09-Student Notes 2015

Tuesday, April 4, 2017 8:02 AM

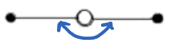
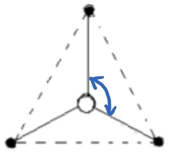
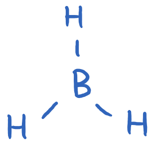
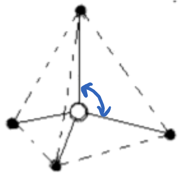
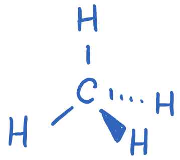
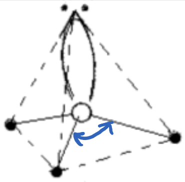
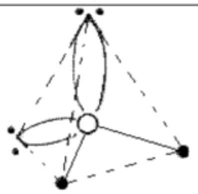
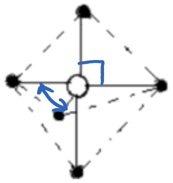
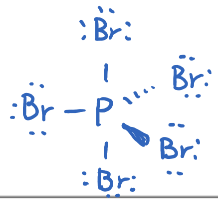
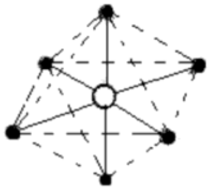
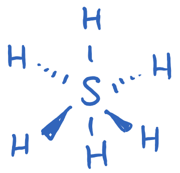
UNIT 9
Solution Chemistry

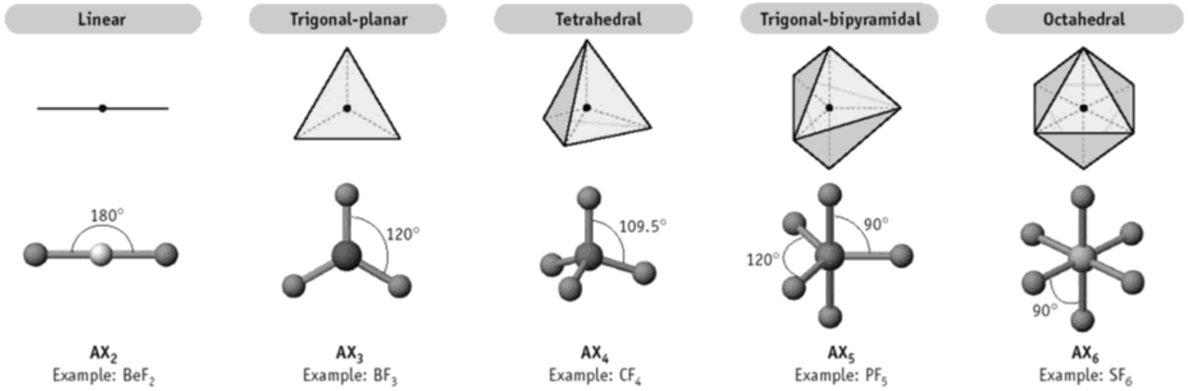
KEY IDEAS	
Vocabulary	What does it mean?
VSEPR	
dipole-dipole	
London forces	
Hydrogen bond	
polar	
solution	
solvent	
solute	
dissolve	
soluble	
solubility	
saturated	
unsaturated	
dilute	
concentration	
molarity	
dilution	
precipitate	
formula equation	
complete ionic equation	
net ionic equation	
conductivity	

9.1 - Valence Shell Electron Pair Repulsion Theory (VSEPR)

Remember, molecules are 3D structures. Their geometric shape is determined by

- $e^- - e^-$ repulsion : electron pairs in bonds will orient as far away from each other as possible
- valence electrons – these occupy space too so these will spread out evenly around the central atom

Name	Shape	Atoms Bonded to Central Atom	Lone Pairs of Electrons Bonded to Central Atom	Bond Angle	Example	
					Formula	Lewis Structure Represented in 3D
Linear		2	0	180°	BeH_2	H – Be – H
Trigonal planar		3	0	120°	BH_3	
Tetrahedral		4	0	109.5°	CH_4	
Trigonal pyramidal		3	1	107°	NH_3	
Angular		2	2	104.5°	H_2O	
Trigonal bipyramidal		5	0	90° 120° 180°	PBr_5	
Octahedral		6	0	90° 180°	SH_6	



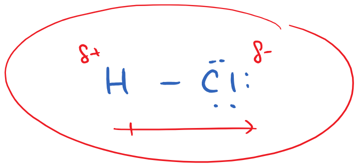
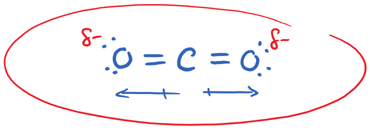
9.2 - Intermolecular Forces (P.203 #13-16, P.208 #23, 24)

Intermolecular forces are attraction forces between molecules and are associated with physical changes.

Intramolecular	Intermolecular
- ionic	- H-bond
- covalent	- dipole-dipole
- polar covalent	- London forces
- break these = chemical reaction	- break these = phase change or dissolving

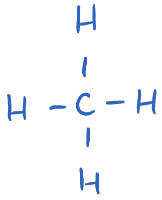
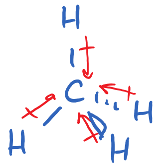
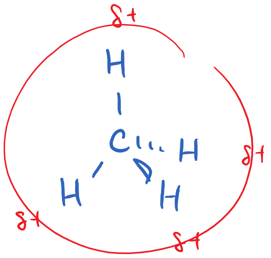
A. Dipole-dipole

- molecule must be ______________ (molecules with polar covalent bonds are not necessarily polar)
- δ^- side of the molecule is attracted to the δ^+ side
- can be intramolecular as well

HCl 1+7 = 8  polar molecule	CO_2 4 + 2(6) = 16  non-polar molecular

Practice: Which of the following molecules are polar?

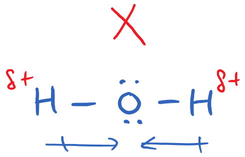
a) CH_4 $4+4(1)=8$

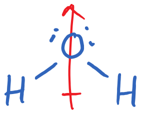
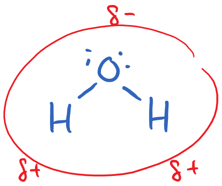




non-polar molec

no dipole-dipole

b) H_2O $2(1)+6=8$

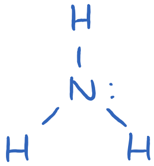
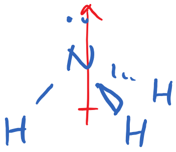
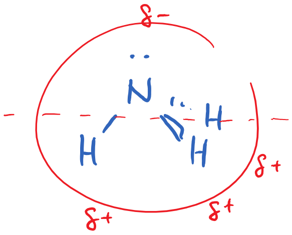


polar molecule

✓ dipole-dipole

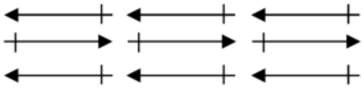
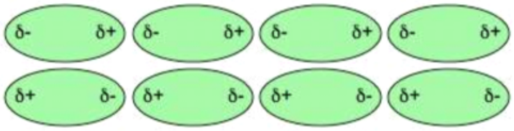
c) NH_3 $5+3(1)=8$

polar molec

✓ dipole-dipole

How molecules arrange themselves when there are dipole-dipole interactions:

B. London forces (induced dipoles)

- all molecules have the ability to develop this intermolecular force
- weak and short-lived attractive force caused by temporary dipoles
    - recall e^- distribution is described as a probability
    - at any given point in time, the distribution might be uneven, creating a dipole moment on the molecule
- increases with increasing #e^- and size of molecule

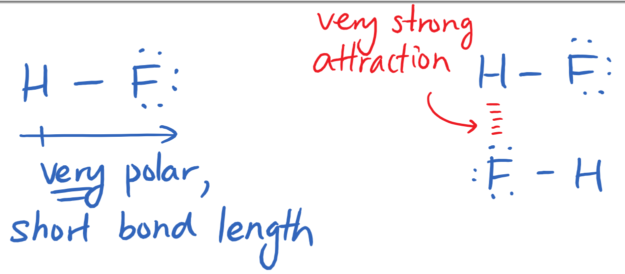
Consider This: Why is chlorine a gas at room temperature, but bromine a liquid?

Br_2 has 70 e^- compared to Cl_2 at 34 e^-

Br_2 has a much larger London force

C. Hydrogen bonds

- molecule contains an H atom bonded to a~~n~~ very electronegative atom (F, O, N)
- the H atom of one molecule is attracted to the F, O, or N on another molecule
- the strongest of the intermediate forces
  - H has no e^- to get in the way of its attraction to F, O, or N

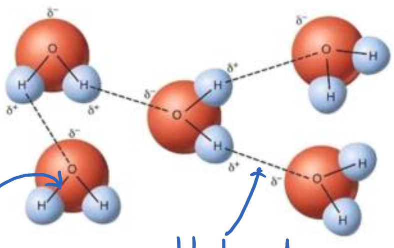


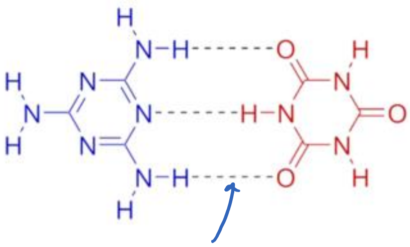
Practice: Which of the following molecules can hydrogen bond?

HCN [✓ H_2O] H_2S [✓ HF]

$H-C\equiv N:$

no

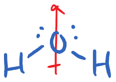
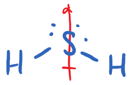




Intermolecular bonds are responsible for how readily covalent substances undergo physical changes

- intermolecular forces must be broken
- the more intermolecular forces present, and the stronger that they are, the higher the melting and boiling points
- the larger the molecule and the higher the mass, the higher b.p

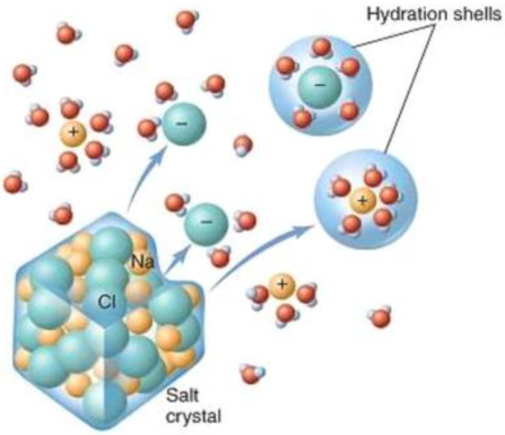
Example: Among H_2O, CO_2, and H_2S, explain why H_2O has the highest boiling point at 100°C, followed by H_2S at -60.33°C, then CO_2 at-78.44°C

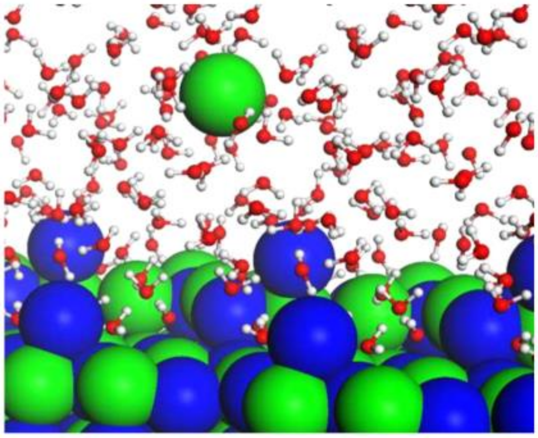
	H-bond	d-d	London	
	✓	✓	✓	← most amount of intermolecular forces, including H-bond, which is the strongest
		✓	✓	
$\ddot{O}=C=\ddot{O}$			✓	← only London forces

9.3 – Like Dissolves Like (P. 207 #18-22, P.208 #25, 27, P. 210 #28-29, P. 212 #30-38)

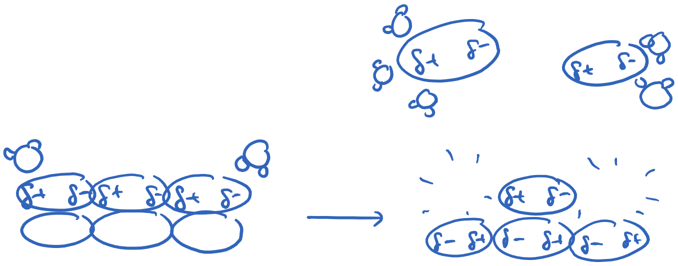
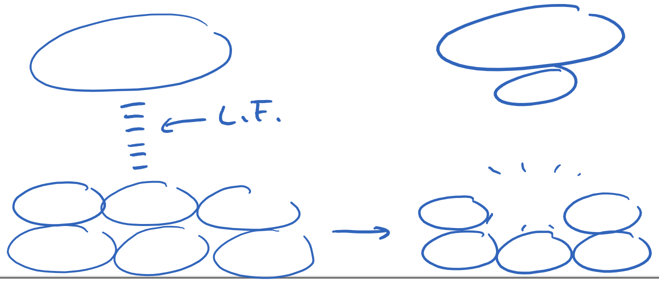
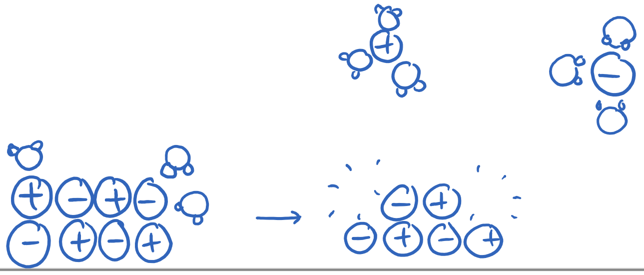
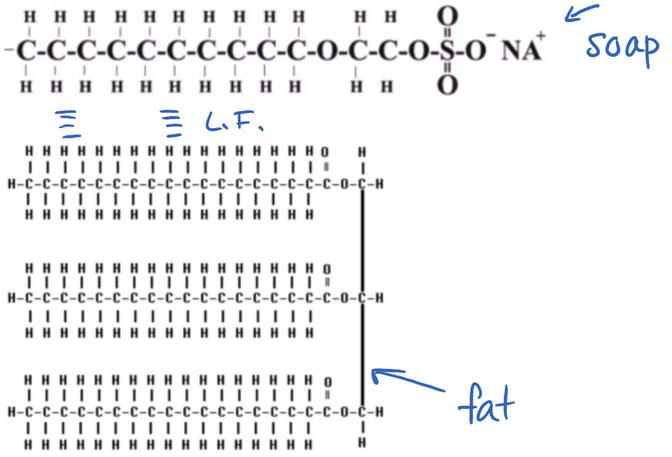
How to things dissolve?

- There are three intermolecular forces to consider:
  1. attraction between solute + solute
  2. attraction between solute + solvent
  3. attraction between solvent + solvent
- The solvent molecule will separate the solute particles by breaking intermolecular bonds between solute molecules
- The solvent molecules will form strong intermolecular bonds with the solute

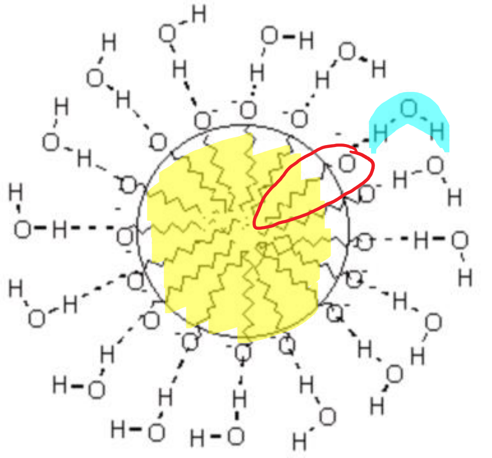




The rule of solubility: "Like Dissolves Like"

Rule	What is the Solvent?	What Happens?
polar solutes will dissolve best in polar solvents	• solvent molecule is very polar • dissolving occurs by dipole-dipole	
non-polar solutes will dissolve best in non-polar solvents	• solvent molecule is capable of forming large London forces • dissolving occurs by London forces	
ionic solutes will dissolve best in very polar solvent	• dissolving occurs by dipole-dipole forces	
organic solutes will dissolve in organic solvents	• solvent molecule is a hydrocarbon (long chain of C and H) • dissolving occurs by London forces	

Example: Soap dissolves in water and fat dissolves in soap.

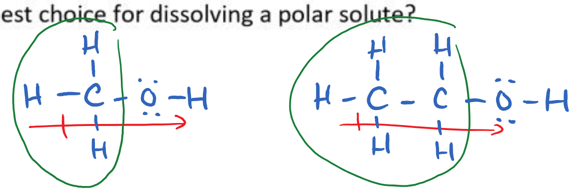


soap dissolves in fat
AND water b/c
it has a non-polar end,
and a polar end

Example: Compare the 3 solvents: water, methanol (CH_3OH) and ethanol (CH_3CH_2OH).

a) Which one is the best choice for dissolving a polar solute?

the most polar



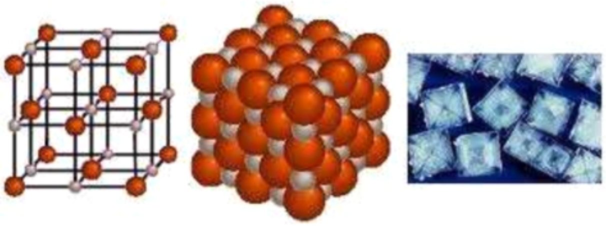
non-polar region
gets in the way

b) Which one is the best choice for dissolving a non-polar solute? Explain using London forces & polarity. Draw a diagram of your molecules to explain your answer.

ethanol, b/c has largest non-polar region

Ionic compounds exist as a crystal lattice, a very organized arrangement of particles.

The crystal lattice of table salt, NaCl



When an ionic solid dissolves in a solvent, we call it a dissociation reaction. Ions separate.

Practice: Write a chemical equation for each of the following ionic compounds to show dissociation.

a) $AlCl_{3(s)} \rightarrow Al^{3+}_{(aq)} + 3Cl^-_{(aq)}$

b) $FeBr_{3(g)} \rightarrow Fe^{3+}_{(aq)} + 3Br^-_{(aq)}$

c) $CH_3COOH_{(l)} \rightarrow CH_3COO^-_{(aq)} + H^+_{(aq)}$

d) $HCN_{(g)} \rightarrow H^+_{(aq)} + CN^-_{(aq)}$

e) $Na_2SO_{4(s)} \rightarrow 2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

f) $Ca(OH)_{2(s)} \rightarrow Ca^{2+}_{(aq)} + 2OH^-_{(aq)}$

When covalent compounds dissolve in a solid, molecules separate.

Molecular Solution	Ionic Solution
NH_3 NH_3 NH_3 NH_3 → NH_3 NH_3 NH_3 NH_3	⊕⊖⊕⊖ ⊖⊕⊖⊕ NaCl NaCl NaCl NaCl → Na^+ Na^+ Cl^- Cl^-

9.4 - Molarity (P.98 #59-71, P.212 #30-38)

Concentration: amount of substance in a solution, standard units mol/L or M called molarity.

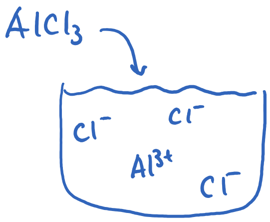
- **concentrated solutions**: there is a lot of substance dissolved
- **dilute** solutions: there is very little substance dissolved
- **saturated** solutions: the solution has the maximum concentration possible
- "the molar concentration of X" can be written as [X] [NaCl] = 5M

**Note: the word "solution" includes the substance being dissolved, solutes have volume too!

Example: What is the molar concentration of the ions in 0.25M $AlCl_{3(aq)}$?

$$\underset{0.25M}{AlCl_3} \rightarrow Al^{3+} + 3Cl^-$$

$$[Al^{3+}] = 0.25M \qquad [Cl^-] = 0.75\ M$$



Practice

$\frac{mol}{L}$

1. What is the [NaCl] in a solution containing 5.12 g of NaCl in 250.0 mL of solution?

$$5.12g \times \frac{1mol}{58.5g} \times \frac{1}{0.2500L} = 0.350\ M$$

2. Find the concentration of 1.222 g of Na_2SO_4 in 500.0 mL of solution.

$$1.222g \times \frac{1mol}{142.1g} \times \frac{1mol}{0.5000L} = 0.0172\ M$$

3. Find the mass of NaOH in 3.50 L of a 0.200 M NaOH.

$$3.50\cancel{L} \times \frac{0.200\,mol}{1\cancel{L}} \times \frac{40.0g}{1mol} = 28.0g$$

4. What is the molarity of H_2SO_4 (d = 1.839 g/mL)?

$$\frac{1.839g}{1mL} \times \frac{1mol}{98.1g} \times \frac{1000mL}{1\ L} = 18.7\ M$$

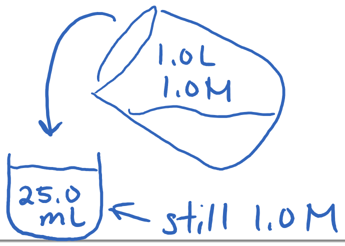
5. How many molecules of $MgCl_2$ are there in a 10.0 mL sample of a 2.50 M solution?

$$0.0100L \times \frac{2.50mol}{1L} \times \frac{6.02\times10^{23}\,molec}{1mol} = 1.51\times10^{22}\ molec$$

6. Find $[Cl^-]$ in a 25.00 mL sample of a 1.0 M $CaCl_2$ solution.

$$\underset{1.0M}{CaCl_2} \rightarrow Ca^{2+} + \underset{2.0M}{2Cl^-}$$

$$[Cl^-] = 2.0M$$



9.5 - Making Solutions

Volumetric flask: the container used to make solutions

- accuracy ± 0.1%
- comes in set sizes: 10 mL, 25 mL, 50 mL, 100 mL, 250 mL, 500 mL, 1000 mL, 2000 mL

Steps:

1. Know how much of the solution you need to use and choose the appropriate volumetric flask
2. Calculate how much mass you need
3. Weigh the mass on a balance into a **small** beaker
4. Wash the substance into the volumetric using a funnel and a wash bottle
5. Rinse the small beaker 3 times
6. Rinse the funnel well
7. Fill the flask until it is about ½ full with **distilled** water
8. Cap the flask and shake until all the substance has dissolved
9. Using a wash bottle, rinse down the neck of the volumetric flask and add distilled water to the mark (meniscus just touches the mark)
10. Invert the flask repeatedly (about 20x) to evenly mix the solution

Think about this: What happens to the concentration of your solution if…

1. You didn't rinse down the beaker: [ ] lower than target
2. You didn't rinse down the funnel: [ ] lower than target
3. You add water past the mark: [ ] lower than target

Think about this:

1. Why do we not add 1.0 L of water first, and then dissolve our solute?

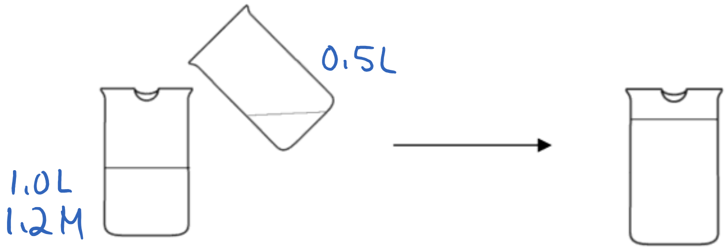
   solute has volume too, you'd go over 1.0 L
2. What should you do if you add water passed the mark? start over
3. What happens if your solution is not properly mixed? conc. gradient

9.6 - Dilutions (P.102 #78-86, 89)

Dilution: lower [ ]

- not all chemicals are solid when you buy them
  - some chemicals are sold as concentrated solution (eg. HCl sold in 12 M)
  - you must perform dilutions to make solutions for experiments

Example: If we start with a 1.0 L solution of 1.2 M NaCl (salt water), and we add 0.5 L of water to it, what is the final concentration of NaCl?



Solve Using Moles:

$$1.0L \times \frac{1.2mol}{1L} \times \frac{1}{1.5L} = 0.80M$$

Before and after a dilution, # moles is constant. We have two equations with something in common, so we can set up the following:

$C_i = \frac{n_i}{V_i}$ $C_f = \frac{n_f}{V_f}$

$C_iV_i = n_i$ $C_fV_f = n_f$

$n_i = n_f$

$C_iV_i = C_fV_f$

Solve Using Equation:

$C_iV_i = C_fV_f$

$(1.2M)(1.0) = C_f(1.5L)$

$C_f = 0.80M$

$C_iV_i = C_fV_f$

Practice

1. If 200.0 mL of 0.500 M NaCl is added to 300.0 mL of water, what is the resulting [NaCl] in the mixture?

$C_iV_i = C_fV_f$

$(0.500M)(200.0mL) = C_f(500.0mL)$

$C_f = 0.200M$

2. If 500.0 mL of 0.1 M CH_3COOH is added to 200.0 mL of water, what is the resulting $[CH_3COOH]$ in the mixture?

$$C_iV_i = C_fV_f$$

$$(0.1M)(500.0\cancel{mL}) = C_f(700.0\cancel{mL})$$

$$C_f = 0.07\ M$$

3. A student mixes 100.0 mL of water with 25.0 mL of sodium chloride solution having an unknown concentration. The molarity of the diluted sodium chloride solution is 0.0876 M, what is the molarity of the original sodium chloride solution?

$$C_iV_i = C_fV_f$$

$$C_i(25.0mL) = (0.0876M)(125.0mL)$$

$$C_i = 0.438M$$

4. How much 12 M HCl is required to make a 1.00 L solution of 2.00 M HCl?

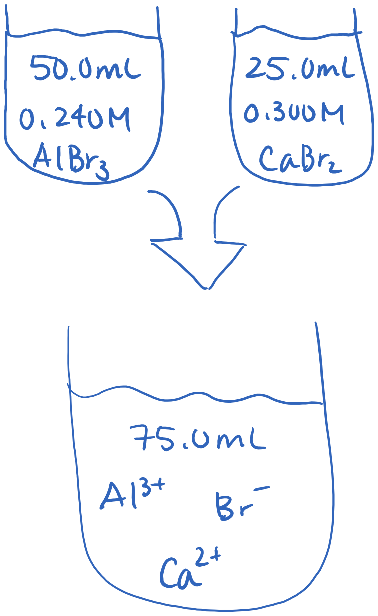
$$C_iV_i = C_fV_f$$

$$(12M)V_i = (2.00M)(1.00L)$$

$$V_i = 0.17L$$

9.7 - Mixing Solutions (P.102 #88, 90)

Example: What is the concentration of each type of ion in a solution made by mixing 50.0 mL of 0.240 M $AlBr_3$ and 25.0 mL of 0.300 M $CaBr_2$?



$$[Al^{3+}] = \frac{(0.240M)(0.0500L)}{0.0750L} = 0.160M$$

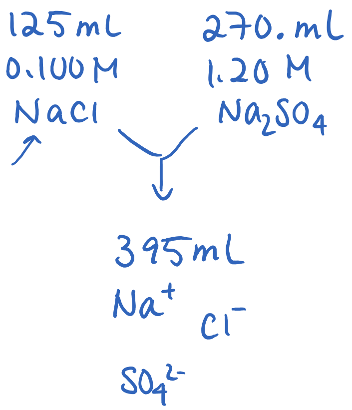
$$[Ca^{2+}] = \frac{(0.300M)(0.0250L)}{0.0750L} = 0.100M$$

$$[Br^-] = (0.160M)(3) + (0.100M)(2)$$

$$= 0.680M$$

Don't need to divide by 0.0750L because I'm already in mol/L. I just added 2 concentrations.

Example: 125 mL of 0.100 M NaCl is mixed with 270. mL of 1.20 M Na_2SO_4. Find the final concentration of each ion.



$$[Cl^-] = \frac{(0.100M)(0.125L)(1)}{0.395L} = 0.0316_{46}M$$

$$[SO_4^{2-}] = \frac{(1.20M)(0.270L)(1)}{0.395L} = 0.820_{25}M$$

$$[Na^+] = (0.\underline{031}6_{46}M)(1) + (0.\underline{820}_{25}M)(2)$$

$$= 1.672M$$

Example: 75 mL of 0.500 M $Ca(NO_3)_2$ is added to 85 mL of 0.600 M NaCl. Find the final concentration of each ion.

160. mL

$$[Ca^{2+}] = \frac{(0.500 M)(75 mL)}{160. mL} = 0.23_{44} M$$

$$[NO_3^-] = (0.23_{44} M)(2) = 0.47 M$$

$$[Na^+] = [Cl^-] = \frac{(0.600 M)(85 mL)}{160. mL} = 0.32 M$$

Review Questions P.103 #95-102

9.8 - Concentration and Stoichiometry (P. 131 #17-24)

Practice:

1. How many grams of copper will react to completely replace silver from 208 mL of 0.100 M solution of silver nitrate?

$$\underset{?g}{Cu} + \underset{\substack{208 mL\\0.100 M}}{AgNO_3} \rightarrow CuNO_3 + Ag$$

$$0.208 L \times \frac{0.100 mol}{1 L} \times \frac{1 Cu}{1 AgNO_3} \times \frac{63.5 g}{1 mol} = 1.32 g$$

2. If 17.5 g of zinc are reacted with phosphoric acid, H_3PO_4, then zinc phosphate and hydrogen are produced. If the phosphoric acid is a 3.00 M solution, how many litres of the solution are needed to completely react with the zinc?

$$\underset{17.5g}{3Zn} + \underset{\substack{3.00 M\\?L}}{2H_3PO_4} \rightarrow Zn_3(PO_4)_2 + 3H_2$$

$$17.5 g\ Zn \times \frac{1 mol}{65.4 g} \times \frac{2\ H_3PO_4}{3\ Zn} \times \frac{1 L}{3.00 mol} = 0.0595 L$$

$$c = \frac{n}{v}$$

$$v = \frac{n}{c}$$

3. What volume of 1.50 M silver nitrate is required to produce 15.0 g of silver when it reacts with copper? The reaction also produces copper (II) nitrate.

$$2AgNO_3 + Cu \rightarrow 2Ag + Cu(NO_3)_2$$

$AgNO_3$: 1.50M, ? L

Ag: 15.0g

$$15.0\,g\ Ag \times \frac{1\,mol}{107.9\,g} \times \frac{2\,AgNO_3}{2\,Ag} \times \frac{1\ \ L}{1.50\ mol} = 0.0927\ L$$

4. A 10.0 mL sample of a saturated solution of calcium hydroxide is needed to neutralize 23.5 mL of 0.0156 M hydrochloric acid.

a) What is the molarity of the calcium hydroxide in the saturated solution?

$$Ca(OH)_2 + 2HCl \rightarrow 2H_2O + CaCl_2$$

$Ca(OH)_2$: 10.0mL, ? M

HCl: 23.5mL, 0.0156M

$$0.0235L \times \frac{0.0156\,mol}{1L} \times \frac{1\ Ca(OH)_2}{2\ HCl} \times \frac{1}{0.0100L} = 0.0183\,M$$

b) What mass of the calcium hydroxide is dissolved in 250.0 mL of saturated calcium hydroxide?

$V = 250.0\,mL$

$C = 0.0183_3\,M$

$$0.2500L \times \frac{0.0183_3\,mol}{1L} \times \frac{74.1g}{1\,mol} = 0.33956$$

$$= 0.340g$$

5. 500.0 mL of a 0.100 M HCl solution is mixed with 250.0 mL of a 0.150 M NaOH solution.

a) What is the limiting reagent?

$$\underset{\substack{500.0\,mL\\0.100\,M}}{HCl} + \underset{\substack{250.0\,mL\\0.150\,M}}{NaOH} \rightarrow H_2O + \underset{?\,M}{NaCl}$$

$$HCl:\ 0.5000\,L \times \frac{0.100\,mol}{L} \times \frac{1\,NaCl}{1\,HCl} \times \frac{1}{0.7500\,L} = 0.0667\,M\ NaCl$$

$$NaOH:\ 0.2500\,L \times \frac{0.150\,mol}{L} \times \frac{1\,NaCl}{1\,HCl} \times \frac{1}{0.7500\,L} = 0.0500\,M\ NaCl$$

since make less NaCl with NaOH, NaOH must be limiting.

b) What is the concentration of NaCl in the final mixture?

0.0500 M from part a)

9.9 – Solubility

Solubility: The maximum amount of solute that can be dissolved in a given amount of solvent at a given temperature. Something is soluble if it can achieve 0.1 M or more at 25°C.

Practice: Use the Solubility Table in the Data Booklet to predict if the following compounds have high solubility or low solubility in water.

Compound	Solubility	Compound	Solubility
PbI_2	low	$MgSO_4$	high
$Sr_3(PO_4)_2$	low	$Ba(OH)_2$	low
*$CuCl_2$	high	$CuCO_3$	low
*CuCl	low	Ag_2S	low

Precipitate: an insoluble compound, often formed from a chemical reaction. These chemical reactions can be represented in three ways:

- **Formula equation**: a complete, balanced chemical equation
- **Complete ionic equation**: shows all soluble ionic species broken up into their respective ions
- **Net ionic equation**: shows only the species which are actively involved in the reaction, removes spectator ions

Example: $AgNO_3$ mixed with Na_2CO_3	
Type of Equation	Equation
Formula	$2AgNO_{3(aq)} + Na_2CO_{3(aq)} \longrightarrow Ag_2CO_{3(s)} + 2NaNO_{3(aq)}$
Complete ionic	$2Ag^+ + 2NO_3^- + 2Na^+ + CO_3^{2-} \longrightarrow Ag_2CO_{3(s)} + 2Na^+ + 2NO_3^-$
Net ionic	$2Ag^+_{(aq)} + CO_3^{2-}{}_{(aq)} \longrightarrow Ag_2CO_{3(s)}$

Practice: For the following mixtures, write the formula, complete ionic, and net ionic equations.

1. MgS and $Sr(OH)_2$

Complete formula $MgS + Sr(OH)_2 \longrightarrow Mg(OH)_{2(s)} + SrS$

Complete ionic $Mg^{2+} + S^{2-} + Sr^{2-} + 2OH^- \longrightarrow Mg(OH)_2 + Sr^{2+} + S^{2-}$

Net ionic $Mg^{2+} + 2OH^- \rightarrow Mg(OH)_{2}(s)$

2. $CuBr_2$ and $Pb(NO_3)_2$

Complete formula $CuBr_2 + Pb(NO_3)_2 \longrightarrow Cu(NO_3)_2 + PbBr_2(s)$

Complete ionic $Cu^{2+} + 2Br^- + Pb^{2+} + 2NO_3^- \longrightarrow Cu^{2+} + 2NO_3^- + PbBr_2(s)$

Net ionic $2Br^- + Pb^{2+} \longrightarrow PbBr_2(s)$

9.10 – Calculations with Solubility

Practice:

1. Find the final ion concentration when 55.0 mL of 2.0 M NaOH is reacted with 75.0 mL of 3.0 M $Ca(NO_3)_2$.

130.0mL

precipitate = $Ca(OH)_2$

$Ca^{2+} + 2OH^- \rightarrow Ca(OH)_{2(s)}$

$$[Na^+] = \frac{(2.0M)(55.0mL)}{130.0mL} = \boxed{0.84_{62} M}$$

$$[NO_3^-] = \frac{(3.0M)(75.0mL)(2)}{130.0mL} = \boxed{3.4_{62} M}$$

$$[Ca^{2+}] = 3.4_{62}/2 = 1.7_{308} M - 0.84_{62}\left(\frac{1}{2}\right) = \boxed{1.3 M}$$

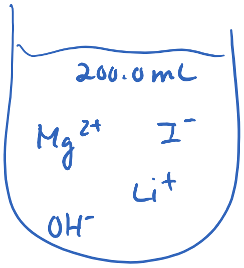
$$[OH^-] = 0.84_{62} M \rightarrow \boxed{0 M}$$

2. Find the final ion concentration when 150.0 mL of 1.2 M MgI_2 is reacted with 50.0 mL of 2.5 M LiOH.

200.0mL

$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_{2(s)}$

$$[Li^+] = \frac{(2.5M)(50.0mL)}{200.0mL} = \boxed{0.62_5 M}$$



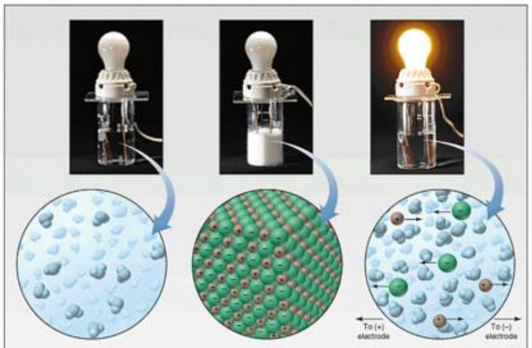
$$[I^-] = \frac{(1.2M)(150.0mL)(2)}{200.0mL} = \boxed{1.8 M}$$

$$[Mg^{2+}] = (1.8M)\left(\frac{1}{2}\right) = \underset{\text{have total}}{0.90 M} - (0.62_5 M)\left(\frac{1}{2}\right) = \boxed{0.59 M}$$

$$[OH^-] = 0.62_5 M \rightarrow \boxed{0 M}$$

9.11 - Conductivity (P.198 #6-8)

Conductivity: the ability of a substance to conduct electricity, or to allow the flow of electrons.
Substances that allow the flow of charge are conductive.



A Distilled water does not conduct a current

B Positive and negative ions fixed in a solid do not conduct a current

C In solution, positive and negative ions move and conduct a current

In order to allow the flow of electrons, a substance must contain ions. The more ions a substance has, the higher the conductivity.

Conductive Substances	Non-conductive Substances
1. metal (s)	• ionic compounds (s)
2. metal (l)	• polar covalent compounds (s)
3. ionic compounds (l)	• polar covalent compounds (l)
4. ionic compound (aq) – includes acid / base	• all non-polar covalent compounds
5. polar covalent compounds (aq) (very poor though)	

Practice: Circle the more conductive substance.

1.	[✓ 2 M NaCl]	0.5 M NaCl
2.	[✓ $Fe_{(s)}$]	0.5 M $CaCl_2$
3.	$CH_3OH_{(l)}$	[✓ $CH_3OH_{(aq)}$]
~~4.~~	~~$NaOH_{(aq)}$~~	~~$CH_3COOH_{(l)}$~~
5.	2 M LiCl	[✓ 2 M $MgCl_2$] → releases 3 ions total per $MgCl_2$