

Observation 1: Valence and the Periodic Table

To begin our analysis of chemical bonding, we define the valence of an atom by its tendencies to form molecules. The inert gases do not tend to combine with any other atoms. We thus assign their valence as 0, meaning that these atoms tend to form 0 bonds. Each halogen prefers to form molecules by combining with a single hydrogen atom (e.g. HF, HCl

). We thus assign their valence as 1, also taking hydrogen to also have a valence of 1. What we mean by a valence of 1 is that these atoms prefer to bind to only one other atom. The valence of oxygen, sulfur, etc. is assigned as 2, since two hydrogens are required to satisfy bonding needs of these atoms. Nitrogen, phosphorus, etc. have a valence of 3, and carbon and silicon have a valence of 4. This concept also applies to elements just following the inert gases. Lithium, sodium, potassium, and rubidium bind with a single halogen atom. Therefore, they also have a valence of 1. Correspondingly, it is not surprising to find that, for example, the combination of two potassium atoms with a single oxygen atom forms a stable molecule, since oxygen's valence of 2 is satisfied by the two alkali atoms, each with valence 1. We can proceed in this manner to assign a valence to each element, by simply determining the number of atoms to which this element's atoms prefer to bind.

In doing so, we discover that the periodic table is a representation of the valences of the elements: elements in the same group all share a common valence. The inert gases with a valence of 0 sit to one side of the table. Each inert gas is immediately preceded in the table by one of the halogens: fluorine precedes neon, chlorine precedes argon, bromine precedes krypton, and iodine precedes xenon. And each halogen has a valence of one. This "one step away, valence of one" pattern can be extended. The elements just prior to the halogens (oxygen, sulfur, selenium, tellurium) are each two steps away from the inert gases in the table, and each of these elements has a valence of two (e.g. H₂O

, H₂S). The elements just preceding these (nitrogen, phosphorus, antimony, arsenic) have valences of three (e.g. NH₃, PH₃), and the elements before that (carbon and silicon most notably) have valences of four (CH₄, SiH₄

). The two groups of elements immediately after the inert gases, the alkali metals and the alkaline earths, have valences of one and two, respectively. Hence, for many elements in the periodic table, the valence of its atoms can be predicted from the number of steps the element is away from the nearest inert gas in the table. This systemization is quite remarkable and is very useful for remembering what molecules may be easily formed by a particular element.

Next we discover that there is a pattern to the valences: for elements in groups 4 through 8 (e.g. carbon through neon), the valence of each atom plus the number of electrons in the valence shell in that atom always equals eight. For examples, carbon has a valence of 4 and has 4 valence electrons, nitrogen has a valence of 3 and has 5 valence electrons, and oxygen has a valence of 2 and has 6 valence electrons. Hydrogen is an important special case with a single valence electron and a valence of 1. Interestingly, for each of these atoms, the number of bonds the atom forms is equal to the number of vacancies in its valence shell.

To account for this pattern, we develop a model assuming that each atom attempts to bond to other atoms so as to completely fill its valence shell with electrons. For elements in groups 4 through 8, this means that each atom attempts to complete an "octet" of valence shell electrons. (Why atoms should behave this way is a question unanswered by this model.) Consider, for example, the combination of hydrogen and chlorine to form hydrogen chloride, HCl

. The chlorine atom has seven valence electrons and seeks to add a single electron to complete an octet. Hence, chlorine has a valence of 1. Either hydrogen or chlorine could satisfy its valence by "taking" an electron from the other atom, but this would leave the second atom now needing two electrons to complete its valence shell. The only way for both atoms to complete their valence shells simultaneously is to share two electrons. Each atom donates a single electron to the electron pair which is shared. It is this sharing of electrons that we refer to as a chemical bond, or more specifically, as a covalent bond, so named because the bond acts to satisfy the valence of both atoms. The two atoms are thus held together by the need to share the electron pair.

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