# Nuclear Radiation

## Types of Nuclear Radiation

The fact that atoms are conserved in one of the distinguishing characteristics of a chemical reaction. Although atoms may re-combine with other atoms, the atoms themselves do not change in chemical reaction, meaning that each atom retains its individual elemental identity. This is not the case for most nuclear reactions. As the name implies, the nature of the atomic nucleus changes in these reactions and with that change, if the number of protons in nucleus changes, the identity of the element changes.

The discovery that atomic nuclei could go under change came as a complete surprise. In 1896, the physicist French Henri Becquerel made the observation that uranium ore released something that exposed photographic film protected from exposure to light. Marie and Pierre Curie followed up on Becquerel's observation and isolated two new elements, polonium, element 84, and radium, element 88. Both of these elements were strong emitters of what Marie Curie called**radiation**, from the Latin radiare, meaning the emit rays.

There are multiple types of rays or radiation. One type that carries a positive charge and has a mass identical to a helium atom or 4 amu is designated**alpha** or **α**, as in the first letter of the Greek alphabet. A second type of radiation that carries a negative charge is termed **beta** or **β**, named for the second letter in the Greek alphabet and a third type, which is uncharged, is designated **gamma** or **γ** for the third letter of the Greek alphabet. Each of the three types of radiation, alpha, beta, and gamma, are distinct from each other. The particle associated with the alpha type radiation or **alpha particle**, is a helium atom that has lost both of its electrons or \(\text{He}^{2+}\). In other words, it is a helium nucleus. The negatively charged **beta particles** associated with beta type radiation is an electron that has been ejected from the nucleus and is not to be confused with electrons found outside of the nucleus that occupy atomic orbitals. In contrast to both the alpha type and the beta type, the unchanged **gamma radiation** is very high-energy electromagnet radiation, similar to X-rays, but of higher energy.

## Nuclear Stability and the Band of Stability

The number of protons in the nucleus of an atom determines the identity of an element. Although the number of protons is set for each element, the number of neutrons in the nucleus is not. The number of protons and neutrons in the nuclei of the lighter elements are about the same, but as the number of protons increase in the nucleus, neutrons increasingly out number protons. Neutrons aid in keeping the atomic nucleus intact, as they function to shield the repulsive, positively charged protons from each other. The heavier elements have more protons and consequently, more neutrons are required in the nuclei of the heavier elements. However, only certain numbers of protons and neutrons within an atomic nucleus result in a stable arrangement. If the balance between protons and neutrons does not result in a stable nucleus, the composition of protons and/or neutrons in the nucleus will change in an effort to form a more stable arrangement of proton and neutrons.

If the atomic number, which is the number of protons, is plotted on the X-axis and the number of neutrons in stable nuclei for each element on the Y-axis, the plot shows an upward slope and depicts what is known as the band of stability. Each stable combination of protons and neutrons on the plot, represent a stable nuclide, which is a general term used to indicate an individual elemental isotope.

## Nuclear Decay

#### Alpha Decay

Atomic nuclei that are inherently unstable undergo spontaneous changes that ultimately, lead to stable nuclei. As this happens, the number of protons in the nucleus can change, resulting in the atom changing its elemental identity. This process is generally referred to as a **decay** process. The loss of an alpha particle from the nucleus of a decaying atom results in the loss of two protons and two neutrons. This drops the atomic number of the atom by 2 and decreases the atomic mass units. Consequently, the elemental identity of the atom drops two positions lower on the periodic table.

For example,radium-238 (\(^{238}\text{U}\)) undergoes alpha decay by emitting an alpha particle (\(^4\_2\text{He}\)). This particle contains 2 protons and 2 neutrons, so the uranium nucleus loses 2 protons and 2 neutrons:

\(^{238}\_{92}\text{U} \rightarrow ^{234}\_{90}\text{Th} + ^4\_2\text{He}\)

As a result: the atomic number drops from 92 (uranium) to 90 (Thorium), the mass number decreased by 4, from 238 to 234, and the elemental identity changes from radium to polonium, moving two positions lower on the periodic table.

#### Beta Decay

The emission of a beta particle or an electron from the nucleus occurs as a neutron in an unstable nucleus decays to produce a proton. This results in increasing the atomic number by one and the elemental identity by one position higher on the periodic table with no change in atomic mass.

For example, carbon-14 (\(^{14}\text{C}\)) undergoes beta decay by emitting a beta particle (\(^0\_{-1}\text{e}\)). This particle is an electron produced when a neutron in the nucleus decays into a proton and an electron:

\(^{14}\_{6}\text{C} \rightarrow ^{14}\_{7}\text{N} + ^0\_{-1}\text{e}\)

As a result: the atomic number increases form 6 (carbon) to 7 (nitrogen), the mass number remains the same at 14, and the elemental identity changes from carbon to nitrogen, moving one position higher on the periodic table.

#### Gamma Decay

When an unstable nucleus undergoes gamma decay, a higher-energy gamma ray is emitted for the nucleus. However in this case, the number of protons or neutrons in the nucleus does not change nor is there any change in atomic mass. The energy associated with the gamma ray the represents the difference between a high-energy nuclear configuration of protons and neutrons and a lower energy unclear configuration of these particles.

For example, cobalt-60 (\(^{60}\text{Co}\)) undergoes gamma decay by emitting a high-energy gamma ray (γ). In this process, there is no change in the number of protons or neutrons, and therefore, no change in atomic number of mass number:

\(^{60}\_{27}\text{Co}^\* \rightarrow ^{60}\_{27}\text{Co} + \gamma\)

The asterisk (\(^\*\)) indicates that the cobalt nucleus is in an excited, high-energy state. The gamma ray that is emitted represents the energy released as the nucleus transitions to a more stable, lower-energy configuration. Because gamma decay involves only a change in energy and not in particle composition, the elemental identity remains the same—in this case, cobalt remains cobalt.

#### Other

There are two additional routes by which unstable nuclei may change. One involves the emission of a **positron**, a particle that is the positively charged equivalent of an electron. The emission of a positron from an unstable nucleus signals that a nuclear proton lost its positive charge and has been converted to a neutron. In this transformation, the atomic number of the atom decreases by one with no change in the atomic mass and the elemental identity of the atom is one position lower on the periodic table. In some cases, a proton within an unstable nucleus can capture an electron occupying an atomic orbital. This results in the conversion of a proton to a neutron. This process is known as **electron capture** and has the same effect on the nucleus and position emission. Namely, the atomic number decreases by one, the elemental identity drops by one position on the periodic table, and there is no change in the atomic mass. These five possible nuclear changes are summarized in this table.

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| --- | --- | --- | --- |
| Decay Type | Radiation Emitted | Generic Equation | Model |
| Alpha decay | \(^4\_2 \alpha\) | \(^A\_ZX \rightarrow ^{A - 4}\_{Z - 2}X' + ^4\_2\alpha\) |  |
| Beta decay | \(^0\_{-1}\beta \) | \(^A\_ZX \rightarrow ^A\_{Z + 1}X' + ^0\_{-1}\beta\) |  |
| Positron emission | \(^0\_{+1} \beta\) | \(^A\_ZX \rightarrow ^A\_{Z - 1}X' + ^0\_{+1}\beta\) |  |
| Electron capture | X rays | \(^A\_ZX + ^0\_{-1}e \rightarrow ^A\_{Z - 1}X' + \text{X ray}\) |  |
| Gamma emission | \(^0\_0 \gamma\) | Relaxation  \(^A\_ZX^\* \rightarrow ^A\_ZX' + ^0\_0 \gamma\) |  |
| Spontaneous fission | Neutrons | \(^{A+B+C}\_{Z+Y}X \rightarrow ^A\_ZX' + ^B\_YX' + C^1\_0\text{n}\) |  |

## Half-life and Measuring Radioactive Decay

Nuclear decay reactions are single atom reactions and every unstable nucleus has its own probability of undergoing a decay reaction. Some unstable nuclei are very unstable and have a high probability of undergoing a nuclear reaction, while others are relatively more stable and have a lower probability. It all depends on the individual nucleus and its combination of protons and neutrons. A convenient way to measure and compare the relative probability that a nucleus will undergo a decay reaction is to determine the time it takes for one-half of the atoms with a particular nuclear composition to decay. This is referred to as the**half-life** of the nucleus. For example lithium-8 has a half-life of 0.838 sec, meaning that after 0.083 seconds, only half of the original lithium-8 atoms initially present still remain. This is contrast to radium-228, which has a half-life of 1600 yrs. After 1600 years, only half of the original radium-228 atoms would still be radium-228. The other half will have undergone a nuclear decay event. Furthermore after an additional 1600 years, only half of the remaining half, or one quarter, of the original number of radium-228 atoms would be present.

The fraction of the original atoms present in a sample can be determined if the half-life of the nuclide is known. For example, after 8 days, one half or 5.00 mg of a 10.00 mg sample of iodine-131, which has a half-life of 8 days, would be present in the sample. After 16 days or two half-lives there would be one half of the remaining 5.00 mg left, or 2.50 mg, and after three half-lives there will be 1.25 mg of the original material, or one half to the remaining 2.50 mg. The relative amount of the original nuclide present is plotted on the y-axis as a function of the number of half-lives on the x-axis. The relative amount of the original nuclide present in a sample can be estimated from this half-life curve.

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* unknown, Co-60 Decay, CollegeSidekick
* unknown, Number of nuetrons graph, CollegeSidekick

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