Inorganic Chemistry

Atoms, Bonds, and Valence for dummies

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1 Few simple concepts

Today we introduce several concepts that explain the rules that govenrn Periodic table's structure, the atomic structure, chemical bond and valence. We introduce these concepts without explanation. We will study them in details later.

These concepts are as follows.

1.1 Electron shell

Simply put, an electron shell is the same as Bohr's orbit. An electron cannot have some arbitrary energy in an atom: its energy can have only some discrete values. The electrons that have roughly the same value form an electron shell. The first shell corresponds to the lowest possible value, the second shell corresponds to the second lowest energy, etc.

Each electron shell has some concrete capacity: thus, the first shell can accommodate up to two electrons, the second shell - eight electrons, the thids shell - 18 electrons, the fourth shell - 32 electrons, etc.

1.2 Orbitals

Orbital is a state of an electron within an electron shell. An orbital can be understood as electron's orbit inside an atom. The word "orbital" is used instead of the word "orbit", because the latter implies some concrete trajectory, whereas it is impossible to speak about electron's trajectory in an atom (we will talk about that later in more details). An orbital can be occupied by zero, one, or two electrons. It cannot be occupied by more than two electrons. Both electrons at the same orbital have exactly the same energy, and they are identical in all aspects[1].

Orbitals can be considered as "bulding blocks" an electron shell is composed of. It is easy to see that the first shell is compposed of just one orbital, the second shell is composed of four orbitals, etc.

[1] Except one; we will talk about that later.

1.3 Open shell

When some orbital in an electron shell are partially occupied by electrons, such a shell is called an *open shell*. As a rule, an open is the outer shell. All other shell are closed. For example, the second shell in a lithium atom is open, because it contains one electron, whereas the first shell is full, or closed.

It is easy to see that the elements from groups 1 to 7 have open shells, whereas in noble gases all shells are closed. From that, we can hypothecise that there is some intrinsic connection between the number of electrons on the outer shell and chemical reactivity. This hypothesis is absolutely correct: noble gases are chemically inert because their outer shell is full.

With regard to the atoms with an open shell (i.e. the atoms of 1st to 7th group elements), they are prone to transform to a state where all shells are full, and this explains their chemical reactivity. A transformation from the open shell state to the closed shell state can be achieved in two ways, and these ways are as follows.

1.4 Ionisation

An atom can lose one or several electrons from its outer shell, and this shell becomes empty. Since the next shell is closed, the new particle that forms in that process is chemically stable. Let's consider a sodium atom as an example. It has one electron at the outer shell, and it can lose it easily. The new particle that forms in that process is similar to a neon atom, except it is positively charged. This particle is called an *ion*. It is denoted as Na^+.

This process can be formally described with an equation:

$$Na - e^- \longrightarrow Na^+$$

Sometimes, to convert from the open shell to a closed shell state atoms do not donate electrons but take them. That usually occurs in the elements that have an outer shell that is almost full. Thus, a chlorine atom has an open shell where just one electron is missing. It can take one electron, thereby converting into a negative ion (Cl^-).

This process can be formally described with an equation:

$$Cl + e^- \longrightarrow Cl^-$$

This new particle, Cl^- has an electronic structure that is identical to the structure of the argon atom, except it is not neutral. This particle is also an ion. Do discriminate between negative and positive ions, scientists use speciall names for them: Positive ions are called *cations*, and negative ions - *anions*[2].

The processes of ion formation is called *ioniisation*.

Obviously, formation of cations and anions cannot go independently from each other: if some atom loses its electron, it actually *donates* it to some other atom or molecule. Accordingly, an atom that gets an electron obtains it from some other atom. For example, the two above processes can occur in parallel when chlorine (an element) reacts with sodium, and

[2] We will learn later why

sodium chloride forms as a result. In sodium chloride, chlorine atoms exist in a form of chlorine ions (Cl^-), and sodium atoms are sodium ions (Na^+), and they from a new compound, NaCl, where sodium and chloruine ions are held together due to electrostatic attraction force (Coulomb force). This type interaction is called an *ionic bond.*

> ***An ionic bond froms between two atoms when first atom donates one or several electrons to other atoms. As a result, electron shells in all atoms become more stable (they become closed), and the atoms are held together due to electrostatic interaction.***

1.5 Oxidation and reduction

As we can see, when chlorine reacts with sodium, it takes an electron from sodium. That means sodium is being *oxidized* in this reaction. Chlorine, which accepts an electron, is being *reduced.*

> ***Oxidation is a process of donation of electron(s). This process always occurs in parallel with reduction. An atom or molecule that takes electrons from another atom or molecule is called an "oxidizer", and it is being reduced in this process. Accordingly, an atom or a molecule that donates electron(s) is called a "reducer", and it is being oxidized in that process. The whole process is called "reduction-oxidation", or redox reaction.***

As a rule, the atoms that have one or few electrons on its outer shell have a tendency to donate electrons. Most metals fit this category. In contrast, the elements that have almost full outer shell (halogens, halkogens) prefer to accept electrons. Accordingly, these elements are strong oxidizerd, whereas metals are reducers.

1.6 Octet rule

This is a popular rule that tells any atom prefers to come to a state where exactly eight electrons are on its outer shell. This rule works mostly for elements of the second and third period of the Periodic table, but it is convenient for understanding of many chemical processes. Thus, it works perfectly for the above reaction: a sodium atom loses one electron, and there are exactly eight electrons at the outer shell of the sodium ion that froms as a result. The same works fro chlorine: it gets one electron, and there are exactly 8 electrons at its outer shell now.

The octet rule is just a consequaence of the fact that atoms prefer to form a state where the outer shell of closed. Obviously, this rule does not work for hydrogen or helium, because the capacity of the first shell is 2. The reason why the octer rule works for heavier elements will be discussed later.

The octet rule perfectly explains why alkali metals are always monivalent: they can donate just one electron, so they form just one ionic bond. The same works for halogens: they accept just one electron (and the outer shell becomes full), so they form just one ionic bond.

Calcium and other alkaline earth metals can donate *two* electrons, so they form two bonds with halogen atoms, hence they are divalent.

We will discull more complex cases later.

1.7 Covalent bond

In a situation when the atoms cannot donate or accept electrons, for example for two identical atoms, another possibility exists for observing the octet rule. They can *share* a pair of electrons. For example, one chlorine atom can meet another chlorine atom, and they can share a pair of electrons. What happens as a result of that?

Each chlorine atom has 7 electrons[3], or three electron pair at three orbitals and one electron at the fourth orbital. If each of two chlorine atoms donates their seventh electron, these electrons form a common orbital, which has two electrons now. One can say each chlorine atom has *four* orbitals each of which has two electrons, so the octet rule is satisfied now, and the electronic shells in both atoms becomes stable.

That explains why all halogens from a diatomic molecules:

$$Cl + Cl \longrightarrow Cl_2$$

In chemistry, this situation described as "formation of a covalent bond between two chlorine atoms".

> ***An covalent bond is a bond between two atoms that forms as a result of sharing of two electrons among them.***

Oxygen has only six electrons, which means two oxygen atom need to share *two* electron pairs to meet the octet rule: each atom has two *their own electron pairs* and they share two electron pairs. Importantly, that does not mean the oxygens are connected with a "four electron" covalent bond. Actually they form *two* separate covalent bonds, or with a double bond.

Homework

1. Using the Periodic table and the octet rule, explain why the valence of aluminium is three, and the valence of sulfur can be 2 and 6.

2. Read the Bottle Imp story `https://en.wikisource.org/wiki/Island_Nights%27_Entertainments/The_Bottle_Imp` (the link is clickable). We will need it during the next class.

My e-mail is mark.lukin@gmail.com

[3]We chemists usually discuss only the electrons at the outer shell, because other electrons play almost no role in chemical interactions. That is why I say chlorine has 7 electrons, despite the fact that it has more.