Chapter 2

Atomic Theory

A theory (or model) of the way matter works goes back to the ancient Greeks. Two competing theories at that time were the idea that matter is continuous and that matter is composed of indivisible particles called atoms. The first states that however finely matter is divided it is the same. The second states that matter has a tiny fundamental unit associated with it. These were just ideas at the time and no experiments were done to distinguish between them.

In the 1800's John Dalton revived the ancient Greek idea of atoms. His theory of atoms had several postulates. (A postulate is a statement that is assumed to be true.)

1. All matter is composed of tiny indivisible particles called atoms.
2. An element is a kind of matter composed of only one kind of atom.
3. A compound is a kind of matter composed of 2 or more kinds of atoms.
4. A chemical reaction is just a rearrangement of the way atoms are connected to each other.

Dalton's theory predicted the Law of Multiple Proportions. The Law of Multiple Proportions states that when more than one kind of compound exists between two elements; the ratio of the masses of the elements is always the ratio of small whole numbers.

Atomic Structure

Atoms were originally thought to be indivisible particles. That is, you could not break a piece off an atom. Experiments by J.J.Thompson in the late 1800's showed this idea to be incorrect. His experiment was the first evidence of the particles known as electrons. Because these electrons have a negative charge and atoms have no charge there must be a part of the atom with a positive charge. The original idea for the structure of the atom was a sphere of positive charge with the negatively charged electrons embedded in it.

This model was destroyed by an experiment by E. Rutherford. He directed a beam of alpha particles (essentially Helium nuclei) at a piece of gold foil. A small percentage of the alpha particles were reflected back toward the source. This indicated to Rutherford that all of the positive charge in an atom must be concentrated in a very small volume at the center of the atom. This was the beginning of the nuclear model of the atom. One problem with the model was, how do the positive charges stick together in the nucleus? This problem was solved with the discovery of the neutron in the 1930's.

The atoms as we know it today has three parts. The protons and neutrons are located in the nucleus, and the electrons surround the nucleus. The protons and neutrons have approximately the same mass (1 in atomic mass units (amu)). The electrons have such a small mass that it is considered to be zero in atomic mass units. The protons have a positive charge (+1 in is electron charge units) and the electrons have a negative charge (-1 in electron units).

An element was defined earlier as all atoms of a given type. This is not exactly true. We now know that the atoms of a given element can vary slightly from one another. The thing that determines the identity of an element is the number of protons in the nucleus, also known as the **atomic number**. Atoms of an element can have varying numbers of neutrons though. The sum of the number of protons and the number of neutrons is known as the **mass number**. If we have a collection of atoms with the same atomic number, they are all the same element. If those atoms have different mass numbers, they are **isotopes** of that element.

Example:

Hydrogen exists in 3 "flavours"

1. An atom with 1 proton, 0 neutrons and 1 electron.
2. An atom with 1 proton, 1 neutron and 1 electron.
3. An atom with 1 proton, 2 neutrons and 1 electron.

We can differentiate between these type of hydrogen by using the complete atomic symbol.

Atomic Symbols

Atomic symbols are a sort of short hand for chemists to denote the various elements. They are 1 or 2 letter symbols and are unique for each element. The ones you should know are 1-92. You are only required to know the name and the atomic number.

The complete atomic symbol also specifies the mass number and the atomic number.

$$ {}^{A}_{Z}E $$

E is the atomic symbol, A is the mass number and Z is the atomic number. So for the hydrogen example here we have:

$$ {}^{1}_{1}H \qquad {}^{2}_{1}H \qquad \text{and} \qquad {}^{3}_{1}H $$

These three symbols show the three isotopes of hydrogen.

Relative Average Atomic Mass

When we look at the periodic table we seen the atomic numbers listed. However, instead of mass numbers listed we see masses (for most of the elements). The masses listed are relative average atomic masses. They are “relative” because they are relative to a reference mass, which is the mass of the isotope of Carbon with a mass number of 12. This isotope is defined to have a mass of 12.00000… atomic mass units. They are “average” because the masses are weighted averages for all of the isotopes of that element.

We can calculate the relative average atomic mass from percent abundance data.

Example:

The element Indium (In) has two naturally occurring isotopes. The data for these isotopes is given below.

Isotope	Mass (amu)	%
$^{113}_{49}In$	112.9041	4.3
$^{115}_{49}In$	114.9057	95.7

The average mass can be calculated as:

(112.9041 amu)(0.043) + (114.9057 amu)(0.957)
= $4.\underline{8}548763$ amu + $10\underline{9}.9647549$ amu (underlined values are the last sig fig)
= 115 amu (calculator gives 114.8196312 amu which matches the value in the periodic table to 2 decimal places)

Periodic Table

Periodic Law

The Periodic Law states that the properties of the elements when arranged in order of increasing atomic number show a periodicity of properties. What this means is that all of the elements in a given column have similar chemical properties. The Periodic Table is a way of showing which elements have similar properties.

Each row in the table is a **period**. Each column is a **group** or **family**. The tall columns (with group numbers ending in A) are called the **main group** elements. The shorter columns are the **transition metals**. The two rows at the bottom are the **inner transition metals** (sometimes also called the **rare earth elements**). The stair step line at the right of the table separates the metals from the non-metals. The elements along the line are the **metalloids** or **semi-metals**.

Some of the groups have special names:

Group IA	the Alkali metals
Group IIA	the Alkaline Earth metals
Group VIIA	the Halogens

Group 0 or VIIIA the Noble Gases

It is important to remember which are the metals and which are the non-metals. Knowing what kinds of elements are present in a compound allows us to name the compound correctly.

Compound involving only non-metals are called covalent or molecular compounds. Compound involving metals and non-metals are called ionic compounds. The way these types of compounds are named is different.

Nomenclature – Naming of compounds

Ionic Compounds

To name ionic compounds you just name the ions that are present. The name of the positive ion (**cation**) is first followed by the name of the negative ion (**anion**)

Naming monatomic ions.

1. Metal ions are named the same as the metal, if there is only one ion.

2. If there is more than one charge on the ion, the ion is named with the metal name with the charge written after it in Roman numerals in parenthesis.

   An older system of naming metals that form more than one kind of ion involves the use of the prefixes –ous and -ic. The stem is derived from the name of the metal if the symbol is not from the Latin name. If the symbol comes from the Latin name the stem is from the Latin name of the metal.

Fe^{2+}	Iron(II) or Ferrous	Cu^{+}	Copper(I) or Cuprous
Fe^{3+}	Iron(III) or Ferric	Cu^{2+}	Copper(II) or Cupric
Au^{+}	Gold(I) or Aurous	Sn^{2+}	Tin(II) or Stannous
Au^{3+}	Gold(III) or Auric	Sn^{4+}	Tin(IV) or Stannic
Pb^{2+}	Lead(II) or Plumbous	Hg_2^{2+}	Mercury(I) or Mercurous
Pb^{4+}	Lead(IV) or Plumbic	Hg^{2+}	Mercury(II) or Mercuric

3. Non-metals: stem name + -ide.

Ionic compounds can also contain **polyatomic ions**. These are groups of atoms that are bonded together that have a charge. A list of these ions is provided in your text and in class. This list ***must be memorized***. You need to know the name, formula and charge of all of the polyatomic ions in the list.

Among the polyatomic ions there are a couple of patterns. If there are two ions with similar names (e.g., sulfate and sulfite), the one whose name ends in –ate has 1 more oxygen than the one whose name ends in –ite. This is can be extended to other ions. If the ion has 1 more oxygen than the –ate ion, it is given the prefix per- (e.g., **per**chlor**ate**, ClO_4^-, chlor**ate**, ClO_3^-). If the ion has one less oxygen than the –ite ion, it is given the prefix hypo- (e.g., **hypo**chlor**ite**, ClO^-, chlor**ite**, ClO_2^-). Also, if an oxygen atom is replaces with a sulfur atom the prefix thio- is added to the name (e.g., CNO^-, cyanate, CNS^-, **thio**cyanate).

The periodic law can also be applied to these patterns. For example ClO_3^- is the chlorate ion and BrO_3^- is the **brom**ate ion.

To get the formula for an ionic compound between any two elements we need to know the charges on the ions.

What is the charge on the ions?

1. Main-group metals: charge = group number.

2. Main-group metal with high atomic number can have more than one charge. Usually the other charge is the group number minus 2.

3. Most transition metals have more than one charge. Most have an ion with a charge of +2. These charges have to be determined from the formula.

4. Non-metals have a charge of the group number minus 8.

The total positive charge must equal the total negative charge in the compound. This can be done by "crossing over" the charges.

Rb^+ and O^{2-} → cross over → Rb_2O

Ca^{2+} and PO_4^{3-} → cross over → $Ca_3(PO_4)_2$

Naming binary molecular compounds

Order of elements in the formula

B Si C Sb As P N H Te Se S I Br Cl O F (by convention)

Rules for naming

1. Name elements in order given above.

2. First element named is given the name of the element with the appropriate prefix see number 4.

3. Name of second element: stem name + -ide.

4. Prefixes used for compounds containing more than one of the same type of element. Mono- not used unless it is needed to distinguish two compounds of the same two elements.

Prefixes

1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Exceptions to the above rule for binary molecular compounds

Some compounds that have been known for hundreds or thousands of years do not follow this naming system. Others, such as organic compounds, follow a different system altogether. The compounds you are required to know the common names of are:

H_2O	Water	NH_3	Ammonia
N_2H_4	Hydrazine	PH_3	Phosphine
AsH_3	Arsine		

Naming acids

Binary acids.

Hydro- stem name of anion -ic acid.

HCl	**Hydro**chlor**ic** acid
HBr	**Hydro**brom**ic** acid

Oxoacids are acids that contain oxygen.

Anion suffix	acid suffix
-ite	-ous
-ate	-ic

NO HYDRO- PREFIX!!!!

Hydrates

Hydrates are ionic compounds with molecules of water associated with them. The prefixes used with molecular compounds are used to denote the number of water molecules present.

$CuSO_4 \cdot 5\ H_2O$ (5 molecules of water for every Copper(II) Sulfate)

This is named as the name of the ionic compound + prefix-hydrate: Copper(II) Sulfate Pentahydrate.

Chemical Equations

A **chemical equation** is a shorthand way of indicating what is going on in a chemical reaction. We could do it the long way…

Two molecules of Hydrogen gas react with one molecule of Oxygen gas to produce two molecule of liquid water.

Or we can use the shorthand…

$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (l)$

The second way is easier to read and keep track of everything going on. The equation above uses **phase symbols**. Phase symbols are used to denote the phase of substances in an equation.

(*g*)	gas
(*s*)	solid
(*l*)	liquid
(*aq*)	aqueous (water solution)

The chemical equation must represent reality. The symbol, Δ, is sometimes used to denote a reaction that is heated and is written above the arrow. Catalyst symbols or formulas are also placed above the arrow.

Balancing equations

An equation is balanced when the number of atoms of each type present is the same on both sides of the equation. The chemical formulas CANNOT be changed in the process of balancing an equation. The process of balancing an equation can sometimes seem to be trial and error. In reality, there is a method to the madness. When we balance a chemical equation we are looking at the relationships between the elements on both sides of the equation. This relationship helps us to figure out what needs to be done. Some basic rules for balancing chemical equations are…

1. Start with the most complicated chemical first and start with the element that appears the most number of times in that compound.

2. Save "free" elements for last.

Example:

CH_4 (*g*) + O_2 (*g*) $\rightarrow$ CO_2 (*g*) + H_2O (*l*)

Here CH_4 is the most complicated and Hydrogen appears the most number of times so we will start with that element. O_2 is a "free" element (not combined with other elements) so we will leave that for last.

There are 4 Hydrogens on the reactant side and 2 on the product side. Therefore, we multiply the water on the product side by 2 and the hydrogens balance.

CH_4 (*g*) + O_2 (*g*) $\rightarrow$ CO_2 (*g*) + 2 H_2O (*l*)

The carbons are already balanced. Now we can balance the oxygens. There are 2 on the reactant side and 4 on the product side. If we multiply the O_2 by 2 we balance the oxygen.

CH_4 (*g*) + 2 O_2 (*g*) $\rightarrow$ CO_2 (*g*) + 2 H_2O (*l*)

Now the equation is balanced.