CHEM 103
Aqueous Solutions

Lecture Notes
February 28, 2006
Prof. Sevian

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Agenda

- What is a solution made of?
- Solubility of ionic compounds (salts), acids, and molecular compounds
- Exchange reactions that produce a precipitate
- Complete vs. net ionic reactions

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Solutions

- Almost nothing in nature occurs naturally as a pure substance
- Most chemical reactions of interest take place in *solution,* between chemicals that are dissolved in water
- Medium in which something is dissolved is called a *solvent*
- Water is often called the "universal solvent"
  - It is possible to have solvents other than water (*e.g.*, tincture of iodine is solid iodine crystals dissolved in ethanol)
  - It is possible to have solutions that are not liquids (*e.g.*, air is a bunch of different gases dissolved in N_2)
- The chemical that dissolves is called the *solute*
- In this course, we will focus on *aqueous solutions*

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What is electrical conductivity?

- Electrical = charged parts due to electrons not balanced with protons on particles
- Conductivity = parts can circulate so that complete circuit can form

Two conditions exist for something to be electrically conductive:

1. Must have charged parts
2. The parts must be mobile

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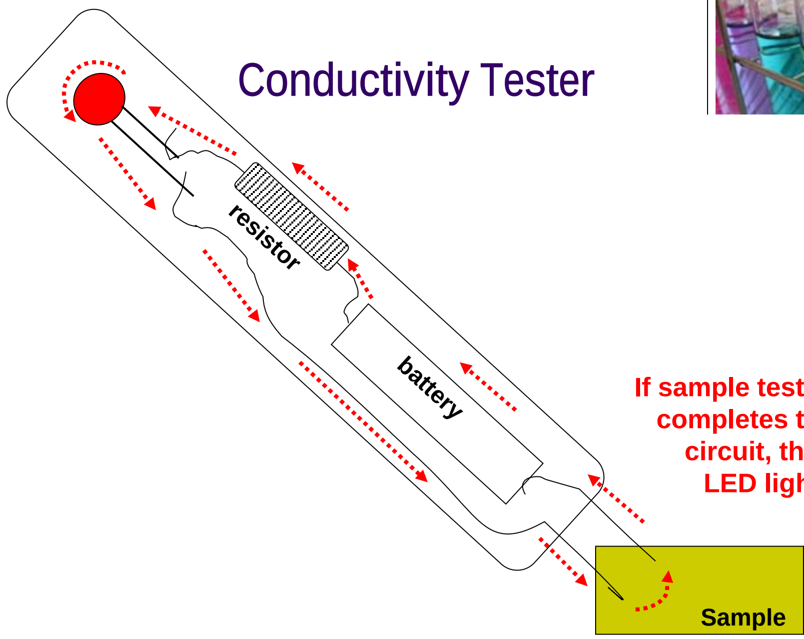
Conductivity Tester



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Demonstration

	Has charged parts?	Parts can move?	Electrically conductive?
Pure water			
Aqueous sugar solution			
Salt crystals at room temperature			
Aqueous salt solution			

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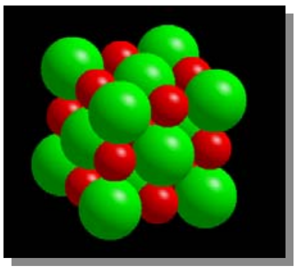
Electrolytes

Electro – lyte

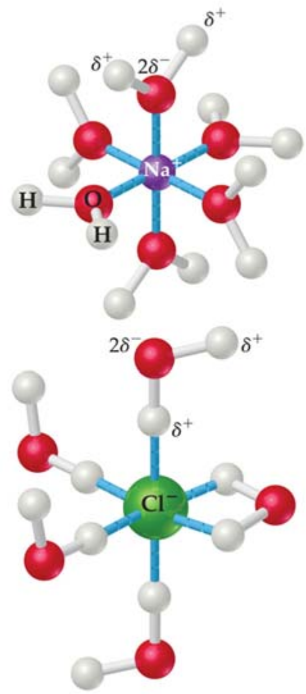
(electricity) – (break apart)



NaCl, salt

When ions dissolve into water

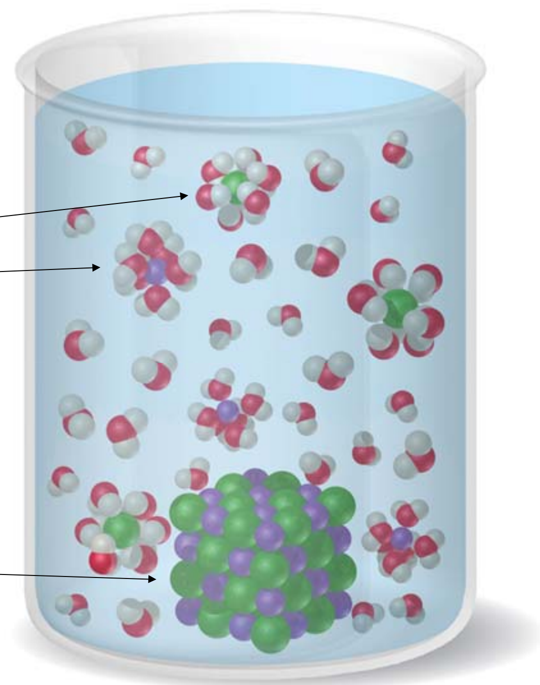
(how? stay tuned 'til ch. 13)



A saturated solution

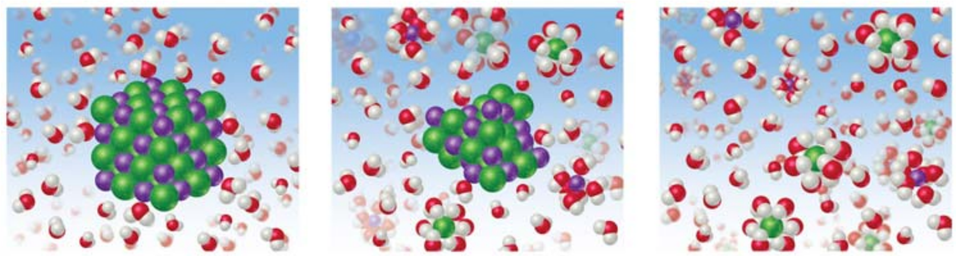
Cl^- ions surrounded by H_2O molecules

Na^+ ions surrounded by H_2O molecules



Some NaCl (*s*) remains undissolved because the solvent is holding the maximum amount of Na+ and Cl^- ions that it can

A particle level view of the solution process



(a) (b) (c)

http://media.pearsoncmg.com/ph/esm/esm_brown_chemistry_10/irc/Chapter_13/Present/eMedia_Library/Animations/Chapter_13/Present/eMedia_Library/DissolutionofNaClinWater/DissolutionofNaClinWater.html

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Some Ions Dissolve in Water Better Than Others

Definitions are fuzzy

Very soluble
- More than 0.10 mol can dissolve in 1 L of water

Moderately soluble
- Something in between

Pretty much insoluble
- Less than 0.01 mol can dissolve in 1 L of water

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Solubility guidelines

If one ion from the "Soluble Compounds" list is in an ionic compound, then the ionic compound will dissolve in water

TABLE 4.1 Solubility Guidelines for Common Ionic Compounds in Water

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	$C_2H_3O_2^-$	None
	Cl^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}
Insoluble Ionic Compounds		**Important Exceptions**
Compounds containing	S^{2-}	Compounds of NH_4^+, the alkali metal cations, and Ca^{2+}, Sr^{2+}, and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of the alkali metal cations, and NH_4^+, Ca^{2+}, Sr^{2+}, and Ba^{2+}

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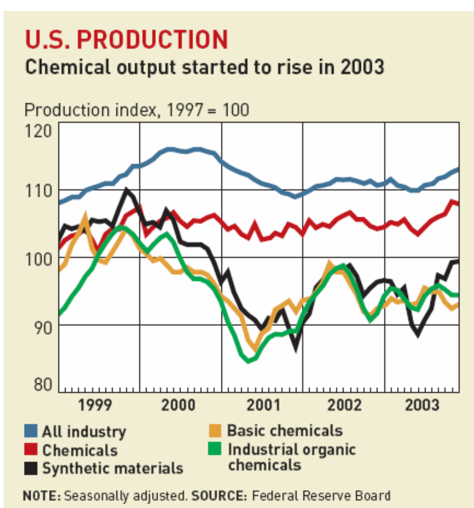
The Chemical Process Industries



From Chemical & Engineering News, "Facts & Figures" 2004, http://pubs.acs.org/cen/coverstory/8227/pdf/8227fandf_production.pdf

Top chemicals produced in the U.S. in 2003

Sulfuric acid	37.1×10^6 metric tons
Nitrogen gas	26.8×10^6 m^3
Ethylene	23.0×10^6 metric tons
Oxygen gas	19.6×10^6 m^3
Hydrogen gas	14.3×10^6 m^3
Propylene	13.9×10^6 metric tons
Phosphoric acid, as P_2O_5	11.0×10^6 metric tons
Chlorine gas	10.7×10^6 m^3
Ammonia gas	10.7×10^6 m^3
Sodium hydroxide	8.7×10^6 metric tons
Polypropylene	8.0×10^6 metric tons

Sulfuric Acid

- Produced by burning iron pyrites or sulfur in air:

$$S_8 + O_2 \rightarrow SO_2$$

  then reacting sulfur dioxide in the presence of a catalyst with more oxygen to produce sulfur trioxide:

$$SO_2 + O_2 \rightarrow SO_3$$

  and finally reacting sulfur trioxide with water to make sulfuric acid:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

- Involved in the production of nearly all manufactured goods
- Used primarily in production of fertilizers (lime, ammonium sulfate)
- Also used in production of other acids, sulfate salts, detergents, dyes & pigments, explosives, drugs
- Other uses include washing gasoline, processing metals, making rayon
- Serves as electrolyte in lead-acid storage battery

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What Kinds of Changes?

How can you tell if a change occurs?

Evidence

Chemical vs. Physical Change

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Three Views of Change

1. Macroscopic
   - What we observe in the laboratory
2. Particle level
   - Model of what we believe is happening that produces the changes we see
3. Symbolic
   - How we represent the model

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Macroscopic Level: How Can You Tell If There Is a Chemical Change?

- We say a chemical reaction has occurred <u>if</u> a chemical is formed that was not present before
- Evidence of chemical change can be:
  - Solid appears (precipitate)
  - Gas forms: bubbles, odor
  - Color change (usually when a solid reacts with chemical dissolved in a solution)
- (Confusing) Other evidence of change that could indicate either chemical or physical change:
  - Heat released (feels warm)
  - Heat absorbed (feels cold)
  - One of the chemicals changes phase (changes to solid, liquid or gas of itself) because the temperature changed

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Macroscopic Level: Classifying Chemical Reactions Based on Evidence Observed

Consider only reactions that occur in aqueous solutions

1. Precipitation reactions
   - Formation of a precipitate (solid) where there wasn't one before
2. Acid-base reactions
   - pH of product solution is different from the pH's of the reactant solutions
3. Oxidation-reduction (redox) reactions
   - If the reactions are separated in a special way, electricity can be generated

*Categories are not unique, in part because 1 and 2 are based on evidence, but 3 is based on particle-level model

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History of Classes of Reactions

- Names of "classes" of chemical reactions reflects the history of understanding them
- Macroscopic = properties observed in laboratory
  - Precipitation
  - Acid-base
  - Combustion
- Particle level = model of underlying process
  - Redox

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Particle Level

Chemical Reactions

- It is called a “chemical reaction” only if a chemical change occurs
- Chemical changes are ALWAYS about ELECTRONS
- Four kinds of processes involved
  - Transfer of a “proton” (a naked hydrogen atom) from one chemical species to another
  - Sharing of electron pairs between chemical species
  - Transfer of an electron from one chemical species to another
  - Sharing of single electrons between chemical species

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Some Types of Reactions (According to Your Textbook)

1. Precipitation reactions
2. Acid-base reactions
3. Oxidation-reduction reactions
4. (Combustion reactions)

Some other ways to categorize reactions

- Based on patterns in the chemical equations
  - Exchange, single replacement, S_N1, S_N2, condensation polymerization, etc.
- Based on functional groups that get replaced
  - Halide-alcohol exchange, others

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Precipitation Rxns
Macroscopic View

- An insoluble compound forms, usually from two soluble compounds (dissolved in water) that react in aqueous solution
- The insoluble compound precipitates
- The insoluble compound can be white or colored
- When the insoluble compound precipitates, it leaves the solution, thereby causing more reaction to occur between reactants
- Some examples

  http://www.jce.divched.org/JCESoft/CCA/samples/index.html
  - Sodium iodide + mercury (II) chloride
  - Cadmium nitrate + sodium sulfide

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Precipitation Rxns
Symbolic Representation

Sodium iodide + mercury (II) chloride

$$2\ NaI\ +\ HgCl_2\ \rightarrow\ HgI_2\ +\ 2\ NaCl$$

$$2\ NaI\ (aq) + HgCl_2\ (aq) \rightarrow HgI_2\ (s) + 2\ NaCl\ (aq)$$

sodium iodide + mercury (II) chloride → mercury (II) iodide + sodium chloride

Many names for this pattern:

- Exchange reaction
- Metathetical reaction
- Double displacement reaction
- Double replacement reaction

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Precipitation Rxns
Symbolic Representation

Sodium iodide + mercury (II) chloride

$$2\ NaI\ (aq) + HgCl_2\ (aq) \rightarrow HgI_2\ (s) + 2\ NaCl\ (aq)$$

2 NaI		HgCl₂		HgI₂	2 NaCl	
~~two Na^+ ions~~ (*aq*)	two I^- ions (*aq*)	one Hg^{2+} ion (*aq*)	~~two Cl^- ions~~ (*aq*)	one unit of HgI_2 ppt (*s*)	~~two Na^+ ions~~ (*aq*)	~~two Cl^- ions~~ (*aq*)

Net reaction: two $\mathbf{I^-}$ ions + one $\mathbf{Hg^{2+}}$ ion → one unit of $\mathbf{HgI_2}$ ppt

$$2\ I^-\ (aq) + Hg^{2+}\ (aq) \rightarrow HgI_2\ (s)$$

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Complete equation vs. Net ionic eqn

$$2\ NaI\ (aq) + HgCl_2\ (aq) \rightarrow HgI_2\ (s) + 2\ NaCl\ (aq)$$

$$2\ I^-\ (aq) + Hg^{2+}\ (aq) \rightarrow HgI_2\ (s)$$

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Writing Net Ionic Equations

1. Start with the balanced reaction, written with phases
2. Identify ions in aqueous solution, ionic solids that precipitate, and any molecules on both sides of the arrow
3. Cross out any spectator ions
4. What's left is the net ionic equation

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Spectator Ions are Vehicles

$$2\ \mathrm{NaI}\ (aq) + \mathrm{HgCl_2}\ (aq) \rightarrow \mathrm{HgI_2}\ (s) + 2\ \mathrm{NaCl}\ (aq)$$

~~two Na^+ ions (aq)~~ | two I^- ions (aq) | one Hg^{2+} ion (aq) | ~~two Cl^- ions (aq)~~ | one unit of HgI_2 ppt (s) | ~~two Na^+ ions (aq)~~ | ~~two Cl^- ions (aq)~~

$$2\ \mathrm{NH_4I}\ (aq) + \mathrm{Hg(NO_3)_2}\ (aq) \rightarrow \mathrm{HgI_2}\ (s) + 2\ \mathrm{NH_4NO_3}\ (aq)$$

~~two NH_4^+ ions (aq)~~ | two I^- ions (aq) | one Hg^{2+} ion (aq) | ~~two NO_3^- ions (aq)~~ | one unit of HgI_2 ppt (s) | ~~two NH_4^+ ions (aq)~~ | ~~two NO_3^- ions (aq)~~

Net reaction: two $\mathbf{I^-}$ ions + one $\mathbf{Hg^{2+}}$ ion $\rightarrow$ one unit of $\mathbf{HgI_2}$ ppt

$$2\ \mathrm{I^-}\ (aq) + \mathrm{Hg^{2+}}\ (aq) \rightarrow \mathrm{HgI_2}\ (s)$$

You Try It

Write the Net Ionic Equation

Cadmium nitrate + sodium sulfide

cadmium nitrate + sodium sulfide → cadmium sulfide + sodium nitrate

$$Cd(NO_3)_2\ (aq) + Na_2S\ (aq) \rightarrow CdS\ (s) + 2\ NaNO_3\ (aq)$$

Net reaction:

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