Radioactivity

Group 2

May 2024

1 History and general concept

Before we delve in the realm of radioactivity we should have to know the definition and where it comes from. The term "radioactivity" was first used by Marie Curie in the late 19th century; however, Henry Becquerel discovered accidentally in 1896 while investigating phosphorescence in uranium salts called pitchblende emits invisible, penetrating radiations that can darken a photographic plate enclosed in an opaque envelope. Later it was found that there are some unstable isotopes that are emitting particles to be stable. It was soon evident that Becquerel's rays originate in the nuclei of the atoms and have other unique characteristics. The emission of these rays is called nuclear radioactivity.[1].
Radioactivity is the emission of ionizing radiation or particles caused by the spontaneous disintegration of atomic nuclei. A substance or object that emits nuclear radiation by destroying some parts of its mass is said to be radioactive. It is the release of energy from the decay of the nuclei of certain kinds of atoms and isotopes. Atomic nuclei consist of protons and neutrons bound together in tiny bundles at the center of atoms. Radioactive nuclei are nuclei that are unstable and that decay by emitting energetic particles such as photons, electrons, neutrinos, protons, neutrons, or alphas (two protons and two neutrons bound together). Some of these particles are known as ionizing particles. These are particles with enough energy to knock electrons off atoms or molecules. The degree of radioactivity depends on the fraction of unstable nuclei and how frequently those nuclei decay.
The effect of radioactivity also depends on the type and energy of the particles produced during nuclear decay. For example, neutrinos pass constantly through the Earth, while alpha particles are blocked by a sheet of paper. Radioactivity can cause damage in materials and in plant, animal, and human tissue. Scientists and engineers use radioactivity as a source of heat for satellites, for medical imaging, for targeted cancer treatments, for radiometric dating, and for research into the laws of nature and the origin of matter.

2 Types of Nuclear Radiation and their Ionization and Penetration Powers

Soon after the discovery of radioactivity, people began digging to know further about radioactivity and eventually, three type of rays were distinguished and named. Alpha, Beta, and Gamma rays, momentarily, like x-rays, their identities were initially unknown. Neutron radiation is also encountered in nuclear power plants and high-altitude flight and emitted from some industrial radioactive sources. With this connection, each of these comes through a different process in the decaying nucleus, each one is composed of different particles and each one has different properties.

2.1 Alpha Particle Radiation

Alpha Particle Radiation Alpha particles are subatomic fragments consisting of two neutrons and two protons or helium nuclei (He-4). Most of alpha particle radiation is not able to penetrate human skin; however, if the materials are inhaled, swallowed can cause series consequence. They are heavy, very short-range particle Alpha radiation occurs when the nucleus of an atom become unstable– the ratio of neutrons to protons is too low. Despite of the ionization power, alpha particles have low penetration power in comparison with gamma and beta radiations. A variety of instruments has been designed to measure alpha radiation, albeit they were unable to detect through even a thin layer of water, dust, paper, or other material due to its penetration power. When a radioactive atom decays by alpha emission, it leaves a daughter nucleus of atomic number less than two than the parent atom of atomic mass number four less than that of the parent atom. Thus,

$$^{A}_{Z}X- >^{A-4}_{Z-2} Y +^{4}_{2} He$$

where X and Y are chemical symbols of the parent and the daughter nuclei, respectively. For example, the abundant isotope of uranium, U-238, decays by alpha emission to give a thorium atom which can be written in a form :

$$^{238}_{92}U- >^{234}_{92} Th +^{4}_{2} He$$

2.2 Beta particle Radiation

Beta particle radiation is a light, a short range particle and is actually an ejected electron. Unlike alpha radioactivity, beta radioactivity requires the weak nuclear force. In comparison with alpha particles they can penetrate human skin to the germinal layer, where new skin cells are produces. There are two types of beta decay types; beta minus and beta plus. Beta minus particle emission occurs when the ratio of neutrons to protons in the nucleus is too high or when a neutron in an unstable nucleus transforms into a proton and electron. Conversely, a beta plus particle is emitted when a proton transforms into a neutron and a positron; the positron is then emitted. Most beta emitters can be detected with a survey instrument and a thin-window GM probe. Some beta emitters; however, produce very low-energy, poorly penetrating radiation that may be difficult or impossible to detect. Examples of these difficult to detect beta emitters are tritium, carbon-14, sulphur-35. Generally, we can conclude that the penetration power of gamma rays are the larger and the alpha particle radiation is the smallest one.in beta minus the process decreases the number of neutrons by one and increases the number of proton by one.

$$^{A}_{Z}X- >^{A}_{Z+1}Y+^{0}_{-1}\beta$$

2.3 Gamma particle Radiation

Gamma radiation is highly penetrating electromagnetic radiation. Nevertheless of their penetration they have least ionization power in comparison with alpha and beta particle radiation. Gamma radiation or x rays are able to travel many feet in air and many inches in human tissue. They readily penetrate most materials and are sometimes called "penetrating" radiation. X rays are like gamma rays. X rays, too, are penetrating radiation. Sealed radioactive sources and machines that emit gamma radiation and x rays respectively constitute mainly an external hazard to humans. they have no charge and no m ass so they rarely interact with particles int heir path

Dense materials are needed for shielding from gamma radiation. Clothing provides little shielding from penetrating radiation, but will prevent contamination of the skin by gamma-emitting radioactive materials. Gamma radiation is easily detected by survey meters with a sodium iodide detector probe. Gamma radiation and/or characteristic x rays frequently accompany the emission of alpha and beta radiation during radioactive decay.Gamma emitting are the most widely used radiation sources.

3 Biological effects of ionizing radiation Dangers of ionizing radiation

The biological effects of ionizing radiation are due to two effects it has on cells: interference with cell reproduction, and destruction of cell function. A cell with a damaged ability to repair DNA, which could have been induced by ionizing radiation, can do one of the following:
The cell can go into an irreversible state of dormancy, known as senescence.
The cell can commit suicide, known as programmed cell death.
The cell can go into unregulated cell division leading to tumors and cancers.[2].
Our nucleus carry out the DNA;however, it can be damaged by different mutagenic agents such as electromagnetic radiation and different radiations. When

radiation passes through cellular tissue, it ionizes water molecules which change into free radicals. These active radicals are highly reactive and have the ability to interact with our genetic materials and cause damage include increase mutation which is permanent. The extent of the potential damage depends upon several factors, including:
The type of radiation
the radioactive isotopes involved
the manner and length of time exposed. etc...

4 Effective Dose

Effective dose refers to the radiation dose that can cause severe health consequences. As we have seen before the effect inside our body depend upon the type of radiation; however, in the reality the absorbed dose also another factor of our health. Absorbed dose refers the amount of energy deposited per unit mass in an object or person. The unit for absorbed dose are gray (Gy), sievert (Sv) and rad; whereas 1Gy=$\frac{1J}{kg}$ and 1rad= 0.01Gy= $\frac{0.01J}{kg}$[3]
Depending upon the type of radiation and absorbed dose within shorter or higher time can cause fatal, with death occurring. Radiation sickness and cancer where the common one.

5 Nuclear Decay and Conservation Laws

Nuclear decay is the most crucial thing that reveal the relationship between mass and energy, and it revealed the existence of the two of the four basic forces in nature. In our case to converse about radioactive elements are the most fundamental things cause some nucleus are stable, apparently living forever, albeit some others are the opposite of this. Due drive and determination it is the transformation of unstable atomic nuclei into more stable configuration. It is a process by which atomic nucleus losses energy by emitting radiation in the form of particles or electromagnetic forms. In the entire decaying process some decays to stable nuclei in one process like that of ^{60}Co, while other changing to stable nuclei in decay series, for example ^{238}U
Depending upon nuclear radiation we have the atom can release energy in one of those radiation:

5.1 Alpha Decay

In this type of decay the daughter nuclei have 2 fewer proton and 2 fewer neutron because ^{4}He nucleus simply breaks away from the parent nucleus. Generally alpha decay equation given as:

$$^{A}_{Z}X_{N} -> ^{A-4}_{Z-2}Y_{N-2} + ^{4}_{2}He_{2}{}^{[1]} .$$

It is pivotal to examine weather the following thing is conserved or not, but in our cases when we see the equation the charge is conserved and also the linear and angular momentum are also conserved. Despite of the conservation of angular momentum, it is not interesting in comparison with linear momentum. If the atom is initially at rest after he decay their momentum increase drastically, granted the total momentum remain the same and this case also raise the idea of collision one to many. The alpha particle carrying away most of the energy. Total mass–energy is also conserved: the energy produced in the decay comes from conversion of a fraction of the original mass.

$$\mathrm{E}= (\delta m)(c)^2$$

5.2 Beta decay

It was quite sophisticated to talk about beta decay like an ordinary decay there are three types of decay. During beta decay, the nucleus undergoes a transformation that changes the numbers of protons and neutrons,leading to the formation of a different element. Beta decay is one of the most important type of decay for radiometric dating and medical imaging. There are ordinary, beta minus and beta plus beta decay.

5.3 Gamma decay

Gamma decay is the simplest form of nuclear decay. In higher orbitals neutrons and protons were found in higher orbitals to fall down to lower orbitals they fall by emission of photon energy, an nucleus have a life time of 10^-14s. Generally gamma decay given by the equation:

$${}^{A}_{Z}X^{*}_{N} - >^{A}_{Z} X_N + \gamma_1 + \gamma_2 ....(\gamma decay)^{[1]}$$

6 Radiation Detectors

Starting from the direct detector of becquerel fogged photographic plate their are different detector. in this day and age there are various type of detector photographic film is one of the most known detector is photographic film usually used in medical field. Another very common radiation detector is the Geiger-Muller tube. And widely known as Geiger counter, which is used to quickly detect and measure radiation. The idea is about there is a gas in a chamber then when we exposed to radioactive radiations, the stable gas in chamber will become ionize over a period of 60 seconds. When ionization occurs and the current is produced, a speaker clicks and a reading is given often in millisieverts (mSv). Geiger counter can detect alpha, beta and gamma rays, however they do not posses the ability to distinguish which is one alpha, beta and gamma.
The other widely used is the scintillators.

A scittillators is a general is a broad term for substances emit fluorescence when exposed to radiations of high energy- it is a type of phosphor.It utilize a material called scintillators use a more complex collaborative process to convert radiation energy into light. It might be a solid, liquid or other material The incident radiation can b e measured quantitatively by photo electrically converting or amplifying the emitted fluorescence with photomultiplier tube (PMT).

7 The Half-Life

In order to have stable nuclei, the unstable one releases energy. As a result unstable nuclei have shorter life span in comparison with the stable one. Assume that you have a system containing many nuclei of the same species at some initial time[3]. Unarguably, the parent nuclei decrease with time since it emits radiation in the form of particle (in most cases).The decay of a particular nucleus cannot be predicted and is not affected by physical influences like temperature.The rate isotope decay depends on the: the total number of undecayed nuclei present in the system and the stability of istope. In general, the decay rate, called the activity, A, is given by:

$$\text{A}= -\lambda N$$

The quantity of the parent radioactive nuclei is subject to exponential decay since it decreases at a rate proportional to its current value. This exponential decay law is given by

$$\text{N}=N_0 e^{-\lambda t}$$

However, in here the main question why half life ?
Since nuclear decay is purely statistical process, a more definition half life is that each nucleus has 50% chance of living for a time equal to one half-life, $t_{\frac{1}{2}}$. The answer can be found examine the exponential decay function for n integral numbers of half-lives, the number of original nuclides left, N,can be calculated by

$$\text{N}=2^{-n} N_0$$

8 Quantum Tunneling

It is a quantum mechanical phenomena in which a particle has a probability of passing through a potential barrier, even if its energy is less than the height barrier. This behavior is forbidden in classical mechanics, here are some properties

8.1 Wave-particle duality

Quantum tunneling is a direct consequences of the wave like properties of particles,as described by quantum mechanics.A particle like electron, was quite difficult to express only the particle nature cause it is not just like a point in space rather, it have to be described the particle nature and the wave nature(electron cloud) represented by wave function, for example.

8.2 Tunneling probability

You can take it as the relation between tunneling and the thickness and the height of the barrier. It is the probability of tunneling decreases exponentially with the thickness and the height of the barrier.[1]

Reference

[1] https://openstax.org/books/college-physics-2e/pages/31
[2] https://courses.lumenlearning.com/suny-physics/chapter/32-2-biological-effects-of-ionizing-radiation/
[3] MOE/ Physics grade 11 student textbook/ New curriculum