}e + {}_{43}^{99}Tc}$$

Ex. 3) ^{207}Bi decays by positron emission (β+).

$$\mathbf{_{83}^{207}Bi \rightarrow {}_{+1}^{0}e + {}_{82}^{207}Pb}$$

Ex. 4) ^{102}Rh decays by electron capture (e.c. or ε).

$$\mathbf{_{45}^{102}Rh + {}_{-1}^{0}e \rightarrow {}_{44}^{102}Ru}$$

II. Bombardments
-linear or cyclotron particle accelerators can be used to combine smaller atoms into larger atoms or to break up large atoms into smaller atoms.

Ex. 1) ^{249}Bk is bombarded by ^{22}Ne to make a new heavier element and 4 neutrons ($_{0}^{1}n$). Write the reaction.

$$_{97}^{249}Bk + {}_{10}^{22}Ne \rightarrow 4\ {}_{0}^{1}n + {}_{107}^{267}Bh$$

#96 Notes III. Half-lives

A half-life is the time it takes for ½ of a sample of a radioactive material to decay into something else.

The rate of radioactive decay reactions is 1st order, so

Rate = k [A]^1 ←decays/sec

$t_{1/2}$ = 0.693 / k {$t_{1/2}$ is the half-life (not t ÷ 2)}

ln [A] = -kt + ln $[A]_o$ {order in textbook equation may be $\ln[A]_o = kt + \ln[A]$}

↑ amount left after time = t

↑ initial amount

Ex. 1) 28 g of ^{87}Sr has a ½ life of 2.8 hrs.

a) Find the decays/sec (decays = atoms).

Rate = k [A]^1 $t_{1/2} = 0.693 / k$ $\frac{2.8\ \text{hr}}{} \left| \frac{3600\ \text{sec}}{1\ \text{hr}} \right. = 10080\ \text{sec}$

$10080\ \text{sec} = 0.693 / k$

$(10080)\ k = 0.693$

$k = 6.875\ \text{X}10^{-5}\ \text{sec}^{-1}$

Rate = k [A]^1 = $(6.875\ \text{X}10^{-5}\ \text{sec}^{-1})\ \left(\frac{28\ \text{g}\ ^{87}\text{Sr}}{} \left| \frac{1\ \text{mol}}{87\text{g}} \right| \frac{6.022\ \text{X}10^{23}\ \text{atoms}}{1\ \text{mol}} \right)$

Rate = 1.3 X10^{19} decays/sec

b) How much is left after 4.0 hrs?

$t_{1/2} = 2.8$ hr $t_{1/2} = 0.693 / k$

$2.8\ \text{hr} = 0.693 / k$

$(2.8)\ k = 0.693$

$k = 0.2475\ \text{hr}^{-1}$

$\ln A = -kt + \ln A_o$

$\ln A = -(0.2475\ \text{hr}^{-1})\ (4.0\ \text{hr}) + \ln (28\ \text{g})$

$\ln A = -0.99 + 3.33$

e^x (ln A = 2.34)

A = 10. g is left

c) How much decayed in 4.0 hrs?

28 g *{initially}* – 10. g *{left}* = **18 g decayed**

Ex.2) How long does it take for 62.3% of ^{133}Xe to decay? (1/2 life = 5.3 days)

$t_{1/2} = 0.693/k$

5.3 d = 0.693/k

(5.3 d) k = 0.693

$k = 0.131\ d^{-1}$

100% initially	$= [A]_o$
<u>-62.3 % decays</u>	
37.7% is left	$= [A]$

$\ln [A] = -kt + \ln [A]_o$
$\ln (37.7) = -(0.131\ d^{-1})\ t + \ln (100)$
$3.63 = -0.131t + 4.605$
$-0.975 = -0.131t$
7.4 d = t

#97 Notes IV. Nuclear Fission / Fusion
(splitting/ breaking apart) (combining)

Fission: ${}_0^1n + {}_{92}^{235}U \rightarrow {}_{52}^{137}Te + {}_{40}^{97}Zr + 2\ {}_0^1n$ (nuclear power plants)
${}_0^1n + {}_{94}^{239}Pu \rightarrow {}_{56}^{146}Ba + {}_{38}^{91}Sr + 3\ {}_0^1n$ (nuclear bombs)

Subcritical mass: the reaction dies out.
Critical mass: for each neutron that reacts, one neutron that is produced, causes a reaction.
Supercritical mass: exponential increase, explosion.

Fusion on the sun:

${}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0e$

$\downarrow$

${}_1^1H + {}_1^2H \rightarrow {}_2^3He$

$\downarrow$

${}_2^3He + {}_2^3He \rightarrow {}_2^4He + 2\ {}_1^1H$

or ${}_2^3He + {}_1^1H \rightarrow {}_2^4He + {}_1^0e$

In Fission and Fusion reactions some mass is lost and converted to energy! $E = mc^2$

V. Nuclear Power Plants

1) Fuel: ${}_{92}^{235}U$ & ${}_{94}^{239}Pu$ (produced in the reaction)

2) Moderator: H_2O, heavy H_2O, graphite, Be
-slows down neutrons, but does not absorb them.

3) Control Rods: B, Cd, or Ga alloyed with Al or steel
-absorbs excess neutrons not needed to keep the chain reaction going.

4) Coolant: He, H_2O, CO_2, liquid metals (Na)
-removes heat from the reactor.

5) Heat Exchanger:
-transfers heat from the hot coolant, to the cool water, that will make steam to turn the turbines.

6) Safety Shields: Pb or thick concrete
-radiation shield around the reactors.

End of Notes (Assignments #98-99 are Review Assignments. There are no notes for these assignments.)