

CHM 101 GENERAL CHEMISTRY

FALL QUARTER 2008

Section 2

Lecture Notes – 10/6/2008

(last revised: 10/6/08)

2.5 The Modern View of Atomic Structure

- The components of an atom are protons, neutrons, and electrons.
 - Electrons
 - The particles discovered by Thompson (Cathode-ray Emissions).
 - Negatively charged.
 - Protons
 - Same charge as electrons, only the opposite sign
 - Approximately 1,800 times the mass of an electron
 - Neutrons
 - Zero charge (electrically neutral).
 - Same mass as the proton.

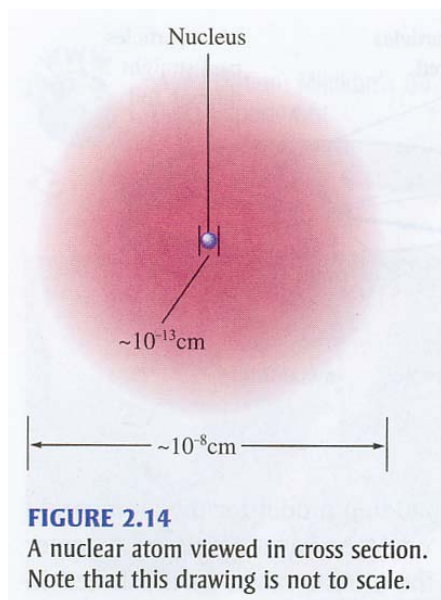
TABLE 2.1 The Mass and Charge of the Electron, Proton, and Neutron

Particle	Mass	Charge*
Electron	9.11×10^{-31} kg	1-
Proton	1.67×10^{-27} kg	1+
Neutron	1.67×10^{-27} kg	None

*The magnitude of the charge of the electron and the proton is 1.60×10^{-19} C.

- Structure of the Atom:
 - A tiny nucleus (diameter $\sim 10^{-13}$ cm), made of protons and neutrons and containing nearly all the mass of the atom

- Surrounded by a sphere (diameter $\sim 10^{-8}$ cm) containing the electrons.



- How Elements Differ
 - The atoms of a given element (Example: gold) each contain the same, characteristic number of protons (Example: An atom of gold always contains 79 protons). This number is called the **Atomic Number** of the element. (The symbol for atomic number is **Z**.)
 - Since atoms are electrically neutral, an atom has the same number of electrons surrounding its nucleus as it has protons in its nucleus.
 - The **number** and the **arrangement** of the **electrons** in the atoms of an element **determine the chemistry of that element**. This is because when atoms come together, it is the electrons that “touch” or interact with each other. To restate this point, the chemistry of a given element depends **critically** on the number of electrons in each of its atoms.
- Isotopes
 - For any element, the particular number of protons in the nucleus of each of its atoms is a characteristic of the element. However, the number of neutrons can vary without changing the chemistry.
 - An example is chlorine. Each chlorine atom contains 17 protons, but some chlorine atoms contain 18 neutrons while others contain 20. If we define the **Mass Number** of a

particular atom as its number of protons plus its number of neutrons, then we can compute the mass numbers of these two kinds of chlorine as 35 and 37, respectively. (The symbol for mass number is **A**.)

- When the atoms of a given element occur in forms that have different numbers of neutrons, we call these forms **isotopes** of that element.
- The isotope of chlorine (atomic symbol: Cl) with mass number 35 (called chlorine 35) can be symbolized:



- Likewise, chlorine 37 can be symbolized:



- In general, an atom with the chemical symbol, Xx, the atomic number, Z, and the mass number, A, is written:



- Now we can work Sample Exercise 2.2 (page 52 in the text). The problem asks us to write the symbol for an atom with an atomic number of 9 and a mass number of 19. It also asks us to determine the numbers of electrons and neutrons in the atom.
 - Step 1: The data we need to look up are on the two facing pages of the inside front cover of the text. Looking in the periodic table, we see that the atomic number (9) is that of the element with the symbol, F. (If we look up F on the opposite page, we can find that it belongs to the element, fluorine.). Thus we can write the complete symbol for this atom (including the atomic number, Z, and the mass number, A, as:



- Step 2: The number of electrons is the same as the number of protons. This answer is given by the atomic number, 9.
- Step 3: The number of neutrons can be calculated by subtracting the atomic number from the mass number:

$$A - Z = 19 - 9 = 10$$

2.6 Molecules and Ions

- Now that we have studied the nuclear model of the atom and learned that electrons are responsible for chemistry, we turn to the study of the ways that atoms interact to form chemical compounds. At this stage we will look only at some simple ideas of chemical bonding. We will study chemical bonding in more depth during CHM 102.
- **Chemical bonds** are what we call the forces that bind atoms together in compounds. At this point we will consider covalent bonds and ionic bonds.
- **Covalent Bonds:** When two or more atoms form a molecule by sharing electrons, we say that these atoms are covalently bonded. We can represent these molecules symbolically in several ways:
 - The simplest representation is the **chemical formula**. The atoms are represented by their chemical symbols. (You will find these in the Table of Atomic Masses in the inside front cover of your text.) For molecules containing 2 or more of the same kind of atom, the number is written as a subscript after the chemical symbol. Thus a water molecule, containing 2 hydrogen (H) atoms and one oxygen (O) atom has the chemical formula



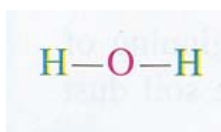
Another example of a chemical formula is that of ammonia, a molecule containing 3 hydrogen atoms and 1 nitrogen (N) atom:



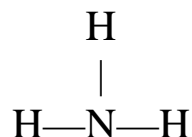
Still another example is methane, a molecule containing 4 hydrogen atoms and 1 carbon (C) atom:



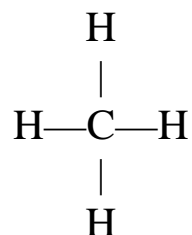
- A **topological formula** is a two dimensional representation of a chemical structure. It shows which atoms are bonded to which. The topological formula for water is:



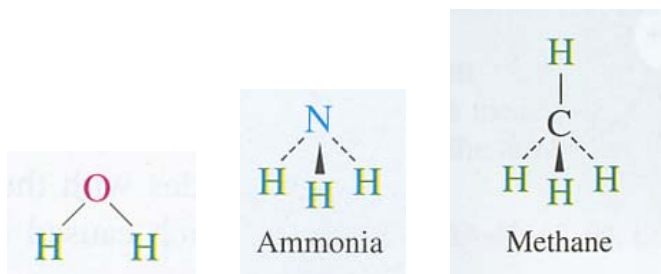
The topological formula for ammonia is:



And the topological formula for methane is:



- o A **structural formula** not only shows which atoms are bonded to which, but it also suggests the true shape of the molecule and the actual angles between the bonds. Here are structural formulas for water, ammonia, and methane:



In these diagrams, the letters represent the atoms, the light, solid lines represent bonds that lie in the plane of the screen (or paper, if this is a printout), the dotted lines represent bonds that project behind the screen, and the dark wedges represent bonds that poke out of the screen.

Note: The text does not give a separate definition of topological formula but includes it as a kind of structural formula without geometric information. (You will not be held responsible for knowing the difference.)

- o A **molecular model** gives the truest representation of the structure and composition of a given molecule. Two commonly used types of models are the **space-filling** model (Figure 2.17) and the **ball-and-stick** model (Figure 2.18).

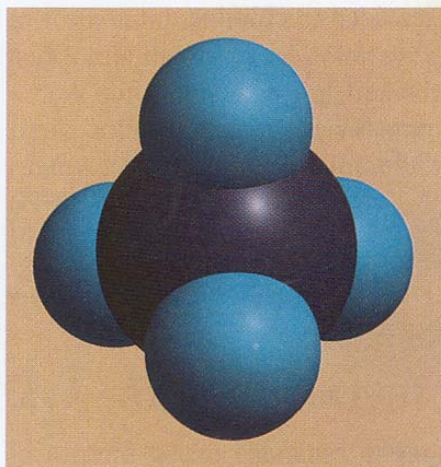


FIGURE 2.17

Space-filling model of methane. This type of model shows both the relative sizes of the atoms in the molecule and their spatial relationships.

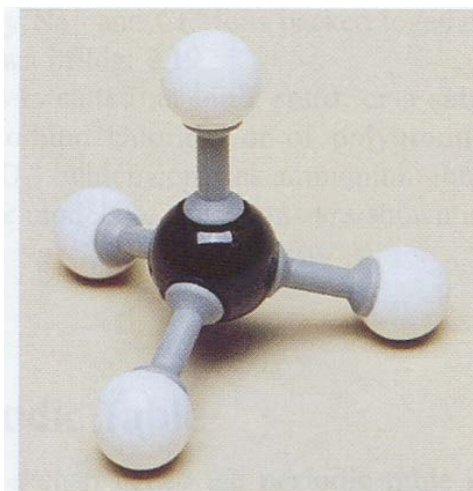
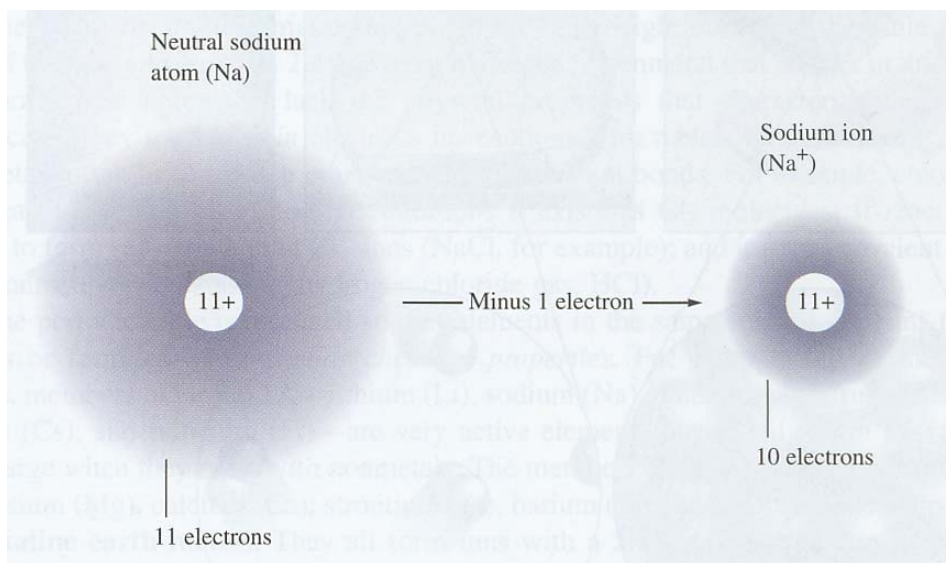


FIGURE 2.18

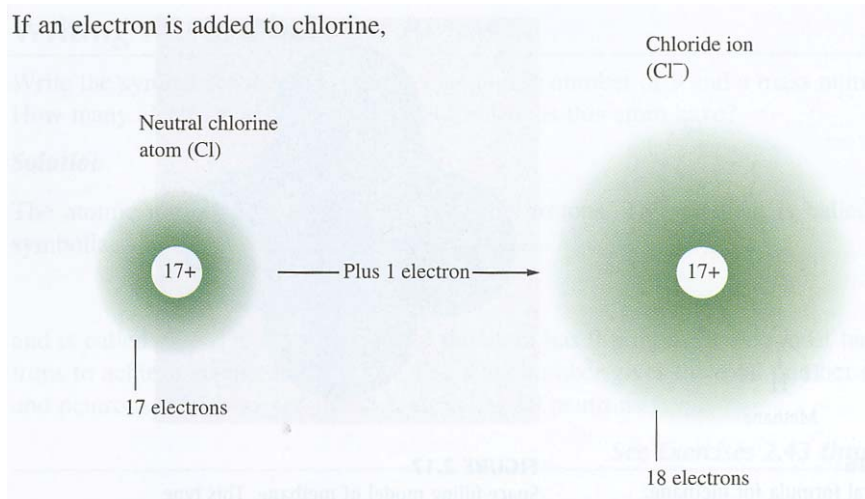
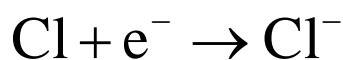
Ball-and-stick model of methane.

- **Ionic Bonds:** Not all chemical compounds are covalently bonded. A familiar example of a chemical compound entirely lacking in covalent bonds is sodium chloride (NaCl), also known as common table salt. The bonding in NaCl is ionic, not covalent. Let's see what leads to ionic bonding in NaCl.
 - **Ionization of Sodium:** A sodium atom, with an atomic number of 11, has 11 electrons. One of the 11 electrons can be dislodged fairly easily, leaving an entity with 10 electrons that are very tightly held by a nucleus with a +11 charge. The charge on this entity is +1, and the entity can be called a sodium positive ion, a sodium cation, or (most commonly) a sodium ion. This ionization process can be written as a chemical equation:





- o **Ionization of Chlorine:** A chlorine atom, with an atomic number of 17, has 17 electrons. These electrons are all tightly held, and there is a driving force to add one more and produce an entity with 18 electrons in a stable structure about a nucleus with a charge of +17. Thus the charge on the entity is -1, and the entity can be called a chlorine negative ion, a chlorine anion, or (most commonly) a chlorine ion. This ionization process can be written as a chemical equation:



- o **Ionic Bonds:** Since oppositely charged ions exert attractive forces on each other, they form bonds without sharing electrons. These are called ionic bonds. Figure 2.19 illustrates the reaction of the element, sodium, a soft metal, with

chlorine, a pale green gas, to form the ionically bonded salt, sodium chloride, a colorless, crystalline solid.

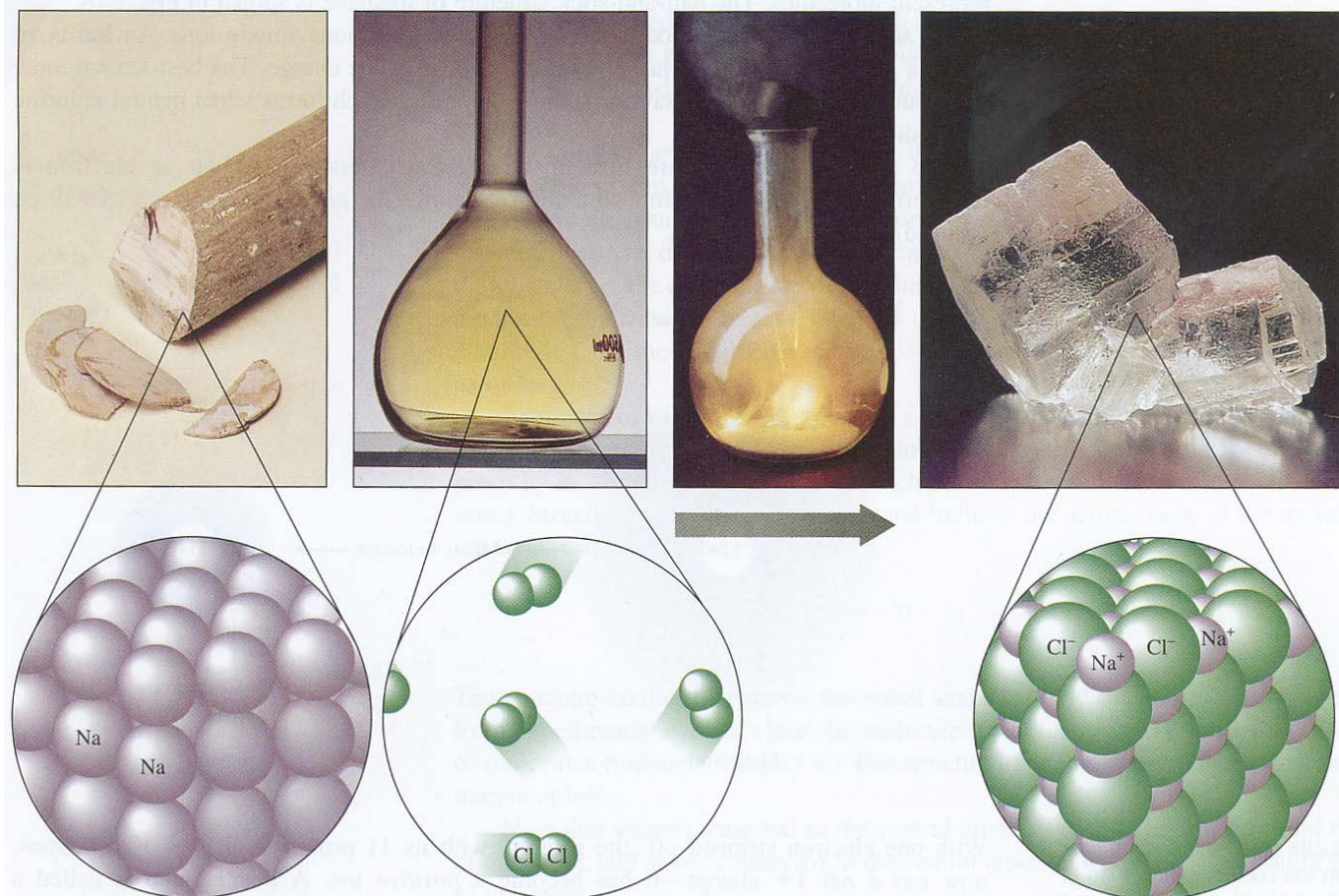
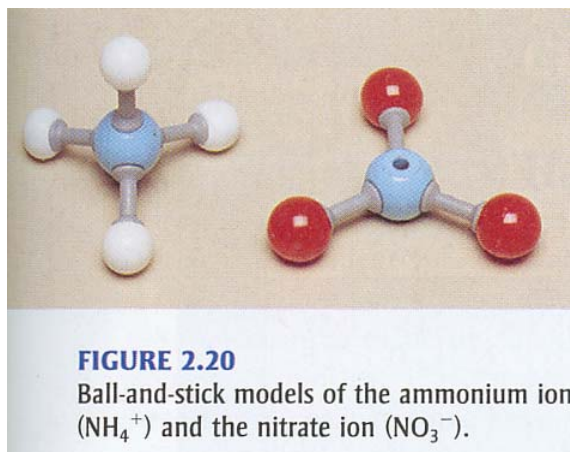


FIGURE 2.19

Sodium metal (which is so soft it can be cut with a knife and which consists of individual sodium atoms) reacts with chlorine gas (which contains Cl₂ molecules) to form solid sodium chloride (which contains Na⁺ and Cl⁻ ions packed together).

- **Ionic Solids:** A solid consisting of oppositely charged ions is an ionic solid or a salt.
- **Types of Ions:**
 - **Simple Ion:** Any ion made from a single atom. Na⁺ and Cl⁻ are good examples.
 - **Polyatomic Ion:** An ion in which two or more atoms are covalently bonded together into a molecule with a net charge. A good example of a compound made from two types of polyatomic ions is ammonium nitrate, NH₄NO₃, which is made of ammonium ions,

NH_4^+ , and nitrate ions, NO_3^- . These two ions are illustrated in Figure 2.20:



- **Metallic Bonding:** (not discussed in Chapter 2, so you don't need to know this yet.): Metal atoms tend to cluster into large aggregates, and the most loosely bound electrons are shared among all the atoms in an aggregate. This gives rise to metallic bonding, as distinct from covalent bonding or ionic bonding.

2.7 Introduction to the Periodic Table

- **What it is:** A Periodic Table is a chart that shows all the known elements giving lots of information about each and organizing them in a particular useful manner.
- **Where to find it:**
 - In textbooks: There are at least 2 versions of the periodic table in your text. (See the inside front cover and page 56.)
 - Posted in class: There is one hanging on the sidewall of D-108 near the door. There is also one posted in the lab (D-103).
 - On the web: If you do a Google search, you will find many different versions of the periodic table. Here is one example: <http://www.webelements.com/>.
- **The Periodic Law:** The Periodic Law states that the chemical properties of the elements are a periodic function of their atomic numbers.
- **Arrangement of the Periodic Table:**
 - **Columns:** The elements in a given column of the periodic table have similar chemical properties. The collection of elements in a column is called a group or a family.

- Rows: The elements in a given row of the periodic table are ordered by atomic number, without any gaps in the number sequence. These rows are also called periods.
- Chemistry of Selected Groups:
 - Metals: Most elements are classed as metals. They are located on the left hand side and in the center of the periodic table, and as you go down the table to heavier and heavier elements, they occur more and more toward the right hand side. For example, in Period 6 (elements with atomic number 55 through 86), fully 30 of the 32 elements are classed as metals. As elements, metals tend to occur as metallically bound solids that are good conductors of heat and electricity, they tend to be malleable and ductile so that they can be hammered into thin sheets or drawn into wires, they often appear shiny or lustrous, and chemically they tend to react by losing electrons to form positive ions.
 - Group 1 (Alkali Metals, such as sodium and potassium): These are all very active metals that readily form ions with +1 charges when they react with non-metals.
 - Group 2 (Alkaline Earths, such as magnesium and calcium): These are metals that form ions with +2 charges.
 - Groups 3-12 (Transition Metals): There are 10 groups of transition metals, but group to group differences among transition metals are not as pronounced as those among the main groups (Groups 1 and 2 and 13 through 18). They tend to have complex chemistries. Many of them have two or more ionic forms, for example: iron (Fe) can lose 2 electrons to form the Fe^{2+} ion, but it can also lose a third electron to form Fe^{3+} . Many of them form 2 or more different kinds of oxide, for example: titanium (Ti) forms TiO and TiO_2 . And many of them are capable of forming polyatomic anions, for example: chromium (Cr) can form the chromate (an)ion, CrO_4^{2-} .
 - Group 18 (Noble Gases, such as helium and argon): These elements all occur in nature as monatomic gases. They were thought never to form chemical bonds until the mid-1960's when several compounds of xenon and fluorine were successfully prepared.

- Group 17 (Halogens, the elements fluorine, chlorine, bromine, and iodine): These non-metals can all form ions with -1 charges when they react with an active metal. They can also form covalent bonds with themselves and with other non-metals. As elements, they occur as diatomic molecules, such as Cl_2 .
- Other Non-Metals: The non-metals other than the halogens are nearly all found in the upper right corner of the periodic table. The most important of these are carbon, nitrogen, oxygen, phosphorous, and sulfur. Like the halogens, they tend to accept electrons and form negative ions when they react with metals, and they tend to form covalent bonds when they react with each other.
- What about Hydrogen? The placement of hydrogen in the periodic table has always been a problem. In some respects its chemistry resembles the chemistry of the alkali metals, but it also behaves as a non-metal. As an element, it occurs as the diatomic gas, H_2 , and it forms covalent bonds with carbon and other non metals. There are valid arguments for placing it in Group 17 above fluorine.
- Using the Periodic Table:
 - As a Predictive Tool: Since its earliest days, the periodic table has been used successfully to predict the properties of unknown, undiscovered elements. When Mendeleev published the very first version of the periodic table, he had to leave several gaps in it where there were no known elements to fit particular combinations of period and group. For example, he could not fit any known element into Period 4 of Group 14. His answer was to predict that such an element could be found and that its chemical properties would resemble those of silicon (Period 3, Group 14) and tin (Period 5, Group 14) and that its physical properties (atomic mass, density, etc.) would be similar to its neighboring elements in Period 4. Given this road map of a prediction, other chemists soon discovered the element, germanium, and found that its actual properties were a close match for Mendeleev's predictions.
 - As a Data Organizer: The periodic table summarizes and correlates a wide variety of information in a compact and easy to use format.

- As a Look-Up Tool: The periodic table charts every element by atomic number, atomic mass, name, chemical symbol, group, and period. Thus if you know some of this information about a given element, you can look up the rest in the periodic table.
- As a Learning Tool: The next section we will cover in General Chemistry is about Naming Simple Compounds. This is likely to be the most heavy duty memorization you will encounter all quarter. We will expect you to know names of elements, their chemical symbols, and the formulas and names of typical compounds they form when they react with other elements. The good news in all this is that of the 110 or so known elements, you will be held responsible for knowing only the 25 or so most important ones. And you can use the periodic table as a graphical device to help you organize and learn this information.