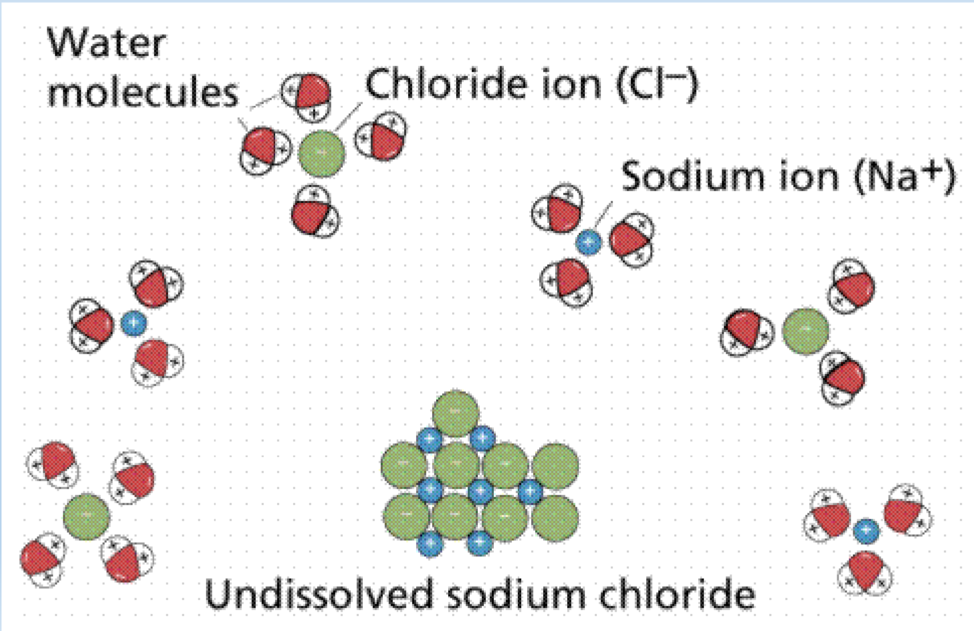
Water II – Solubility, Acids/Bases and Titration

Unit 15, Chemistry Themed

Solubility

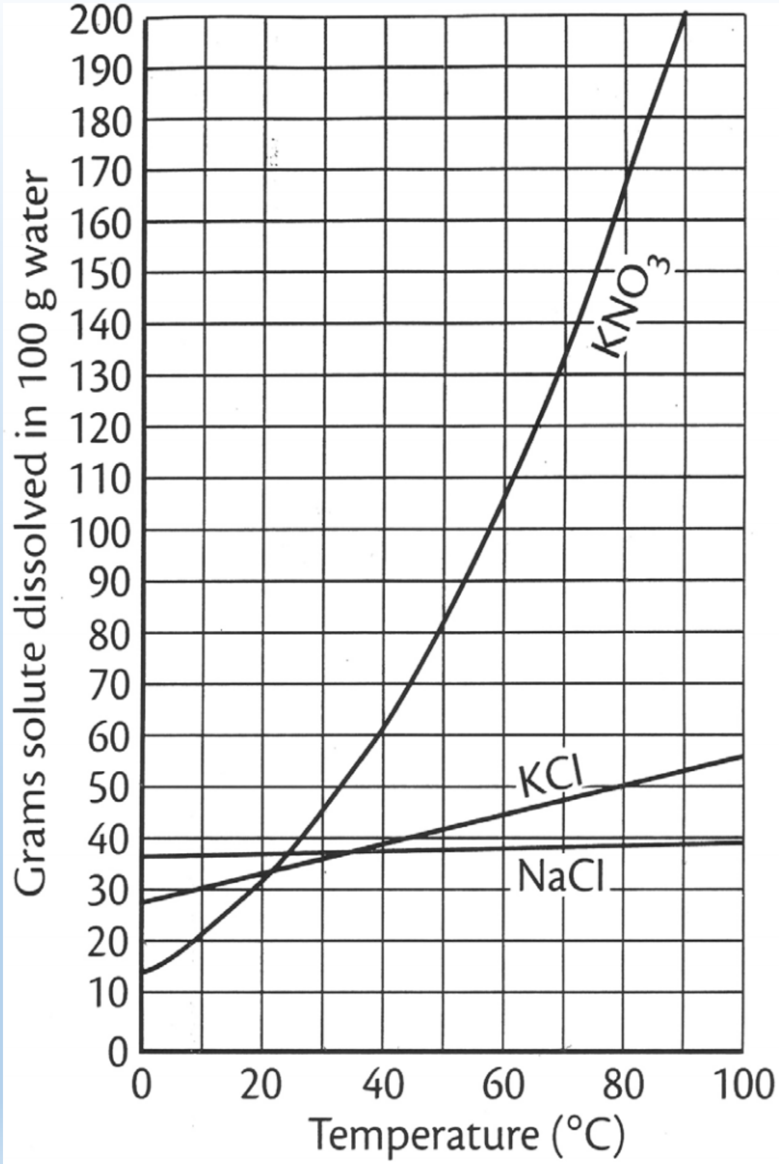
- **Solubility:** The ability of a substance to dissolve (break down and mix thoroughly)
- **Solvent:** Substance into which a substance dissolve (generally a fluid, water is a very common solvent)
- **Solute:** The substance that dissolves into the solvent. Example: When salt is mixed into water, the water is the solvent and the salt is the solute.
- Right: NaCl dissolves into water. Notice:

1. Solid NaCl crystal is broken apart by electrical attraction to negative and positive parts of polar water molecules
2. The solid NaCl is dismantled one ion at a time
3. It's depicted that it takes several water molecules per Na or Cl ion – implying a limit as to how much NaCl can be dissolved before the solution is full (SATURATED)



Understanding Saturation

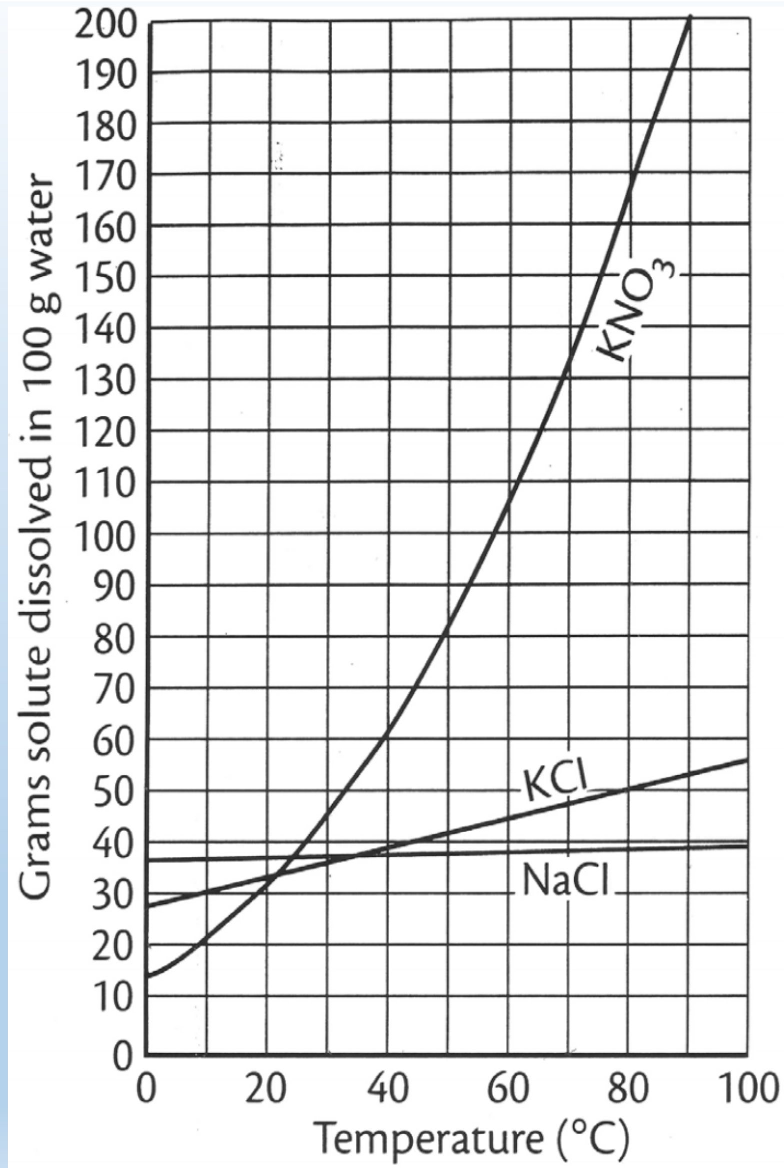
- Saturated means "full"
  - Hydrocarbons: Has as many hydrogens as possible (alkanes)
  - Solutions: Has a much solute dissolved as possible
- Saturation depends on
  - **Solvent quantity:** Two liters of water can dissolve twice as much salt as one liter
  - **Temperature:** More solid can dissolve into a warm solvent than a cool one; gases are the opposite: More gas can dissolve into a cold solvent than a warm one;
- Solubility tables depict saturation lines and take into account
  - Solvent quantity: By plotting m of solute per mass of solvent as the Y-axis (ex: g of salt per 100 g of H_2O)
  - Temperature: By plotting this as the "X" axis



Understanding Saturation

- Saturation line: A graphical representation of the maximum amount of solute that can be dissolved
- Example: For KNO_3 (right →), at 40° C, the most that can be dissolved into 100 g of water is 60 g.
  - To dissolve this amount would require vigorous stirring and the resulting solution is "saturated"
  - To dissolve less is easier and the resulting solution would be considered "unsaturated"

  SUPERSATURATED mystery: How can I make a solution with more solute than is possible to mix?
  - You cannot dissolve more KNO_3 directly, but you can possibly get more to KNO_3 be dissolved by dissolving a larger quantity at a higher temperature than 40° C, THEN cooling the solution. If the KNO_3 does not precipitate out, you have created a "supersaturated" solution



Saturation problems

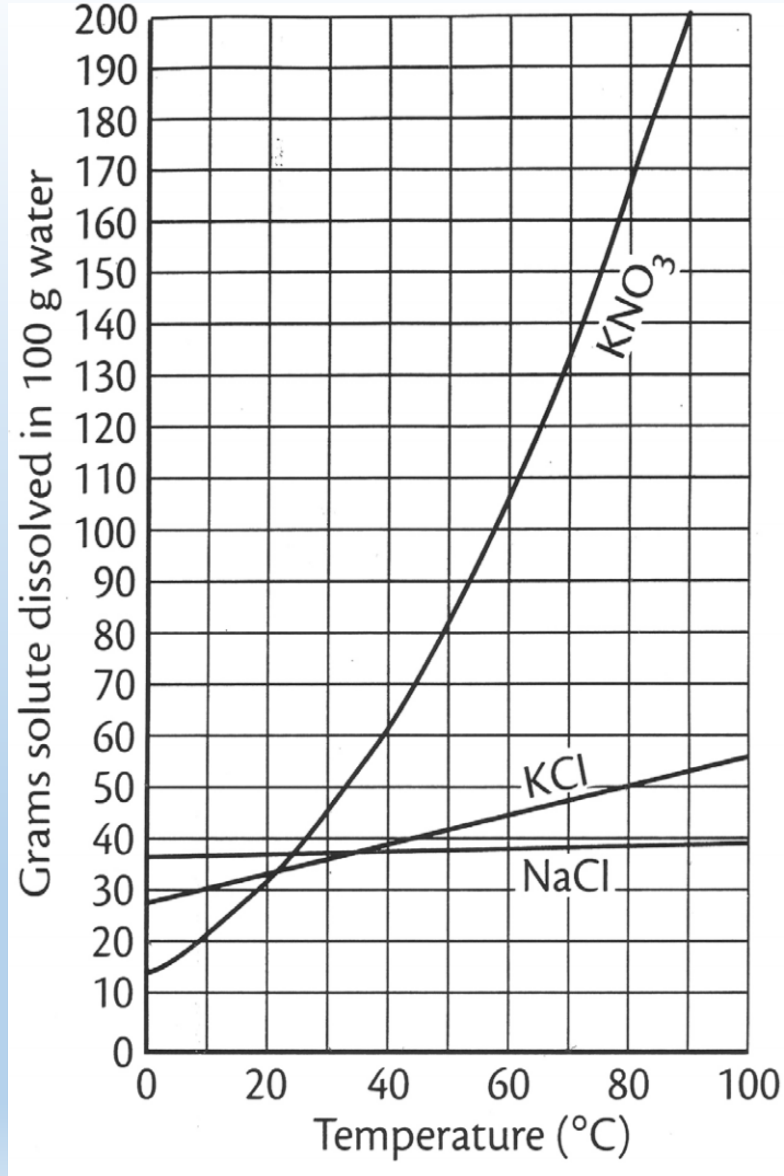
- You may be asked to determine if a given quantity of solute can be dissolved at a given temperature, or what temperature is required
- To solve these problems, use a T-chart
- Use the saturation line value to create an equality (a conversion factor)
- Example: How much KCl can be dissolved in 75 mL of water at 60° C? (75 mL water = 75 g)

From Table:

45 g KCl = 100 g water

given — *conversion factor*

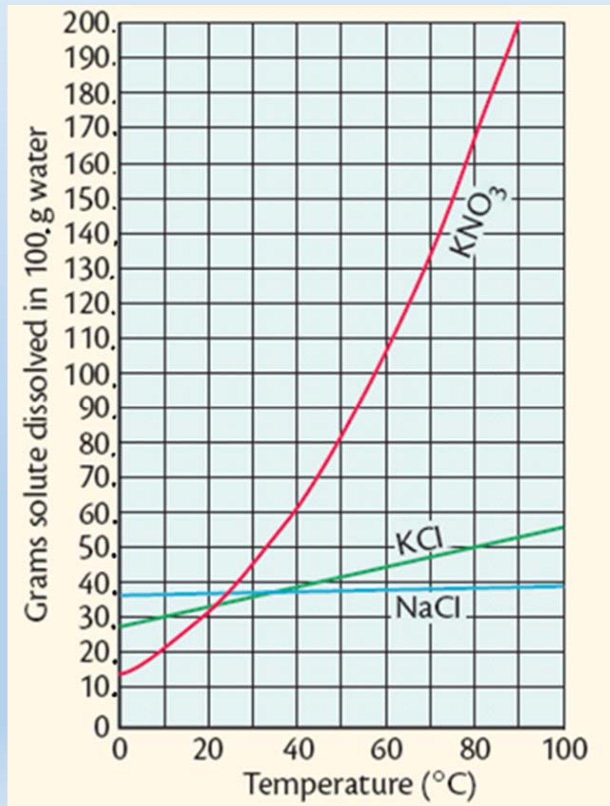
$$\frac{75\text{ g water}}{} \left| \frac{45\text{ g KCl}}{100\text{ g water}} \right. = 34\text{ g KCl}$$



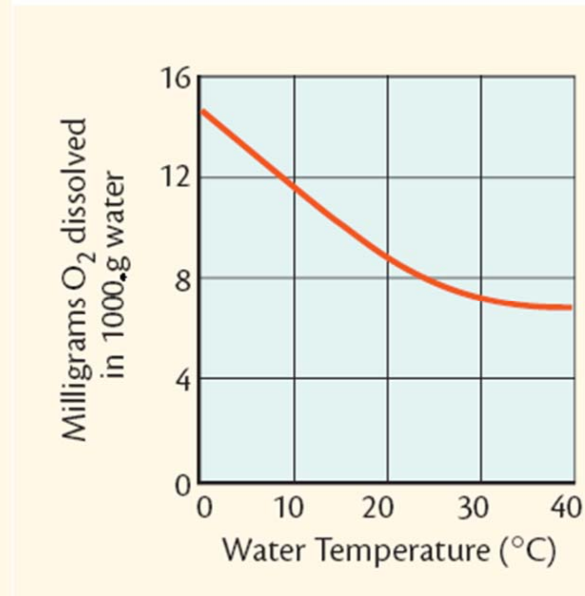
Solubility in water based on temperature: (Ionic) solid and gas solutes behave oppositely

- Warming water **increases** the amount of a solid that can be dissolved
- Warming water **decreases** the amount of a gas that can be dissolved
- Want to dissolve more KNO_3? Increase water temperature
- Want to help a fish breathe by dissolving more O_2? Decrease water temperature

Left: more solid with higher water temp.



Right: Less O_2 with higher water temp.

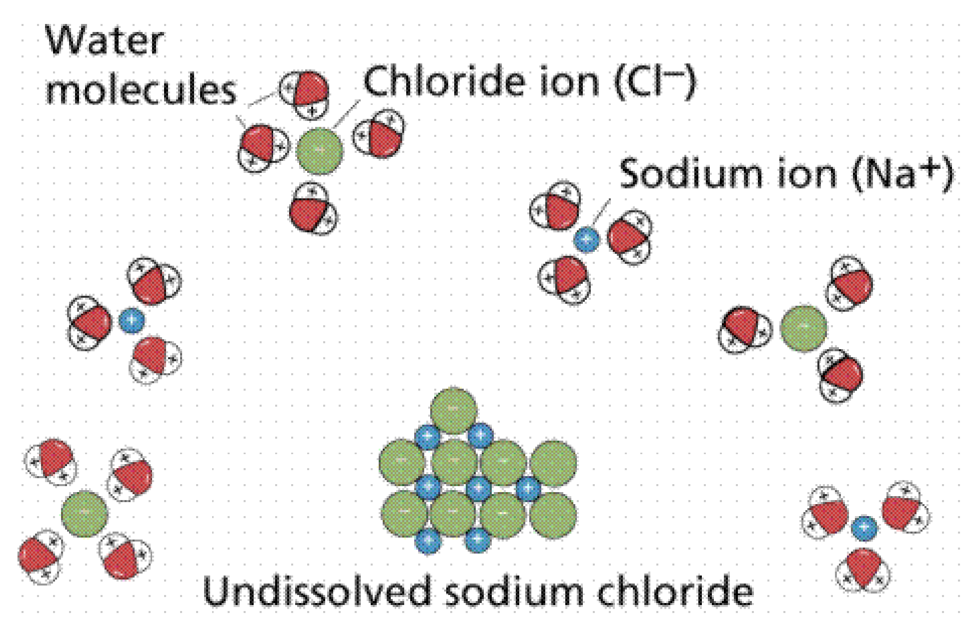


Recognizing Ionic/Covalent substances based on formula

- The formula for a covalent substances begins with a non-metal
  - Examples: CO_2, C_4H_{10}, NH_3, $C_6H_{12}O_6$, N_2O_4
- The formula for an ionic compound begins with a metal (only exception in this course, NH_4)
- Examples: $FeCl_3$, $NaOH$, NH_4Cl, Mg_3N_2, $CuCl_2$

Solubility – Super Strong and Pretty Strong ionic compounds

- Remember how NaCl dissolves in water?
  - Polar water has a negative end (oxygen end) and positive end (hydrogen end)
  - These ends can attract and pull off (dismantle) the crystalline solid structure one ion at a time
  - If the attractive force between adjacent is too strong for water to pull off ions ("Super Strong"), the ionic compound is insoluble (won't dissolve in water)
- Example: **Super Strong** Ionic Compound – $CaCO_3$ (chalk): The attractive force between carbonate and calcium ions is too large for water to overcome and is insoluble
- Example: **Pretty Strong** Ionic Compound – NaCl (salt): The attractive force between sodium and chloride ions is not strong enough to prevent (polar) water molecules from plucking apart Na an Cl ions



Dissolving

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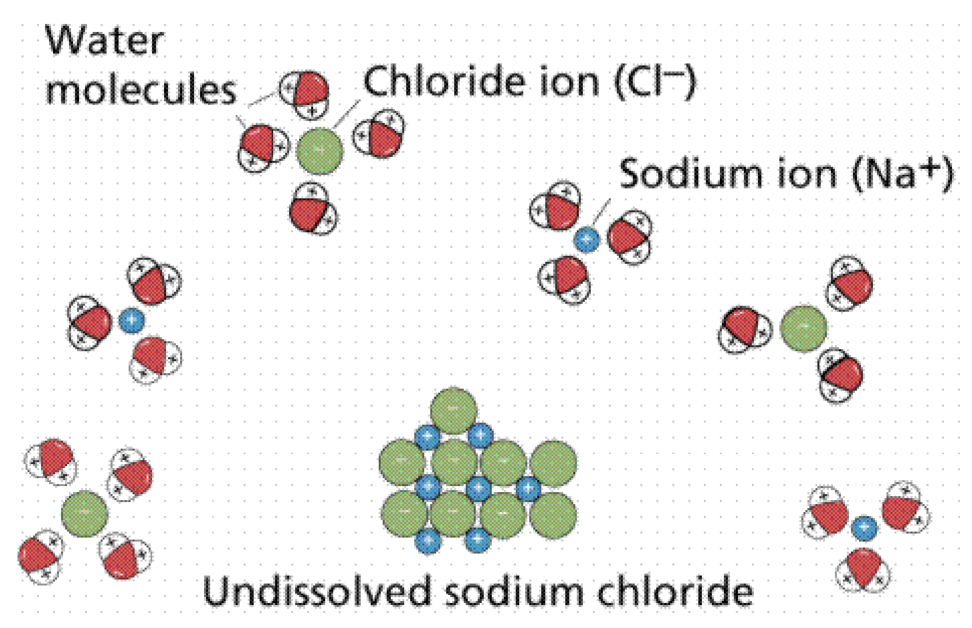

Dissolving – Non-polar substances & general rule "Like dissolves like"

- Substances with similar intermolecular forces (remember "IMF"?) will dissolve in each other
- Ionic compounds dissolve in polar solvents (water), because both have "pretty strong" attractive forces toward each other
- Covalent compounds come in two varieties:
  - Polar: Molecules have strong IMF because there is a + side and - side to each molecule
  - Non-polar: Electrons are evenly distribute; Without a + or – side, IMF is weak
- Molecules with weak IMF's can never separate molecules with strong IMF's – all the strong IMF molecules remain with each other and no mixing (dissolving) occurs
- Non-polar molecules dissolving with other non-polars because nobody has a strong IMF

Summarizing “Like dissolves like”

- Polar covalent solvents (water) dissolve other substances with strong IMF
  - Ionic “pretty strong” compounds
  - Polar covalent compounds (those with uneven distribution of electrons)
  - “Super strong” ionic compounds have such strong attractive forces that water won’t dissolve them
- Non-polar covalent solvents (oil, etc.) have weak IMF and dissolve other substances that also have weak IMF
  - Non-polar covalent substances (solutes) dissolve into non-polar solvents
- Super strong ionic compounds don’t dissolve in any solvent
- Pretty strong ionic compounds dissolve in polar covalent solvents (water)
- Polar covalent compounds dissolve in polar covalent solvents (water)
- Non-polar covalent compounds dissolve in non-polar solvents (oil, etc.)

Identifying molecular vs. ionic

- There are four ways you're expected to recognize for identifying substances

1. From the formula: Is there a metal present as 1st element?
   - Ionic compounds generally have a metal as the 1st element
2. Water vs. oil solubility: Like dissolves like
   - Substances that dissolve in oil must be non-polar covalent
   - Substances that dissolve in water must be either "pretty strong" ionic or polar covalent
   - Substances that don't dissolve must be "super strong" ionic
3. Does this substance conduct electricity when dissolved?
   - Only ionic compounds dissolved in water conduct electricity (and must be "pretty strong" or wouldn't dissolve in the first place
4. Melting point: Does this substance have a high or MP?
   - Ionic compounds have a high MP; covalent compounds have a low MP

Acids and bases

- pH is the measurement of how acidic a solution is
  - pH ranges from 0 to 14
  - pH <7 is acidic; pH = 7 is neutral; pH >7 is basic
- pH paper (litmus test) follows the rule: “acid turns red, base turns blue”
  - Blue litmus paper can confirm an acid, but turning red when dipped in a solution
  - Red litmus paper can confirm a base by turning blue
  - If neither paper changes color, the solution is said to be neutral
- pH is a logarithmic scale: pH of 4 is 10x more acidic than pH of 5
- pH of 3 is 100x more acidic than pH of 5
- pH of 2 is 10^(5-2) = 1,000 x more acidic than pH of 5
- Acids usually begin with H: HNO_3, H_2SO_4, HCl
- Bases usually end with OH: KOH, NaOH, $Mg(OH)_2$
- Acids put H^+ in solutions while bases put OH^-
  - The concentration of these two is what determines how acidic or basic a solution is

Heavy metals and acids

- Heavy metals, like lead, mercury, cadmium, etc. are toxic and animals have a hard time getting rid of them once ingested
- Larger animals eat smaller ones in the food chain and over the life time of a large animal, it will tend to accumulate large amounts of heavy metals
- We need to minimize the amount of heavy metals in our drinking water
  - Lower pH (more acidic) water tends to dissolve more heavy metals from pipes
  - Hotter water also tends to increase the amount of heavy metals from pipes too
- Heavy metals are particular harmful to children

Molarity

- Molarity (M) is the measure of concentration of a solution
- M = mols/Liters
  - M is the molarity. Example: you are given a 3.5 M solution of NaOH would be pronounced: “3.5 molar solution” or “a solution whose molarity is 3.5”
  - Moles is the amount (mass) of solute
  - Liters is the amount (volume) of solution
- Problem solving: Treat this like an equation with three variable: M, moles, liters

Solving Titration Problems

- Titration is adding either acid or base to a solution to neutralize it
- 1 mol of H^+ neutralizes 1 mole of OH^-
- Example: 2 moles of H_3PO_4 (phosphoric acid) contains 6 moles of H^+ so it will take 6 mols of OH^- to neutralize it
  - Yes, this means you need to do some stoichiometry and balance reactions!
- Titration uses a chemical: Phenolphthalein
- Phenolphthalein is pink in basic solutions and clear in acid
- Phenolphthalein is added to an unknown solution and enough base or acid is added to make a clear solution just barely turn pink, or make a pink solution barely become clear
- Using the molarity equation and the solution is neutralized with a known base or acid, you can solve with the molarity of an unknown acid or base

Solved Titration Problem – Example 1

4. $H_2SO_4 + LiOH \rightarrow$ (3 sig)

50.0 mL of 1.00 M lithium hydroxide titrates a sulfuric acid solution. The buret labeled A originally has a buret level of 15.60 mL and after titrating, the new level is 36.80 mL. What is the concentration of the sulfuric acid solution? $H_2SO_4(AQ) + 2LiOH(AQ) \rightarrow 2H_2O(l) + Li_2SO_4(AQ)$

LiOH

.0500 L

1.00 M

mols = ?

LiOH

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

$1.00 = \frac{x}{.05}$

x = .05 mols LiOH

$\frac{.05 \text{ mol LiOH}}{} \times \frac{1 \text{ mol } H_2SO_4}{2 \text{ mol LiOH}} = .025 \text{ mol } H_2SO_4$

H_2SO_4

36.80 − 15.60

21.20 ml = .0212 L

M = ?

$M = \frac{mol}{L} = \frac{.025}{.0212} = 1.18 M\ H_2SO_4$

Solved Titration Problem – Example 2

5. $H_2SO_3 + Ba(OH)_2 \rightarrow$ (3 sig)

22.70 mL of 0.850 M sulfurous acid titrates a barium hydroxide solution. The buret labeled B originally has a buret level of 7.25 mL and after titrating, the new level is 22.75 mL. What is the concentration of the $Ba(OH)_2$ solution? $H_2SO_3 (AQ) + Ba(OH)_2 (AQ) \rightarrow 2H_2O (l) + BaSO_3 (AQ)$

H_2SO_3

.02270 L

@ 0.850 M

mols = ?

$Ba(OH)_2$

22.75 - 7.25 =

15.50 mL

.0155 L

M = ?

H_2SO_3

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

$.850 = \frac{x}{.02270}$

x = .019295 mols H_2SO_3

$Ba(OH)_2$

.019295 mols ← same coeffs = same conc.

.0155 L

M = ?

$M = \frac{mols}{L} = \frac{.019295}{.0155} = 1.24 M \; Ba(OH)_2$