4. Aqueous Solutions

Solution
homogeneous mixture
of two components

Many chemical reactions occur in solution
Solutions in water called aqueous

Definitions

Solute component(s) in smaller amount
2 types: electrolytes & nonelectrolytes

Solvent component in greatest amount
disperses reactants so they can react

Precipitate excess solute that falls out of solution as a solid

Definitions

Electrolytes

dissociate in solution to form ions
conduct electricity
may be strong or weak

strong: HCl H_2SO_4 NaOH *{ionic}*
weak: CH_3COOH NH_3 HF tap water

Hydration

$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$

Ions surrounded by H_2O & dissolve

Polar & Nonpolar substances

Why do salt and water mix?

Both are polar substances

NaCl (s) ¸ Na^{+} (aq) + Cl^{-} (aq)

Oil and water DON'T mix?

Oil is non-polar

Precipitation Reactions

$$AB + CD \rightarrow CB + AD$$

$$AB + CD \rightarrow CB + AD$$

Precipitation Reactions

$$Pb(NO_3)_2 + 2\ KI \rightarrow PbI_2 + 2\ KNO_3$$

white white yellow

Precipitation Reactions

$$Pb(NO_3)_2 + 2\ KI \rightarrow PbI_2 + 2\ KNO_3$$

white white yellow

Solubility Rules

1. Compounds of Gp 1 metals and NH_4^+
   soluble
2. Compounds of NO_3^-, acetate, ClO_4^-
   soluble
3. Compounds of hydroxide
   insoluble
   Exceptions:
   Gp 1 metals, Ba^{2+} Sr^{2+} Ca^{2+} (slightly)

Solubility Rules

4. Most compounds of Cl^- Br^- I^-

   soluble Exceptions: Ag^+ Pb^{2+} Hg_2^{2+}

5. Compounds of carbonate, phosphate, sulfide

   insoluble Exceptions: group 1, NH_4^+

6. Most compounds of sulfate

   soluble

   Exceptions: Ba^{2+} Pb^{2+} (Ca^{2+} Ag^+ slightly)

Will precipitate form?

$AgNO_3$ (aq) + NaCl (aq) →

$AgNO_3$ (aq) + NaCl (aq) → $NaNO_3$ (aq) + AgCl (s)

molecular equation

all nitrates soluble   insoluble

Ag^+ (aq) + Cl^- (aq) → AgCl (s)   ionic equation

Will precipitate form?

$$PbCl_2\ (aq) + K_2SO_4\ (aq) \rightarrow 2\,KCl\ (aq) + PbSO_4\ (s)$$

soluble insoluble

Will precipitate form?

$PbCl_2$ (aq) + K_2SO_4 (aq) , 2 KCl (aq) + $PbSO_4$ (s)

Acids and Bases

Acids: vinegar, lemons, gastric juice

Bases: ammonia, baking soda, drano

Salts: table salt

Acids and Bases

Properties

Acids: 1. sour

2. change color of dyes
3. dissolve metals to form hydrogen
4. react with carbonates to form CO_2
5. neutralize bases

water soluble acids form hydrogen ions

Acids and Bases

Properties

Bases: 1. bitter

2. change color of dyes
3. soapy feel
4. neutralize acids

In water, soluble bases can form OH^- or CO_3^{2-} or O^{2-} ions
These ions react with H^+ ions

NH_3 another common base

Acid-Base Theory

Davy (1811)

all acids contain hydrogen

Acid-Base Theory

Arrhenius (1884)

acid: form H^+ in water
base: form OH^- in water

Acid-Base Theory

Bronsted

Lowry

(1923)

Acid: lose or donate H^+
Base: gain or accept H^+

Acids and Bases

Acid Definition:
substance that produces hydrogen ions in water called a Lowry-Bronsted acid

HCl H_2SO_4 HNO_3 H_3PO_4 CH_3COOH

Dissociation

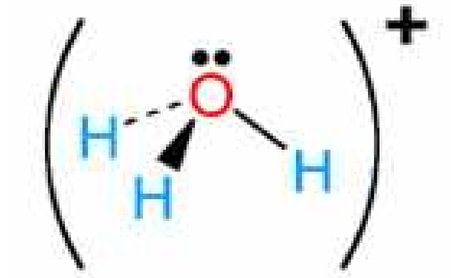
Acids and bases dissociate or ionize in water

$$HCl\ (aq)\quad 6\quad H^{+}\ (aq) + Cl^{-}(aq)$$

$$KOH\ (aq)\quad 6\quad K^{+}\ (aq) + OH^{-}\ (aq)$$

The Hydronium Ion

H_3O^+



self ionization of water

Some Reactions

In general:

acid + base 6 salt + H_2O

HCl + NaOH 6 NaCl + H_2O

2 HCl + Na_2CO_3 6 NaCl + CO_2 + H_2O

Both are neutralization reactions

Salts

Product of acid + base reaction

HCl + NaOH 6 **NaCl + H_2O**

when an acid reacts with a base a salt and water form

carbonates 6**CO_2 gas**

Polyprotic Acids

HCl: monoprotic acid

H_2SO_4 : diprotic acid

H_3PO_4 : triprotic acid

H_2SO_4 (aq) o H^+ (aq) + HSO_4^- (aq)

HSO_4^- (aq) o H^+ (aq) + SO_4^{2-} (aq)

Common Acids

HCl	**cleans metals, brick, cement**
H_2SO_4	**car batteries, fertilizers, industrial chemicals, nitroglycerin**
HNO_3	**fertilizers, dyes, plastics, explosives**

All are corrosive

Common Bases

NaOH	drain cleaner, soap manufacture
$Ca(OH)_2$	lime, mortar, plaster, cement
NH_3	cleaner
$Mg(OH)_2$	milk of magnesia

Many drugs: cocaine, morphine, nicotine

Oxidation & reduction Reactions

Electron transfer reactions

$$2\,Mg\,(s) + O_2\,(g) \rightarrow 2\,MgO\,(s)$$

really two reactions

oxidation: loss of electrons

reduction: gain of electrons

Break into 2 half reactions

Oxidation & reduction Reactions

Oxidation Loss of electrons
Mg oxidized

Half-reaction: Mg ¸ $Mg^{2+} + 2\ e^{-}$

Reduction Gain of electrons
O_2 reduced

Half-reaction: $O_2 + 4\ e^{-}$ ¸ $2\ O^{2-}$

Overall: $2\ Mg + O_2$ ¸ $2\ Mg^{2+}O^{2-}$

Oxidation & reduction Reactions

Overall: 2 Mg + O_2 , 2 $Mg^{2+}O^{2-}$

reducing agent **oxidizing agent**

Oxidation & reduction Reactions

magnesium oxidized

Overall: $2\ Mg + O_2$, $2\ Mg^{2+}O^{2-}$

oxygen reduced

oxidation numbers

Oxidation Numbers

Keeps track of electrons

Uses

naming compounds
classifying reactions
writing formulas

Oxidation Numbers

Summary of rules

1. free elements = 0
2. monatomic ions = ionic charge
3. F = -1   O = -2
4. H = +1 (with nonmetals)
H = -1 (with metals)

Oxidation Numbers

Summary of rules

5. some elements >1 oxidation number
   N,S,P,Cl; transition metals

6. Neutral compounds:
   sum of oxidation numbers = 0

Be able to assign oxidation numbers to elements in a compound.
Use above rules.

Oxidation Numbers

Examples: NaF H_3PO_4

NaF: F always -1

Na must be +1

H_3PO_4 : O = -2; H = +1

$\{3 \times (+1)\} + P + \{4 \times (-2)\} = 0$

P = +5

Oxidation & reduction Reactions

magnesium oxidized

Overall: 2 Mg + O_2 , 2 $Mg^{2+}O^{2-}$

oxygen reduced

Oxidation & reduction Reactions

oxidation

Overall: $2\ Mg + O_2$, $2\ Mg^{2+}O^{2-}$

reduction

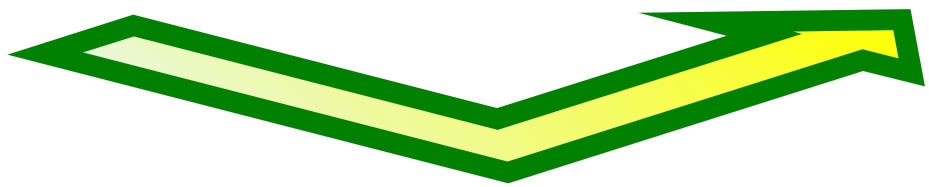
oxidation: increase in oxidation number

reduction: decrease in oxidation number

Activity Series

If element A is more reactive then element B, it can displace element B from a compound

$$Mg \quad + \quad 2\,HCl \quad \pm \quad MgCl_2 \quad + \quad H_2$$



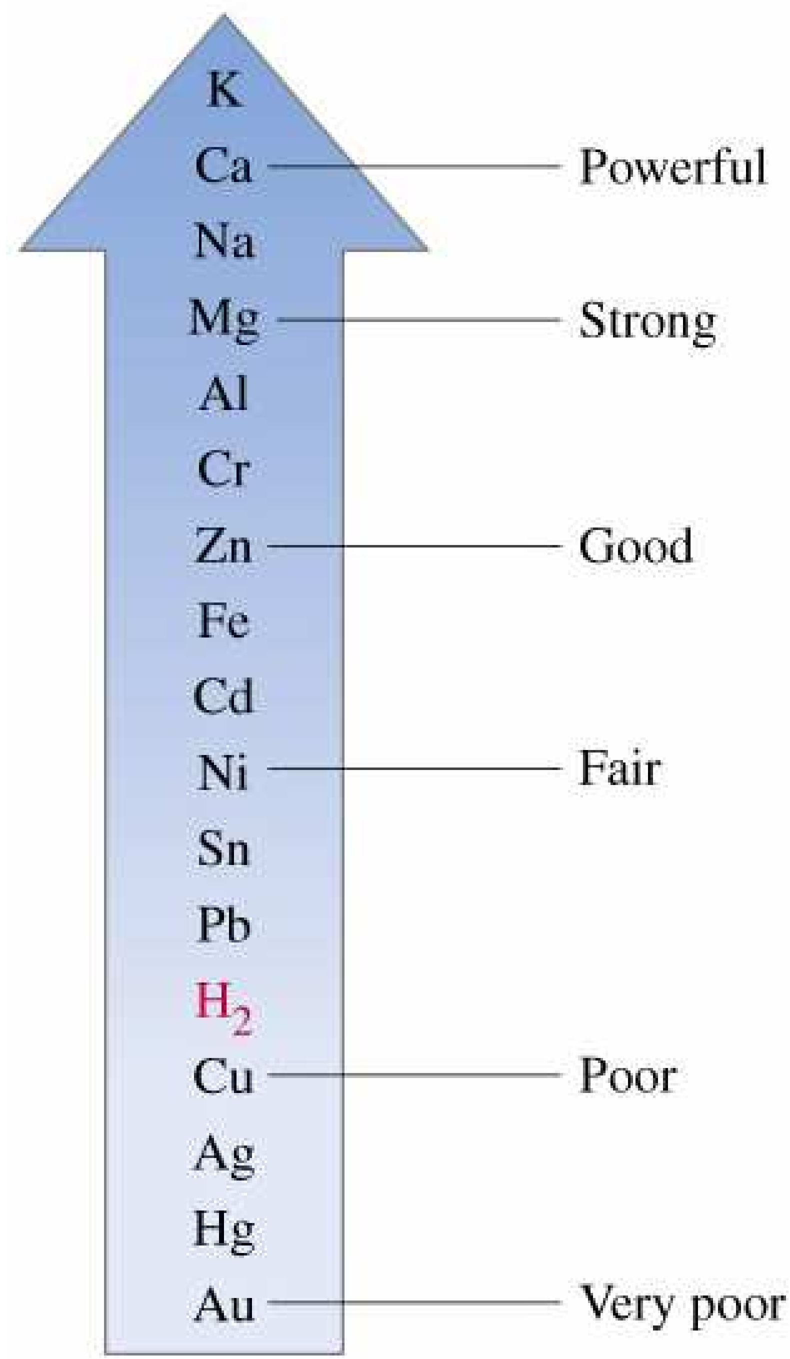
magnesium displaces hydrogen

Activity Series

Fig 4.14
describes order of displacement reactions

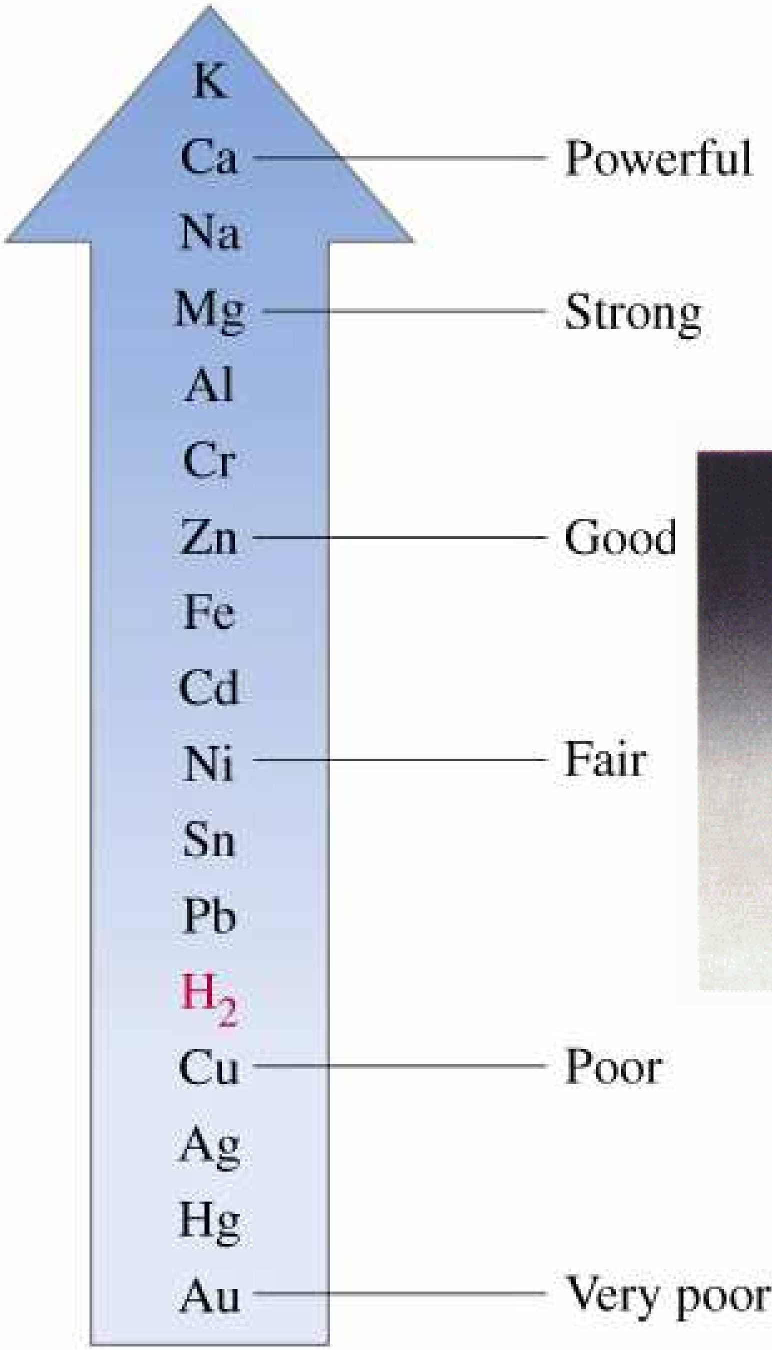
$$Mg \; + \; 2\,HCl \; \pm \; MgCl_2 \; + \; H_2$$

magnesium higher than hydrogen



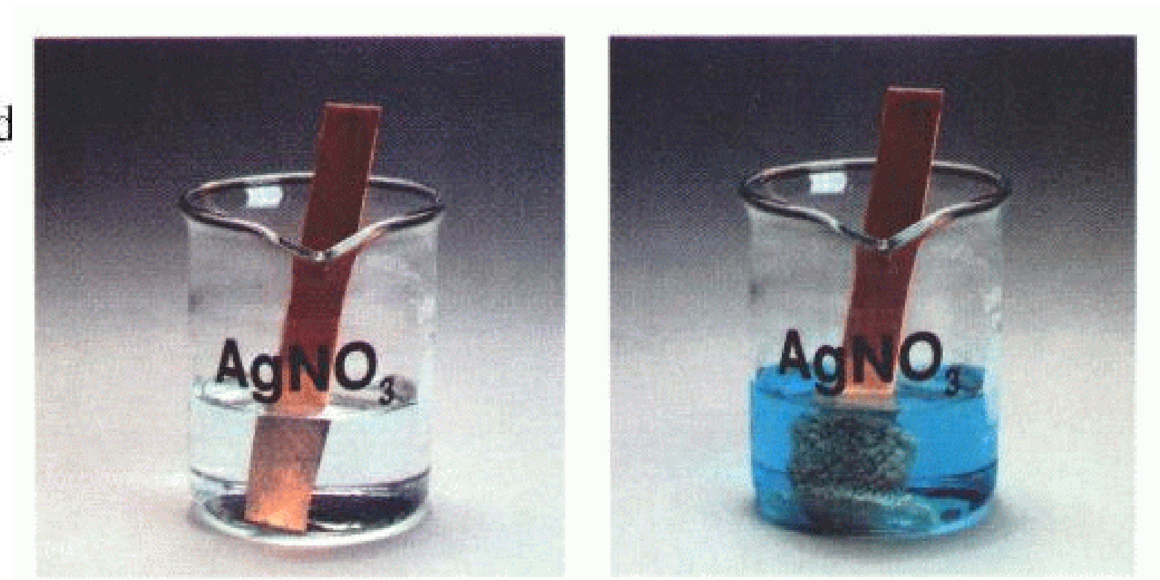
order of reactivity

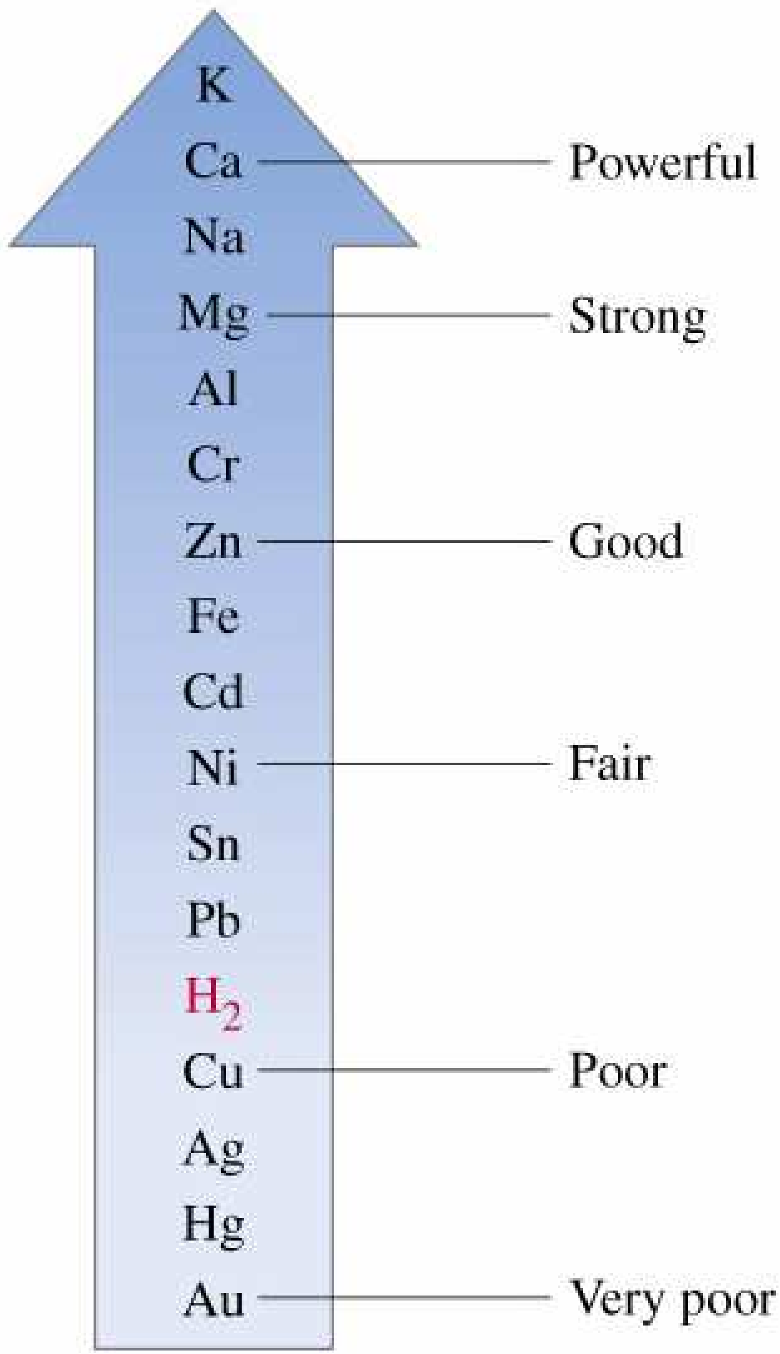
most reactive at top



order of reactivity

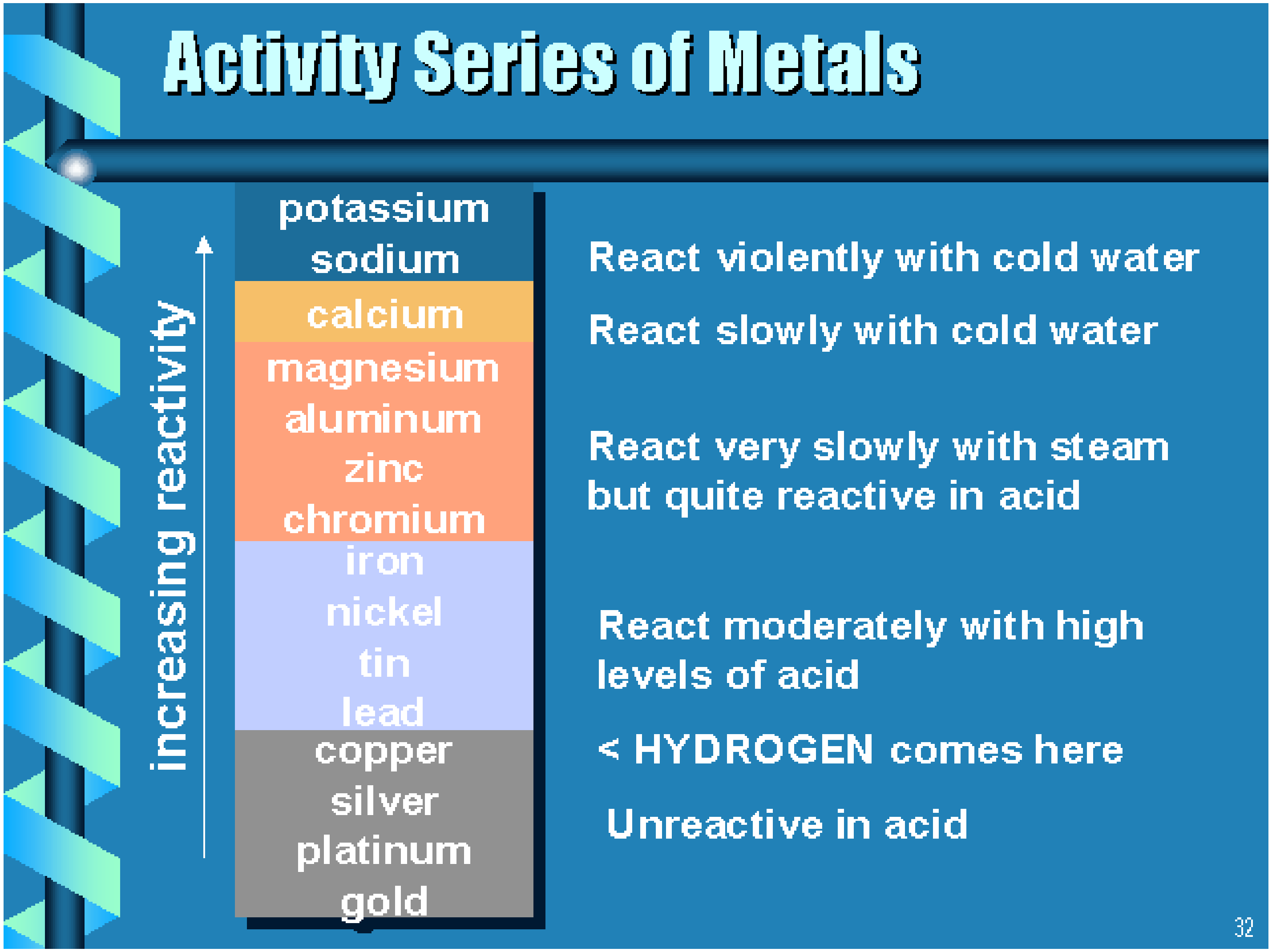
most reactive at top





order of reactivity

most reactive at top


Activity Series of Metals
increasing reactivity
potassium
sodium
calcium
magnesium
aluminum
zinc
chromium
iron
nickel
tin
lead
copper
silver
platinum
gold
React violently with cold water
React slowly with cold water
React very slowly with steam but quite reactive in acid
React moderately with high levels of acid
< HYDROGEN comes here
Unreactive in acid
32

see fig 4.14

Concentration

Measure amount of solute in a solution

weight / volume %
volume / volume %
weight / weight %
molarity

Concentration

Saline: 0.9 wt/vol %

Alcohol in wine: 6 vol/vol %

Fat in ham: 3 wt/wt %
(or 97% fat free)

Molarity: no consumer use
used by chemists

Concentration

$$\text{molarity} = \frac{\text{moles solute}}{\text{volume of solution}}$$

volume in liters

symbol: M units: mol/L

A 1 M = a one molar solution

[ ] means molar eg [NaCl] = 2.0 M

Molarity Calculations

Calculate the molarity of a 2.0 L solution containing 10.0 moles of NaOH

$$\text{molarity} = \frac{\text{moles solute}}{\text{volume of solution}}$$

$$M = \frac{10.0 \text{ mol NaOH}}{2.0 \text{ L}} = 5.0 \text{ M}$$

Molarity Calculations

Calculate the molarity of 2.0 L of a solution containing 18.23 g of HCl

Need moles HCl **Use formula weight**

$$\text{F.Wt.}_{(HCl)} = 1.008 + 35.34 = 36.46$$

$$\text{moles}_{(HCl)} = \frac{\text{mass}}{\text{F.Wt.}} = \frac{18.23\ \text{g}}{36.46} = 0.50\ \text{mol}$$

$$\text{molarity}_{(HCl)} = \frac{0.50\ \text{mol}}{2.0\ \text{L}} = 0.25\ \text{M}$$

Molarity Calculations

$$\text{molarity} = \frac{\text{moles solute}}{\text{volume of solution}}$$

$$M = \frac{mol}{V}$$

$$mol = MV$$

Molarity Calculations

$$\text{molarity} = \frac{\text{moles solute}}{\text{volume of solution}}$$

$$M = \frac{mol}{V}$$

$$mol = MV$$

Making Solutions

Solutions are prepared in two ways:

Weighing proper amount of solute and diluting to volume

Note: water mixed with concentrated solution makes a diluted (less concentrated) solution

Making Solutions

How would you prepare 100 mL of a 0.5000 M NaCl solution ?

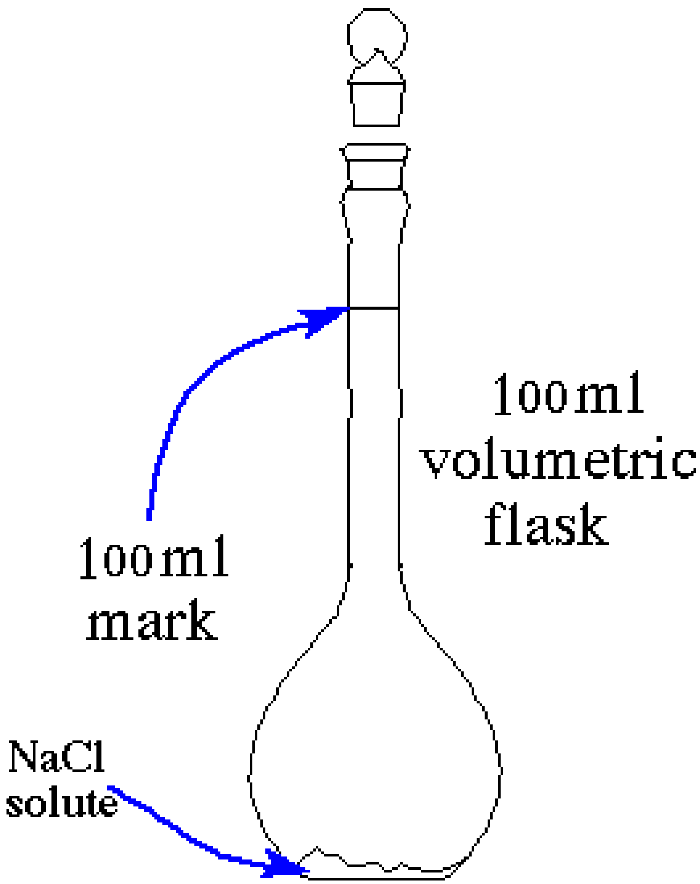
First calculate moles of NaCl needed

mol = MV = 0.5000 x 0.1000 L
= 0.05000 moles NaCl

Next, find mass of NaCl needed

mass = mol x F. Wt. = 0.5000 x 58.44
= 2.922 grams NaCl

Making Solutions



To make solution:
Weigh out exactly
2.922 g dry NaCl
Transfer to a
volumetric flask

Fill about 1/3
with pure water
Shake to dissolve
Dilute to 100 mL mark

Dilutions

solutions can be easily diluted
by adding more solvent (water)

$$M_1V_1 = M_2V_2$$

where 1 is initial solution
2 is diluted solution

can use any volume or concentration unit as long as same units on both sides of equation

Dilutions

What is concentration of a solution produced by diluting 100.0 mL of a 1.5 M NaOH solution to 2.000 L ?

$M_1V_1 = M_2V_2$

$M_1 = 1.5$ M $\quad V_1 = 100.0$ mL

$M_2 = ??$ $\quad V_2 = 2000$ mL

$$M_2 = (M_1V_1)/V_2 = \frac{1.5 \text{ M} \times 100.0 \text{ mL}}{2000 \text{ mL}}$$

$= 0.075$ M

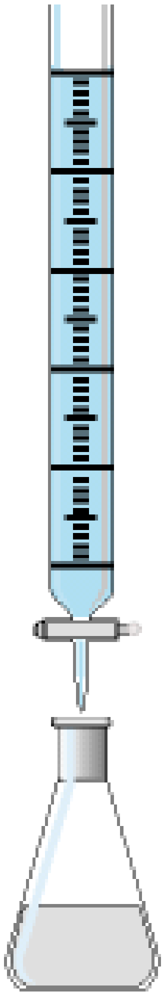
Titrations

A reaction between two reactants where the amount of one reactant is unknown

Often, one is an acid and one is a base: acid-base titration

Both reactants need to be in solution

Reactants must be carefully measured and mixed together



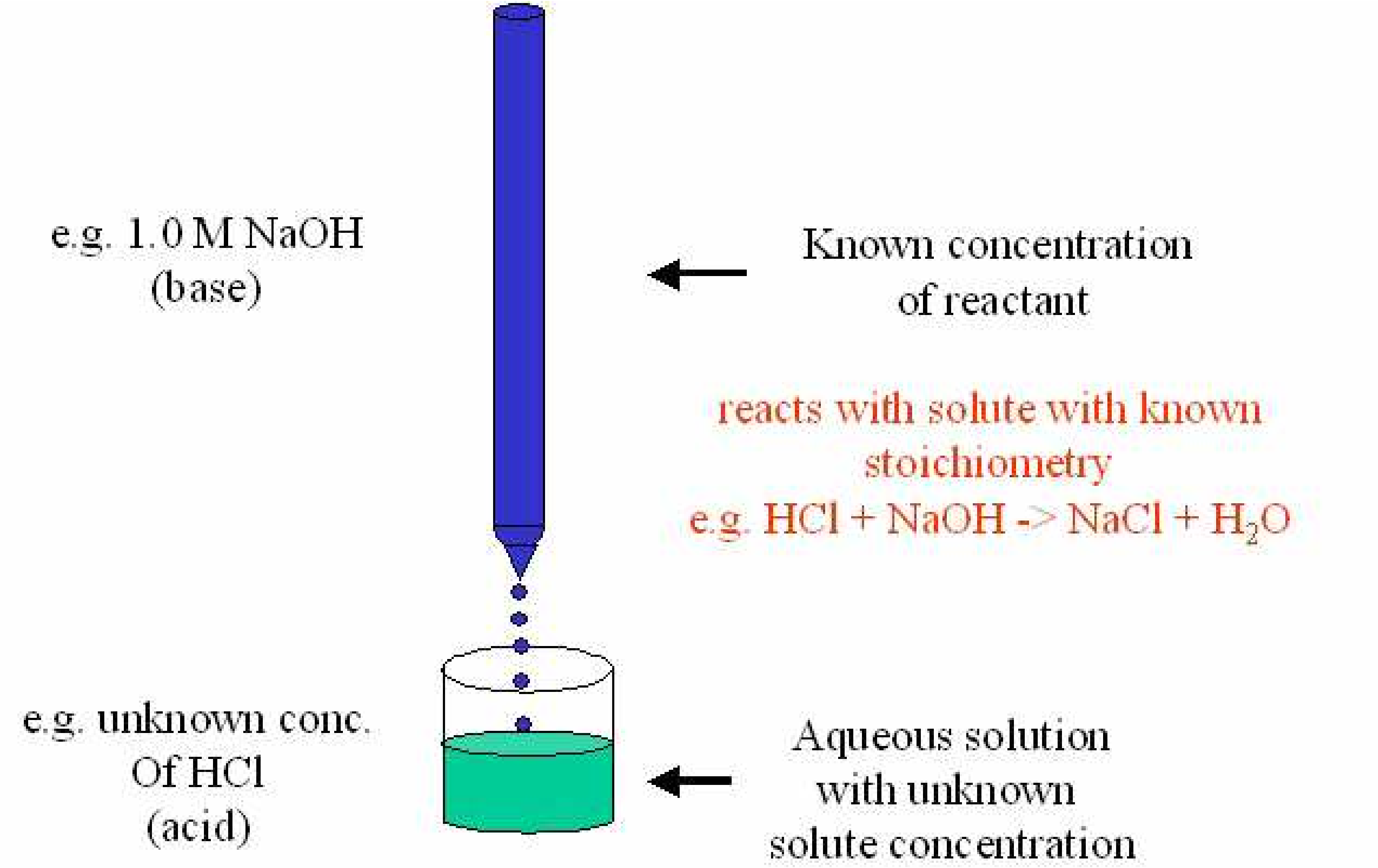
Titrations

Solution of known concentration called **titrant** and placed in **buret**

Solution of unknown concentration measured with a **pipet** and placed in a flask with an **indicator**

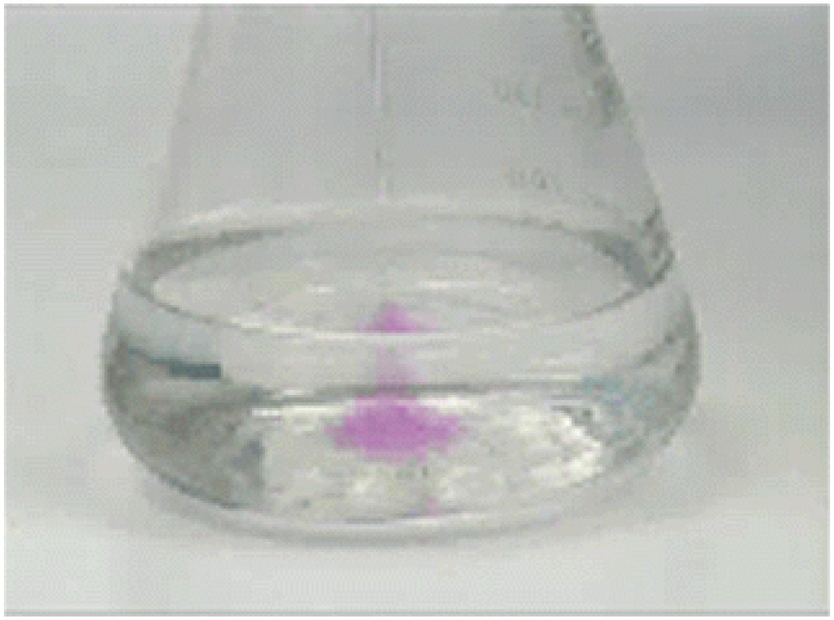
Titrant added to flask until indicator changes color = **equivalence point**

Titrations


e.g. 1.0 M NaOH
(base)
Known concentration
of reactant
reacts with solute with known
stoichiometry
e.g. HCl + NaOH -> NaCl + H_2O
e.g. unknown conc.
Of HCl
(acid)
Aqueous solution
with unknown
solute concentration

Titrations

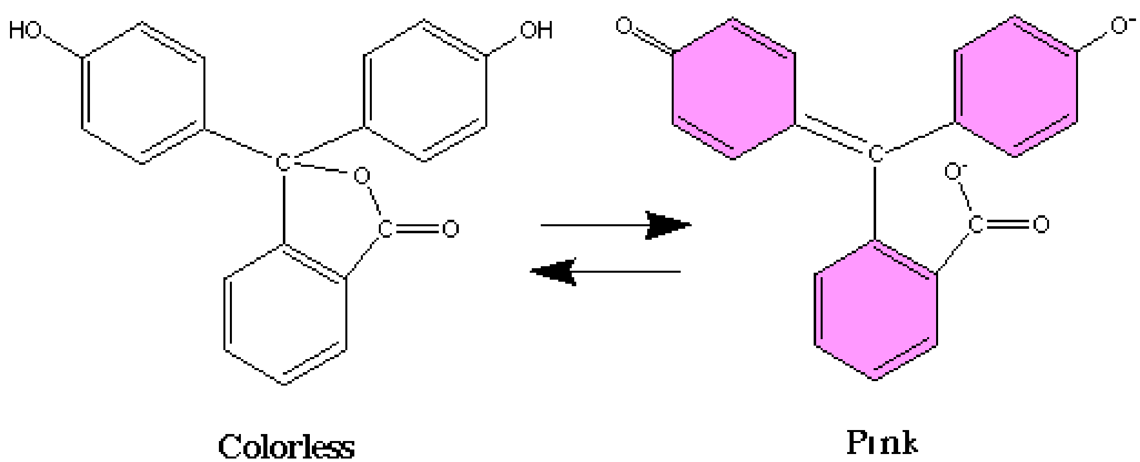
Indicators: dyes that change color at end of reaction phenolphthalein



In acid: colorless **In base: pink**

Titrations

Indicators: dyes that change color at end of reaction phenolphthalein



$H_2In(aq) + 2H_2O \rightleftharpoons In^{2-}(aq) + 2H_3O^+$

Titration Calculations

First step is to determine the number of moles based on solution concentration and volume.

Final step is to convert back to volume or concentration as required by the problem.

You still need a balanced equation and must use the coefficients for working the problem.

Titration Calculations

Determine the volume of 0.1 M HCl that must be added to completely react with 250 mL of 2.5 M NaOH

$$HCl + NaOH \pm NaCl + H_2O$$

Step 1 calculate the moles of NaOH

Titration Calculations

Step 1 calculate the moles of NaOH

Have 250 mL of a 2.5 M NaOH solution

$$mol_{NaOH} = MxV = 0.25\ L \times 2.50\ mol/L$$
$$= 0.625\ mol$$

Titration Calculations

Step 2 calculate mole of HCl

$HCl + NaOH \pm NaCl + H_2O$

1 mole HCl needs 1 mole NaOH

Therefore need 0.625 mol HCl

Titration Calculations

Step 3 calculate volume of HCl

$$V = mol/M$$

$$= \frac{0.625 \text{ mol}}{0.100 \text{ mol/L}} = 6.25 \text{ L}$$

Titration Calculations

Determine the molarity an HCl solution if 150 mL of the HCl neutralizes 50.0 mL of a 0.150 M NaOH solution

$$HCl + NaOH \pm NaCl + H_2O$$

Step 1 calculate the moles of NaOH

$$mol_{NaOH} = MxV = 0.050\ L \times 0.150\ mol/L$$
$$= 0.0075\ mol\ NaOH$$

Titration Calculations

Step 2 calculate mole of HCl

$HCl + NaOH \pm NaCl + H_2O$

1 mole HCl needs 1 mole NaOH

Therefore need 0.0075 mol HCl

Titration Calculations

Step 3 calculate molarity of HCl

$M = mol/L$

$$= \frac{0.0075\ mol}{0.150\ L} = 0.050\ mol/L$$

Titration Calculations

Caution what if mole ratio not 1:1 ?

$$H_2SO_4 + 2\,NaOH \quad \pm \quad Na_2SO_4 + 2H_2O$$

1 mole H_2SO_4 needs 2 mole NaOH

Titration Calculations

In general: aA + bB ± products

When A and B both in solution:

$$\frac{1}{a} \times M_A V_A = \frac{1}{b} \times M_B V_B$$

Titration Calculations

When A is solid and B in solution:

$$\frac{1}{a} \times \frac{\text{mass}_A}{\text{F. wt.}_A} = \frac{1}{b} \times M_B V_B$$

End of Chapter 4