PHYSICAL SCIENCE 20 (PRE-AP CHEMISTRY)

UNIT TWO

ATOMS, MOLECULES AND IONS

I CAN…

- Describe the **history of atoms**, beginning with John Dalton's work.
- **Explain *landmark* discoveries** with respect to the substructures of the atom which provided the foundation of the nuclear model of the atom.
- **Use terms to describe modern atomic theory** which include: atomic number, mass numbers and isotopes.
- **Provide in depth explanation of atomic weights** and the relation to atomic masses of individual atoms.
- **Examine the periodic table and the trends** that the elements exhibit with respect to location on the table and the family it resides in.

THE ATOMIC THEORY OF MATTER

- For centuries there have been people who speculated about the **fundamental nature of matter**.
- Democritus theorized that matter was built of '**tiny indivisible particles'** called ***atomos*** but this idea was lost due to Aristotelian philosophies.
- It was not until the 17th century that the idea of atoms re-emerged due to the work of John Dalton. Chemists of the time were beginning to understand the **connection between atoms and elements**.

THE ATOMIC THEORY OF MATTER

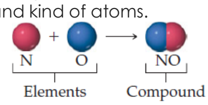
- Dalton devised a new atomic theory based on the understandings of his time (e.g., *law of conservation of mass*).
  - Each element is composed **of extremely small particles called atoms**.

  - All atoms of a given **element are identical**, but the atoms of one element are different from the atoms of all other elements.

THE ATOMIC THEORY OF MATTER

- Atoms of one element **cannot be changed** into atoms of different element buy chemical reactions; atoms are neither created or destroyed.

- **Compounds** are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms.



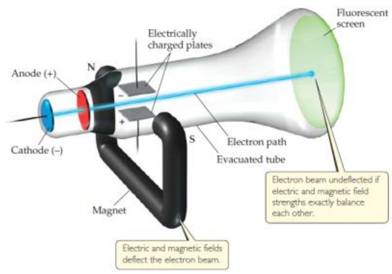
ATOMIC SUBSTRUCTURE

- Dalton's work was based on experimental data, neither him nor the 100 years of scientists after him had direct proof of the atom.
- Today we know that the atom has component particles by using the simple fact:

Particles with the same charge repel one another, whereas particles with opposite charges attract.

CATHODE RAYS & ELECTRONS

- Scientists in the mid-1800's began to experiment with tubes pumped empty of air.
- When a high voltage was applied to this 'vacuum' tube radiation **(cathode rays)** was produced between the electrodes.
- While the rays themselves could not be seen it caused the material in the tube to ***fluoresce*** (glow)



CONSIDER…

1. How do we know that cathode rays travel from **cathode (−) to anode (+)**?
2. If no **magnetic field** were applied, would you expect the electron beam to be deflected upward or downward by the electric field?

CATHODE RAYS SIGNIFICANCE

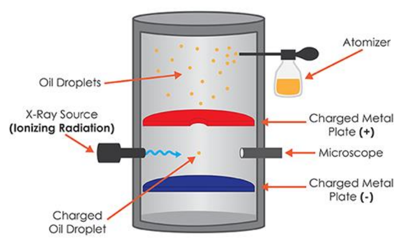
- In 1897 Thomson published a paper stating that the cathode rays were steams of negatively charged particles, regardless of the cathode material. This paper is considered to be the discovery of what eventually would become the 'electron'.
- Using the two perpendicular fields Thomson was able to discover the charge to mass ratio of the electron:

1.76×10^8 coulomb per gram

MILLIKEN DROP EXPERIMENT

- Once the charge to mass ratio was discovered, scientists would be able to measure either quantity to calculate the other.
- In 1909 Robert Milliken used the oil-drop experiment to determine the charge of a single electron to be:

1.602×10^{-19} Coulombs



MASS OF THE ELECTRON

$$\text{Electron Mass} = \frac{1.602 \times 10^{-19}\text{C}}{1.76 \times 10^{8}\ \text{C/g}} = 9.10 \times 10^{-28}\ \text{g}$$

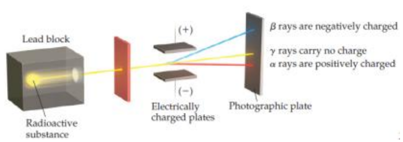
- Despite technological limitations of 1909, this result agrees well with the current accepted value for electron mass.
- What important conclusion can be drawn about the mass of the first* discovered subatomic particle?

RADIOACTIVITY

- Radiation, as discovered by Henri Becquerel in 1896, was the emission of energy.
- Further work by Marie Curie and her husband, Pierre, determine there were three types:
  - Alpha (α) – These fast moving particles were attracted to a negative plate, with +2 charge.
  - Beta (β) – These particles were attracted to a positive plate with a -1 charge.
  - Gamma (γ) – No particle, nor charge but very high energy levels.

EXAMPLE: RADIOACTIVITY

1. Which type of radiation consists of electrons?
2. Why is the degree to which they are deflected greater than the other radiation types?

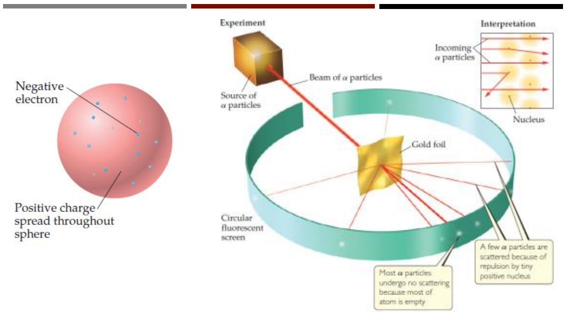


NUCLEAR MODEL OF THE ATOM

- By the 1900's there was a growing bank of evidence the atom consisted of smaller particles.
- JJ Thomson surmised that because of the mass of the electron was very small, it stands to reason that it contributes very little to the size of the atom.
- He compared the atom to a watermelon (seeds=electrons) or ***plum pudding*** were the electrons were negative particles embedded in a positive 'dough'

NUCLEAR MODEL OF THE ATOM

- In 1910 Ernest Rutherford conducted experiments investigated the degree to which alpha particles scatted when passed through a thin sheet of **gold foil**.
- **Most of the atoms** passed right through the gold foil, those that interacted showed only deflection of about 1 degree.
- For the sake of completeness, Rutherford searched for evidence of large angle scattering. To his surprise not only was there same **large angle scattering** but **evidence of particles coming back in the direction of the source**.



NUCLEAR MODEL OF THE ATOM

- Rutherford explained the results by postulating the nuclear model of the atom.
- He stated that most of the **atom was empty space**, with a extremely **region of dense matter** (positively charged) in the center **called the *nucleus***.
- Subsequent experiments lead to the discovery of the proton (1919) and the neutron (1932).
- The atom is comprised of three subatomic particles, **the electron, proton and neutron.**

MODERN VIEW OF ATOMIC STRUCTURE

- Since 1932, scientists have continued to advance the understandings of the atom.
- Chemistry only deals with **three subatomic particles** (electron, proton and neutron) as they are the only ones that have bearing on chemical bonding.

MODERN VIEW OF ATOMIC STRUCTURE

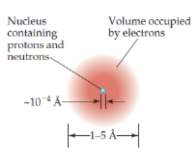
- While **electric charge is measured in coulombs** (the electron having a 1.602×10^{-19} C, proton has the same magnitude though opposite charge) **we refer to these charges as -1 or +1 respectively**.
- It is important to note that all ***atoms* have equal number of electrons as protons,** therefore atoms have no net charge.
- Protons and neutrons reside in the nucleus, electrons occupy a large space outside.

ATOMIC MASS

- Atoms have extremely small masses (about 4×10^{-22} g). Instead of using grams we use ***atomic mass units* which is equivalent to 1.66054×10^{-24} g**.
- Protons have an mass of 1.0073 amu, a neutron is 1.0087 and an electron is 5.486×10^{-4} amu.
  - It takes 1836 electrons to be equivalent to the mass of one proton or neutron therefore the ***vast majority of mass* is in the nucleus of the atom**.

ATOMIC SIZE

- Atoms are measured in a non-SI unit called the **Angstrom (Å) which is equal to 1×10^{-10} m**.
- **Atoms range** from 1×10^{-10} m to 5 10^{-10} m, thus **1-5 Å**
  - Chlorine is approximately 200 pm, therefore 2.0 Å



EXAMPLE: ATOMIC DIMENSION

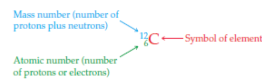
- The diameter of a dime is 17.9 mm, and the diameter of a silver atom is 2.88Å. How many atoms could be arranged side by side across the diameter of a dime?

ATOMIC NUMBERS, MASS NUMBERS, AND ISOTOPES

- The number of protons determines the characteristic of an element. The number of protons is called the **atomic number**.
- Because atoms have no net charge the number of protons is **equal to the number of electrons**.
  - All carbon atoms have 6 protons, and therefore 6 electrons.
  - All oxygen atoms have 8 protons, and therefore 8 electrons.
- While all atoms of an element have the same number of protons and electrons, the **number of neutrons can vary.** These are called isotopes.

ISOTOPE NOTATION

- While the number of neutrons does not impact chemical bonding to a significant degree sometimes the type of isotope is important to designate.
- In the notation shown to the right the top number is referred to as the **mass number** (number of neutrons and protons) while the bottom number refers to **the number of protons**.



ISOTOPES

- Because all atoms of an element will have the same number of protons variations are usually identified by the mass number.
  - $^{12}_{6}C$ is referred to as carbon-12, while $^{14}_{6}C$ is referred to as carbon-14.

TABLE 2.2 • Some Isotopes of Carbon*

Symbol	Number of Protons	Number of Electrons	Number of Neutrons
^{11}C	6	6	5
^{12}C	6	6	6
^{13}C	6	6	7
^{14}C	6	6	8

EXAMPLE: ISOTOPE NOTATION

- How many protons, neutrons and electrons are in each of the following:

  a) An atom of ^{197}Au?

  b) An atom of strontium-90?
- Write the isotope notation for magnesium with mass numbers 24, 25 and 26.

THE ATOMIC MASS SCALE

- Scientists in the 19th century knew different elements had different masses. They were to separate 100.0 grams of water into 11.1 grams of hydrogen and 88.9 g of oxygen.
- Eventually as they better understand the structure of compounds they were able to determine that oxygen's mass was roughly 16 times that of hydrogen.
- Using hydrogen (eventually carbon-12) as the standard they began to record the atomic masses of each element.

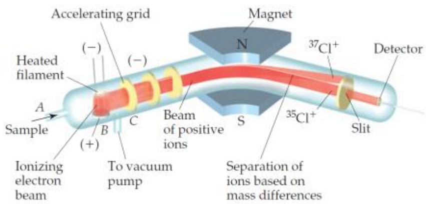
ATOMIC WEIGHT

- Most elements occur naturally with more than one isotope.
- Chemists generally use large numbers of atoms in experiments and therefore use the *weighted* average of atoms to determine the atomic weight of an element.

Atomic Weight = Σ[(isotope mass × fractional abundance)]

{over all isotopes of the element}

MASS SPECTROMETER



EXAMPLE: ATOMIC WEIGHT OF CARBON

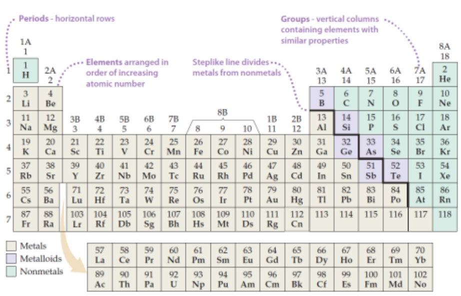
- Naturally occurring carbon is composed of 98.93% carbon-12 and 1.07% carbon-13. The masses of these are exactly 12.00000 and 12.00335 amu respectively. Determine the average atomic mass of carbon.

EXAMPLE: ATOMIC WEIGHT OF CHLORINE

- Naturally occurring chlorine is 75.78% ^{35}Cl (atomic mass 34.969 amu) and 24.22% ^{37}Cl (atomic mass 36.966 amu). Calculate the atomic weight of chlorine.

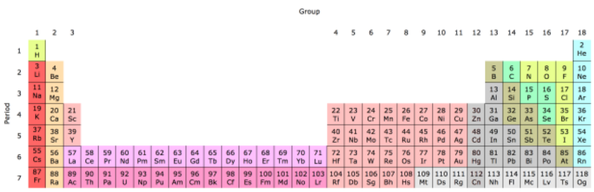
THE PERIODIC TABLE

- As the list of known elements increased in the 1800's, scientists of the day attempted to organize the periodic table into **groups of similarity**.
- When arranged by reactivity patters the periodic table exhibited **periodicity**.
- The periodic table is the most significant tool chemists use for organizing and remembering chemical facts.



PERIODS

- The first period contains only two elements (hydrogen and helium)
- The second period and third periods contain 8 elements each.
- Fourth and fifth periods have 18 elements.
- Sixth and seventh periods have 32, but to save space 14 elements (57-70) are written below.



GROUPS

- There are **two systems** for applying **group designation**.
- Traditionally in North America the first two groups are 1A, 2A followed by the last 6. For example oxygen is 6A. The metals in between are labelled 3B-8B followed by 1B and 2B.
- IUPAC (International Union of Pure and Applied Chemistry) standardized this number for N.A and Europe by lasting them as 1-18 without any letter.
- Elements in a group show similar characteristics because of their electronic arrangement (discussed later)

GROUPS AND PERIODS

- The elements can be separated into three main categories: **metals, non-metals and metalloids**.
- **Metals** lie on the left side of the staircase and tend to be silver in color, high lustre and transmit heat and electricity well. There are far more metals than non-metals.
- **Non-metals** are to the right of the staircase and have few properties in common (e.g., many are in each state, different colors, reactivity).

GROUPS AND PERIODS

- The **metalloid elements** separate metals and non-metals. They 'touch' the staircase and have properties of both.
- This makes then unique suited for circuit (based on their conductivity profiles).

EXAMPLE: THE PERIODIC TABLE

1. Chlorine is a halogen, part of group 17 (7A).
   a. What is it's symbol?
   b. In which period and in which group is the element located?
   c. What is it atomic number?
   d. Is it a metal or non-metal?

EXAMPLE: PERIODIC TABLE

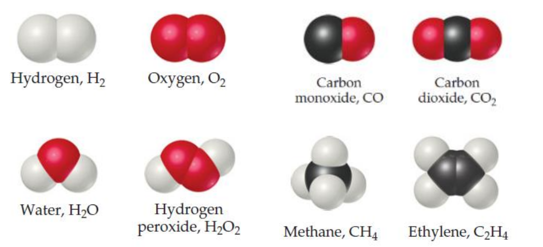
Which two of these elements would you expect to show the greatest similarity in chemical and physical properties: B, Ca, F, He Mg, and P?

MOLECULES AND MOLECULAR COMPOUNDS

- Several atoms in nature are found in **molecular form** – two or more of the same type of atom bound together.
  - For example oxygen binds to itself to form O_2 and O_3. Oxygen gas (O_2) is essential for life on Earth while ozone (O_3) is toxic.
- Atoms made up of two of the same element are **diatomic elements**.
  - The diatomic elements are (H, N, O, F, Cl, Br and I).

MOLECULES

- Atoms made of two or more elements bound to each other are called **molecular compounds**.
  - Methane (CH_4) is made of one carbon and 4 hydrogen atoms.
- Most molecular compounds will only have non-metals!



MOLECULAR AND EMPIRICAL FORMULA`S

- Chemical formula that show the actual number of atoms in a molecule are called the **molecular formula.**
- Chemical formula that show the relative number of atoms in a molecule are called **empirical formula**. To determine an empirical formula reduce whole number ratios by the same factor.
- For many compounds the **molecular formula and empirical formula are the same**.

EXAMPLE: EMPIRICAL FORMULA

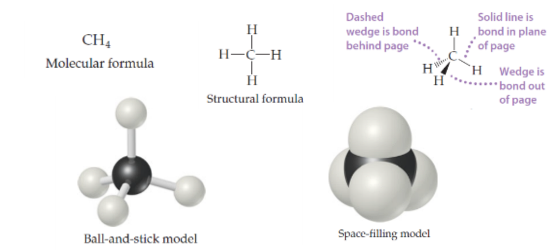
- Write the empirical formula for the following:

a. Glucose, a substance also known as either blood sugar or dextrose, molecular formula $C_6H_{12}O_6$

a. Nitrous oxide, a substance used as a anesthetic and commonly known as laughing gas, molecular formula N_2O

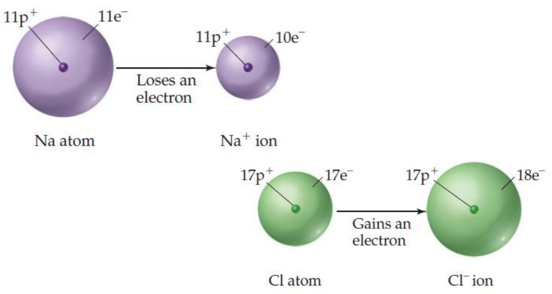
PICTURING MOLECULES

- There are many ways to show a molecule, each used for different purposes:
  - **Structural formula**: Used to determine aspect of the molecule (polarity) but does not show bond angles.
  - **Perspective Drawing:** These can be drawn to show 3D models, but atoms that are larger tend to be more difficult to draw.
  - **Ball and Stick** – Shows 3D shape with proper angles. Elements are identified by color.
  - **Space Filling Model** – Shows the approximate size of atom but is difficult to tell angle geometry.



IONS AND IONIC COMPOUNDS

- The nucleus of an atom does not change via chemical bond, however an atom can readily gain or lose electrons to form ions.
- Atoms that **gain electrons** form **anion**.
- Atoms that **lose electrons** form **cations**.
- For the most part non-metals form anions while metals form cations, thus **ionic compounds are the combination of a metal and a non-metal**.



EXAMPLE: IONS & NOTATION

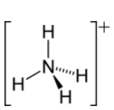
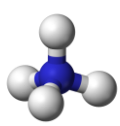
- Give the chemical symbol, including superscript indicating mass number, for:

a. The ion with 22 protons, 26 neutrons, and 19 electrons

a. The ion of sulfur that has 16 neutrons and 18 electrons.

POLYATOMIC IONS

- Polyatomic atoms, more than one atom joined as a molecule with a charge, (such as ammonium NH_4^+) can form ions too.
- It is important to note these ions are very different then the component elements within the group.

PREDICTING CHARGE

- Many atoms can or lose electrons to increase their **stability**.
- **Noble gases** are considered to be the most stable (non-reactive) and atoms work to gain or lose electrons.
  - For example sodium loses one electron to have the same number as nearby neon while chlorine gains one to have the same number as Argon.
- The **transfer of electrons is more complex** than this simple pattern but for now this can explain the formation of ions.

EXAMPLE: CHARGE

- Predict the charge of the most stable ion of the following:
  a. Oxygen
  b. Barium
  c. Nitrogen

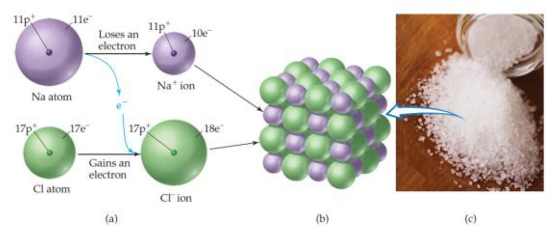
IONIC COMPOUNDS

- A large portion of chemistry deals with the transfer of electrons from one substance to the next.
- When a metal transfers an electron to a non-metal the metal **becomes positively charged** while the non-metal has an **overall negative charge**.
- Objects with opposite charges attract, therefore the opposite charged ions bind to form a **ionic compound**.

IONIC COMPOUNDS

- Ionic compounds only form 3D solids, they are not 'bonded' to each other and there no **discrete 'molecule'**.
- The formula of an ionic compound is *always* the **empirical formula** based on the charges.
- All ionic compounds must have a **neutral charge** (Na^+ and Cl^- has a net charge of zero)

$$Mg^{2+} \quad N^{3-} \longrightarrow Mg_3N_2$$



RULES

- **Ionic compounds** are usually (vast majority) the result of a **metal and non-metal** while,
- **Molecular compounds** are those in which the composition is only **non-metals**.
  - This will be discussed in further detail in chemical bonding.

EXAMPLE: COMPOUND TYPE

- Which of these compounds would you expect to be ionic: N_2O, Na_2O, $CaCl_2$, SF_4?
- Which of those compounds would you expect to be molecular: CBr, FeS, P_4O_6, PbF_2?

DISCUSSION

Explain why calcium oxide, formed by Ca^{2+} and O^{2-} **does not** have the formula Ca_2O_2 .

EXAMPLE: IONIC CHARGES W, FORMULAS

- Write the empirical formula of the compound formed by:
  - a. aluminium and chlorine
  - b. aluminium and oxygen
  - c. Magnesium and nitrate (NO_3^-) ions.

NOMENCLATURE

PAY ATTENTION!

IONIC COMPOUNDS

1. Cations

A. Cations formed from metal atoms have the same name.

Na^+	sodium ion	Zn^{2+}	zinc ion	Al^{3+}	aluminum ion

B. If a metal can form more than one cation then roman numerals are used to indicate the charge.

Fe^{2+}	iron(II) ion	Cu^+	copper(I) ion
Fe^{3+}	iron(III) ion	Cu^{2+}	copper(II) ion

MULTIVALENT METALS

- Group 1 and 2 metals will only ever form +1 and +2 cations respectively.
- Aluminum is always +3
- Of the transition metals, most form multiple ions, however silver will only form a +1 ion whereas zinc is only ever a +2.

DISCUSSION

Why is CrO named using Roman numerals, but CaO is not?

IONIC COMPOUNDS

2. Anions

A. The names of monoatomic anions are formed by replacing the ending of the name of the element with –ide.

H^-	hydride ion	O^{2-}	oxide ion	N^{3-}	nitride ion

- Some polyatomic ions end in –ide as well.

OH^-	hydroxide ion	CN^-	cyanide ion	O_2^{2-}	peroxide ion

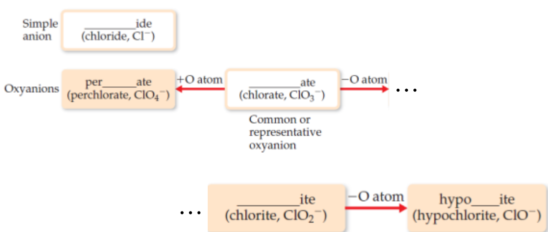
B. Polyatomic anions containing oxygen are called oxyanions and end in –ate or –ite.

NO_3^-	nitrate ion	SO_4^{2-}	sulfate ion
NO_2^-	nitrite ion	SO_3^{2-}	sulfite ion

IONIC COMPOUNDS

- When a group of similar anions is formed with the same 'base' element hypo- and per- are used.

ClO_4^-	perchlorate ion (one more O atom than chlorate)
$\mathbf{ClO_3^-}$	**chlorate ion**
ClO_2^-	chlorite ion (one O atom fewer than chlorate)
ClO^-	hypochlorite ion (one O atom fewer than chlorite)



Maximum of 3 O atoms in period 2.

	Group 4A	Group 5A	Group 6A	Group 7A
Period 2	CO_3^{2-} **Carbonate ion**	NO_3^- **Nitrate ion**		
Period 3		PO_4^{3-} **Phosphate ion**	SO_4^{2-} **Sulfate ion**	ClO_4^- **Perchlorate ion**

Maximum of 4 O atoms in period 3.

EXAMPLE: NAMING IONIC COMPOUNDS

- Based on the formula for the sulfate ion, predict the formula for (hint: selenium is analogous to sulfur):

a. Selenate ion

b. Selenite ion

IONS

C. Anions derived by adding H^+ to an oxyanion are named by adding as a prefix the word hydrogen or dihydrogen, as appropriate.

CO_3^{2-}	carbonate ion	PO_4^{3-}	phosphate ion
HCO_3^-	hydrogen carbonate ion	$H_2PO_4^-$	dihydrogen phosphate ion

3. Ionic Compounds

A. Ionic compounds are named by using the name of the cation followed by the anion name.

$CaCl_2$	calcium chloride
$Al(NO_3)_3$	aluminum nitrate
$Cu(ClO_4)_2$	copper(II) perchlorate

EXAMPLE: NAMING IONIC COMPOUNDS

a. K_2SO_4

b. $Ba(OH)_2$

c. $FeCl_3$

d. NH_4Br

e. Cr_2O_3

f. $Co(NO_3)_2$

EXAMPLE: WRITING IONIC FORMULAE

- Potassium sulfide
- Calcium hydrogen carbonate
- Nickel (II) perchlorate
- Iron (III) dihydrogen phosphate

ACID NOMENCLATURE

1. Acids containing anions whose names end in –ide are named by changing the ide to –ic and adding the prefix hydro- to this anion name, and then following the word acid.

Anion	Corresponding Acid
Cl^- (chloride)	HCl (hydrochloric acid)
S^{2-} (sulfide)	H_2S (hydrosulfuric acid)

ACID NOMENCLATURE

2. Acids containing anions whose names end in –ate or –ite are named by changing –ate to –ic and –ite to –ous then adding the word acid.

- I ate an icky apple, the snakes bite was poisonous.

Anion	Corresponding Acid
ClO_4^- (perchlorate)	$HClO_4$ (perchloric acid)
ClO_3^- (chlorate)	$HClO_3$ (chloric acid)
ClO_2^- (chlorite)	$HClO_2$ (chlorous acid)
ClO^- (hypochlorite)	HClO (hypochlorous acid)

EXAMPLE: ACID NOMENCLATURE

- Name the following acids:
  - HF
  - H_2SO_4
  - H3N
  - HCH_3COO
  - $HBrO_3$

EXAMPLE: ACID FORMULA

- Write the formula of the following acids:
  - hydrofluoric acid
  - chromic acid
  - permanganic acid
  - oxalic acid
  - hydroxic acid
  - sulfurous acid

BINARY MOLECULAR COMPOUNDS

1. The name of the element furthest to the left is named first. (Exception includes any halogen & oxygen, unless it's fluorine.
2. If both elements are in the same group, the lower one is named first.
3. The name of the second element is given the –ide ending.
4. Greek prefixes are used, except mono- on the first element
   - Vowels are dropped to avoid double vowels (usually)

Cl_2O	dichlorine monoxide
N_2O_4	dinitrogen tetroxide

NF_3	nitrogen trifluoride
P_4S_{10}	tetraphosphorus decasulfide

TABLE 2.6 • Prefixes Used in Naming Binary Compounds Formed between Nonmetals

Prefix	Meaning
Mono-	*1*
Di-	*2*
Tri-	*3*
Tetra-	*4*
Penta-	*5*
Hexa-	*6*
Hepta-	*7*
Octa-	*8*
Nona-	*9*
Deca-	*10*

EXAMPLE: MOLECULAR COMPOUNDS

a. SO_2

b. PCl_5

c. Cl_2O_3

d. silicon tetrabromide

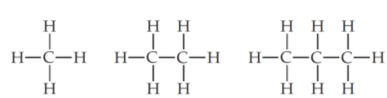
e. disulfur dichloride

SIMPLE ORGANIC COMPOUNDS

- Organic molecules are those that primarily involve **carbon and hydrogen** although oxygen, nitrogen, phosphorous can be present in small quantities.
- As these **molecules can be complex** (involving tens of atoms) the naming system becomes quite complicated.
- We will focus on **alkanes** and some **simple substitutions**.

ALKANES

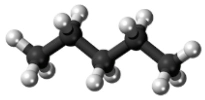
- The simplest compounds that involve only carbon and hydrogen are called alkanes.
- The four smallest of these are called methane, ethane, propane and butane.



Methane Ethane Propane

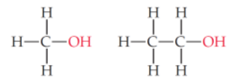
ALKANES

- In each of these molecules, each carbon is bonded to 4 other atoms.
- Alkanes past butane are named using a Greek prefix indicating the number of carbon.
  - **Pent**ane, **hex**ane, **hept**ane, **oct**ane, **non**ane, **dec**ane, ….



ALCOHOLS

- In organic chemistry a compound's characteristics can be changed with a functional group.
- One example of a common functional group is –OH which is an alcohol.
- Alkanes can have one hydrogen replaced with an alcohol which changes the ending.



Methanol   Ethanol

EXAMPLE

- Assuming that the carbon atoms in pentane are in a linear chain write the:

a. the structural formula and,

b. molecular formula