Inorganic Chemistry
Lesson 3
Chemical bonds and structural formulas.

October 1, 2017

1 Structure of molecules

The concept of valence allows us to make some important conclusions about structure of molecules. Indeed, if we know that oxygen, being divalent, interacts with monovalent substances to give chemical compounds with general formula X_2O, it is reasonable to suggest that happens because each atom X forms one *chemical bond* with other atoms, but each oxygen atom can form two chemical bonds. It can be represented graphically, using solid lines for each chemical bond:

H—O—H, or Na—O—Na, or Ag—O—Ag

Obviously, since hydrogen, sodium, and silver are monovalent, only one solid line can start from H, Na, or K atom. Oxygen is divalent, therefore, two lines come to (or go from) each oxygen atom. When oxygen is bound to itself, or to another atom with valence greater that one, it can form a *double bond*, which is shown in chemical formulas as a double line.[1] For example, a molecule of carbon dioxide, a gas used for preparation of soda water, can be drawn as follows:

O=C=O

In other words, molecules are not random clods. Their structure is strictly defined, and can be drawn based on chemical laws.

> **Atoms in molecules are connected together *via* chemical bonds. A graphical representation of molecular structure that shows chemical bonding within the molecule is called a *structural formula.***

[1] triple bonds are also possible between two atoms whose valence is equal or greater than three. Quadrupole bonds are not possible. We will discuss it in more details next year.

Structural formulas can help us to predict the composition of chemical compounds, especially of binary ones.[2] For example, if some element X is divalent, its binary compound with a monovalent element Y has a structure:

Y—X—Y

which means the formula of this compound is Y_2X (or XY_2, which is the same). The examples are H_2O, Ag_2O, $CuCl_2$.

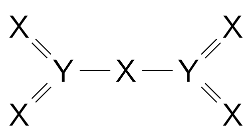
If both X and Y are divalent, the structure of the binary compound is:

X═Y

Accordingly, its chemical formula will be XY. The examples are CuO, CaO, MgO. If the atom Y is tetravalent, the structural formula is:

X═Y═X

That corresponds to the chemical formula X_2Y (or YX_2, which is the same). The examples are CO_2, SO_2. A situation when a valence of one element is odd, but a valence of another element is even is a little bit more tricky. Thus, when the element X is divalent, and the element Y is pentavalent, a structural formula will be:



The examples of such compounds are N_2O_5, P_2O_5.

You have probably noticed that in all above formulas, every chemical bond that starts from one atom ends at another one. There is no "free" valences (i.e. the chemical bonds that go to nowhere) in molecules. However, does it mean that the molecule like those listed below do not exist?

H—S—, or Na—O—, or Ag—O—

Actually, it doesn't. Yes, such particles may exist. However, such a particle would be very active. It would try to use its "free valence" (i.e. a broken chemical bond) to bind to another particle of the same or different type. That means such a particle cannot form a bulk substance.

In stable chemical compounds, there are no chemical bonds that go to nowhere.

[2]Binary compounds are the compounds formed by two different elements. CuO, CO_2, or Fe_2O_3 are the examples of binary compounds.

2 Valence of different elements. Polyvalence

Why different elements have different valence? Actually, the chemists answered this question only in the middle of XX century, after the atomic structure had been determined, and quantum mechanics had been developed. We will definitely talk about that ... later. For now, we study the foundations of chemistry, and we simply have no time or sufficient factual background to dive into the details of electronic structure of atoms. What you currently need is to know that some elements have a certain valence when they are chemically bound to other atoms. Below is the table that lists most common elements and their valences. That is pretty sufficient for a while.

Table 2. Most common elements, their atomic masses and common valences[3]

Element's name	Element's symbol	Atomic mass	Valence
Hydrogen	H	1	1
Sodium	Na	23	1
Silver	Ag	108	1
Calcium	Ca	40	2
Copper	Cu	64	2 (1)
Magnesium	Mg	24	2
Iron	Fe	56	3 or 2
Oxygen	O	16	2
Tin	Sn	119	2 (4)
Zinc	Zn	65	2
Aluminium	Al	27	3
Phosphsorus	P	31	3, 5
Carbon	C	12	4 (2)
Nitrogen	N	14	3, 4, 5
Silicon	Si	28	4
Sulfur	S	32	2, 4, 6
Chlorine	Cl	35	1, 3, 5, 7

As you can see from this table,[4] some elements (such as sodium or hydrogen) always have the same valence, whereas the valence of others may vary. These elements are called *polyvalent* , or *multivalent*. Their valence depends on the type of the molecules they are a part of. For example, valence of chlorine is always 1 when it is bound to hydrogen, but it can be 3, 5, or 7 when chlorine is bound to oxygen. Usually, most multivalent elements, such as sulfur, chlorine, or nitrogen, have lower valence when bound to metals (sodium, iron, tin), and higher valence when bound to oxygen, or chlorine. We will discuss all of that later,

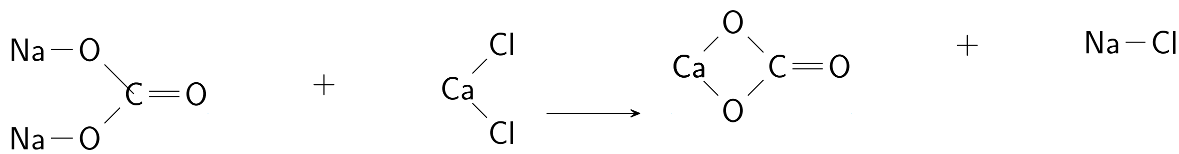
[3]Sometimes, very infrequently, they may have valences not listed in this table. However, these are just rare exceptions; rare valent states are shown in parentheses

[4]this table lists the same elements as the Table 1 (Lesson 3) does; three more elements have been added: magnesium (Mg), phosphorus (P) and silicon (Si).

and for now, try to memorize the above table. The valence state of polyvalent elements is denoted using Roman numbers. For example, a compound with a formula Fe_2O_3 (iron is trivalent there) is called “Fe (III) oxide”.

3 Structural formulas and reaction schemes

Structural formulas allows a better understanding of what is going on during chemical reactions. Thus, using structural formulas, the reaction scheme **1** from lesson 2 can be redrawn as follows:



Sodium carbonate Calcium chloride Calcium carbonate Sodium chloride

As we can see from this scheme, only two types of bonds had been affected during this reaction: the bonds between sodium and oxygen, and the bonds between calcium and chlorine. Other bonds (the bonds between sulfur and oxygen) remained unaffected. That means that, in these particular reaction conditions, the latter bonds are stable (do not break).

> **In molecules, different chemical bonds have different stability. Depending on reaction conditions, some bonds break easily, whereas others remain unchanged. As a rule, just one (or few) chemical bond is affected during a certain reaction.**

It is very important to understand the reasons for stability or instability of chemical bonds in molecules. That will allow us to understand mechanisms of chemical reactions and to predict which compounds react with each other, and what the reaction products are.

Homework

1. Try to memorize valences of the elements from the table 2.
2. Using the table 2, draw structural formulas for each compound from the is list and find correct coefficients in the formulas: Al_xS_y, Cu_xCl_y, Sn_xS_y, Ca_xN_y, Ca_xCl_y, Zn_xN_y, Al_xCl_y, Ag_xCl_y, H_xN_y, Mg_xN_y, Mg_xC_y, Al_xP_y, Ca_xSi_y, Si_xC_y, Si_xP_y, P_xO_y, P_xS_y (for polyvalent elements, draw separate formulas for each valence state).
3. Draw structural formulas and calculate percentage (by mass) of: (a) phosphorus in a compound formed by phosphorus (III) and magnesium; (b) sulfur in a compound formed by sulfur (II) and aluminium; (c) zinc in a compound formed by zinc and chlorine[5].

As usually, I would be grateful if you sent me your homework by evening of next Saturday. My e-mail is mark.lukin@gmail.com.

[5] Chlorine is monovalent.