

1025 Basic Atomic Terminology Notes

Atoms are the basic building blocks of matter. Atoms are extremely small. A sugar cube sized sample of most materials has on the order of 10^{23} atoms!

Atoms are composed of a **nucleus** (central part) which contains **protons** and **neutrons**, and **electrons**, which surround (orbit) the nucleus at varying distances. Protons have a positive electrical charge, electrons have a negative electrical charge and neutrons have no electrical charge. The nucleus of the atom occupies a very small part of the total space taken by the atom, so most of the volume of an atom is actually empty space. In most naturally occurring atoms, the number of electrons is equal to the number of protons, so the electrical charges cancel out and the atom as a whole is electrically neutral.

Atoms are classified according to the number of protons in the nucleus, which is called the **atomic number**. So, for example, all hydrogen atoms have one proton in the nucleus, all uranium atoms have 92 protons in the nucleus. **Elements** are substances which contain all the same kind of atoms, like gold and silver. There are about 90 identified naturally occurring elements, which are listed on the **Periodic Table of the Elements**. All other substances are combinations of different kinds of atoms.

A **molecule** is a combination of atoms which are chemically (electrically) attached (bound) to one another. Molecules can be as small as two atoms (like O_2 or CO) and as large as thousands of atoms (like most proteins).

In a **compound**, different elements are chemically bound as molecules. So, for example, carbon dioxide is made of CO_2 molecules, with one carbon atom and two oxygen atoms each. Water is composed of H_2O molecules, with two hydrogen and one oxygen atom in each molecule. Ethyl alcohol, C_2H_5OH is composed of molecules with two carbon, one oxygen and six hydrogen atoms each.

In a **mixture**, the different atoms are not chemically combined. Air is a mixture of mostly nitrogen (about 80%) and oxygen (about 20%). The nitrogen atoms do not normally combine chemically with the oxygen atoms, so there are no "air molecules". It is therefore relatively easy to separate the oxygen from the nitrogen. This would not be the case if the nitrogen and oxygen atoms combined chemically to make molecules of nitrogen dioxide (NO_2), which sometimes happens under high temperature conditions (like in your car's engine).

The **atomic mass** of an atom is the number of protons plus the number of neutrons. Many elements have several different varieties, or **isotopes**, which have the same number of protons but different number of neutrons. For example, normal carbon has 6 protons and 6 neutrons in the nucleus (atomic mass = 12), but there is one isotope of carbon that has 6 protons and 8 neutrons in the nucleus (atomic number = 14). Carbon 12 and carbon 14 atoms are chemically identical (they react the same way with other atoms) because they have the same number of electrons, and it is the electrons that determine the chemical properties of an atom. C_{12} and C_{14} do have different radioactive properties because these arise from the nucleus. We will not discuss radioactive properties in this section of the course.

The chemical properties of an atom (what other atoms it will react with) are due to the electrons, specifically the **valence** electrons. The electrons surrounding an atom have different energy levels (sometimes called "shells"), similar to planets orbiting the sun at different distances with different velocities. In general, the higher the energy level of an electron, the further it is found from its nucleus. The energy levels that electrons can have are very well defined, and only a certain number of electrons can be in each energy level in a particular atom. **Valence** electrons are those electrons in an atom that have the highest energy levels, and it is these electrons that are involved in chemical reactions with other atoms.

The lowest energy level can have up to 2 electrons; the next two levels can have up to 8 electrons. Electrons are almost always found in the lowest available energy levels. So, in a normal hydrogen atom with one electron, the

electron is in the lowest energy level and the valence is 1. Carbon, as we have seen, has 6 electrons, so it would have 2 in the lowest energy level and 4 in the next level, giving it a valence of 4.

Let's compare sodium (Na) and potassium (K). Sodium has 11 electrons, so it has 2 in the first level, 8 in the next level, and 1 in the highest energy level, for a valence of 1. Potassium has 19 electrons, so it has 2 in the first level, 8 in the next level, 8 in the third level, and 1 in the highest energy level, for a valence of 1. Both sodium and potassium thus have a valence of 1 (1 electron in the outermost energy level). Since they have the same number of valence electrons, sodium and potassium are chemically very similar and tend to form the same kinds of compounds. So we have NaCl (sodium chloride), which is normal table salt, and we have KCl (potassium chloride), which also has a salty flavor.

The **Periodic Table of the Elements** arranges the different elements by atomic number (bottom to top, left to right). Elements with the same valence are in columns, which is why potassium is directly below sodium on the periodic table. The periodic table has only one spot for each element, but each element can have different isotopes with different atomic masses. As a result, the atomic mass listed on most periodic tables is actually a weighted average of the atomic masses of the different isotopes of that element. The table lists the atomic mass of carbon as 12.011. This is because the vast majority of naturally occurring carbon is C_{12} with a very small proportion of C_{13} and C_{14} mixed in. Thus, the atomic mass is listed as 12.011 rather than just a simple average of the different possible atomic masses, which would be 13.

You will often see elements referred to like this:



The C stands for carbon, the 6 is the atomic number (number of protons, also equal to the number of electrons) and the 14 is the atomic mass. So the number of neutrons here would be $14 - 6 = 8$.

Ions are atoms or molecules that have had electrons either removed or added. In an ion, therefore, the number of electrons is not equal to the number of protons, so ions as a whole have an electrical charge, which makes them chemically reactive. A negative ion has more electrons than protons (it has gained one or more electron) whereas a positive ion has fewer electrons than protons (it has lost one or more electrons). Ions are usually denoted by putting one or more + or - signs after the symbol, so Na^+ is a positive sodium ion (a normal sodium atom that has lost one electron) and O^{2-} or O^{--} is a negative oxygen ion (a normal oxygen atom that has gained two electrons).