8.1: Introduction to nuclear chemistry

What is a nuclear reaction?

Unlike chemical reactions that involve valence electrons, **nuclear reactions involve changes in the nucleus of an atom,** as shown in Fig. 8.1.1.

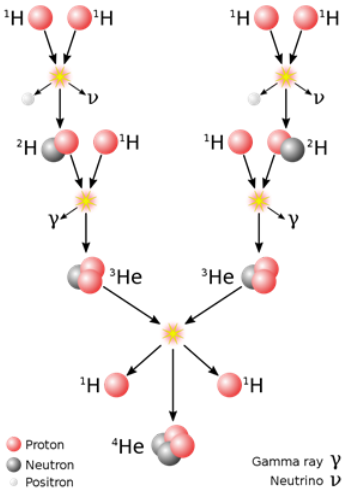

Figure 8.1.1: The proton-proton chain reaction, branch I, dominates in stars the size of the Sun or smaller. Source: Sarang, Public domain, via Wikimedia Commons

Nuclear reaction

Nuclear reactions involve changes in the nucleus of an atom. A nuclear reaction may result in one or more of the following: i) conversion of an atom to its isotope or an atom of another element, ii) conversion of mass into energy or vice versa, and iii) release of nuclear radiations.

Although nuclear reactions are less numerous than chemical reactions, they are essential in many aspects, e.g., they are the source of energy in the sun and stars and the synthesis of elements in the universe. Nuclear reactions are becoming essential in human life in the form of electricity production from nuclear power plants, a source of radioisotopes for medical imaging to visualize organs and diagnose diseases, to treat tumors, and cancerous cells, as shown in Fig. 8.1.2.

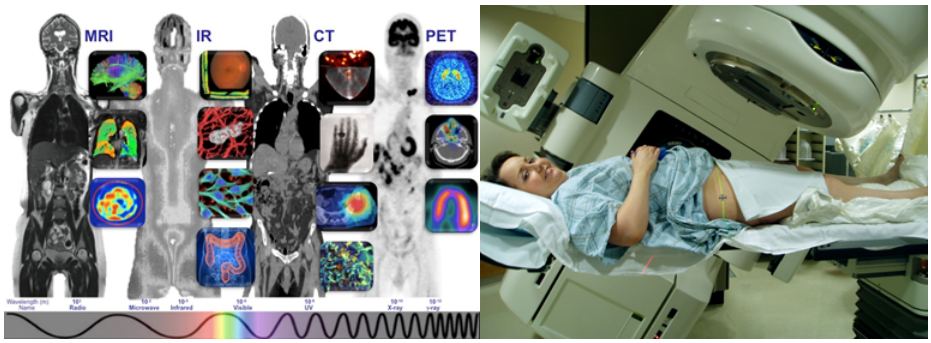

Figure 8.1.2: Spectrum of medical imaging (left) and radiation therapy of the pelvis. (right). Source: Martin Tornai, CC BY 4.0 <https://creativecommons.org/licenses/by/4.0>, via Wikimedia Commons, and Dina Wakulchik from Indianapolis, Indiana, USA / CC BY (https://creativecommons.org/licenses/by/2.0)

Nuclear nomenclature and symbols

Nucleoid

Nucleoid is another name for the nucleus of an atom, that is often used in nuclear chemistry

The composition of a nucleoid is represented by the same symbol that represents the isotopes of elements, as ${}^{A}_{Z}X$, where X is the element symbol, Z is the number of protons, and A is the number of protons and neutron in the nucleus. For example, carbon exists as a mixture of ${}^{12}_{6}C$, and ${}^{13}_{6}C$ isotopes. The name of the element, followed by the number of nucleons separated by a hyphen, is another way of representing a nucleoid. For example, carbon-12, carbon-13, and carbon-14 represent the carbon nucleoids having 6 protons each, but 6, 7, and 8 neutrons, respectively. Similarly, hydrogen exists as a mixture of ${}^{1}_{1}H$, ${}^{2}_{1}H$, and ${}^{3}_{1}H$, that can also be represented as hydrogen-1, hydrogen-2, and hydrogen-3, respectively.

Nucleons

The protons and neutrons are also called nucleons.

Nuclear reaction

A nuclear reaction is a process in which two nuclei, or a nucleus and an external subatomic particle, collide to produce one or more new nuclides.

The nuclear reaction is a reaction that involves nucleoids. The reactant nucleoid, called the **parent nucleoid**, usually transforms into a different nucleoid called the **daughter nucleoid**. The daughter nucleoid may be an isotope of the parent nucleoid, or it may be a different element. The conversion of an isotope to another isotope of the same or a different element is a nuclear reaction that is called **transmutation** or a nuclear transformation, as shown in Fig. 8.1.3.

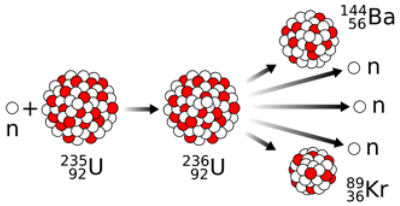

Figure 8.1.3: A nuclear fission reaction in which a partent nucleoid ${}^{235}_{92}U$ absorbs a neutron and transforms to a daughter nucleoid ${}^{236}_{92}U$, which later on transforms to two daughter nucleoids ${}^{144}_{56}Ba$ and ${}^{89}_{36}Kr$ along with emission three protons. Copy and Paste Caption here. Source: MikeRun, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

Nuclear radiations

Nuclear radiation or radioactivity is the particles and energy emitted by the nucleus during a nuclear reaction.

The nuclear reaction is accompanied by the emission of nuclear radiations including high-energy electromagnetic traditions called gamma-rays (γ-rays), subatomic particles like electrons, positrons, protons, neutrons, or a small nucleus, like ${}^{4}_{2}He^{2+}$ called alpha-particles (α-particles). Nuclear radiations are ionizing radiations, i.e., they can knock off electrons from the atoms they come in contact with.

Radioactive

The nucleoids that are capable of spontaneous disintegration, causing the emission of nuclear radiation, are called radioactive.

The process of emission of nuclear radiation by a spontaneous disintegration of radioactive nucleoids is called radioactivity, as illustrated in Fig. 8.1.4.

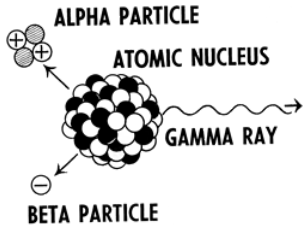

Figure 8.1.4: Illustration of radioactive decay of a nucleoid. Source: Pearson Scott Foresman, Public domain, via Wikimedia Commons

The nuclear radiations include gamma-rays (γ-rays), alpha-particles (α-particles), beta-particle (β-particles), neutrons (n), and positron ($\beta+$-particles).

Gamma-rays

The gamma-rays are electromagnetic radiations that have no mass and have energy higher than that of X-rays. The symbol γ, ${}^{0}_{0}\gamma$, or γ-ray represents a gamma-ray.

Alpha-particles

The alpha-particles (α-particles) are helium nuclei with two protons, two neutrons, and without electrons, i.e., ${}^{4}_{2}\mathrm{He}^{2+}$. The α-particles are also represented as ${}^{4}_{2}\mathrm{He}$ or Helium-4.

Beta-particles

The beta-particles (β-particles) are fast-moving electrons that have atomic number -1, charge -1, and negligible mass. The symbol β, β^{-}, ${}^{0}_{-1}\beta$, or ${}^{0}_{-1}\mathrm{e}$ also represents a β-particle.

Positrons

Positrons are anti-particle of electron, i.e., they have the same mass but opposite charge than that of an electron. The symbol $+\beta$, β^{+}, ${}^{0}_{+1}\beta$, or ${}^{0}_{+1}\mathrm{e}$ represents a positron.
