Chapter 14

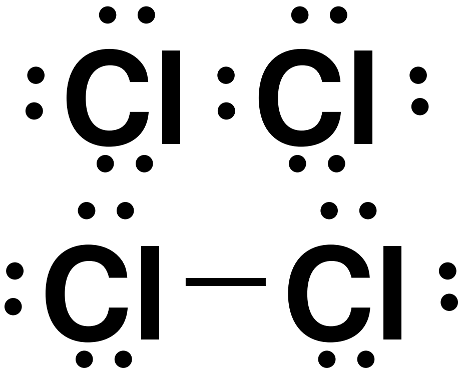
Solutions & Molarity

Bonding in Chemical Compounds:

We have previously seen that in *molecular compounds*, atoms *share* electrons in covalent bonds.

In chlorine, we constructed this covalent bond by *sharing* the unpaired electron from two chlorine atoms, giving each atom an octet of electrons.

The covalent bond formed is generally shown using a dash to connect the two atoms.



Bonding in Chemical Compounds:

For chemical compounds which were *not molecular*, electrons were completely transferred from one atom to another to form ionic bonds.

An example of this is sodium chloride, where the electron from the metal (sodium) is completely transferred to the nonmetal (chlorine) to give the pair of ions.

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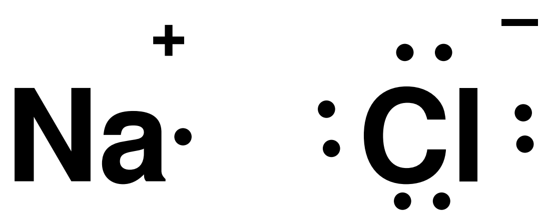
An example of this is sodium chloride, where the electron from the metal (sodium) is completely transferred to the nonmetal (chlorine) to give the pair of ions. A CATION AND AN ANION. In ionic compounds we talk about formula units, not molecules.

Ionic bonding involves the complete transfer of electrons from one atom to another.

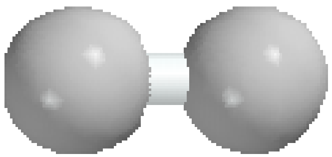


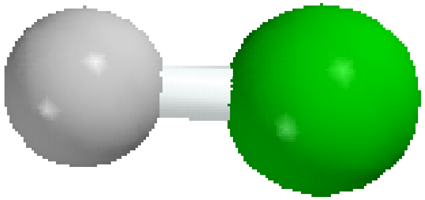
Bonding in Chemical Compounds:

Ionic bonding between *different* elements and covalent bonding between atoms of the *same* element can be thought of as limits of electron distribution in compounds, either uniformly shared or completely transferred.

But *most* covalent bonds occur between different elements, and in these bonds, *electron distribution is not necessarily uniform. That is they do not share the electron pair equally.*

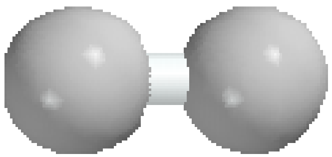
Bonding in Chemical Compounds:

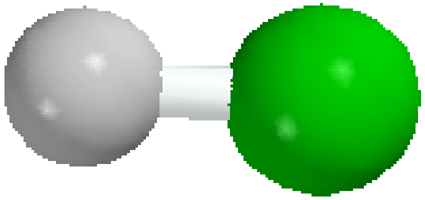




Consider molecular hydrogen (H_2) and hydrogen fluoride (HF). Both of these are molecular compounds which can be represented by the molecular models shown above.

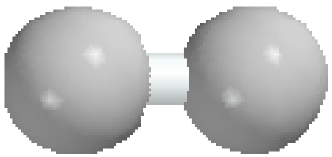
Bonding in Chemical Compounds:

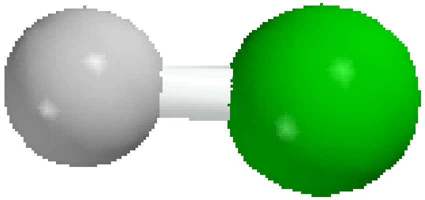


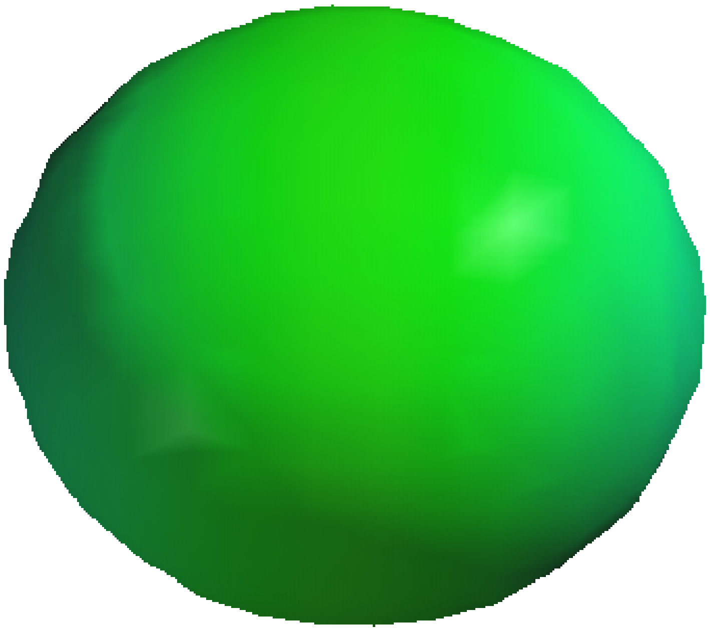


The electron distribution within a molecular compound can be *calculated* from the properties of each atom and is conveniently shown using an electrostatic potential map which uses a color gradient to show charge distribution.

Bonding in Chemical Compounds:

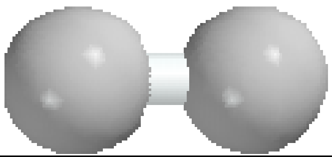


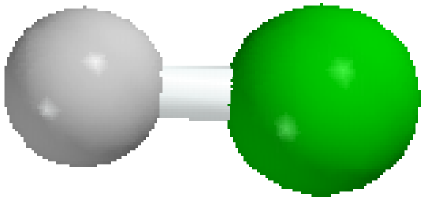




For **molecular hydrogen**, the electrostatic potential map is **uniform**, showing equal distribution of electron density around both hydrogen atoms.

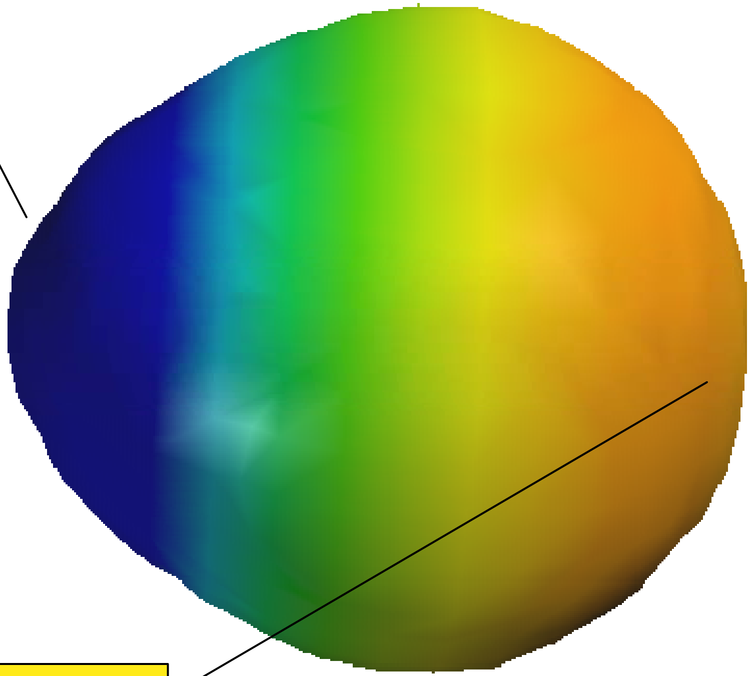
Bonding in Chemical Compounds:





The blue color is associated with positive charge.

For hydrogen fluoride, however,the electrostatic potential map shows a significant polarization of the electron density, with the greatest charge associated with the fluorine atom.

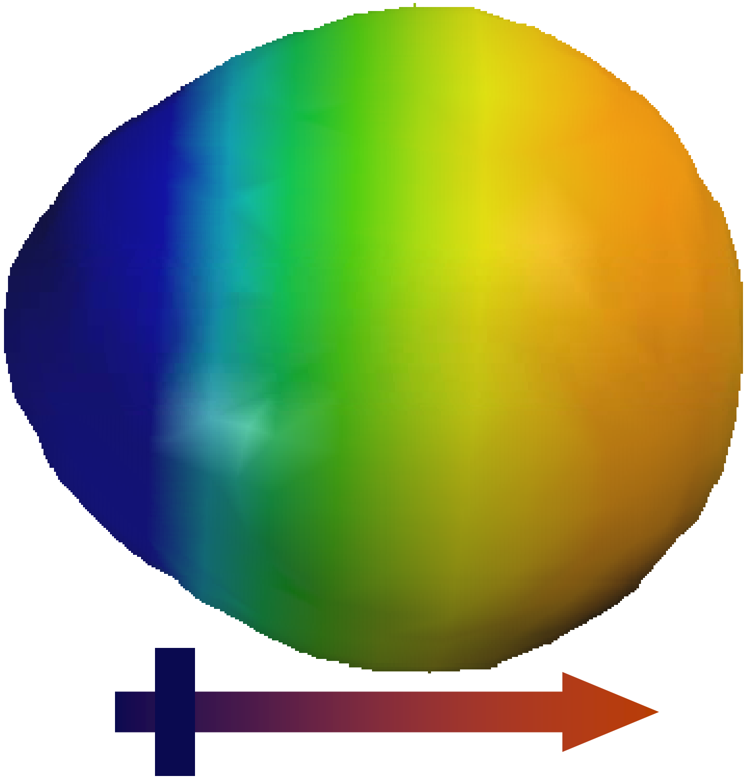


The red color is associated with a negative charge.

Bonding in Chemical Compounds:

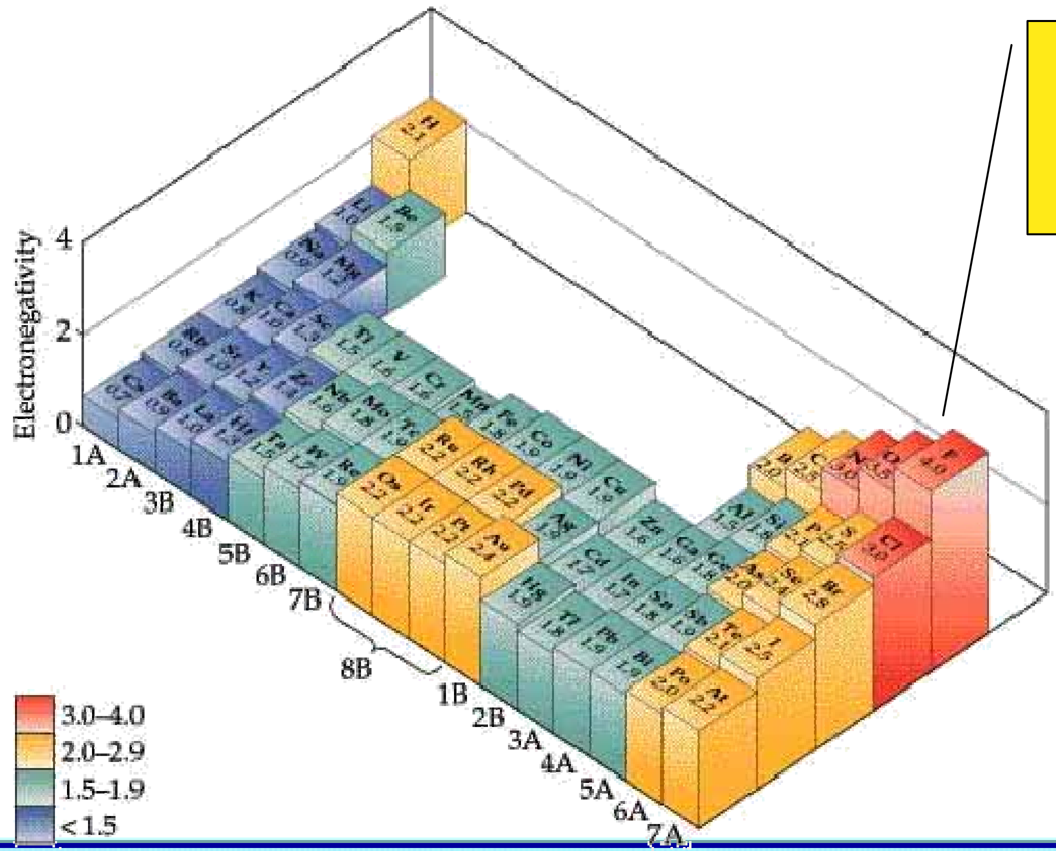
Molecular compounds in which electron distribution is unsymmetrical are called polar compounds and the *direction* of the polarization is often shown using an arrow with a positive charge on one end.

This unsymmetrical charge distribution is also called a dipole.



Electronegativity:

The tendency of an element to attract electrons towards itself is called electronegativity. The relative electronegativities of the elements are shown in the modified periodic table shown below.



These elements have the highest electronegativities.

Electronegativities for the main group elements.

H = 2.1

Li = 1.0 Be = 1.5 B = 2.0 C = 2.5 N = 3.0 O = 3.5 F = 4.0

Na = 0.9 Mg = 1.2 Al = 1.5 Si = 1.8 P = 2.1 S = 2.5 Cl = 3.0

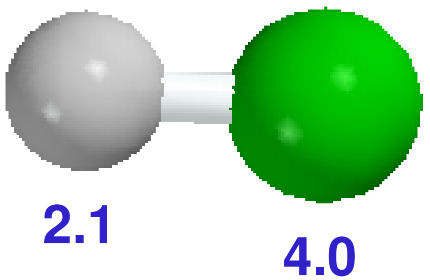
K = 0.8 Ca = 1.0 Ga = 1.6 Ge = 1.8 As = 2.0 Se = 2.4 Br = 2.8

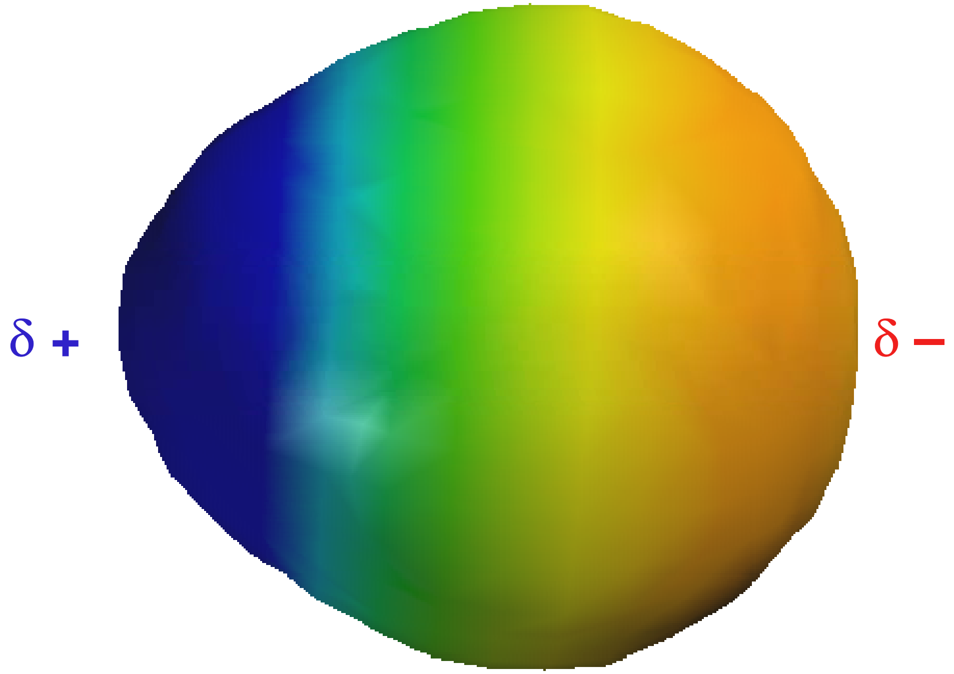
Rb = 0.8 Sr = 1.0 In = 1.7 Sn = 1.8 Sb = 1.9 Te = 2.1 I = 2.5

Cs = 0.7 Ba = 0.9 Tl = 1.8 Pb = 1.9 Bi = 1.9 Po = 2.0 At = 2.2

Electronegativities in HF:

The electronegativity of the hydrogen in HF is 2.1 and the electronegativity of the fluorine is 4.0, resulting in the polarization shown below.





Water is a strange duck!

Water is a substance whose properties we take for granted actually acts like almost no other liquid on earth. It expands when freezes, holds heat exceptionally well (allowing Europe to have a moderate climate instead of like Siberia- global warming may change this!), and has a high surface tension allowing plants to pull water and materials up via roots. Fish survive winter because water's maximum density is at 4 ^{0}C, not 0 ^{0}C it's freezing point.

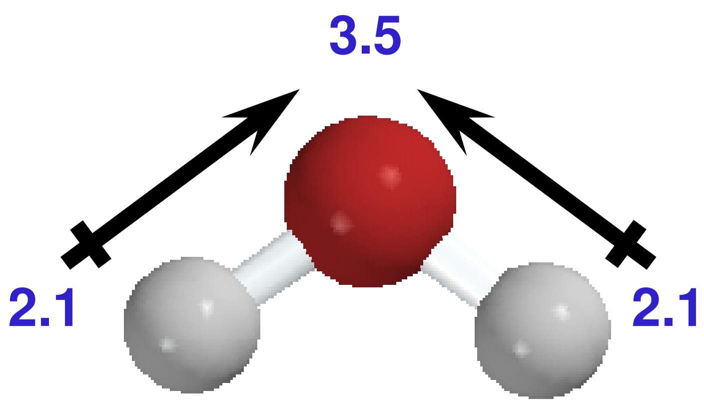
So cold water sinks to the bottom, but water close to the freezing point is at the top, ultimately forming a protective layer of ice. Water can put out fires yet hydrogen burns and oxygen supports combustion. Liquid water is an excellent solvent for both ionic, biological molecules and helps us circulate oxygen in our bodies.

We all know the formula for water and that there are intramolecular covalent bonds that hold it together but scientist are still working on how the intermolecular bonds form. These intermolecular forces, hydrogen bonding, are responsible for the anomalies in water. They are MUCH weaker than the intramolecular covalent bonds. Hydrogen bonds break and form easily allowing DNA to unzip to make copies and zip together again. Hydrogen bonds are how nature comes alive and how nature makes changes.

***These ideas come from "Slippery Substance by Heather R. Woods in Symmetry V03/Issue2 Fermilab**

Polarization in Water:

The electronegativity of oxygen is 3.5 and the electronegativity of hydrogen is 2.1. The prediction is that the O–H bond in water should therefore be polar.



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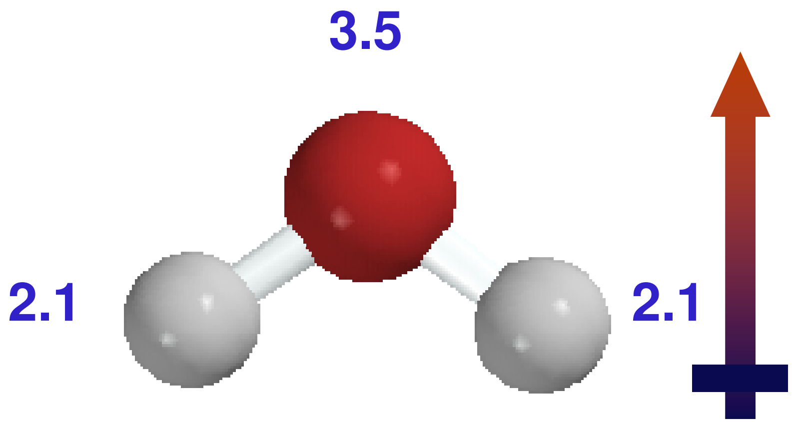
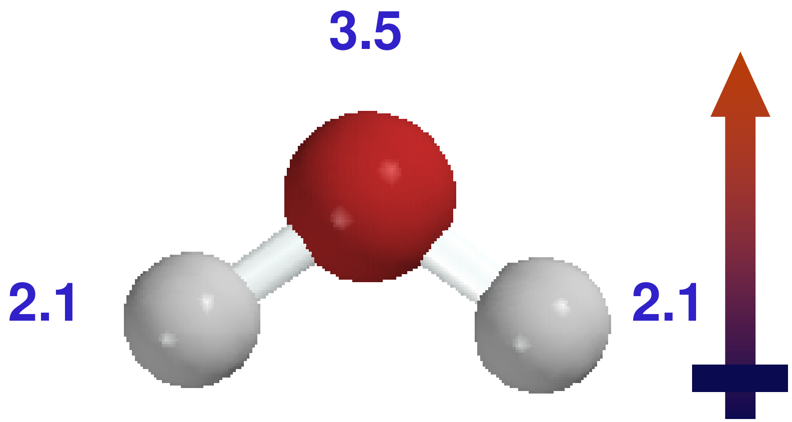


The combination of these two local dipoles will generate a molecular dipole with enhanced negative charge towards the oxygen and enhanced positive charge towards the hydrogen.

Polarization in Water:

The predicted molecular dipole of water is confirmed by the electrostatic potential map, which shows the oxygen being electron-rich and the hydrogens being electron-poor.



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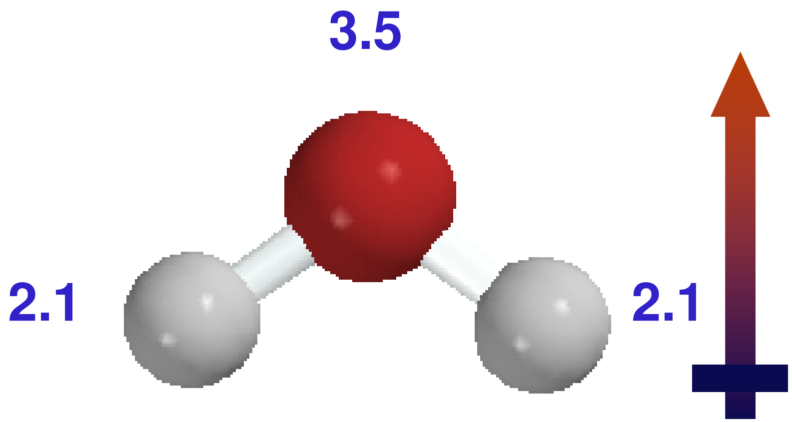
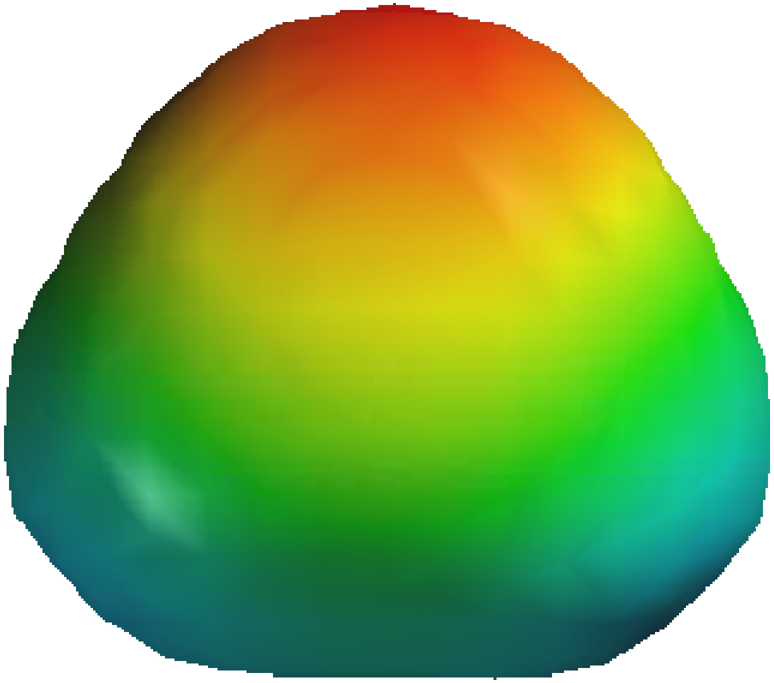
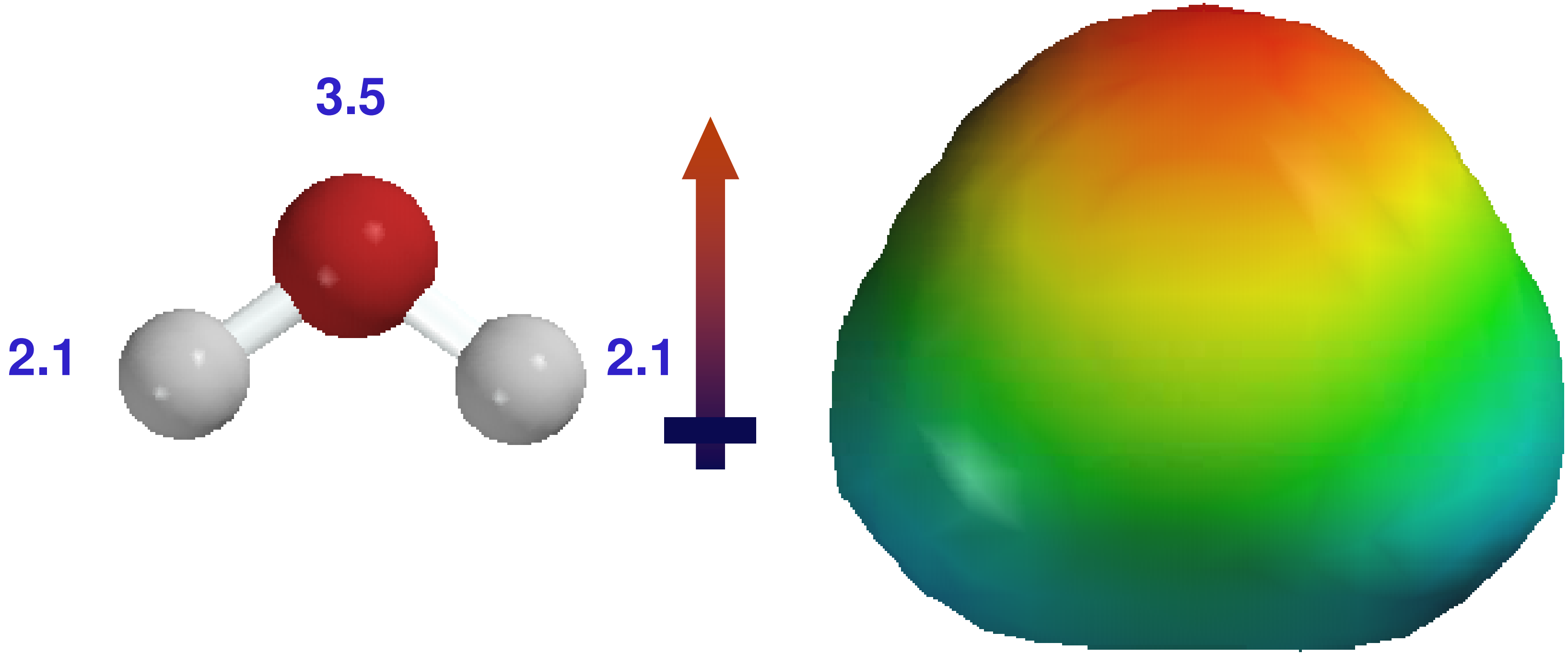




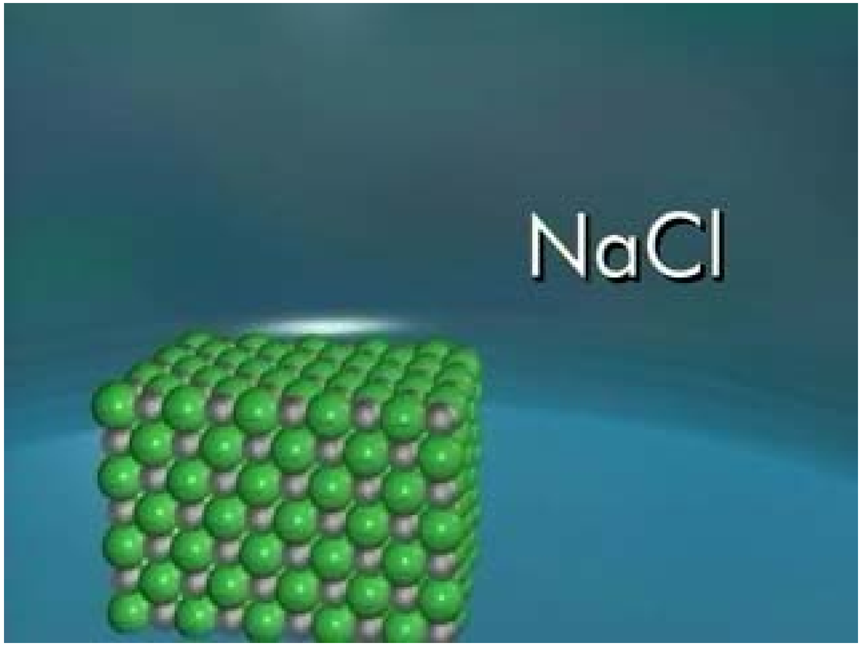
Polarization in Water:

It is the polar nature of water that allows water to *dissolve* ionic compounds (such as sodium chloride) to form solutions. Recall that solutions are defined as homogeneous mixtures.



Dissolution of Ionic Compounds in Water:

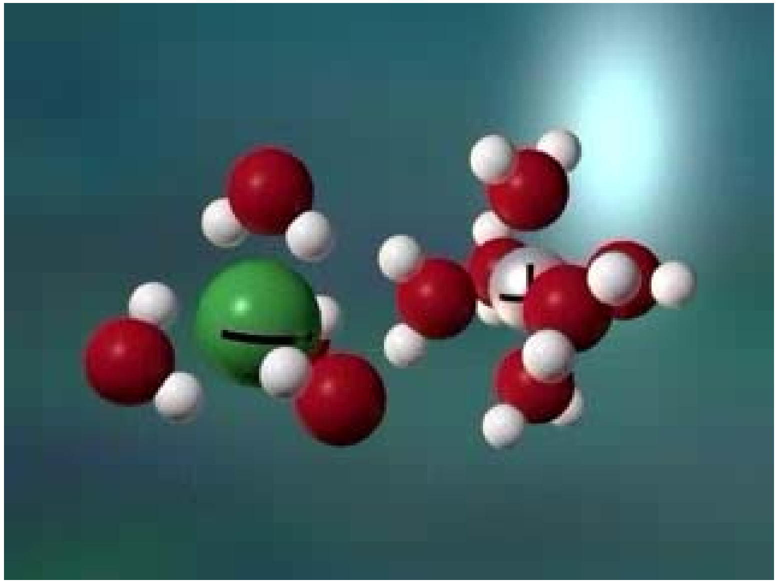
The process of dissolution of sodium chloride in water is shown in the animation below.



http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/058_DissolutNaCl.MOV

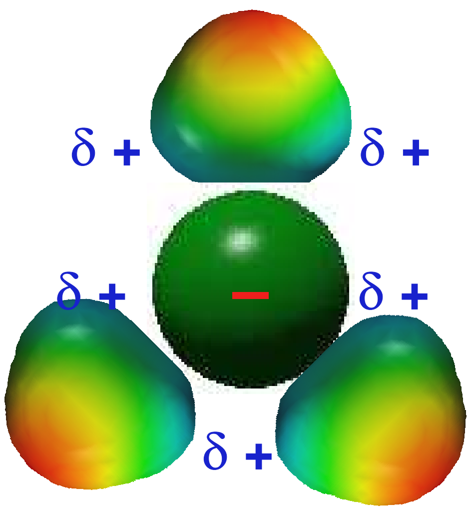
Dissolution of Ionic Compounds in Water:

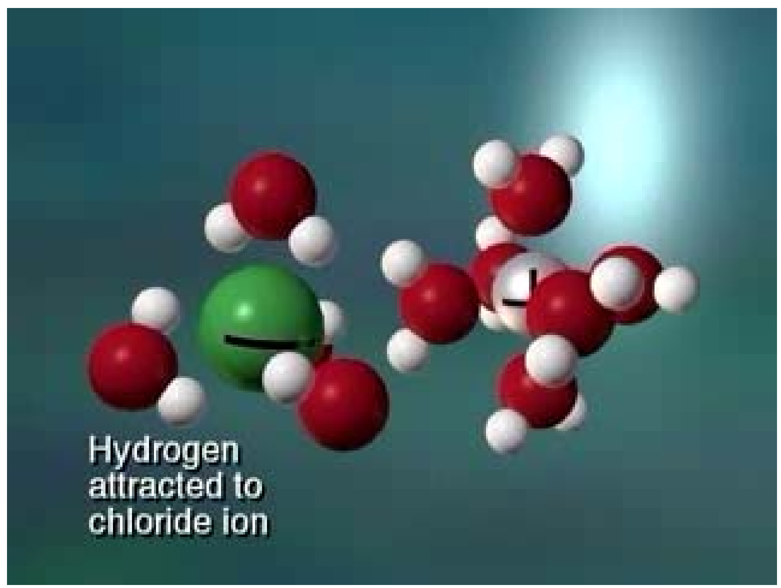
Note that the sodium and chloride ions are *surrounded* in the solution by the polar water molecules.



Dissolution of Ionic Compounds in Water:

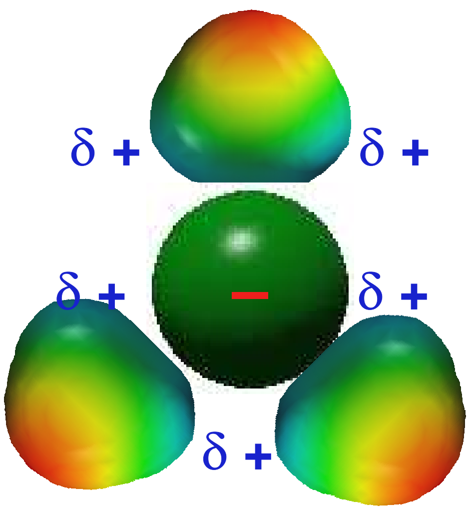
The positive end of the water molecule (the hydrogens) is attracted to the negative chloride ion,

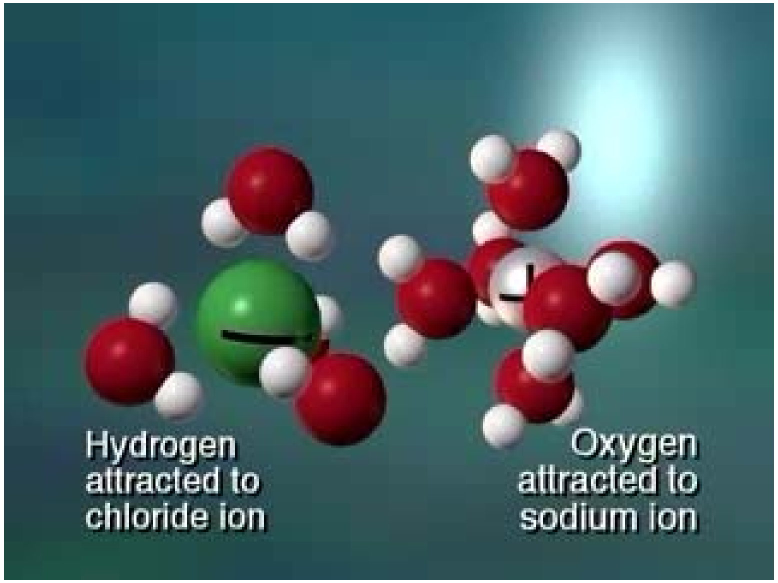


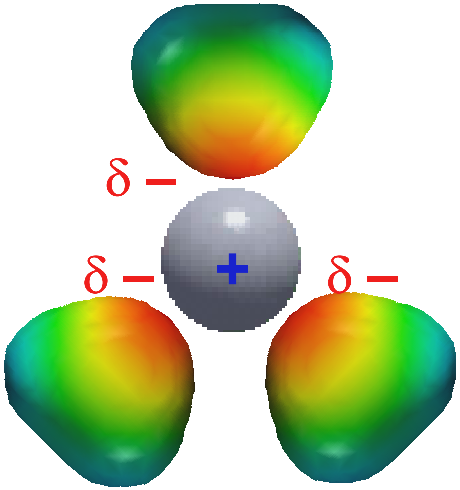


Dissolution of Ionic Compounds in Water:

The positive end of the water molecule (the hydrogens) is attracted to the negative chloride ion, and the negative end (the oxygen) is attracted to the positive sodium cation.







Solubility.

If a substance dissolves in a liquid, it is said to be *soluble* in that liquid. The term solubility gives the maximum amount of a substance that can dissolve in a given liquid under a set of defined conditions.

For example, at 298 K and 1.0 atm, $MgCO_3$ has a solubility in water of 0.53 g L^{-1}.

Solutions that contain the maximum amount of a substance that can dissolve in that liquid under the conditions specified are said to be *saturated*.

Solvent: Thing doing the dissolving.
Solute: Thing being dissolved.
Saturated: Solution holding the max amount of solute at a given condition, usually!

Honey. To make this delicious treat, foraging bees start out by guzzling nectar, a dilute solution of sugars in flowers. Then, they mix the nectar with enzymes in their stomach like honey sacs. Back at the hive, the foragers pass the digested material to house bees who reduce the moisture content of the mixture by ingesting and regurgitating it. They then deposit concentrated drops into honeycomb cells. Over the next few days, bees fan the fluid with their wings to further concentrate it, and finally, they cap the cells with wax. At the same time, enzyme-mediated changes produce a range of sugars and acids in the honey.

So honey is bee barf!

Electrolytes and Non-electrolytes.

A compound which dissolves in a polar liquid (such as water) to form ions will allow that solution to conduct an electric current. Such a compound is called an *electrolyte*.

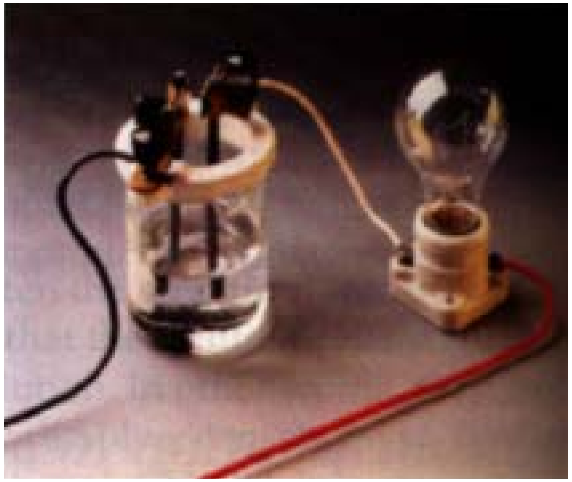
Compounds which dissolve, but do not allow the resulting solution to conduct electricity are called *non-electrolytes*.

Link to electrolyte/non-electrolyte

http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch18/soluble.php

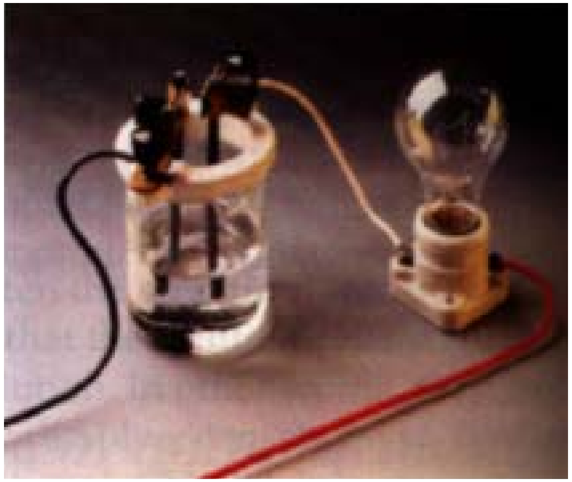
Electrolytes and Non-electrolytes.

The conductivity of a solution can be conveniently tested using a simple apparatus such as that shown below. A non-electrolyte, such as distilled water, will not conduct electricity and light the bulb, while the bulb glows brightly in an electrolyte, such as a salt solution.



Electrolytes and Non-electrolytes.

In general, compounds that can form **ions** in a solution will be **electrolytes** and compounds that **cannot form ions** (molecular substances) will be **non-electrolytes**.



Soluble ionic compound break up into ions in water .
If you can follow this idea, chem 112 will be a lot sweeter!
These ions, electrolytes, carry the charge.

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

$CaCl_2(s) \rightarrow Ca^{2+}(aq) + 2Cl^{-}(aq)$

$AlCl_3(s) \rightarrow Al^{3+}(aq) + 3Cl^{-}(aq)$

$Ca(NO_3)_2(s) \rightarrow Ca^{2+}(aq) + 2NO_3^{-}(aq)$

It is reallllllllly important in 112 you understand this!

Solutions in Chemistry

Many chemical reactions, especially those involving ionic compounds, take place readily in aqueous solution.

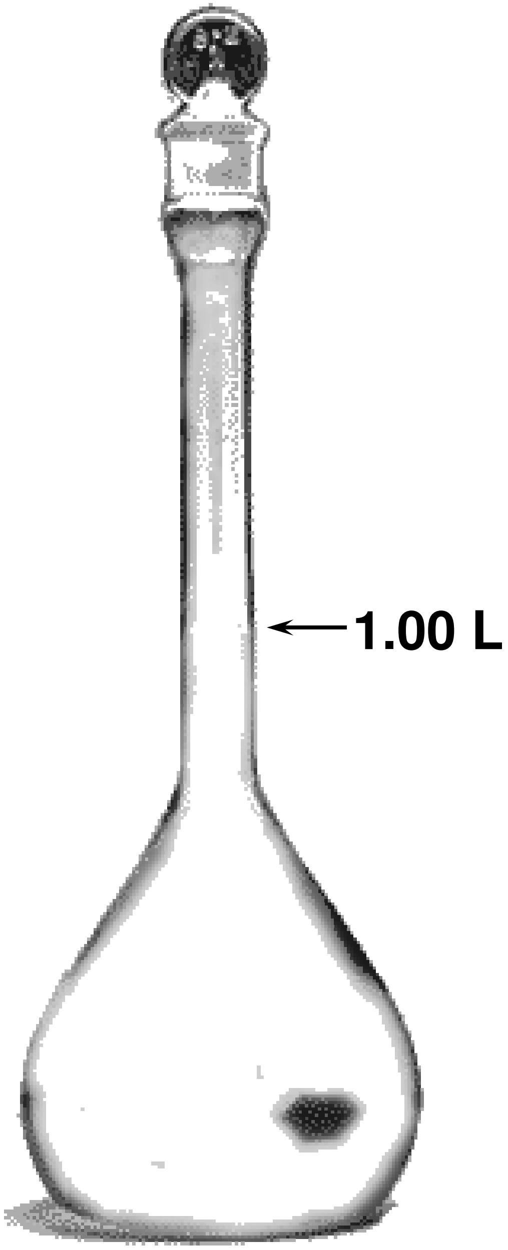
In order to be able to calculate the parameters for these reactions, it is necessary to know exactly how much of a given solute there is dissolved in a given amount of solvent.

Previously, we have used the concept of parts-per-million (ppm) to describe concentrations, but a more useful measure is molarity (M).

Concentration of Solutions

The **molarity** of a solution is simply defined as the **number of moles** of a solute dissolved in a given **volume** of solution:

$$\text{molarity, M} = \left(\frac{\textit{moles} \text{ of solute}}{\textit{volume} \text{ of solution, L}} \right)$$



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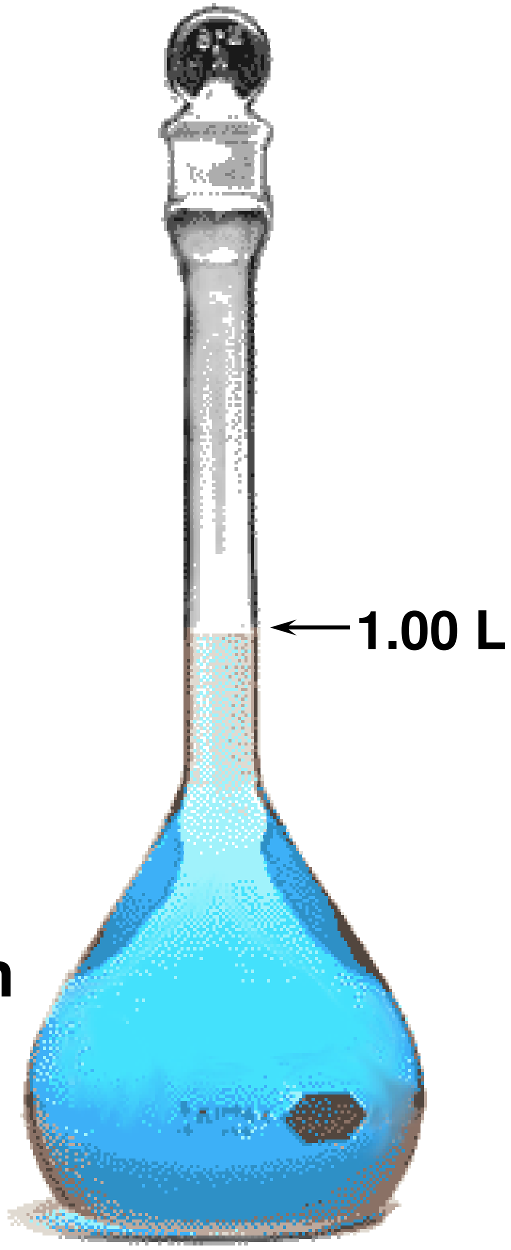
Experimentally, a solution with a known **molarity** can be prepared by diluting a known amount of solute with a carefully measured volume of solvent using a **volumetric flask**.



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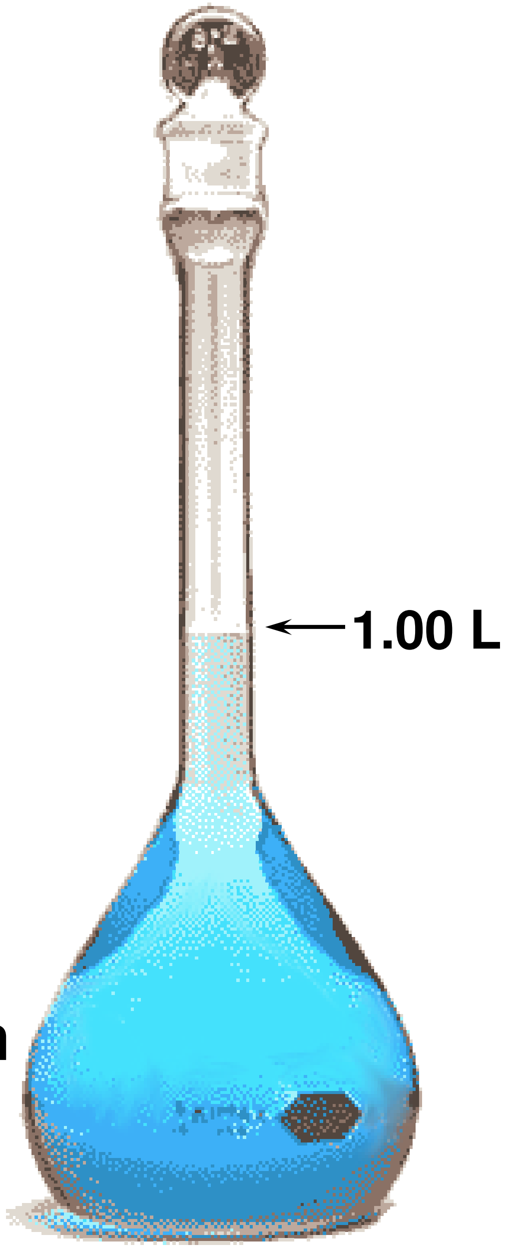

In-Class Problem:

A solution is prepared by dissolving 3.25 grams of NaBr in 1250.0 mL of solution. What is the molarity of this solution?

In order to calculate **molarity**, we need to know how many **moles** of NaBr there are in 3.25 grams of NaBr, and then divide that by the number of **liters**.

Given:

Mass = 3.25g

V = 1250.0 mL

Find:

Molarity M (mol/L)

$$M = moles/V$$

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M = moles/V

$$M = \frac{\left(\dfrac{3.25 \text{ grams NaBr}}{102.894 \text{ grams NaBr mol}^{-1}}\right)}{1.2500 \text{ L}} = 0.0253 \text{ moles L}^{-1}$$

[NaBr]= 0.0253 M

[ ] mean the concentration of whatever is inside

In-Class Problem:

What mass of sucrose ($C_{12}H_{22}O_{11}$) must be dissolved in 150 mL of distilled water in order to prepare a solution of sucrose that is 0.25 M?

Given:

V = 150 mL

$[C_{12}H_{22}O_{11}] = M_{sucrose} = 0.25$ M = 0.25 moles/L

Find:

Mass sucrose

In order to calculate grams, we need to know how many moles of sucrose there are in 150 mL of 0.25 M sucrose, and then multiply that by the number of grams mol^{-1} of sucrose.

$$M = \text{moles}/V$$

$$\text{moles} = M \times V$$

In-Class Problem:

What mass of sucrose ($C_{12}H_{22}O_{11}$) must be dissolved in 150 mL of distilled water in order to prepare a solution of sucrose that is 0.25 M?

moles = M x V

x moles of sucrose = (0.25 moles L^{-1})(0.15 L)

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= 0.0375 moles

x **grams of sucrose = (0.0375 moles)(342.295 grams mol^{-1})**

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= 13 grams

In-Class Problem:

A solution is labeled 2.5 M Na_2SO_4. How many *moles* of sulfate anions are present in 150 mL of this solution? How many *moles* of sodium ions are present in this same volume?

In order to calculate moles of ions, we need to know how many moles of Na_2SO_4 there are in 150 mL of 2.5 M Na_2SO_4 , and then multiply that by the number of sodium ions or sulfate anions in Na_2SO_4 .

$$Na_2SO_4(s) \dashrightarrow 2Na^+(aq) + SO_4^{2-}(aq)$$

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$$\text{moles} = M \times V$$

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$$x \text{ moles of } Na_2SO_4 = (2.5 \text{ moles } \cancel{L^{-1}})(0.15\ \cancel{L})$$

$$= 0.38 \text{ moles } Na_2SO_4$$

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$$Na_2SO_4(s) \dashrightarrow 2Na^+(aq) + SO_4^{2-}(aq)$$

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$$= 0.38 \text{ moles } Na_2SO_4$$

$$0.38 \text{ mol}\cancel{es} \; Na_2SO_4 \left(\frac{2 \text{ mole } Na^+}{1 \text{ mole } \cancel{Na_2SO_4}} \right) = 0.76 \text{ moles } Na^+$$

In-Class Problem:

A solution is labeled 0.180 M KCl. What *volume* of this solution must we use in order to have 0.010 moles of KCl?

Given:

M = 0.180 M KCl

moles = 0.010 moles KCl

Find:

V = ?L

M = moles/V

V = moles/M

In order to calculate the required volume, we simply need to divide moles by moles L^{-1}.

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In-Class Problem:

An experiment requires exactly 4.50×10^{-2} moles of HCl. The stock solution is labeled 0.368 M. what volume of this stock solution must you use?

Given:

Moles HCl = 4.50×10^{-2} moles

M = 0.368 M = 0.368 mole/L

Find:

V = ?

Again, in order to calculate the required volume, we simply need to divide moles by moles L^{-1}.

$$M = moles/V$$

$$V = moles/M$$

In-Class Problem:

An experiment requires exactly 4.50×10^{-2} moles of HCl. The stock solution is labeled 0.368 M. what volume of this stock solution must you use?

$$V = \text{moles}/M$$

$$x \text{ L of solution} = \left(\frac{4.50 \times 10^{-2} \text{ moles}}{0.368 \text{ moles L}^{-1}} \right)$$

In-Class Problem:

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$$x \text{ L of solution} = \left(\frac{4.50 \times 10^{-2} \text{ moles}}{0.368 \text{ moles L}^{-1}} \right)$$

$$= 0.122 \text{ L} \quad \textit{or} \quad 122 \text{ mL}$$

In-Class Problem:

Barium nitrate and sodium sulfate react to form barium sulfate which is insoluble in aqueous solution. How many grams of $BaSO_4$ will be formed when 15.0 mL of 0.998 M Na_2SO_4 reacts with an excess of $Ba(NO_3)_2$ solution?

$$Na_2SO_4 + Ba(NO_3)_2 \longrightarrow BaSO_4(s) + 2\ NaNO_3$$

In order to calculate grams of $BaSO_4$, we need to know how many moles of Na_2SO_4 there are in 15.0 mL of 0.998 M Na_2SO_4, and then multiply that by the number of grams mol^{-1} of $BaSO_4$.

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$$Na_2SO_4 + Ba(NO_3)_2 \longrightarrow BaSO_4(s) + 2\ NaNO_3$$

moles = M x V

$$x \text{ moles of } Na_2SO_4 = (0.998 \text{ moles } L^{-1})(0.0150 \text{ L})$$

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$$Na_2SO_4 + Ba(NO_3)_2 \longrightarrow BaSO_4(s) + 2\,NaNO_3$$

$$\text{moles} = M \times V$$

$$x \text{ moles of } Na_2SO_4 = (0.998 \text{ moles } \cancel{L}^{-1})(0.0150\ \cancel{L})$$

$$= 0.01497 \text{ moles } Na_2SO_4$$

Because the ratio of Na_2SO_4 to $BaSO_4$ is 1 to 1 we can get grams directly

$$x \text{ grams of } BaSO_4 = (0.01497 \text{ moles})(233.392 \text{ grams mol}^{-1})$$

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$$x \text{ grams of } BaSO_4 = (0.01497\ \cancel{\text{moles}})(233.392 \text{ grams } \cancel{\text{mol}}^{-1})$$

$$= 3.49 \text{ grams } BaSO_4$$

In-Class Problem:

Sulfuric acid and sodium hydroxide react to give sodium sulfate and water. In an experiment, 300.0 mL of 0.0215 M sodium hydroxide solution is required to *completely* react with a 100. mL sample of a sulfuric acid solution. What is the concentration of the sulfuric acid solution?

According to the equation, two moles of NaOH are required to react with one mole of H_2SO_4. Therefore, we simply need to calculate the number of moles of NaOH that there are in 300.0 mL of 0.0215 M solution and divide that by two to get moles of H_2SO_4. To get concentration, we need to then divide by 0.100 L.

$$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O$$

In-Class Problem:

Sulfuric acid and sodium hydroxide react to give sodium sulfate and water. In an experiment, 300.0 mL of 0.0215 M sodium hydroxide solution is required to *completely* react with a 100. mL sample of a sulfuric acid solution. What is the concentration of the sulfuric acid solution?

$$\text{moles} = M \times V$$

$$x \text{ moles of NaOH} = (0.0215 \text{ moles L}^{-1})(0.3000 \text{ L})$$

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$$

In-Class Problem:

Sulfuric acid and sodium hydroxide react to give sodium sulfate and water. In an experiment, 300.0 mL of 0.0215 M sodium hydroxide solution is required to *completely* react with a 100. mL sample of a sulfuric acid solution. What is the concentration of the sulfuric acid solution?

$$\text{moles} = M \times V$$

$$x \text{ moles of NaOH} = (0.0215 \text{ moles } L^{-1})(0.3000 \; L)$$

$$= 6.45 \times 10^{-3} \text{ moles NaOH}$$

$$6.45 \times 10^{-3} \text{ moles NaOH} \left(\frac{1 \text{ mole } H_2SO_4}{2 \text{ moles NaOH}} \right)$$

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$$

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$$6.45 \times 10^{-3} \cancel{\text{moles}} \text{ NaOH} \left(\frac{1 \text{ mole } H_2SO_4}{2 \cancel{\text{moles}} \text{ NaOH}} \right)$$

$$= 3.225 \times 10^{-3} \text{ moles } H_2SO_4$$

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$$

In-Class Problem:

Sulfuric acid and sodium hydroxide react to give sodium sulfate and water. In an experiment, 300.0 mL of 0.0215 M sodium hydroxide solution is required to *completely* react with a 100. mL sample of a sulfuric acid solution. What is the concentration of the sulfuric acid solution?

$$M = \text{moles}/V$$

$$[H_2SO_4] = M\ H_2SO_4 = \left(\frac{3.225 \times 10^{-3} \text{ moles } H_2SO_4}{0.100 \text{ L}} \right)$$

0.0322 M H_2SO_4

$$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O$$

In-Class Problem: Dilution problems

A solution of sodium chloride is 0.53 M. A 500. mL aliquot of this solution is diluted to a final volume of 1750. mL. What is the final concentration of sodium chloride in the diluted solution?

In this problem, the number of moles does not change, only the volume. Moles can be calculated by (volume x molarity); therefore we need to set up an equation relating the initial and final states.

$$(L)(\text{moles } L^{-1}) = \text{moles}$$

$$V_1 C_1 = V_2 C_2$$

C = concentration

In-Class Problem:

A solution of sodium chloride is 0.53 M. A 500. mL aliquot of this solution is diluted to a final volume of 1750. mL. What is the final concentration of sodium chloride in the diluted solution?

$$V_1 C_1 = V_2 C_2$$

$$(0.500 \text{ L})(0.53 \text{ M}) = (1.750 \text{ L})(C_2)$$

$$C_2 = \frac{(0.500 \text{ L})(0.53 \text{ M})}{1.750 \text{ L}}$$

In-Class Problem:

A solution of sodium chloride is 0.53 M. A 500. mL aliquot of this solution is diluted to a final volume of 1750. mL. What is the final concentration of sodium chloride in the diluted solution?

$$V_1 C_1 = V_2 C_2$$

$$(0.500\ L)(0.53\ M) = (1.750\ L)(C_2)$$

$$C_2 = \frac{(0.500\ \cancel{L})(0.53\ M)}{1.750\ \cancel{L}}$$

$$= 0.15\ M$$

In-Class Problem:

Calcium metal reacts with water to produce calcium hydroxide and hydrogen gas. A sample of calcium metal weighing 0.21 grams is reacted with 100. mL of water. After the reaction is completed, the solution is diluted with distilled water to a volume of 500.0 mL. What is the final concentration of hydroxide anion in the solution?

$$Ca + 2\,H_2O \longrightarrow Ca(OH)_2 + H_2\,(g)$$

According to the equation, one mole of Ca produces two moles of hydroxide anion. Therefore, we simply need to calculate the number of moles of Ca that there are in 0.21 grams of Ca and multiply that by two to get moles of OH^-. To get the final concentration, we need to then divide by 0.500 L.

$$Ca(OH)_2 \text{ --> } Ca^{2+} + 2OH^-$$

In-Class Problem:

Calcium metal reacts with water to produce calcium hydroxide and hydrogen gas. A sample of calcium metal weighing 0.21 grams is reacted with 100. mL of water. After the reaction is completed, the solution is diluted with distilled water to a volume of 500.0 mL. What is the final concentration of hydroxide anion in the solution?

$Ca(OH)_2 \text{ --> } Ca^{2+} + 2OH^-$

$$x \text{ moles of Ca} = \left(\frac{0.21\ \text{g}}{40.08\ \text{g mol}^{-1}} \right)$$

In-Class Problem:

Calcium metal reacts with water to produce calcium hydroxide and hydrogen gas. A sample of calcium metal weighing 0.21 grams is reacted with 100. mL of water. After the reaction is completed, the solution is diluted with distilled water to a volume of 500.0 mL. What is the final concentration of hydroxide anion in the solution?

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$$

$$x \text{ moles of Ca} = \left(\frac{0.21 \text{ g}}{40.08 \text{ g mol}^{-1}} \right)$$

$$= 5.2 \times 10^{-3} \text{ moles Ca}$$

$$5.2 \times 10^{-3} \text{ moles Ca} \left(\frac{2 \text{ mole OH}^-}{1 \text{ mole Ca}} \right)$$

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$$Ca(OH)_2 \text{ --> } Ca^{2+} + 2OH^-$$

$$x \text{ moles of Ca} = \left(\frac{0.21 \text{ g}}{40.08 \text{ g mol}^{-1}} \right)$$

$$= 5.2395 \times 10^{-3} \text{ moles}$$

$$5.2395 \times 10^{-3} \text{ moles Ca} \left(\frac{2 \text{ mole OH}^-}{1 \text{ mole Ca}} \right) = 0.010479 \text{ moles OH}^-$$

In-Class Problem:

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$Ca(OH)_2 \text{ --> } Ca^{2+} + 2OH^-$

$$M = \text{moles}/V$$

$$[OH^-] = \text{concentration } OH^- = \frac{0.010479 \text{ mole } OH^-}{0.5000 \text{ L}}$$

$$= 0.0209581 \text{ M} = 0.021 \text{ M } OH^-$$