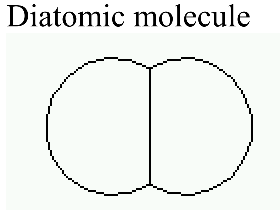
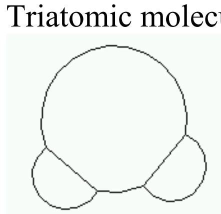
Chemistry

Chemical Names and Formulas
Lesson 5
Lesson Plan
David V. Fansler

Intro to Chemical Bonding

Objectives: Distinguish between ionic and molecular compounds; Define cation and anion and relate them to metal and nonmetal

- Molecules and Molecular Compounds
    - While there are only ~ 100 elements, they form millions of compounds
    - Only the noble gases exist as isolated atoms
        - Monatomic – a single atom
        - He, Ne, Ar
    - Most elements occur as **molecules**
        - Smallest electrically neutral unit of a substance that still has the properties of the substance
            - Oxygen occurs as 2 atoms (O_2)
            - Ozone occurs as 3 atoms (O_3)
    - When atoms of different elements combine chemically to form compounds made of molecules, they are called **molecular compounds**
        - Molecular compounds tend to have relatively low melting and boiling points, thus occur as gases or liquids at room temperature
        - Molecular compounds tend to be composed of two or more nonmetals
            - CO – one atom of carbon and one atom of oxygen
                - Poisonous gas from burning of petrochemical products
                - Diatomic molecule
                - 
            - H_20 – two atoms of hydrogen and one oxygen atom
                - Triatomic molecule
                - 

- Ions and Ionic Compounds
    - Not all compounds are molecular
    - Many compounds are composed of ions
        - Atoms or groups of atoms that have a positive or negative charge
        - Formed when an atom or group of atoms loses or gains electrons
        - Take Sodium (Na) atomic number of 11
            - At atom of Na has 11 protons and 11 electrons for a net charge of 0
            - In forming a chemical compound, an atom of Na tends to loose an electron – the number of electrons no longer equals the number of protons and the atom of Na becomes an ion – the Na ion has a +1 charge
    - Metallic elements atoms tend to form ions by loosing one or more electrons
        - These ions with a positive charge are called **cations**
        - They are written by using the symbol and indicating the charge as a superscript on the right
            - For a +1 charge, the 1 is understood and only the + is displayed
            - Na^{+}, Mg^{2+}
    - For metals, the name of the cation is the same as the element + cation
        - Mg^{2+} magnesium cation, Al^{3+} aluminum cation
        - Cations are often very different from the same elements
            - Na is very reactive in water Na^{+} is not (such as in table salt)
    - Nonmetallic element atoms tend to form ions by gaining one or more electrons
        - These ions with a negative charge are called **anions**
        - The are written by using the symbol and indicating the charge as a superscript on the right
            - For a –1 charge, the 1 is understood and on the – is displayed
            - Cl^{-}, O^{2-}
            - The name of an anion is not the same as the element – typically the name ends in ide (oxide, sulfide or bromide)
- Compounds composed of cations and anions are called **ionic compounds**
    - Ionic compounds are usually composed of metal cations and nonmetal anions

- NaCl – Sodium Chloride (sodium cations, chloride anions)
- Ionic compounds are electrically neutral
- Ionic compounds are usually solid crystals at room temperature and have high melting points

Characteristics of Molecular and Ionic Compounds		
Characteristic	Molecular compound	Ionic Compound
Representative Unit	Molecule	Formula unit (balance of oppositely charged ions)
Types of elements	Nonmetallic	Metallic combined with nonmetallic
Physical State	Solid, liquid or gas	Solid
Melting Point	Low (usually below 300ºC)	High (usually above 300ºC)

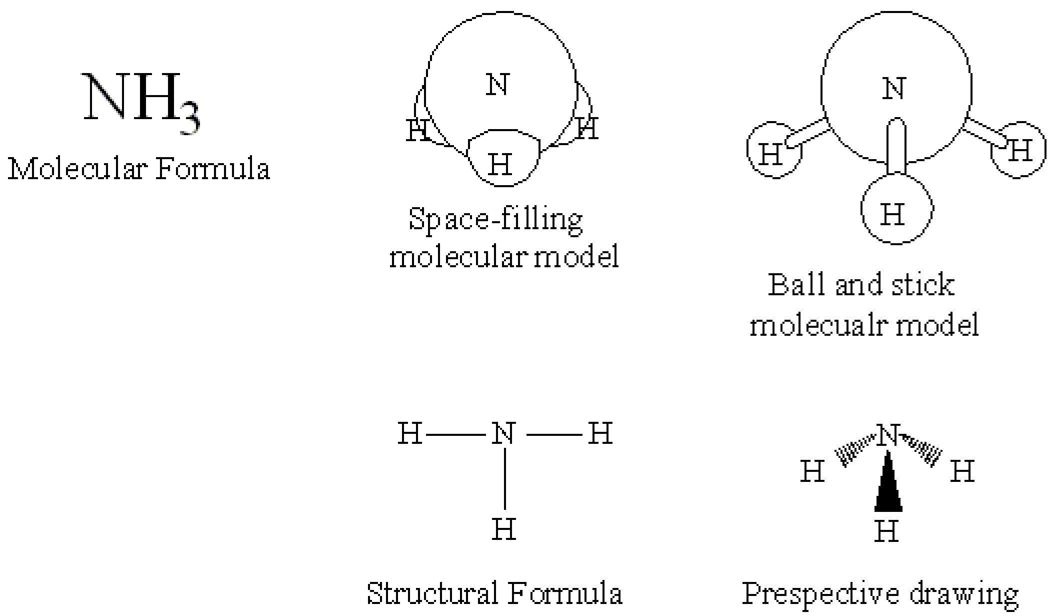
Representing Chemical Compounds

Objectives: Distinguish among chemical formulas, molecular formulas, and formula units; Use experimental data to show that a compound obeys the law of definite proportions

-Representing Chemical Compounds

- Chemists have identified over 10 million chemical compounds
  - Some are molecular
    - Proteins and hormones in your body
  - Some are ionic compounds
    - Salts in body fluids
- A **chemical formula** shows the kinds and numbers of atoms in the smallest representative unit of the substance
  - Monatomic elements are just their symbol
    - He, Ne
  - If molecules of an element have more than one atom, a number is used as a subscript
    - H_2, F_2, Cl_2, Br_2, I_2, O_2, N_2, O_3
- A **molecular formula** shows the kinds and numbers of atoms present in a molecule of a compound
  - H_2O shows that a water molecule has 2 hydrogen and 1 oxygen atom
    - The subscript showing how many of each atoms of each element are present (if 1, the one is understood and not written)
    - CO_2 – carbon dioxide 1 carbon and 2 oxygen atoms
    - C_2H_6 – ethane (natural gas) 2 carbon and 6 hydrogen atoms

        - NH_3 – ammonia gas 1 nitrogen and 3 hydrogen atoms
- While a molecular formula shows the composition of a molecule, it does not tell you about the molecule's structure
    - There are several diagrams and models that can be used to show the arrangement of a molecule



    - Formula Units
        - Chemical formulas can be written for ionic compounds
            - Formula does not represent a molecule
            - Most ionic compounds occur as solid crystals
                - NaCl – salt is arranged as a continuous array of ions – no separate molecular units
        - To represent an ionic compound the **formula unit** is used – the lowest whole number ratio of ions
            - For NaCl it is 1:1 (one Na^+ and Cl^-)
                - While we use the charges to get the formula unit, we do not show the charges in the formula unit
            - For magnesium chloride, we have magnesium cations (Mg^{2+}) and chloride anions (Cl^-). The ratio of magnesium cations to chloride anions is 2:1, giving us a formula unit of MgCl2 – since there are twice as many chloride anions as magnesium cations.
            - For $AlCl_3$? (1:3)
        - Remember that there is no molecule of sodium chloride or magnesium chloride – instead these compounds exist as a

collection of positively and negatively charged ions arranged in a repeating 3D pattern.

- The Laws of Definite and Multiple Proportions
  - If you had 100.0 g of magnesium sulfide (MgS) and could break it down into magnesium and sulfur, you would always get 43.13 g of magnesium and 56.87 g of sulfur.
    - The ratio of their masses is $\frac{43.13}{56.87} = .7584:1$
    - No matter how small or how large the sample of MgS, you will always have this ratio
  - **The law of definite proportions** states that in samples of any chemical compound, the masses of the elements are always in the same proportions
  - Sometimes two elements can form more than one compound – oxygen and hydrogen
    - H_20 we know as water and has two hydrogen atoms for every one oxygen atoms
    - H_20_2 we know as hydrogen peroxide and has two hydrogen atoms for every two oxygen atoms
    - In every sample of hydrogen peroxide, 16.0g of oxygen are present for every 1.0 g of hydrogen
      - The mass ratio for oxygen to hydrogen is 16:1
    - In every sample of water, the mass ratio for oxygen and hydrogen is 8:1
    - So in a sample of hydrogen peroxide that has the same mass of hydrogen as a sample of water, the ratio of the masses of oxygen in the two compounds is 2:1
    - $\frac{16.0gO(in\_H_2O_2\_sample\_that\_has\_1gH)}{8.0gO(in\_H_2O\ \_sample\_that\_has\_1gH)} = \frac{16}{8} = \frac{2}{1} = 2:1$

- **Law of multiple proportions** – whenever two elements form more than one compound, the different masses of one element that combine with the same mass of the other element are in the ratio of small whole numbers
  - Compare CO and CO_2 (1:2)

Ionic Charges

Objectives: Use the Periodic Table to determine the charge on an ion; Define a polyatomic ion and give the names and formulas of the most common polyatomic ions

- Monatomic Ions
  - To write chemical formulas for ionic compounds, you must know the type of ions that atoms tend to form – the ionic charge

- Monatomic ions can often be determined by the periodic table
  - Group 1A elements loose 1 electron to have a +1 charge (cations)
    - Li^+, Na^+, K^+, Rb^+
  - Group 2A elements loose 2 electrons to have a +2 charge
    - Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}
  - Group 3A – only Al follows the rule loosing 3 electrons
    - Al^{3+}
- What is seen above is that the metals in Groups 1A, 2A and 3A loose electrons when they form cations
  - The ionic charge is positive and numerically equal to the group number

- For Group A Non-Metals
  - Subtract the group number from 8
    - Remember that non-metals tend to gain electrons (thus are negatively charged) and are called anions
    - For Group 5, 8-5 = 3
      - N^{3-}, P^{3-}, As^{3-}
    - For Group 6, 8-6 = 2
      - O^{2-}, S^{2-}, Se^{2-}
    - For Group 7, 8-7 = 1
      - F^-, Cl^-, Br^-, I^-

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Ionic Charges of Representative Elements							
1A	**2A**	**3A**	**4A**	**5A**	**6A**	**7A**	**0**
Li^+ Na^+ K^+, Rb^+ Cs^+	Be^{2+} Mg^{2+} Ca^{2+} Sr^{2+} Ba^{2+}	Al^{3+}		N^{3-} P^{3-} As^{3-}	O^{2-} S^{2-} Se^{2-}	F^- Cl^- Br^- I^-	

- Note that Group 4A and 0 are empty - they usually do not form ions
  - Group 0 rarely form compounds
  - The 2 non-metals in Group 4A (carbon and silicon) are found in molecular compounds

- Transition Metals
  - Typically have more than one common ionic charge
    - Iron for example can be Fe^{2+} and Fe^{3+}
  - There is a naming scheme for such cations

- The Stock System
  - A Roman numeral is placed after the name of the element, in parentheses to indicate the value of the charge
  - Fe^{2+} would be iron(II) – iron 2 ion
  - Fe^{3+} would be iron(III) – iron 3 ion
- Older method uses a root word with a suffix
  - The suffix *ous* is used for the cation with the lower of two ionic charges
  - The suffix *ic* is used for the cation with the higher of two ionic charges
  - So Fe^{2+} would be ferrous cation
  - And Fe^{3+} would be the ferric cation
  - Name does not tell you the charge of the ion, only which has the larger charge and which has the smaller charge
- A few transition metals have only one ionic charge – these cations do not have a Roman numeral

- Polyatomic Ions
  - Monatomic ions are composed of only one type of element
  - Polyatomic ions are composed of 2 or more elements
    - Sulfate ion is SO_4^{2-}, one sulfur atom and four oxygen atoms with a –2 charge
    - Polyatomic ions are tightly bound groups of atoms that behave as a unit and carry a charge
  - Most polyatomic ions are anions (have a – charge)
    - Most notable exception is NH_4^+ - ammonium
- Most common polyatomic ions end in *ite* or *ate*
  - Most notable exceptions are ammonium cation, and the cyanide (CN^-)and hydroxide ions (OH^-)
  - Examine the following polyatomic ions for a pattern
  -

-ite	*-ate*
SO_3^{2-}, sulfite	SO_4^{2-}, sulfate
NO_2^-, nitrite	NO_3^-, nitrate
ClO_2^-, chlorite	ClO_3^-, chlorate

  - The charge on the pairs is the same, but the *ite* endings indicate one less oxygen than the *ate* ending
    - This does not tell us the number of oxygen atoms in the ion – just which has more
- When an ion begins with hydrogen, it is easiest to imagine that a hydrogen ion (H^+) has combined with another polyatomic ion. The resulting ion carries the algebraic sum of the charges
  - $H^+ + CO_3^{2-}$ yields HCO_3^- (hydrogen + carbonate = hydrogen carbonate)
  - $H^+ + PO_4^{3-}$ yields HPO_4^{2-} (hydrogen + phosphate = hydrogen phosphate)

- $H^+ + HPO_4^{2-}$ yields $H_2PO_4^{1-}$ (hydrogen + hydrogen phosphate = dihydrogen phosphate)
  - These three anions are important components to living systems
- CN^- is the cyanide ion – poisonous to living systems – blocks the cell's means of producing energy
- ClO^- is the hypochlorite ion – common to most laundry and household bleaches
- What would be the formula for the hydrogen sulfite polyatomic ion?
  - $H^+ + SO_3^{2-}$ yields HSO_3^-

Ionic Compounds

Objectives: Apply the rules for naming and writing formulas for binary ionic compounds; Apply the rules for naming and writing formulas for ternary ionic compounds

- Writing Formulas for Binary Ionic Compounds
  - Before chemistry was developed into a true science people name compounds whatever they wanted
    - Potash - K_2CO_3 – potassium carbonated - obtained by boiling ashes in iron pots
    - Laughing Gas – N_20 – dinitrogen monoxide – because people who inhaled it laughed.
    - Baking soda, Plaster of Paris, lye
    - These names do not tell you about the chemical composition of the compound
- As time passed by, chemistry became more structured and a naming convention was developed that could tell you a compounds composition
  - NaCl is an ionic compound (sodium chloride) composed of sodium cations (Na^+) and chloride anions (Cl^-).
    - Being composed of two elements, it is called a **binary compound**
    - The positive cation must balance the negative anion so that the net ionic charge of the formula is 0
      - For NaCl, there is one Na^+ ion for ever one Cl^- ion
      - The cation is written first
- For calcium bromide, another binary compound, calcium cation (Ca^{2+}) combines with the bromide anion (Br^-). Since calcium cations have a 2+ charge, it takes two bromide anions with a 1- charge to balance the end result – so there are the ratio would be 1:2 with a formula of $CaBr_2$.
- Rust – is iron(III)oxide.
  - iron(III) indicates the Fe^{3+} cation
  - oxide we know to be O^{2-} anion
  - When writing a compound the final result will have a net charge of 0 and be in the lowest whole number ratio
  - $Fe^{3+} + O^{2-} = Fe_2O_3$

- The simplest way to get the formula is to cross the superscript charges to become the subscript of the other ion – do not carry the sign
- Fe^{3+} ⟷ O^{2-} = Fe_2O_3
- To check we multiply the charge of the ion by it's new subscript and add the values together – it should equal 0
  - (3 x 2) + (-2 x 3) = 6 + -6 = 0
- If we do this for calcium sulfate, we have Ca^{2+} and S^{2-}
  - Crossing gives us Ca_2S_2, checking for net charge
    - (2 x 2) + (-2 x 2) = 4 + -4 = 0
  - However Ca_2S_2 is not the lowest whole number ratio
    - This can be reduced to CaS

- Naming Binary Ionic Compounds
  - We have written formulas for ionic compounds when given their names – how about naming an ionic compound
    - CuO – a binary ionic compound of copper and oxygen
      - The first impression would be copper oxide, however copper has two common cations copper(I) and copper(II) – so which would you use?
      - Working backwards, we note that there are no subscripts for either ion in the formula, there is a 1:1 ratio - whatever the ionic charge for O is, Cu would be the same – but opposite sign.
        - The oxygen ion is O^{2-}, so the copper ion must be a +2 for the net charge to be 0 – therefore the ionic compound is named copper(II) oxide
        - Recall that iron is another element that forms 2 cations Fe^{2+} and Fe^{3+}
    - Tin also comes in two cations with charges of 2+ and 4+
      - For SnO_2, which tin would be used?
      - The ratio is 1:2, meaning that there are twice as many oxide anions as tin cations to have a net charge of 0
      - Again, we know that the oxygen ion has a 2- charge, so (-2 x 2) = |4| (take the absolute value) – it must be tin(IV)
      - Tin(IV) oxide
      - What would you name SnO? tin(II) oxide

- Ternary Ionic Compounds
    - Have you ever seen a oyster shell or a pearl?
      - Calcium carbonate – $CaCO_3$ – an ionic compound
      - Notice that we have three elements making this compound: calcium, carbon and oxygen

        - Compounds with 3 elements are called ternary compounds
        - Ternary ionic compounds usually contain a polyatomic ion
            - In the case of $CaCO_3$ the CO_3 is the polyatomic ion carbonate - CO_3^{2-}
    - You write the formula for a ternary compound with a polyatomic ion just as you would a binary ionic compound
        - First write the formula (symbol and charge) for each ion
        - Balance the charges
        - For calcium carbonate
            - Ca^{2+} $(CO_3)^{2-}$
            - $Ca_2(CO_3)_2$
            - Since we want the lowest whole number ratios

              $Ca(CO_3) \longrightarrow CaCO_3$
            - For calcium nitrate
                - Ca^{2+} $(NO_3)^{1-}$
                - $Ca(NO_3)_2$
                - Parentheses are used to indicate that there are two nitrates for every calcium
            - For strontium sulfate
                - Sr^{2+} $(SO_4)^{2-}$
                - $SrSO_4$
                - No parentheses are needed since we have only 1 sulfate ion
            - For lithium carbonate
                - Li^{+} $(CO_3)^{2-}$
                - Li_2CO_3
                - Parentheses again are not needed since there is only 1 carbonate ion, even though there are 2 lithium ions
    - Naming Ternary Ionic Compounds
        - You must first recognize the polyatomic ion
        - Name the cation first, then add the name of the polyatomic anion
            - $K_2Cr_2O_7$
            - Two K^{+} cations and one $Cr_2O_7^{2-}$ anion
            - Potassium dichromate

Molecular Compounds and Acids

Objectives: Apply the rules for naming and writing formulas for binary molecular compounds; Name and write formulas for common acids

- Binary Molecular Compounds
    - Remember that binary ionic compounds were composed of a metal and a non-metal

- Binary molecular compounds are composed of two non-metals
- This difference affects how we name and write molecular compounds
- Take carbon and oxygen – they can form two gaseous compounds CO and CO_2 (they also can form 2 different polyatomic ions CO_3^{2-} and $C_2O_4^{2-}$ - so always watch for exceptions!
    - What would you name a binary compound formed with carbon and oxygen atoms – carbon oxide?
    - CO and CO_2 – we could do this but as we know they are different gases with different characteristics
        - CO is deadly to breath and we give off CO_2 when we breathe
- A naming convention is called for – the use of prefixes

Prefixes Used in Naming Binary Molecular Compounds	
Prefix	Number
mono-	1
di-	2
tri-	3
tetra-	4
penta-	5
hexa-	6
hepta-	7
octa-	8
nona-	9
deca-	10

- Prefixes tell how many atoms of each element are present in each molecule (and in the formula)
- For CO – carbon monoxide
    - Do not use mono on the first element – not monocarbon
    - If the last element begins with a vowel, then drop the last letter of the prefix before it to the element – oxygen becomes monoxide not monoxide
    - And lastly, for binary molecular compounds, the ending element is changed to *ide*
- CO_2 would be written carbon dioxide
- Writing formulas for binary molecular compounds – just use the prefixes to tell you the subscripts of each element
    - What is the formula for carbon tetrachloride – CO_4
        - a toxic substance that used to be used in dry cleaning
    - tetraiodine nonoxide I_4O_9
    - sulfur trioxide SO_3
    - phosphorus pentafluoride PF_5

- Naming Common Acids
  - What do you know about acids?
  - They are a special group of compounds – several definitions
    - For now – they are compounds that produce H ions when dissolved in water
    - Consider them to be combinations of anions connected to as many hydrogen ions H^+ as are needed to make them electrically neutral
    - Acids are used in industry
      - Steel manufacturing
      - Fertilizer manufacturing

Common Acids to Know	
Hydrochloric Acid	HCl
Sulfuric Acid	H_2SO_4
Nitric Acid	HNO_3
Acetic Acid	$HC_2H_3O_2$
Phosphoric Acid	H_3PO_4
Carbonic Acid	H_2CO_3