

11.1: Nuclear Reactions

Learning Objectives

- Describe nuclear structure in terms of protons, neutrons, and electrons
- Identify a nuclear reaction
- Identify the key characteristics separating nuclear and chemical reactions

Nuclear chemistry is the study of reactions that involve changes in nuclear structure. The chapter on atoms, molecules, and ions introduced the basic idea of nuclear structure, that the nucleus of an atom is composed of protons and, with the exception of ${}^1_1\text{H}$, neutrons. Recall that the number of protons in the nucleus is called the atomic number (Z) of the element, and the sum of the number of protons and the number of neutrons is the mass number (A). Atoms with the same atomic number but different mass numbers are isotopes of the same element. When referring to a single type of nucleus, we often use the term **nuclide** and identify it by the notation:

$${}^A_Z\text{X} \quad (11.1.1)$$

where

- X is the symbol for the element,
- A is the mass number, and
- Z is the atomic number.

Often a nuclide is referenced by the name of the element followed by a hyphen and the mass number. For example, ${}^{14}_6\text{C}$ is called “carbon-14.” The element in this example, represented by the symbol C , is carbon. Its atomic number, 6, is the lower left subscript on the symbol and is the number of protons in the atom. The mass number, the superscript to the upper left of the symbol, is the sum of the number of protons and neutrons in the nucleus of this particular isotope. In this case, the mass number is 14, which means that the number of neutrons in the atom is $14 - 6 = 8$ (that is, the mass number of the atom minus the number of protons in the nucleus equals the number of neutrons). Occasionally, the atomic number is omitted in this notation because the symbol of the element itself conveys its characteristic atomic number. The two isotopes of hydrogen, ${}^2\text{H}$ and ${}^3\text{H}$, are given their own names: deuterium (D) and tritium (T), respectively. Another way of expressing a particular isotope is to list the mass number after the element name, like carbon-12 or hydrogen-3.

Nuclear reactions are very different from chemical reactions. In chemical reactions, atoms become more stable by participating in a transfer of electrons or by sharing electrons with other atoms. In **nuclear reactions**, it is the nucleus of the atom that gains stability by undergoing a change of some kind. The energies that are released in nuclear reactions are many orders of magnitude greater than the energies involved in chemical reactions. Unlike chemical reactions, nuclear reactions are not noticeably affected by changes in environmental conditions, such as temperature or pressure.

As the following Sections will discuss, there are three main forms of radioactive emissions. The first is called an alpha particle, which is symbolized by the Greek letter α . An alpha particle is composed of two protons and two neutrons, and so it is the same as a helium nucleus. (We often use ${}^4_2\text{He}$ to represent an alpha particle.) It has a $2+$ charge. When a radioactive atom emits an alpha particle, the original atom's atomic number decreases by two (because of the loss of two protons), and its mass number decreases by four (because of the loss of four nuclear particles). We can represent the emission of an alpha particle with a **nuclear equation**—for example, the alpha-particle emission of uranium-235 is as follows:



Chemists often use the names **parent isotope** and **daughter isotope** to represent the original atom and the product other than the alpha particle. In the previous example, ${}^{235}_{92}\text{U}$ is the parent isotope, and ${}^{231}_{90}\text{Th}$ is the daughter isotope. When one element changes into another in this manner, it undergoes *radioactive decay*.

Major Differences between Nuclear and Chemical Reactions

1. Nuclear reactions involve a change in an atom's nucleus, usually producing a different element. Chemical reactions, on the other hand, involve only a rearrangement of electrons and do not involve changes in the nuclei.

2. Different isotopes of an element normally behave similarly in chemical reactions. The nuclear chemistry of different isotopes vary greatly from each other.
3. Rates of chemical reactions are influenced by temperature and catalysts. Rates of nuclear reactions are unaffected by such factors.
4. Nuclear reactions are independent of the chemical form of the element.
5. Energy changes accompanying nuclear reactions are much larger. This energy comes from destruction of mass.
6. In a nuclear reaction, mass is not strictly conserved. Some of the mass is converted into energy.

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