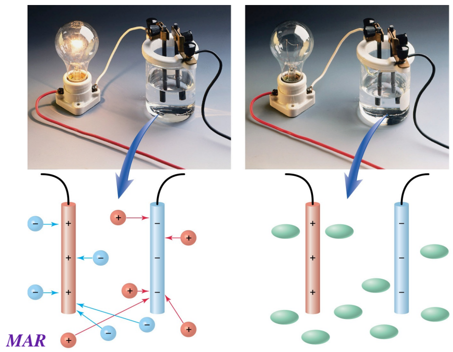


Solution Stoichiometry and Chemical Reactions

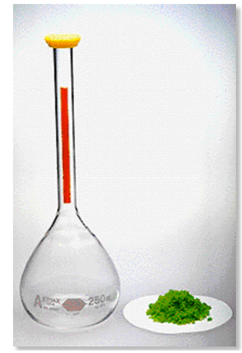
Chapter 3 & Chapter 4, or "Chapter 4 Part II"

Chemistry 221
Professor Michael Russell

Last update: 4/29/24

MAR

Terminology



In **SOLUTION** we need to define the -

- **SOLVENT**

the component whose physical state is preserved when solution forms

- **SOLUTE**

the other solution component

- Compounds are ***soluble*** when they dissolve, ***insoluble*** when they stay as solids

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Water Solubility of Ionic Compounds

SOLUBLE COMPOUNDS	EXCEPTIONS
Almost all salts of Na^+, K^+, NH_4^+	
Salts of nitrate, NO_3^-; chlorate, ClO_3^-; perchlorate, ClO_4^-; acetate, $CH_3CO_2^-$	
Almost all salts of Cl^-, Br^-, I^-	Halides of Ag^+, Hg_2^{2+}, Pb^{2+}
Compounds containing F^-	Fluorides of Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}
Salts of sulfate, SO_4^{2-}	Sulfates of Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}

INSOLUBLE COMPOUNDS	EXCEPTIONS
Most salts of carbonate, CO_3^{2-}; phosphate, PO_4^{3-}; oxalate, $C_2O_4^{2-}$; chromate, CrO_4^{2-}	Salts of NH_4^+ and the alkali metal cations
Most metal sulfides, S^{2-}	
Most metal hydroxides and oxides	

If one ion from the "Soluble Compd." list is present in a compound, the compound is water soluble.

$Ba(NO_3)_2(aq)$? **soluble**

$BaCl_2(aq)$? **soluble**

$BaSO_4(aq)$? **insoluble** *should write $BaSO_4(s)$!*

Use this solubility guide in CH 221-223!

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WATER SOLUBILITY OF IONIC COMPOUNDS

Not all ionic compounds dissolve in water. Some are INSOLUBLE.

Many ions, however, make compounds SOLUBLE *all* of the time.

Examples: **Na^+, K^+, Li^+, NH_4^+, NO_3^-, ClO_3^-, ClO_4^-, $CH_3CO_2^-$, and *most* SO_4^{2-}, Cl^-, Br^- and I^- compounds.**

SOLUBLE COMPOUNDS	EXCEPTIONS
Almost all salts of Na^+, K^+, NH_4^+	
Salts of nitrate, NO_3^-; chlorate, ClO_3^-; perchlorate, ClO_4^-; acetate, $CH_3CO_2^-$	
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INSOLUBLE COMPOUNDS	EXCEPTIONS
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Most metal sulfides, S^{2-}	
Most metal hydroxides and oxides	

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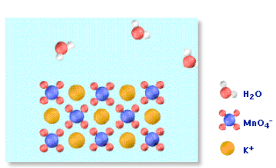
Ionic Compounds in Aqueous Solution

Many reactions involve soluble ionic compounds, especially reactions in water - aqueous solutions.

$KMnO_4$ in water



$K^+(aq)$ + $MnO_4^-(aq)$

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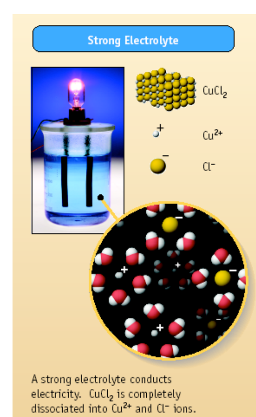
Aqueous Solutions

How do we know ions are present in aqueous solutions?

The solutions conduct electricity! The ions are called ELECTROLYTES

HCl, $KMnO_4$, $MgCl_2$, and NaCl are strong electrolytes. They dissociate completely (*or nearly so*) into ions.

$KMnO_4(aq)$ ---> $K^+(aq)$ + $MnO_4^-(aq)$



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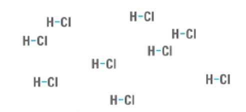
Aqueous Solutions

HCl, $MgCl_2$, and NaCl are **strong electrolytes.** They dissociate completely (or nearly so) into ions.



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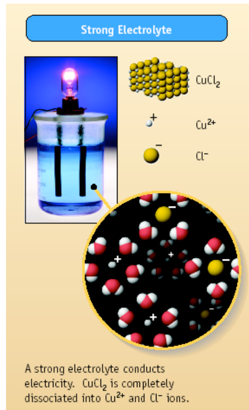
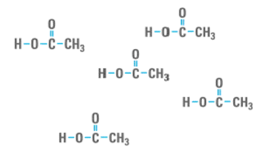


Aqueous Solutions

Acetic acid ionizes only to a small extent, so it is a **weak electrolyte**

$CH_3CO_2H(aq)$ --->

$CH_3CO_2^-(aq)$ + $H^+(aq)$



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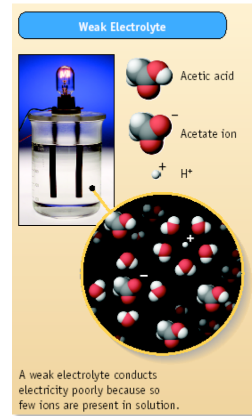
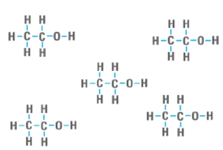


Aqueous Solutions

Some compounds (sugar, ethanol, acetone, etc.) dissolve in water but do not conduct electricity. They are called **nonelectrolytes.**



See "Dissolve, Dissociate and Electrolyte" Guide

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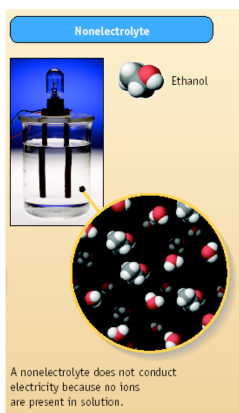


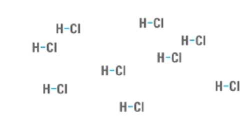
Acids

An acid -------> H^+ in water

Some **strong** acids include:

HCl	hydrochloric
HNO_3	nitric
$HClO_4$	perchloric
H_2SO_4	sulfuric

All strong acids are strong electrolytes



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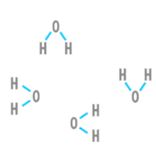
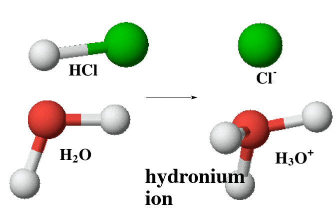


The Nature of Acids



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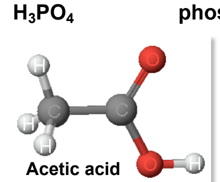
Weak Acids

All weak acids are **weak electrolytes**

CH_3CO_2H	acetic acid
H_2CO_3	carbonic acid
H_3PO_4	phosphoric acid



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BASES

Base ---> OH^- in water

Bases are often metal hydroxides
$NaOH(aq)$ ---> $Na^+(aq)$ + $OH^-(aq)$

NaOH is a strong base

NaOH NaOH NaOH NaOH NaOH NaOH

All strong bases are strong electrolytes

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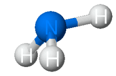
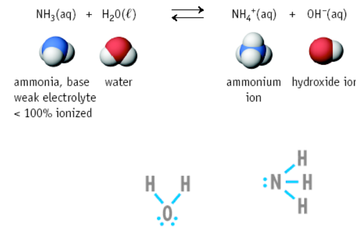
Ammonia, NH_3
An Important Weak Base





All weak bases are weak electrolytes

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Common Acids and Bases

Strong Acids (Strong Electrolytes)		Strong Bases (Strong Electrolytes)	
HCl	Hydrochloric acid	LiOH	Lithium hydroxide
HBr	Hydrobromic acid	NaOH	Sodium hydroxide
HI	Hydroiodic acid	KOH	Potassium hydroxide
HNO_3	Nitric acid		
$HClO_4$	Perchloric acid		
H_2SO_4	Sulfuric acid		
Weak Acids (Weak Electrolytes)*		**Weak Base (Weak Electrolyte)**	
H_3PO_4	Phosphoric acid	NH_3	Ammonia
H_2CO_3	Carbonic acid		
CH_3CO_2H	Acetic acid		
$H_2C_2O_4$	Oxalic acid		
$C_4H_6O_6$	Tartaric acid		
$C_6H_8O_7$	Citric acid		
$C_9H_8O_4$	Aspirin		

*These are representative of hundreds of weak acids.

Know the strong acids & bases!

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Net Ionic Equations

$Mg(s)$ + 2 $HCl(aq)$ --> $H_2(g)$ + $MgCl_2(aq)$

We really should write:

$Mg(s)$ + 2 $H^+(aq)$ + 2 $Cl^-(aq)$ --->
$H_2(g)$ + $Mg^{2+}(aq)$ + 2 $Cl^-(aq)$

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Net Ionic Equations

$Mg(s)$ + 2 $HCl(aq)$ → $H_2(g)$ + $MgCl_2(aq)$

Aqueous solutes (HCl, $MgCl_2$) dissociate; we *really* should write:

$Mg(s)$ + 2 $H^+(aq)$ + 2 $Cl^-(aq)$ →
$H_2(g)$ + $Mg^{2+}(aq)$ + 2 $Cl^-(aq)$

We leave the spectator ions (Cl^-) out in writing the NET IONIC EQUATION:
$Mg(s)$ + 2 $H^+(aq)$ → $H_2(g)$ + $Mg^{2+}(aq)$

See Net Ionic Reactions Handout

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Net Ionic Equations

$K_2CrO_4(aq)$ + $Pb(NO_3)_2(aq)$ -->
$PbCrO_4(s)$ + 2 $KNO_3(aq)$

NET IONIC EQUATION
$Pb^{2+}(aq)$ + $CrO_4^{2-}(aq)$ ---> $PbCrO_4(s)$

K^+ and NO_3^- are spectators

See Net Ionic Reactions Handout

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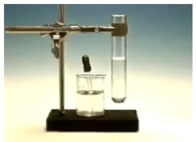
CHEMICAL REACTIONS IN WATER

We will look at
EXCHANGE REACTIONS

AX + BY ⟶ AY + BX



The anions exchange places between cations

$Pb(NO_3)_2(aq) + 2\ KI(aq)$ ----> $PbI_2(s) + 2\ KNO_3(aq)$

Exchange reactions often called Double Displacement Reactions

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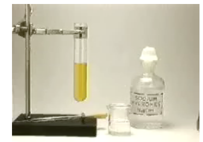
Precipitation Reactions

The "driving force" is the formation of an insoluble compound - a precipitate.

$Fe(NO_3)_3(aq) + 3\ NaOH(aq)$ -----> $3\ NaNO_3(aq) + Fe(OH)_3(s)$



Net ionic equation

$Fe^{3+}(aq) + 3\ OH^-(aq)$ ---> $Fe(OH)_3(s)$

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See "Five Types of Reactions" Handout

Acid-Base Reactions

Acids react readily with bases. The "driving force" is the formation of water.

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(liq)$

Net ionic equation:

$OH^-(aq) + H^+(aq) \rightarrow H_2O(liq)$

This applies to ALL reactions of STRONG acids and bases.

Acid-base reactions often called "neutralizations", water and "salt" created

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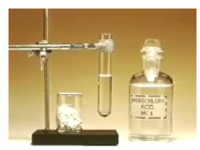
See "Five Types of Reactions" Handout



Gas-Forming Reactions

$CaCO_3(s) + 2\ HCl(aq)$ ---> $CaCl_2(aq) + H_2CO_3(aq)$

Carbonic acid is unstable and forms CO_2 & H_2O

$H_2CO_3(aq)$ ---> $CO_2(g)$ + water

Another gas forming species:

$NH_4OH(aq)$ ---> $NH_3(g)$ + water

MAR

See "Five Types of Reactions" Handout

Combustion Reactions

A special example of a gas-forming reaction

Used in quantitative chemistry; high temperatures

Reactants: oxygen (O_2) *and* "*something organic*" *(C, H, sometimes O or N)*

Products: water *and* carbon dioxide (*also* NO_2 *if N present)*

Examples:

$$C_2H_{4(g)} + 3\ O_{2(g)} \rightarrow 2\ H_2O_{(g)} + 2\ CO_{2(g)}$$

$$4\ C_6H_5NO_2 + 29\ O_{2(g)} \rightarrow 10\ H_2O_{(g)} + 24\ CO_{2(g)} + 4\ NO_{2(g)}$$

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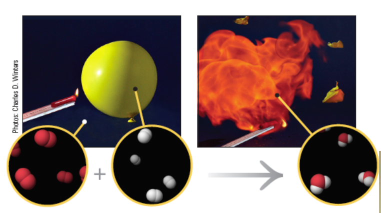
See "Five Types of Reactions" Handout

Oxidation-Reduction Reactions

REDOX = reduction & oxidation

$2\ H_2(g) + O_2(g)$ ---> $2\ H_2O(liq)$



See "Five Types of Reactions" Handout

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LEO says GER

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LEO says GER

Lose **E**lectrons **O**xidized

Gain **E**lectrons **R**educed

Zn(s) → Zn^{2+} + 2e- ***Oxidized***

Cu^{2+} + 2e- → Cu(s) ***Reduced***

*Can also use **"OIL RIG":***
***OIL = "Oxidation is Losing"** (electrons)*
***RIG = "Reduction is Gaining"** (electrons)*

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REDOX REACTIONS

In all reactions: if something has been oxidized then something has also been reduced:

Cu(s) + 2 Ag^+(aq) → Cu^{2+}(aq) + 2 Ag(s)

Redox reactions incredibly useful (fuels, batteries, much more)

Oxidation numbers help visualize electron transfer pathways

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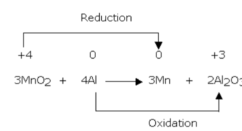
*Use **oxidation number rules** to determine redox activity:*

- **Atoms in free element have ox. no. = 0**
  Zn(s), O_2(g), Br_2(liq)
- *In simple ions,* **ox. no. = charge on ion**
  -1 for Cl^-, +2 for Mg^{2+}
- **In compounds, F is *always* -1, O is -2** *(except peroxides (O = -1) and with F) and* **H is +1** *(except hydrides (H = -1))*
- **Sum of oxidation numbers = 0** *for a* **compound or equals the overall charge** *for an* **ion**

OXIDATION NUMBERS



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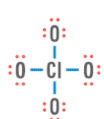
OXIDATION NUMBERS

Determining oxidation numbers takes practice

HF
H: +1
F: -1



ClO_4^-
Cl: +7
O: -2

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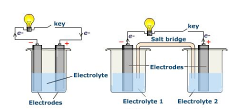
Recognizing a Redox Reaction

2 Al(s) + 3 Cu^{2+}(aq) ---> 2 Al^{3+}(aq) + 3 Cu(s)

Al(s) --> Al^{3+}(aq) + 3 e^-

- **Ox. no. of Al *increases* as e^- are donated by the metal; Al is OXIDIZED (or the REDUCING AGENT)**



Cu^{2+}(aq) + 2 e^- --> Cu(s)

- **Ox. no. of Cu *decreases* as e^- are accepted by the ion; Cu^{2+} is REDUCED (or the OXIDIZING AGENT)**

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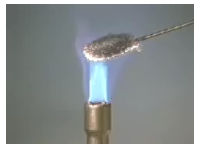
Examples of Redox Reactions

NO = reducing agent
O_2 = oxidizing agent
$2\ NO + O_2 \rightarrow 2\ NO_2$



Fe = reducing agent
Cl_2 = oxidizing agent
$2\ Fe + 3\ Cl_2 \rightarrow 2\ FeCl_3$

reducing agent = oxidized
oxidizing agent = reduced

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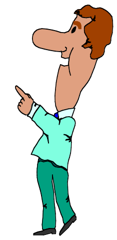
Concentration (Molarity) of Solute

The amount of solute in a solution is given by its concentration

$$\text{Molarity (M)} = \frac{\text{moles solute}}{\text{liters of solution}}$$



Concentration (M) = […]
"3.6 M" means a concentration of 3.6 molarity
"concentration" and molarity often the same

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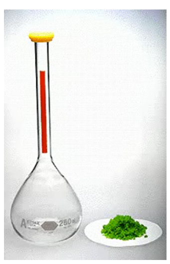
PROBLEM: Dissolve 5.00 g of $NiCl_2 \bullet 6\ H_2O$ in enough water to make 250. mL of solution. Calculate molarity.



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PROBLEM: Dissolve 5.00 g of $NiCl_2 \bullet 6\ H_2O$ in enough water to make 250. mL of solution. Calculate molarity.

Step 1: Calculate moles of $NiCl_2 \bullet 6H_2O$

$$5.00\ \text{g} \cdot \frac{1\ \text{mol}}{237.7\ \text{g}} = 0.0210\ \text{mol}$$

Step 2: Calculate molarity

$$\frac{0.0210\ \text{mol}}{0.250\ \text{L}} = 0.0841\ \text{M}$$

$[NiCl_2 \bullet 6\ H_2O] = 0.0841\ M$

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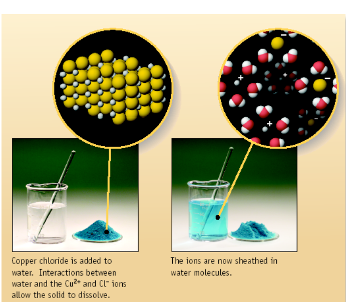
The Nature of a $CuCl_2$ Solution Ion Concentrations



$CuCl_2(aq)$ -->
$Cu^{2+}(aq) + 2\ Cl^{-}(aq)$

If $[CuCl_2]$ = 0.30 M, then

$[Cu^{2+}]$ = 0.30 M

$[Cl^{-}]$ = 2 x 0.30 M = 0.60 M

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USING MOLARITY

What mass of oxalic acid, $H_2C_2O_4$, is required to make 250. mL of a 0.0500 M solution?

$$\text{moles} = M \bullet V$$

Step 1: Calculate moles of acid required.

(0.0500 mol/L)(0.250 L) = 0.0125 mol

Step 2: Calculate mass of acid required.

(0.0125 mol)(90.00 g/mol) = 1.13 g

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Preparing Solutions

Weigh out a **solid** solute and dissolve in a given quantity of solvent

or

Dilute a **concentrated solution** to give one that is less concentrated.

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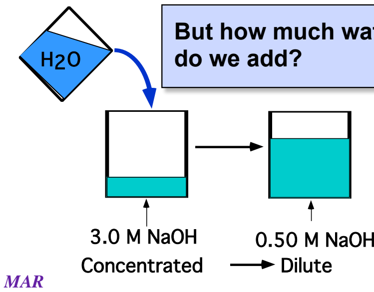
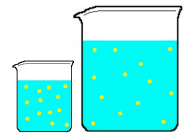
You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?



But how much water do we add?

The important point:

moles of NaOH in ORIGINAL solution = moles of NaOH in FINAL solution



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You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

Moles of NaOH in original solution =

M * V =

(3.0 mol/L)(0.0500 L) = 0.15 mol NaOH

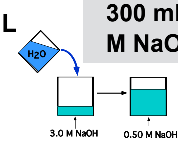
Therefore, moles of NaOH in final solution must also = 0.15 mol NaOH

(0.15 mol NaOH)(1 L/0.50 mol) = 0.30 L

or 300 mL = volume of final solution

Conclusion:

add 250 mL of water to 50.0 mL of 3.0 M NaOH to make 300 mL of 0.50 M NaOH.



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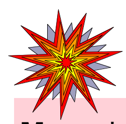
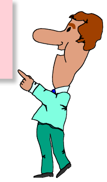
Preparing Solutions by Dilution



A shortcut

$$M_{initial} * V_{initial} = M_{final} * V_{final}$$



Often abbreviated: $M_iV_i = M_fV_f$ ***or*** $C_1V_1 = C_2V_2$

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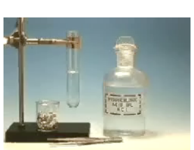
SOLUTION STOICHIOMETRY

Zinc reacts with acids to produce H_2 gas. What volume of 2.50 M HCl is needed to convert 10.0 g of Zn?



$Zn(s) + 2 HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

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Zinc reacts with acids to produce H_2 gas. What volume of 2.50 M HCl is needed to convert 10.0 g of Zn?

Step 1: Calculate moles of Zn

$$10.0 \text{ g Zn} \bullet \frac{1.00 \text{ mol Zn}}{65.39 \text{ g Zn}} = 0.153 \text{ mol Zn}$$

Step 2: Use the stoichiometric factor

$$0.153 \text{ mol Zn} \bullet \frac{2 \text{ mol HCl}}{1 \text{ mol Zn}} = 0.306 \text{ mol HCl}$$

Step 3: Calculate volume of HCl required

$$0.306 \text{ mol HCl} \bullet \frac{1.00 \text{ L}}{2.50 \text{ mol}} = 0.122 \text{ L HCl}$$

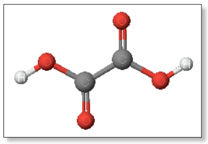
$Zn(s) + 2 HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

MAR

ACID-BASE REACTIONS
Titrations

$H_2C_2O_4(aq)$ + 2 $NaOH(aq)$ --->
acid base
$Na_2C_2O_4(aq)$ + 2 $H_2O(liq)$

Carry out this reaction using a TITRATION.



Oxalic acid, $H_2C_2O_4$

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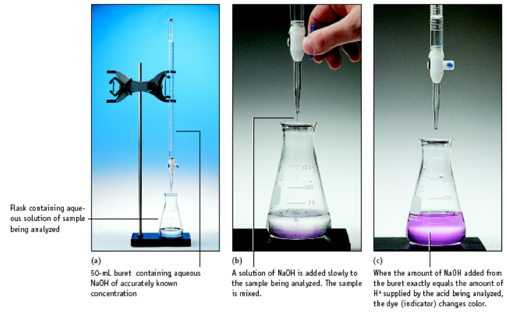
Setup for titrating an acid with a base



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LAB PROBLEM #1: Standardize a solution of NaOH - i.e., accurately determine its concentration.

1.065 g of $H_2C_2O_4$ (oxalic acid) requires 35.62 mL of NaOH for titration to an equivalence point. What is the concentration of the NaOH?

MAR

$H_2C_2O_4(aq)$ + 2 $NaOH(aq)$ ---> $Na_2C_2O_4(aq)$ + 2 $H_2O(liq)$

1.065 g of $H_2C_2O_4$ (oxalic acid) requires 35.62 mL of NaOH for titration to an equivalence point. What is the concentration of the NaOH?

Step 1: Calculate moles of $H_2C_2O_4$

$$1.065 \text{ g} * \frac{1 \text{ mol}}{90.04 \text{ g}} = 0.01183 \text{ mol}$$

Step 2: Calculate moles of NaOH req'd

$$0.01183 \text{ mol acid} \bullet \frac{2 \text{ mol NaOH}}{1 \text{ mol acid}} = 0.02366 \text{ mol NaOH}$$

MAR

$H_2C_2O_4(aq)$ + 2 $NaOH(aq)$ ---> $Na_2C_2O_4(aq)$ + 2 $H_2O(liq)$

1.065 g of $H_2C_2O_4$ (oxalic acid) requires 35.62 mL of NaOH for titration to an equivalence point. What is the concentration of the NaOH?

Step 1: Calculate moles of $H_2C_2O_4$

= 0.01183 mol acid

Step 2: Calculate moles of NaOH req'd

= 0.02366 mol NaOH

Step 3: Calculate concentration of NaOH

$$\frac{0.02366 \text{ mol NaOH}}{0.03562 \text{ L}} = 0.6642 \text{ M}$$

[NaOH] = 0.6642 M

MAR

$H_2C_2O_4(aq)$ + 2 $NaOH(aq)$ ---> $Na_2C_2O_4(aq)$ + 2 $H_2O(liq)$

LAB PROBLEM #2: Use standardized NaOH to determine the amount of an acid in an unknown.

Apples contain malic acid, $C_4H_6O_5$.

$C_4H_6O_5(aq)$ + 2 $NaOH(aq)$ --->
$Na_2C_4H_4O_5(aq)$ + 2 $H_2O(liq)$

76.80 g of apple requires 34.56 mL of 0.6642 M NaOH for titration. What is weight % of malic acid?

MAR

76.80 g of apple requires 34.56 mL of 0.6642 M NaOH for titration. What is weight % of malic acid?

Step 1: Calculate moles of NaOH used.

M * V = (0.6642 M)(0.03456 L)

= 0.02295 mol NaOH

Step 2: Calculate moles of acid titrated.

$$0.02295 \text{ mol NaOH} \bullet \frac{1 \text{ mol acid}}{2 \text{ mol NaOH}}$$

= 0.01148 mol acid

MAR

$C_4H_6O_5(aq) + 2\ NaOH(aq) \longrightarrow Na_2C_4H_4O_5(aq) + 2\ H_2O(liq)$

76.80 g of apple requires 34.56 mL of 0.6642 M NaOH for titration. What is weight % of malic acid?

Step 1: moles of NaOH = 0.02295

Step 2: moles of acid titrated = 0.01148

Step 3: Calculate mass of acid titrated.

$$0.01148 \text{ mol acid} \bullet \frac{134.1 \text{ g}}{\text{mol}} = 1.539 \text{ g}$$

Step 4: Calculate % malic acid.

(1.539 g acid / 76.80 g apple) *100 =

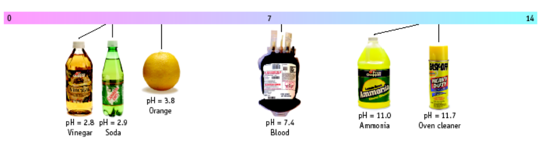
2.004 %

MAR

$C_4H_6O_5(aq) + 2\ NaOH(aq) \longrightarrow Na_2C_4H_4O_5(aq) + 2\ H_2O(liq)$

pH, a Concentration Scale

pH: a way to express acidity - the concentration (M) of H^+ in solution.



Low pH: high $[H^+]$ High pH: low $[H^+]$

Acidic solution	pH < 7
Neutral	pH = 7
Basic solution	pH > 7

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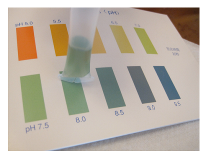


The pH Scale

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

$[H^+]$ often written as $[H_3O^+]$

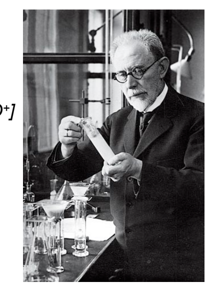
In a neutral solution,

$[H^+] = [OH^-] = 1.00 \times 10^{-7}$ M at 25 °C

pH = - log $[H^+]$

= -log (1.00×10^{-7})

= - (-7) = 7



Søren Sørensen, creator of the pH scale

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$[H^+]$ and pH

If the $[H^+]$ of soda is 1.6×10^{-3} M, the pH is ____?

Because pH = - log $[H^+]$

then

pH= - log (1.6×10^{-3})

pH = - (-2.80)

pH = 2.80

MAR

pH and $[H^+]$

If the pH of Coke is 3.12, it is ___________.

Because pH = - log $[H^+]$ then

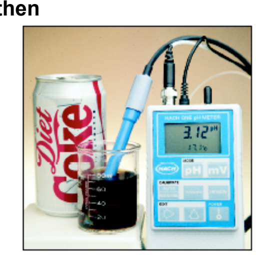
log $[H^+]$ = - pH

Take antilog and get

$$[H^+] = 10^{-pH}$$

$[H^+] = 10^{-3.12}$

$[H^+] = 7.6 \times 10^{-4}$ M



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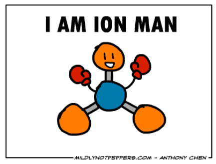
more on acids, bases and pH in CH 223...

End of Chapter Four Part 2

See also:

- *Chapter Four Part 2 Study Guide*
- *Chapter Four Part 2 Concept Guide*
- *Important Equations (following this slide)*
- *End of Chapter Problems (following this slide)*



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Important Equations, Constants, and Handouts from this Chapter:

- Know how the **solubility guide** works
- Know what makes an acid acidic (and bases basic) and strong or weak; know how to use the pH scale
- Know how to write and determine net ionic equations and find spectator ions
- Know how to use molarity with solution stoichiometry problems
- Molarity (M) = mol of solute per Liter of solution
- $M_1V_1 = M_2V_2$

Solutions: Solute, solvent, aqueous, electrolyte (strong, weak, non), solubility (use the Net Ionics solubility table), precipitation, types of reactions, molarity (M)

Know the five types of reactions: precipitation, acid-base, gas forming, combustion and redox. Know how to determine if something has been **oxidized** or **reduced** (and the **oxidizing agent** and **reducing agent**)

MAR

End of Chapter Problems: *Test Yourself*

1. Predict whether these compounds would be labeled as insoluble or soluble: HCl, NaCl, AgCl
2. Predict the products of this precipitation reaction and write the net ionic equation: $NiCl_2(aq) + (NH_4)_2S(aq) \rightarrow$? List any spectator ions.
3. In the following reaction, decide which reactant is oxidized and which is reduced. Designate the oxidizing agent and the reducing agent. **$Si(s) + 2\ Cl_2(g) \rightarrow SiCl_4(l)$**
4. Identify the ions and their concentration that exist in this aqueous solution: **0.25 M $(NH_4)_2SO_4$**
5. What volume of 0.109 M HNO_3, in milliliters, is required to react completely with 2.50 g of $Ba(OH)_2$? **$2\ HNO_3(aq) + Ba(OH)_2(s) \rightarrow 2\ H_2O(l) + Ba(NO_3)_2(aq)$**
6. A table wine has a pH of 3.40. What is the hydrogen ion concentration of the wine? Is it acidic or basic?
7. If 50.0 mL of 0.0135 M $BaCl_2$ is diluted to a total of 400. mL, what is the new concentration of $BaCl_2$?

MAR

End of Chapter Problems: *Answers*

1. Soluble: HCl(aq), NaCl(aq). Insoluble: AgCl(s)
2. $NiCl_2(aq) + (NH_4)_2S(aq) \rightarrow NiS(s) + 2\ NH_4Cl(aq)$
   $Ni^{2+}(aq) + S^{2-}(aq) \rightarrow NiS(s)$ *Spectator ions:* NH_4^{+1} and Cl^{-1}
3. Si is oxidized and is the reducing agent; Cl_2 is reduced and is the oxidizing agent
4. 0.50 M NH_4^{+1}; 0.25 M SO_4^{2-}
5. 268 mL
6. acidic; $[H^+] = 4.0 \times 10^{-4}$ M
7. 0.00169 M

MAR