General Chemistry

202-SN1-RE

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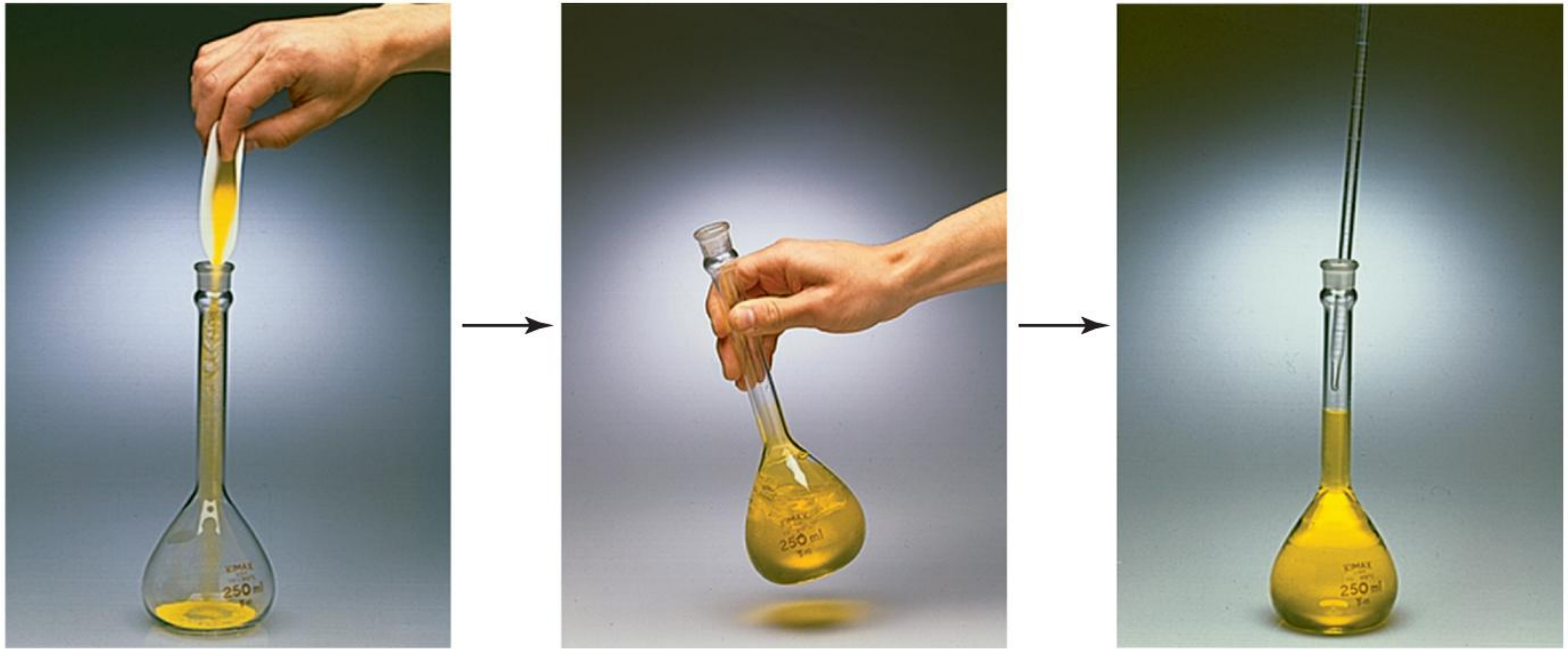
Unit 3 – Types of Chemical Reactions

Solution Terminology

Solution: A homogeneous mixture

Solute: The dissolved substance in a solution

Solvent: The major component in a solution



A measured number of moles of solute is placed in a volumetric flask.

Enough solvent is added to dissolve the solute by swirling.

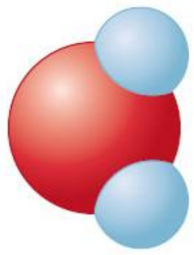
Further solvent is added to reach the calibration mark on the neck of the flask, and the solution is mixed until uniform.

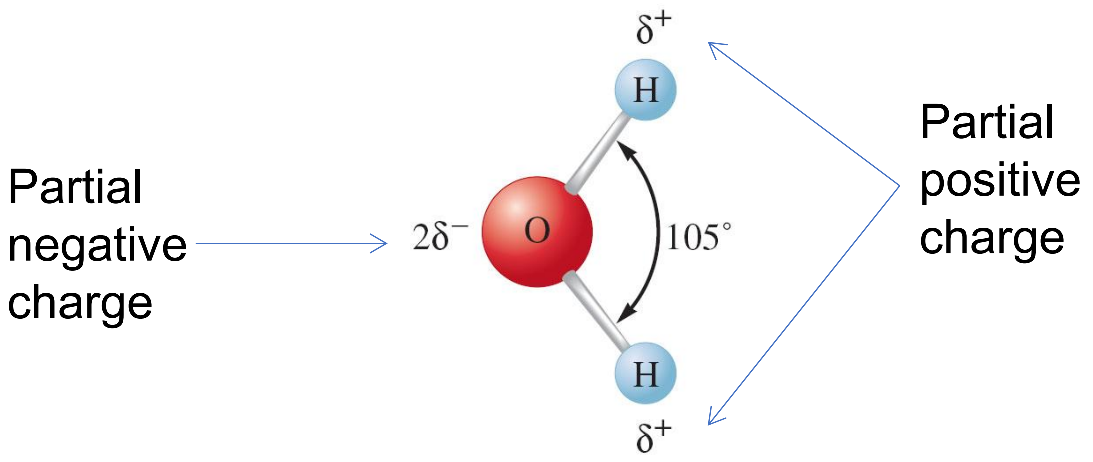
Water, the Common Solvent

- Water is one of the most important substances on earth.

- When water is used as the dissolving medium (solvent), the solution is called an aqueous solution.

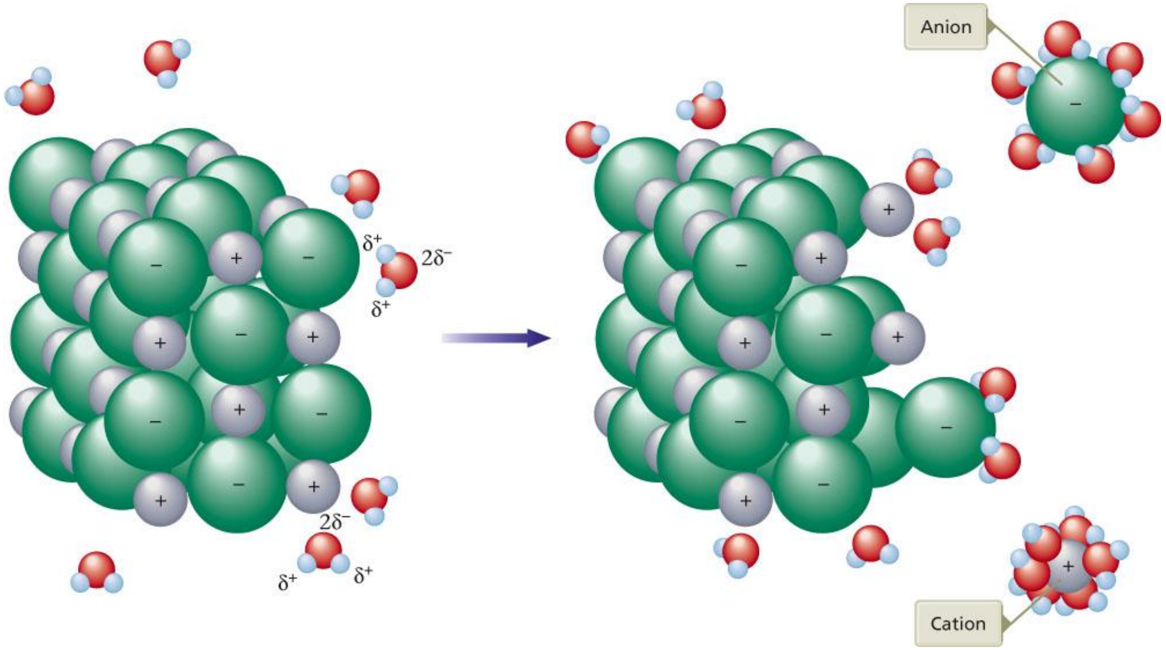
- Water molecules are polar, because of their unequal charge distribution, and thus are able to dissolve polar and ionic substances.





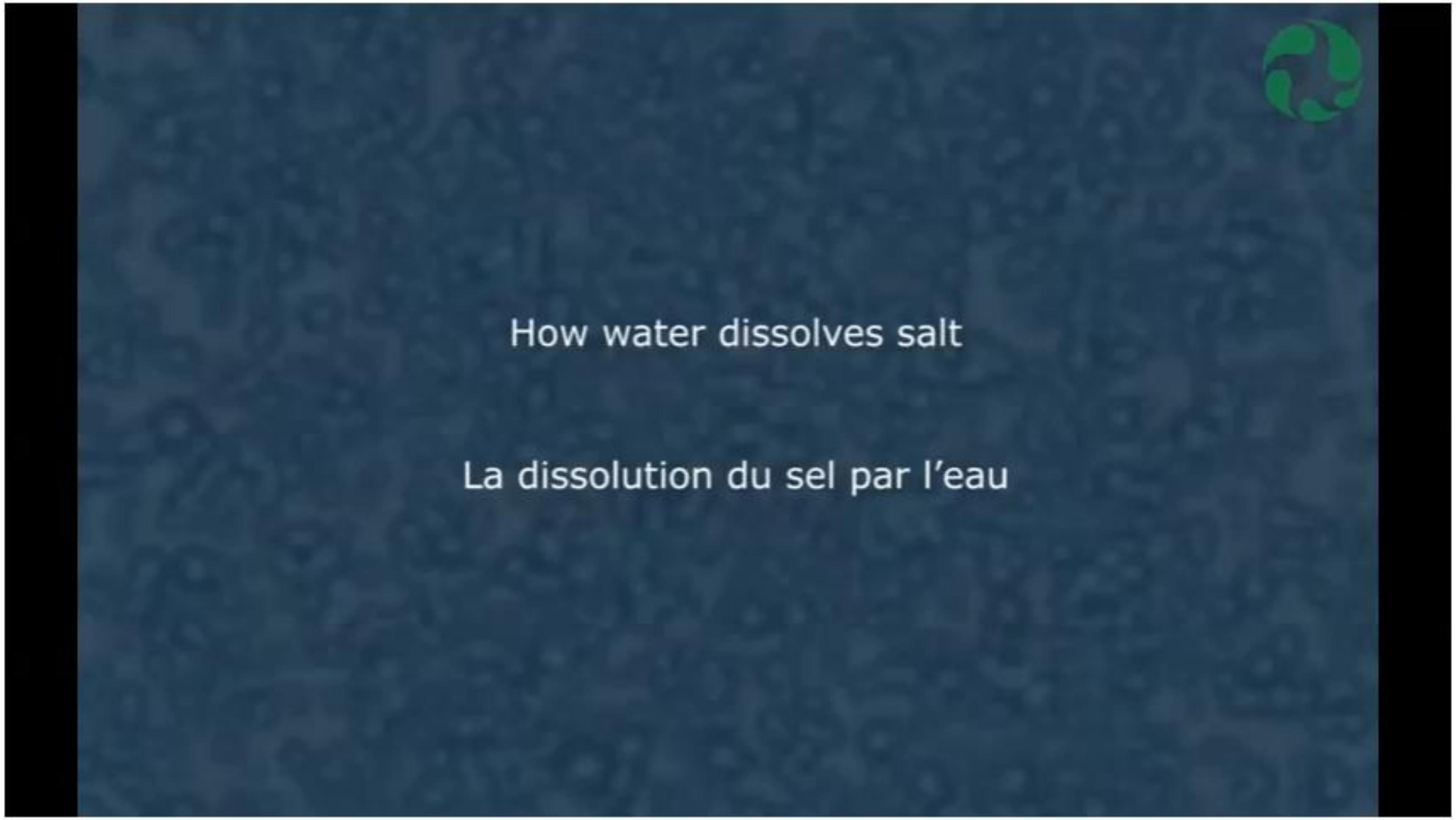
Solubility of Ionic Substances

- **What is really happening?**
  - In the solid state, the ions are packed closely together through strong ionic forces.
  - In the presence of water, those ionic forces are overcome by the strong attractions between the ions and the polar water molecules.



The polar water molecules interact with the positive and negative ions of a salt.

Dissolution of a Solid in a Liquid

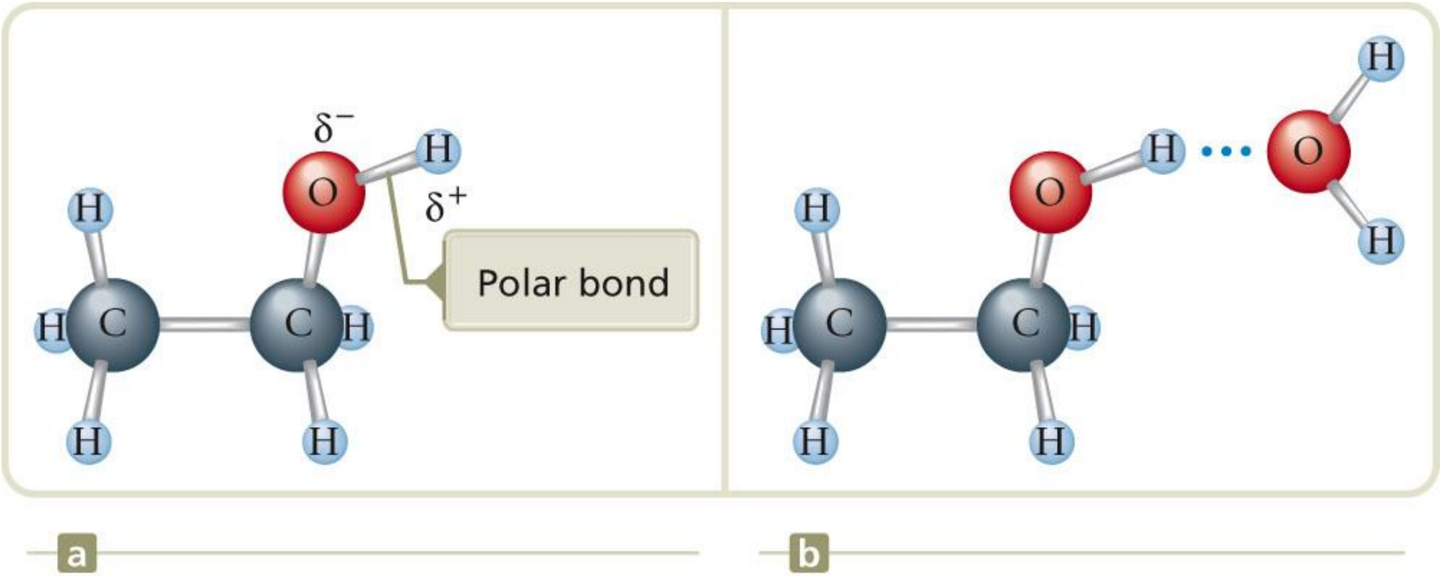


Source: https://youtu.be/xdedxfhcpWo

Solubility of Polar Substances

- Water can also dissolve nonionic substances, as long as they are polar.

- For example, ethanol, found in alcoholic drinks, is soluble in water because of the polar OH bond.



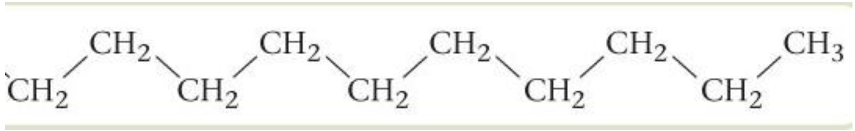
The ethanol molecule contains a polar O—H bond similar to those in the water molecule.

The polar water molecule interacts strongly with the polar O—H bond in ethanol.

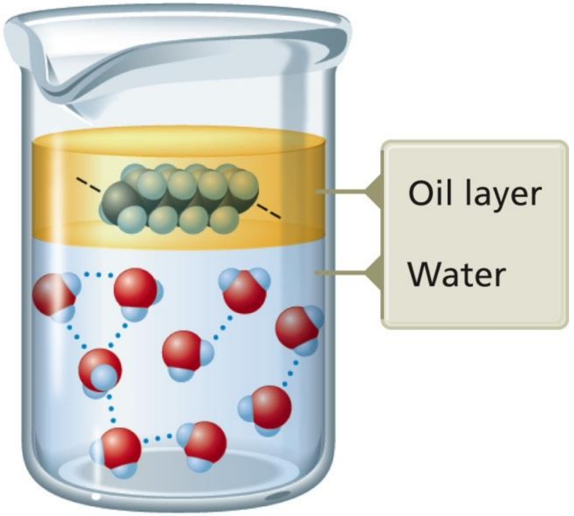
How Substances Dissolve

- The lost water-water interactions must be replaced by water-solute interactions that are just as strong.

- Nonpolar oil does not dissolve in water because the nonpolar bonds cannot form attractions to the polar water molecules.



- 'Like Dissolves Like'
  - Polar solvents (like water) dissolve polar solutes.
  - Nonpolar solvents dissolve nonpolar solutes.



The Nature of Aqueous Solutions: Strong and Weak Electrolytes

- When a substance (solute) is dissolved in water (solvent) it can dissociate into ions to a large or small degree, such solutions (and the substances themselves) are called electrolytes.

- **Electrolyte**: a substance (usually a solution) that contains **free ions** and is able to **conduct electricity** (also refers to the material that is dissolved).

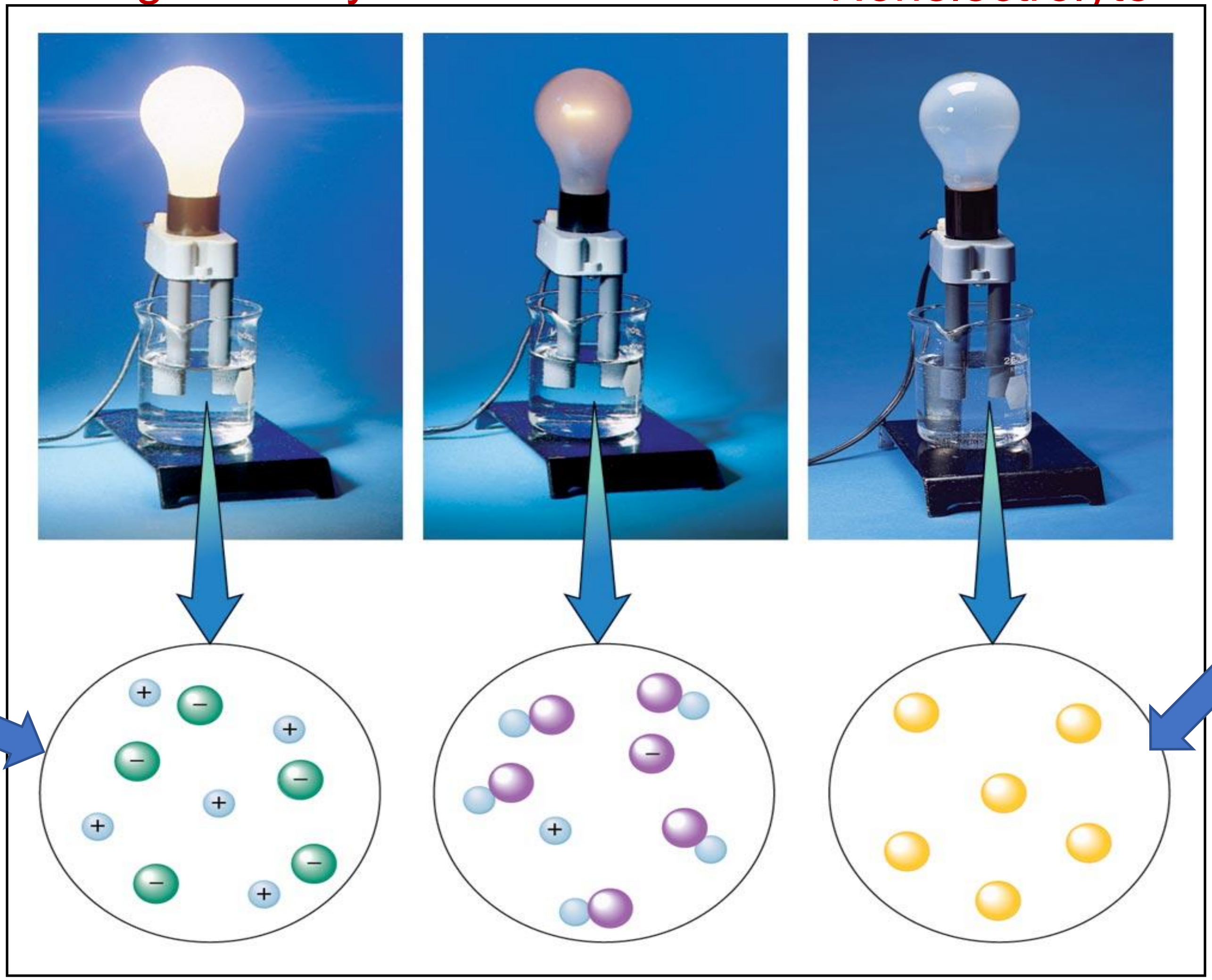
- The more ions there are in a solution the greater the conductivity of the solution.

Electrical Conductivity and Solutions

Strong Electrolyte

Weak Electrolyte

Nonelectrolyte



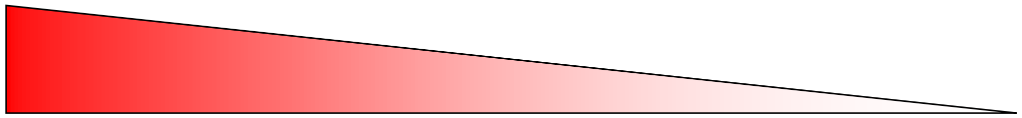
Many ions to carry charge

No ions to carry charge

Electrolytes

- Strong Electrolytes – conduct current very efficiently (bulb shines brightly).
- Weak Electrolytes – conduct only a small current (bulb glows dimly).
- Nonelectrolytes – no current flows (bulb remains unlit).

Summary of Electrolytes



Type of solution	**Strong Electrolyte**	**Weak Electrolyte**	**Nonelectrolyte**
Degree of ionisation	Complete	Small	None
Ions Present	All of solute is ions	Relatively Few	NONE
Ability to conduct electricity	Excellent	Poor	NONE
Examples	Salts Strong Acids/Bases Gatorade	Weak Acids/Bases	Sugars Alcohols Other Organic Molecules

Electrolytes

Table 4.1 Electrolyte Classification		
Strong Electrolytes	**Weak Electrolytes**	Nonelectrolytes
HCl, HBr, HI	CH_3CO_2H	H_2O
$HClO_4$	HF	CH_3OH (methanol)
HNO_3	HCN	C_2H_5OH (ethanol)
H_2SO_4		$C_{12}H_{22}OH_{11}$ (sucrose)
KBr		Most organic compounds
NaCl		
NaOH, KOH		
Other soluble ionic compounds		
Dissociate 100% in water.	Slightly dissociate in water.	Do NOT dissociate in water.

Exercise

Which of the following statements is true?

a) If a substance is soluble, it must be an electrolyte.

b) If a substance is an electrolyte, it must be soluble.

c) Weak electrolytes must be less soluble than strong electrolytes.

d) Nonelectrolytes are nonsoluble.

Exercise

Which of the following statements is true?

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c) Weak electrolytes must be less soluble than strong electrolytes.

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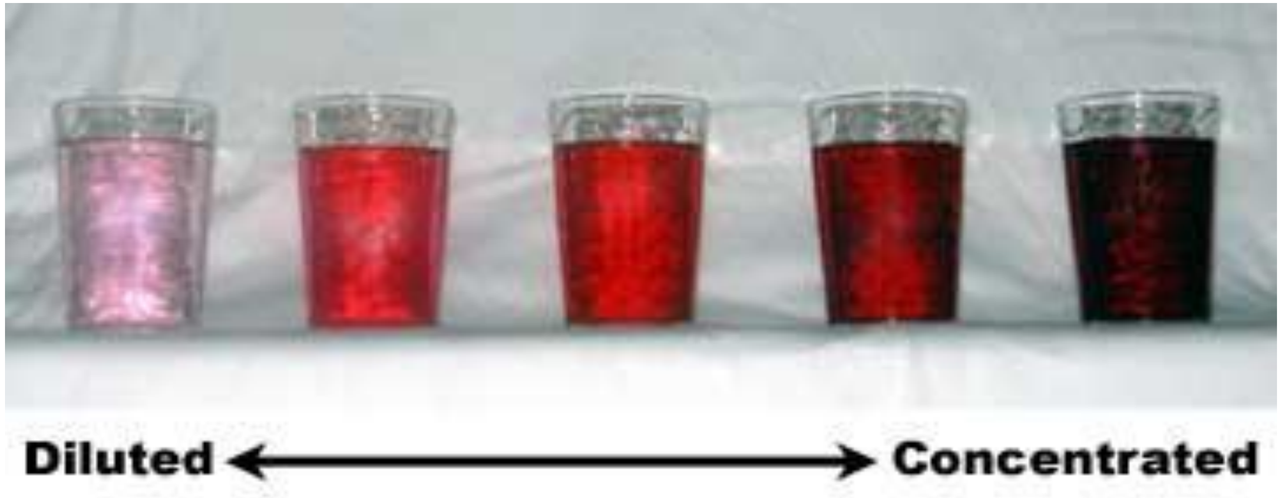
Solution Composition

Composition of Solutions

- Generally, two things are important when handling solutions:

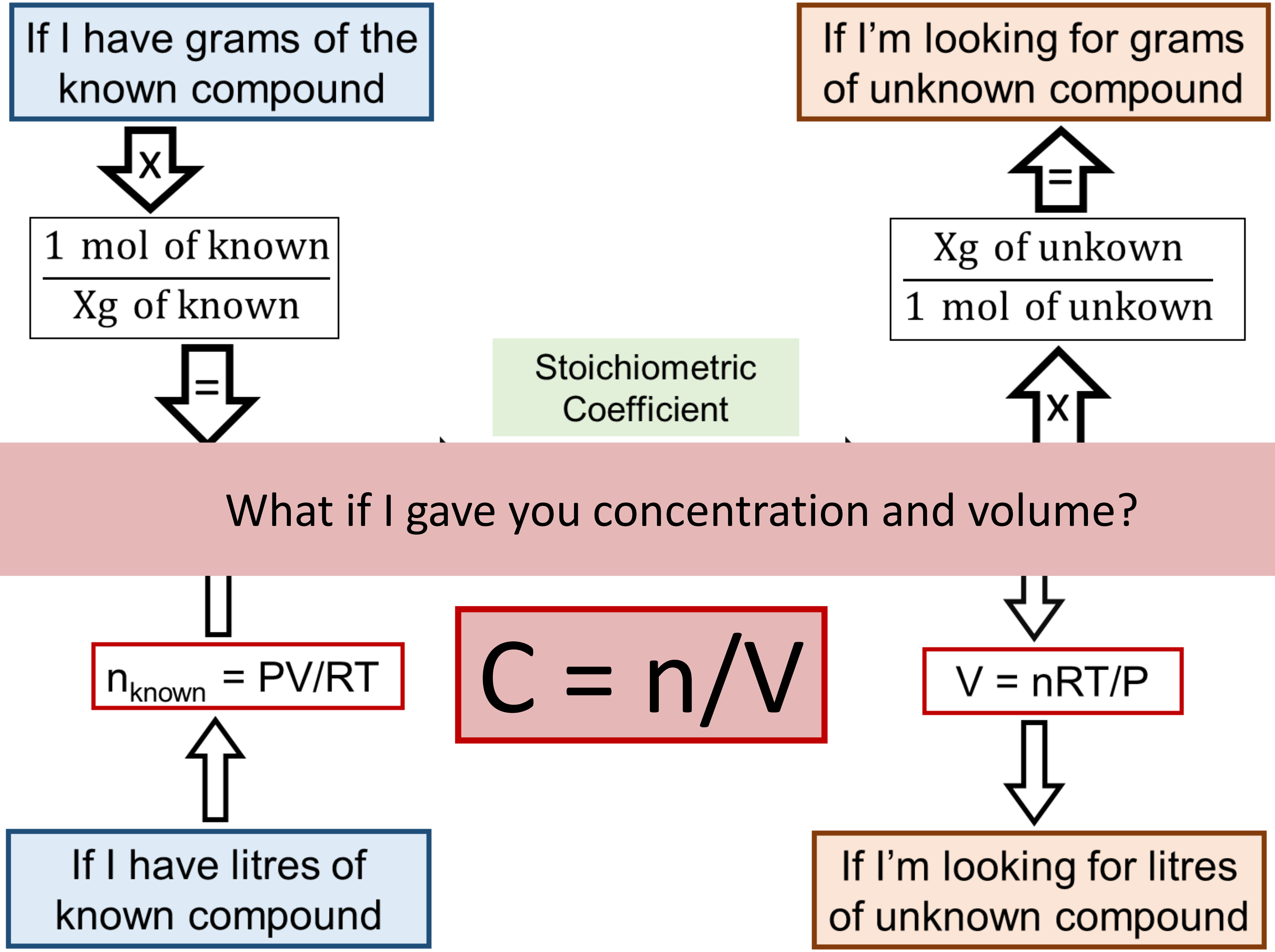
- What are the dissolved solutes?

- How much of each solute is there?



(Weak) (Strong)

Combining Stoichiometry and Aqueous Solutions



What if I gave you concentration and volume?

Combining Stoichiometry and Aqueous Solutions

$$aA + bB \rightarrow cC + dD$$

Volume of solution of A → Moles of A → Moles of B → Volume of solution of B

- Volume of solution of A → Moles of A: Molarity of A
- Moles of A → Moles of B: Mole ratio between A and B (coefficients)
- Moles of B → Volume of solution of B: Molarity of B

$$C = n/V$$

Solution Composition: Molarity

- Solutions are commonly described in terms of concentration, which is the amount of solute in a given volume of solution.

- Molarity (M) is the number of moles of solute per volume of solution in liters.

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

$$3\ M\ \text{HCl} = \frac{6\ \text{moles of HCl}}{2\ \text{liters of solution}}$$

Exercise

1. Calculate the molarity of a solution prepared by dissolving 10.5 g of baking soda ($NaHCO_3$) in water and diluting to a total volume of 500.0 mL.

2. A laboratory assistant needs to prepare 225 mL of 0.150 M $CaCl_2$ solution. How many grams of calcium chloride will they need?

Exercise

1. Calculate the molarity of a solution prepared by dissolving 10.5 g of baking soda ($NaHCO_3$) in water and diluting to a total volume of 500.0 mL.

   Molar mass of $NaHCO_3$ = 84.006 g/mol
   Moles of $NaHCO_3$ = 0.12499 mol

   0.250 M

1. A laboratory assistant needs to prepare 225 mL of 0.150 M $CaCl_2$ solution. How many grams of calcium chloride will they need?

   Molar mass of $CaCl_2$ = 110.984 g

   225 mL = 0.225 L

   Moles of $CaCl_2$ = 0.03375 mol

   3.75 g of $CaCl_2$ (3 sig figs because 225 mL is 3 sig figs)

Solution Composition: Molarity

Concentration of Ions

- Remember, ionic compounds separate into the component ions when they dissolve in water.

$$Co(NO_3)_{2\,(s)} \xrightarrow{H_2O} Co^{2+}{}_{(aq)} + 2NO_3{}^{-}{}_{(aq)}$$

$$FeCl_{3\,(s)} \xrightarrow{H_2O} Fe^{3+}{}_{(aq)} + 3Cl^{-}{}_{(aq)}$$

- For a 0.25 M $CaCl_2$ solution:

$CaCl_2 \rightarrow Ca^{2+} + \mathbf{2}Cl^{-}$

Concentration of Ca^{2+} = 1 x 0.25 M = 0.25 M

Concentration of Cl^{-} = **2** x 0.25 M = 0.50 M

Exercise

Calculate the number of moles of the indicated ion present in each of the following solutions.

a) Br^- ion in 1.00 L of 0.251 *M* $MgBr_2$ solution.

b) NH_4^+ ion in 250 mL of 0.350 *M* $(NH_4)_2SO_4$ solution.

Exercise

Calculate the number of moles of the indicated ion present in each of the following solutions.

a) Br^- ion in 1.00 L of 0.251 *M* $MgBr_2$ solution.

0.502 mol Br^-

b) NH_4^+ ion in 250 mL of 0.350 *M* $(NH_4)_2SO_4$ solution.

0.175 mol NH_4^+

Exercise

Which of the following solutions contains the greatest number of ions?

a) 400.0 mL of 0.10 M NaCl.

b) 300.0 mL of 0.10 M $CaCl_2$.

c) 200.0 mL of 0.10 M $FeCl_3$.

d) 800.0 mL of 0.10 M sucrose ($C_{12}H_{22}O_{11}$).

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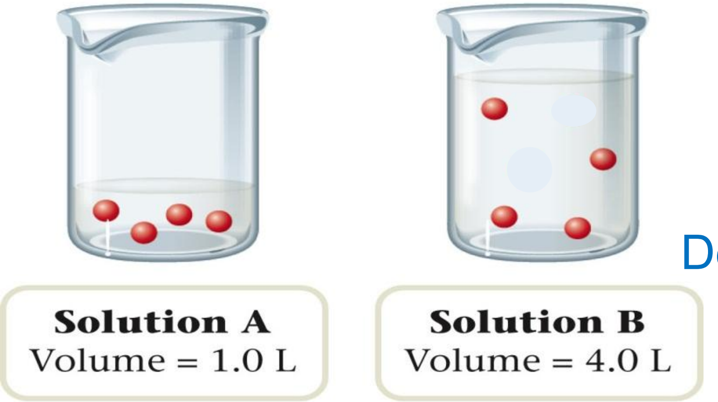
Notice: the solution with the greatest number of ions is ***not*** necessarily the one in which:

- The volume of the solution is the largest.
- The formula unit has the greatest number of ions.

Dilution

- The process of adding water to a concentrated or stock solution to achieve the molarity desired for a particular solution.

- Dilution with water *does not* alter the number of moles of solute present.



Remains constant

$$M = \frac{\text{Moles of solute}}{\text{Liters of solution}}$$

Decreases

Increases because of added H_2O

- Moles of solute before dilution

  = Moles of solute after dilution.

$$M_1V_1 = M_2V_2$$

Exercise

1. Concentrated nitric acid is sold commercially as 15.9 *M* HNO_3. How many mL of the concentrated reagent are needed to prepare 200.0 mL of 0.050 *M* HNO_3?

1. If 25.5 mL of 0.100 *M* NaOH is diluted to 500.0 mL, what is the molarity of the diluted solution?

Exercise

1. Concentrated nitric acid is sold commercially as 15.9 *M* HNO_3. How many mL of the concentrated reagent are needed to prepare 200.0 mL of 0.050 *M* HNO_3?

   0.63 mL

1. If 25.5 mL of 0.100 *M* NaOH is diluted to 500.0 mL, what is the molarity of the diluted solution?

   0.00510 *M*

Exercise

A 0.50 *M* solution of sodium chloride in an open beaker sits on a lab bench. Which of the following would ***decrease*** the concentration of the salt solution?

1. Add water to the solution.

2. Pour some of the solution down the sink drain.

3. Add more sodium chloride to the solution.

4. Let the solution sit out in the open air for a couple of days.

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Exercise

You add 300.0 mL of water to 300.0 mL of a 2.00 *M* sugar solution. How many of the following will change?

a) total volume of the solution

b) mass of solute in the solution

c) concentration of the solution

d) number of solute molecules in the solution

Exercise

You add 300.0 mL of water to 300.0 mL of a 2.00 *M* sugar solution. How many of the following will change?

a) total volume of the solution

b) mass of solute in the solution

c) concentration of the solution

d) number of solute molecules in the solution

Types of Chemical Reactions

Chemical Reactions

- In this course, we will be discussing the following types of reactions:

  - **Precipitation**
    - Formation of an insoluble solid (precipitate)

  - **Acid-Base**
    - Formation of a salt and water

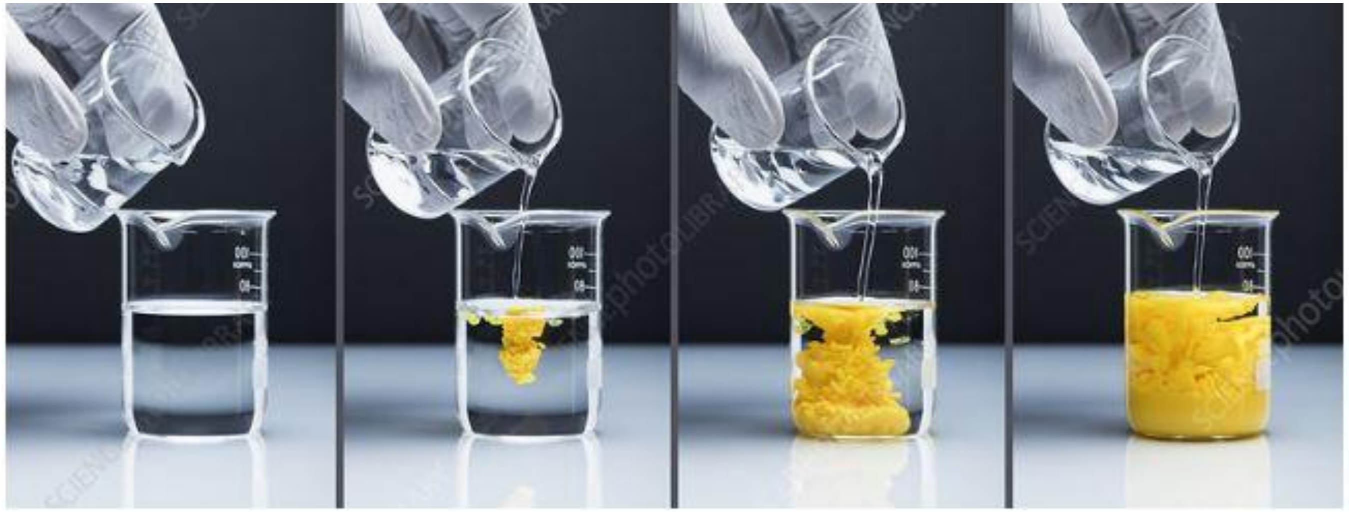
  - **Oxidation-Reduction**
    - Transfer of electrons from a reductant (electron donor) to an oxidant (electron acceptor)

Precipitation Reactions

Precipitation Reactions

Precipitation Reactions: Processes in which soluble reactants yield an insoluble solid product that falls out of solution

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

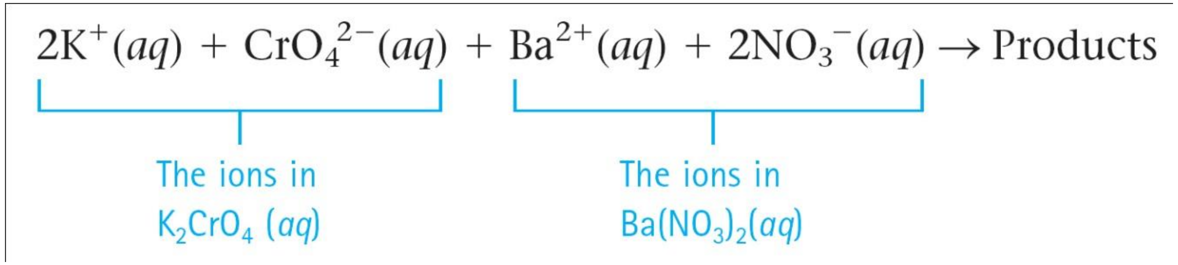


What Happens in a Precipitation Reaction?

When mixing aqueous solutions of $Ba(NO_3)_2$ and K_2CrO_4, a yellow solid is observed. What is the identity of this solid?

$$K_2CrO_{4(aq)} + Ba(NO_3)_{2(aq)} \rightarrow Products$$

- First off, separate into the individual ions present in each solution:



What is Happening?

$$K_2CrO_{4\,(aq)} + Ba(NO_3)_{2\,(aq)} \rightarrow Products$$

- What are the possible products?
  - Keep in mind:
    - Solid compounds must have a net zero charge
    - Most ionic materials contain only two types of ions (one type of anion, with one type of cation)
- The mixed solution contains four types of ions: K^+, CrO_4^{2-}, Ba^{2+}, and NO_3^-
- Therefore, the possible products are:

	NO_3^-	CrO_4^{2-}
K^+	KNO_3	K_2CrO_4
Ba^{2+}	$Ba(NO_3)_2$	$BaCrO_4$

General Solubility Rules of Ionic Compounds in Water

1. A compound is probably <u>SOLUBLE</u> if it contains one of the following ***<u>cations</u>***:

   + Group 1A cation: Li^+, Na^+, K^+, Rb^+, Cs^+

   + Ammonium ion: NH_4^+

2. A compound is probably <u>SOLUBLE</u> if it contains one of the following ***<u>anions</u>***:

   - Halides: Cl^-, Br^-, I^-

     ▪ **EXCEPT** when forming compounds with Ag^+, Hg_2^{2+}, Pb^{2+}

   - NO_3^- (nitrate), ClO_4^- (perchlorate), $CH_3CO_2^-$ (acetate)

   - SO_4^{2-} (sulfate)

     ▪ **EXCEPT** when forming compounds with Sr^{2+}, Ba^{2+}, Hg_2^{2+}, Pb^{2+}

General Solubility Rules of Ionic Compounds in Water

Table 4.2 Solubility Guidelines for Ionic Compounds in Water	
Soluble Compounds	**Common Exceptions***
Group 1A cations: Li^+, Na^+, K^+, Rb^+, Cs^+	None
Ammonium ion: NH_4^+	None
Halides: Cl^-, Br^-, I^-	Halides of Ag^+, Hg_2^{2+}, Pb^{2+}
NO_3^- (nitrate)	None
ClO_4^- (perchlorate)	None
$CH_3CO_2^-$ (acetate)	None
SO_4^{2-} (sulfate)	Sulfates of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, Pb^{2+}

** These are insoluble.*

General Solubility Rules of Ionic Compounds in Water

Table 4.2 Solubility Guidelines for Ionic Compounds in Water	
Insoluble Compounds	**Common Exceptions***
CO_3^{2-} (carbonate)	Carbonates of group 1A cations, and NH_4^+
S^{2-} (sulfide)	Sulfides of group 1A cations, NH_4^+, Ca^{2+} ,Sr^{2+}, Ba^{2+}
PO_4^{3-} (phosphate)	Phosphates of group 1A cations, and NH_4^+
OH^- (hydroxide)	Hydroxides of group 1A cations, NH_4^+, Ca^{2+}, Sr^{2+}, Ba^{2+}

** These are soluble.*

How to Predict When A Precipitate Forms

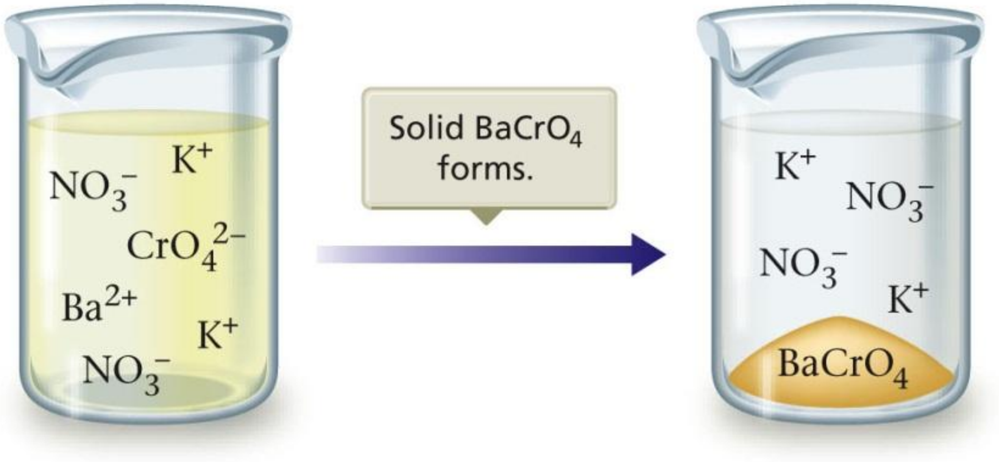
1. Write the reactants as they actually exist before any reaction occurs. Remember that when a salt dissolves, its ions separate.

2. Consider the various solids that could form. To do this, simply exchange the anions of the added salts.

3. Use the solubility rules to decide whether a solid forms and, if so, to predict the identity of the solid.

General Solubility Rules of Ionic Compounds in Water

- Based on the solubility rules, KNO_3 is soluble in water.
- The yellow precipitate is $BaCrO_4$ because it is insoluble in water.



Unbalanced Equation:

$$K_2CrO_{4\,(aq)} + Ba(NO_3)_{2\,(aq)} \rightarrow BaCrO_{4\,(s)} + KNO_{3\,(aq)}$$

Describing Reactions in Solution

Types of Equations for Reactions in Aqueous Media

1. Complete Molecular Equation

$$K_2CrO_{4(aq)} + Ba(NO_3)_{2(aq)} \rightarrow BaCrO_{4(s)} + 2KNO_{3(aq)}$$

2. Complete Ionic Equation

$$2K^+{}_{(aq)} + CrO_4{}^{2-}{}_{(aq)} + 2NO_3{}^-{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)} + 2K^+{}_{(aq)} + 2NO_3{}^-{}_{(aq)}$$

3. Net Ionic Equation

$$CrO_4{}^{2-}{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)}$$

Complete Molecular Equation

- Shows the complete formulas of all reactants and products.

- It does not give a very clear picture of what actually occurs in solution.

$$K_2CrO_{4(aq)} + Ba(NO_3)_{2(aq)} \rightarrow BaCrO_{4(s)} + 2KNO_{3(aq)}$$

Complete Ionic Equation

- All reactant and products that are strong electrolytes are shown as ions.
  - Strong electrolytes: a substance that completely breaks apart into ions when dissolved in water. The resulting solution readily conducts an electric current.

$$K_2CrO_{4(aq)} + Ba(NO_3)_{2(aq)} \rightarrow BaCrO_{4(s)} + KNO_{3(aq)}$$

$$2K^+{}_{(aq)} + CrO_4{}^{2-}{}_{(aq)} + 2NO_3{}^-{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)} + 2K^+{}_{(aq)} + 2NO_3{}^-{}_{(aq)}$$

Complete Ionic Equation

- Spectator Ions: Ions which do not participate directly in a reaction in solution.

$$2K^+{}_{(aq)} + CrO_4{}^{2-}{}_{(aq)} + 2NO_3{}^-{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)} + 2K^+{}_{(aq)} + 2NO_3{}^-{}_{(aq)}$$

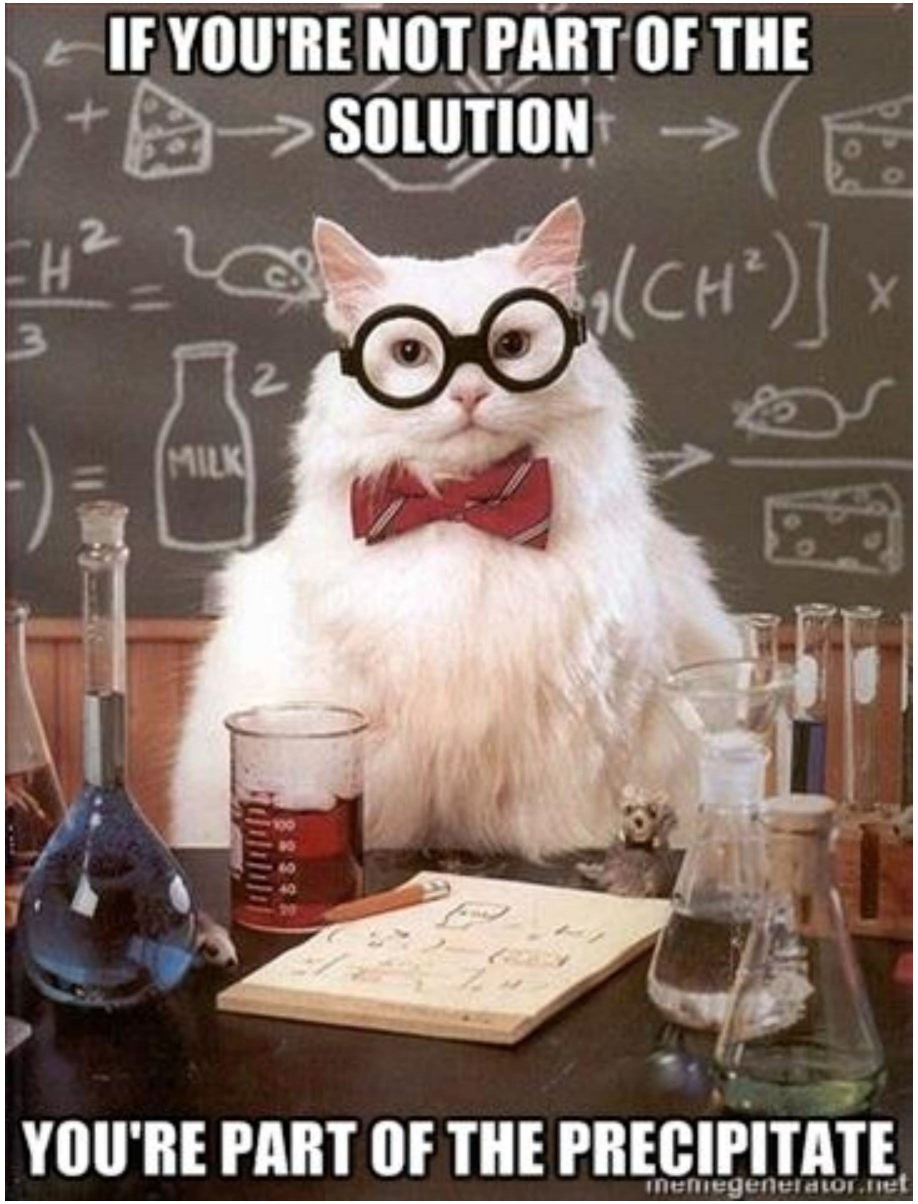
- K^+ and NO_3^- ions are present in solution both before and after the reaction. They are spectator ions.

Net Ionic Equation

- Includes only those components that undergo a change. Spectator ions are ***not*** included.

$$2K^{+}_{(aq)} + CrO_4{}^{2-}{}_{(aq)} + 2NO_3{}^{-}{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)} + 2K^{+}_{(aq)} + 2NO_3{}^{-}{}_{(aq)}$$

$$CrO_4{}^{2-}{}_{(aq)} + Ba^{2+}{}_{(aq)} \rightarrow BaCrO_{4(s)}$$


IF YOU'RE NOT PART OF THE SOLUTION
MILK
YOU'RE PART OF THE PRECIPITATE
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Precipitate Reactions (Example)

What will happen when KOH(*aq*) and $Fe(NO_3)_3$(*aq*) are mixed? Write the balanced equation.

Step 1: K^+, OH^-, Fe^{3+}, and NO_3^-

Step 2: K^+ + OH^-

Possible Products

Fe^{3+} + NO_3^-

Step 3:

Balanced equation:

Precipitate Reactions (Example)

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Step 1: K^+, OH^-, Fe^{3+}, and NO_3^-

Step 2: K^+ + OH^-

Possible Products

Fe^{3+} + NO_3^-

Step 3:

Balanced equation:

$$3KOH_{(aq)} + Fe(NO_3)_{3(aq)} \rightarrow 3KNO_{3(aq)} + Fe(OH)_{3(s)}$$

Types of Equations (Example)

Write the correct molecular equation, complete ionic equation, and net ionic equation for the reaction between cobalt(II) chloride and sodium hydroxide.

Molecular Equation:

Complete Ionic Equation:

Net Ionic Equation:

Types of Equations (Example)

Write the correct molecular equation, complete ionic equation, and net ionic equation for the reaction between cobalt(II) chloride and sodium hydroxide.

Molecular Equation:

$$CoCl_2(aq) + 2NaOH(aq) \rightarrow Co(OH)_2(s) + 2NaCl(aq)$$

Complete Ionic Equation:

Net Ionic Equation:

$$Co^{2+}(aq) + 2OH^-(aq) \rightarrow Co(OH)_2(s)$$