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Study on Radioactive Decay and Activity of Iodine 131, Carbon 14 and Cobalt 60

دراسة حول الاضمحلال الإشعاعي ونشاط اليود 131 والكربون 14 والكوبالت 60

A project Submitted in Partial Fulfillment of the Requirements for the Degree of B. Sc. in Physics

Research Project (Phys. 498)

By

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DEDICATION

I dedicate this project to Allah, who created me, provides unwavering support, and inspires my ideas. I also want to dedicate this project to my family and friends, whose unwavering support and praise have helped me the whole way through this academic journey.

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المستخلص

تلعب المواد المشعة أدوارًا محورية في مختلف المجالات. في هذه الدراسة، استُخدم نموذج الاضمحلال الأسّي لدراسة النشاط الأشعاعى للمواد المشعة، مثل اليود 131 والكربون 14 والكوبالت 60. يُظهر نموذج الاضمحلال الأسّي هذا أن النشاط الاشعاعى للمواد المشعة يتناقص بمرور الوقت، حيث يُحدد معدل الاضمحلال بثابت الاضمحلال λ. يُعد هذا النموذج بالغ الأهمية في مجالات مثل الفيزياء النووية والأشعة وعلوم البيئة لفهم سلوك المواد المشعة بمرور الوقت.

أظهرت هذه الدراسة أن نشاط اليود-131 يتغير على مدار عشرة أيام، بفواصل زمنية 0، 1، 2، 3، 4، 5، 6، 7، 8، 9، و10 أيام. ويعود هذا التغير إلى اضمحلاله الإشعاعي؛ حيث يبلغ نشاطه الابتدائي $A_0 = 100$ ملي كوري، وثابت الاضمحلال المحسوب 0.115 يوم $^{-1}$. أما بالنسبة للكربون-14، فيتغير نشاطه على مدار ألف عام، بفواصل زمنية 0، 100، 200، 300، 400، 500، 600، 700، 800، 900، و1000 عام. ويعود هذا التغير إلى اضمحلاله الإشعاعي؛ حيث يبلغ نشاطه الابتدائي 100 بيكريل، وثابت الاضمحلال المحسوب 1.21×10^{-4} سنة $^{-1}$.
كذلك، يتغير نشاط الكوبالت-60 على مدار 1000 عام في نقاط زمنية محددة (مثل 0، 100، 200، 300، 400، 500، 600، 700، 800، 900، و1000 عام) بسبب اضمحلاله الإشعاعي، بدءًا من نشاط ابتدائي 100 بيكريل وثابت اضمحلال 0.131 سنة $^{-1}$. وقد أكدت الدراسة أن نموذج الاضمحلال الأسي يُعد طريقة مفيدة لحساب نشاط المواد المشعة. وقد تم عرض ومناقشة تفاصيل طريقة الحساب والنتائج.

ABSTRACT

Radioactive materials play crucial roles across various fields. In this study the exponential decay model was used to study the activity A(t) of radioactive materials, such as iodine 131, carbon 14, and cobalt 60. This exponential decay model shows that the activity of radioactive materials decreases over time, with the rate of decay determined by the decay constant, λ. This model is crucial in fields such as nuclear physics, radiology, and environmental science for understanding the behavior of radioactive substances over time. The results of this study showed that the activity of Iodine-131 changes over a period of 10 days, with time intervals at 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 days. This change is due to its radioactive decay; the initial activity is A_0=100 mCi and the calculated value of the decay constant is $\lambda = 0.115$ days^{-1}. For carbon-14, the activity changes over a period of 1000 years, with time intervals at 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 years. This change is due to its radioactive decay; the initial activity is A_0=100 Bq and the calculated decay constant is $\lambda=1.21\times10^{-4}$ years^{-1}. Also, the activity of cobalt-60 changes over 1000 years at specific time points (like 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 years) because of its radioactive decay, starting with an initial activity of A0=100 Bq and a decay constant of λ=0.131 years^{-1}. The investigation confirmed that the exponential decay model is a useful method for the calculation of the activity of radioactive materials. Details of the calculation method and results are given and discussed.

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Chapter 1: Introduction

1.1 The Project Motivation

Studying radioactive materials can be incredibly motivating for several reasons. Radioactive materials are fundamental to understanding atomic structure, nuclear reactions, and the origins of elements in the universe. Research in radioactivity leads to breakthroughs in physics, including insights into fundamental forces and particles. Radioactive materials are used in medical imaging and cancer treatments. Understanding the radioactive materials leads to improved therapies and diagnostic techniques. Nuclear energy is a significant power source. Studying radioactive materials contributes to safer and more efficient energy production. Research can lead to better methods for handling and disposing of nuclear waste, addressing environmental concerns. Understanding radiation helps in developing protective measures for people and the environment. Expertise in radioactive materials opens doors in various fields, including healthcare, energy, research, and regulatory sectors. There is a constant need for professionals skilled in nuclear science, ensuring job security and opportunities for advancement. The study of radioactive materials intersects with chemistry, biology, geology, and engineering, encouraging collaboration and innovative approaches. Addressing issues like climate change and energy sustainability often involves nuclear science, making it relevant to global challenges.

1.2 The Project Importance

Radioactive materials contribute to advances in science, medicine, and technology while safeguarding public health and the environment. The radioactive materials play a vital role in medical imaging (e.g., PET scans) and cancer treatment (e.g., radiotherapy). Research in this area can lead to improved diagnostic and therapeutic techniques. Nuclear power is a significant energy source. Studying radioactive materials is essential for developing safer nuclear reactors and managing nuclear waste.

Research helps monitor and mitigate the environmental impacts of radioactive materials, especially in areas affected by nuclear accidents or mining. Radioactive isotopes are used in various scientific fields, including archaeology (radiocarbon dating), geology, and physics, providing insights into the age, composition, and processes of natural materials. Knowledge of radioactive materials informs regulations and policies that govern their use, ensuring they are handled safely and responsibly.

1.3 The Project Problem Statement

Radioactive materials are defined as substances that emit radiation because of the decay of unstable isotopes. These materials have significant applications in medicine, energy production, and scientific research, but they also pose health risks and environmental concerns. This study aims to enhance knowledge of radioactive materials, mitigate risks associated with their use, and inform policy decisions for public health and environmental safety. Despite the extensive theoretical framework surrounding radioactive materials, practical calculations and predictions for various materials remain a challenge for students and researchers. The project aims to analyze the parameters of radioactive materials and perform relevant calculations to enhance understanding of their properties and behavior. The task includes calculating the half-life of various isotopes. We calculate the decay constant based on the half-life values. We estimate the activity of radioactive samples and its implications for safety standards.

1.4. The Project Objectives

The project aims to achieve the following:

- To identify key parameters affecting the analysis of radioactive materials.
- To perform calculations related to half-life, decay constant, and activity of some radioactive materials.

Expected Outcomes

A comprehensive project detailing the parameters and calculations related to radioactive materials. Recommendations for safety measures based on calculated activity levels.

Insights into the implications of radioactive decay in various fields.

1.5. The Project Scope

Chapter one introduces the motivation, importance, problem statement, objectives, and scope of a project focused on radioactive materials. Chapter two deals with literature review for radioactive materials. A literature review on radioactive materials typically covers several key areas, such as definition and types of radioactive materials, properties of radioactive materials, applications of radioactive materials. Chapter three focuses on the materials and methodology study of radioactive materials. This chapter includes research design, materials used, sampling methods, Data collection techniques and statistical analysis. Chapter four presents' data and key findings of the results. In discussion, interpretation of results and comparison with existing literature are presented. In conclusion, a summary of key points, recommendations for future research and final thoughts on the importance of the study are given.

Chapter 2: Literature Review

2.1 Radioactive Materials

In 1896, Henri Becquerel discovered radioactivity while investigating the phosphorescence of uranium salts **[1].** He discovered that these salts released photons capable of exposing photographic plates without any additional energy source. In 1898, Marie Curie and Pierre Curie extracted radium and polonium from uranium ore. The term "radioactivity" was coined to characterize the phenomena and enhance the comprehension of radioactive elements **[2].** In 1902, Ernest Rutherford found alpha and beta radiation and subsequently suggested the nuclear model of the atom **[3].** He also elucidated the mechanism of alpha decay. In 1903, Frederick Soddy elucidated the notion of isotopes, demonstrating that elements can manifest in forms with varying atomic masses while retaining identical chemical properties **[4].** James Chadwick (1932) identified the neutron, which is essential for nuclear processes and the stability of atomic nuclei **[5].** Glenn T. Seaborg (1940) had a pivotal role in the discovery of numerous trans uranium elements and was crucial in the formulation of the actinide concept within the periodic table **[6].** The Manhattan Project (1940s): This project resulted in the creation of nuclear weapons and enhanced the comprehension of nuclear processes and radiation in a practical framework **[7].** Medical Applications in the Twentieth Century. The comprehension of radioactivity resulted in substantial medical applications, including radiation therapy for cancer treatment and the utilization of radioactive isotopes in diagnostics. These findings established the groundwork for contemporary nuclear physics and have significantly impacted several domains, including medicine, energy generation, and our comprehension of the universe.

Radioactive materials are substances that release radiation due to the disintegration of unstable atomic nuclei. This decay process may yield alpha particles, beta particles, gamma rays, or neutrons. The majority of the 92 naturally occurring elements on Earth are unstable and can transform into different forms **[8].**

2.2 Radioactive Material Types

Radionuclides (or radioactive materials) are a class of chemicals where the nucleus of the atom is unstable **[8].** They achieve stability through changes in the nucleus (spontaneous fission, emission of alpha particles, or conversion of neutrons to protons or the reverse) **[8].** This process is called radioactive decay or transformation and often is followed by the release of ionizing radiation (beta particles, neutrons, or gamma rays). Radioactive materials can be categorized into many classifications according to their characteristics and use **[9].** There are many radioactive materials and elements. There are naturally occurring and man-made radioactive materials. Some naturally occurring radioactive elements include (e.g., uranium, radon, and thorium). Some man-made radioactive elements include plutonium, cesium-137 and einsteinium. Man-made radioactive materials are **p**roduced in nuclear reactors or particle accelerators and are common in medical applications (e.g., cancer treatment). Radioactive materials can be categorized into several types based on their properties and uses. In this project the radioactive materials, such as iodine 131, carbon-14 (Beta emitters), cobalt-60 (Gamma emitters) and are selected.

2.2.1 Iodine 131

Iodine-131 (I^{131}), also called radioiodine, is an important radioisotope of iodine discovered by Glenn Seaborg and John Livingood in 1938 at the University of California, Berkeley **[10].** It has a radioactive decay of about eight days. Emits beta particles and gamma rays, making it useful for both therapeutic and diagnostic purposes. It is associated with nuclear energy, medical diagnostic and treatment procedures, and natural gas production. It also plays a major role as a radioactive isotope present in nuclear fission products and was a significant contributor to the health hazards from open-air atomic bomb testing in the 1950s, and from the Chernobyl disaster, as well as being a large fraction of the contamination hazard in the first weeks in the Fukushima nuclear crisis. This is because I-131 is a major uranium, plutonium fission product, comprising nearly 3% of the total fission products (by weight). See fission product yield for a comparison with other radioactive fission products. I-131 is also a major fission product of uranium- 233, produced from thorium. Iodine is among the most widely used radio nuclide's, mostly in the medical field.

Because of its short half-life and useful beta emission, iodine-131 is used extensively in nuclear medicine **[11].**

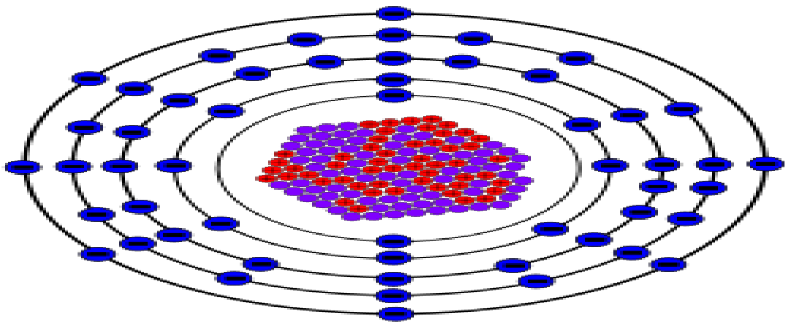

Figure 2.1: Iodine 131 **[10]**

Iodine-131 is an example of a nuclide which decays by beta minus decay. We can write

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{131}_{54}\mathrm{Xe} + \text{neutrino} + \text{beta particle} + \text{gamma ray} \qquad \textbf{(2.1)}$$

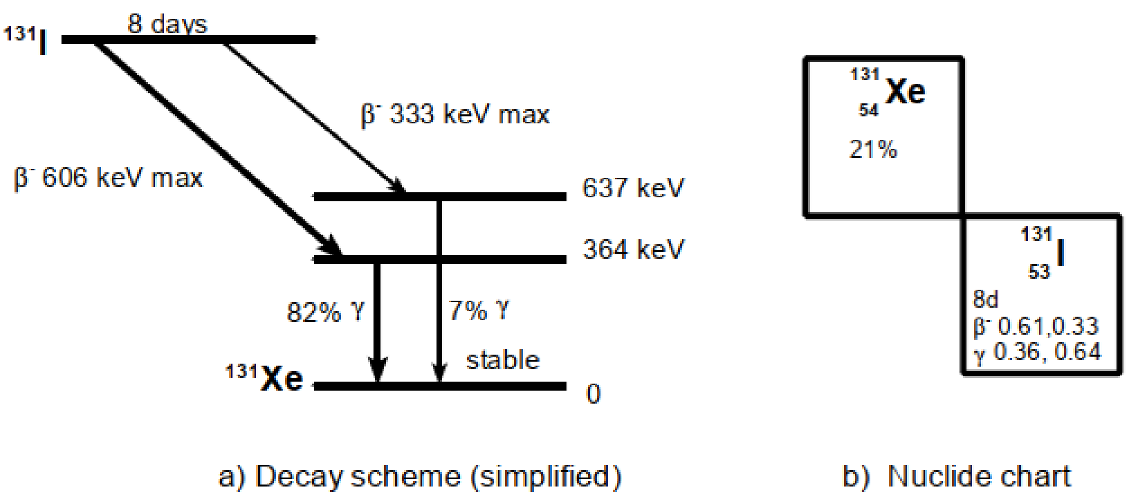

Figure 2.2: Decay of Iodine-131 **[10]**

2.2.2 Carbon 14

Carbon-14 (C-14) is a radioactive isotope of carbon that is used extensively in radiocarbon dating **[12].** Carbon-14 (C-14) is a radioactive isotope of carbon with a nucleus containing 6 protons and 8 neutrons. C-14 is formed in the atmosphere when cosmic rays interact with nitrogen-14 (N-14) atoms. The half-life of C-14 is about 5,730 years, meaning it takes this amount of time for half of a sample of C-14 to decay into nitrogen-14. C-14 is used to date organic materials, such as wood, bone, and shell, by measuring the remaining C-14 in a sample. C-14 dating is effective for samples up to about 50,000 years old. Beyond this, the amount of C-14 becomes too small to measure accurately. C-14 is a crucial tool in fields such as archaeology, geology, and environmental science, helping to uncover the past through the study of organic materials **[13].**

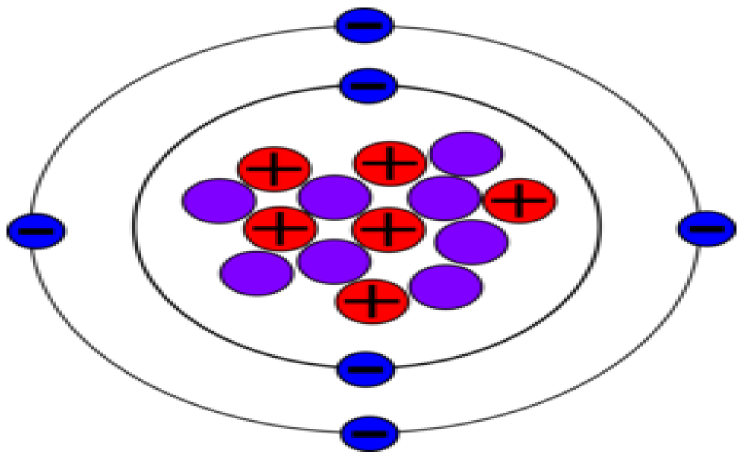

Figure 2.3: Carbon 14 **[13]**

2.2.3 Cobalt 60

Cobalt-60 is a radioactive isotope of cobalt. It is commonly used in various applications, primarily in medical and industrial fields **[14].** Cobalt-60 has a half-life of about 5.27 years. It emits gamma rays, which are highly penetrating and useful for various applications. It is widely used in radiation therapy for cancer treatment, helping to target and destroy malignant cells. Cobalt-60 is utilized for sterilizing medical equipment, food irradiation, and in certain types of radiography to inspect welds and materials.

Cobalt-60 is produced in nuclear reactors by irradiating cobalt-59 with neutrons. Handling Cobalt-60 requires strict safety measures due to its radioactive nature, including shielding and proper waste disposal.

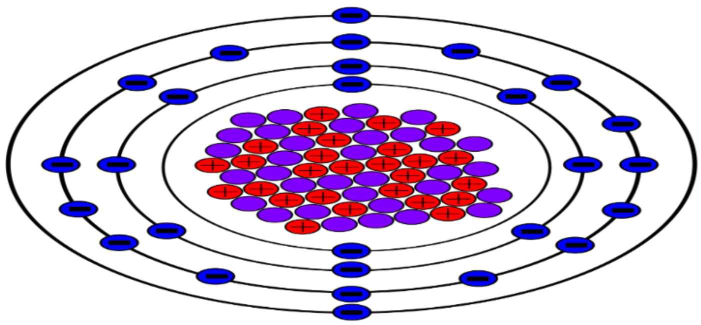

Figure 2.4: Cobalt 60 **[14]**

Table 2.1: Parameters for Iodine 131, Carbon 14 and Cobalt 60

Parameter	**Lodine-131**	**Carbon-14**	**Cabalt-60**
Half-Life	8.02 days	5730 years	5.27 years
Type of Radiation	Beta, Gamma	Beta	Beta, Gamma
Main Uses	Thyroid cancer treatment	Radiocarbon dating	Cancer treatment, Industrial Radiography
Decay Mode	Beta decay	Beta decay	Beta decay
Energy of Beta Particles	0.6 – 0.9 MeV	0.156 MeV	0.31 MeV
Primary Gamma Energy	0.364 MeV	N/A	1.173 MeV, 1.332 MeV
Biological Half-Life	5-10 days (varies)	40-60 days	30 days (in humans)
Specific Activity	1.34×10^{12} Bq/g	2.2×10^{-12} Bq/g	3.7×10^{13} Bq/g
Atomic Mass	130.906 u	14.003 u	59.933 u
Units	Bq (Becquerel)	Bq (Becquerel)	Bq (Becquerel)

2.3 Radioactive Materials Properties

2.3.1 Radioactive Decay

When the nucleus of a radionuclide spontaneously gives up its extra energy, that energy is called ionizing radiation. Ionizing radiation may take the form of alpha particles, beta particles, or gamma rays. The process of emitting radiation is called radioactive decay**15].** Radioactive decay is the process by which unstable atomic nuclei lose energy by emitting radiation. Decay can be characterized by parameters. The analysis of radioactive materials involves measuring various parameters that influence their behavior, such as half-life, activity, decay constant, radiation type and radiation shielding calculations.

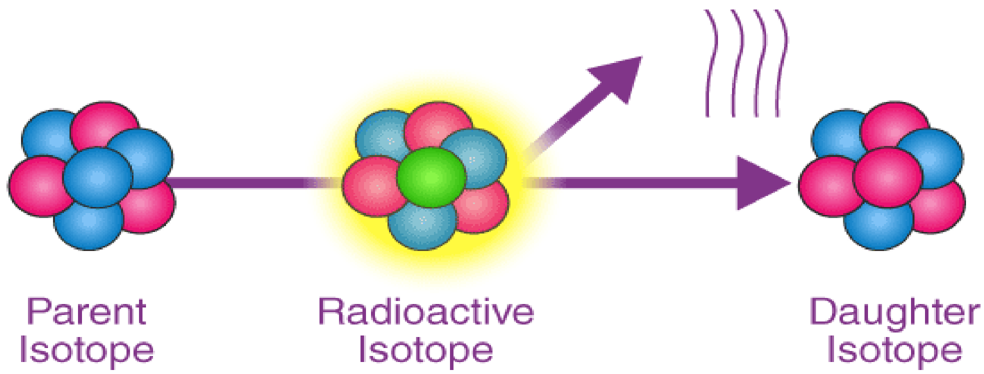

Figure 2.5: Radioactive Decay **[15]**

Due to the radioisotope of the element having an unstable nucleus, the atom particles cannot be bonded since there is no energy. The isotopes constantly decay to stabilize themselves by releasing a significant amount of energy in the form of radiation. Transmutation is referred to as the process of isotope transformation into an element of a stable nucleus. It can occur both in natural and artificial ways. There are several types of radiation present in nature and manmade sources, namely alpha particles, beta particles, gamma rays, X-rays and neutrons.

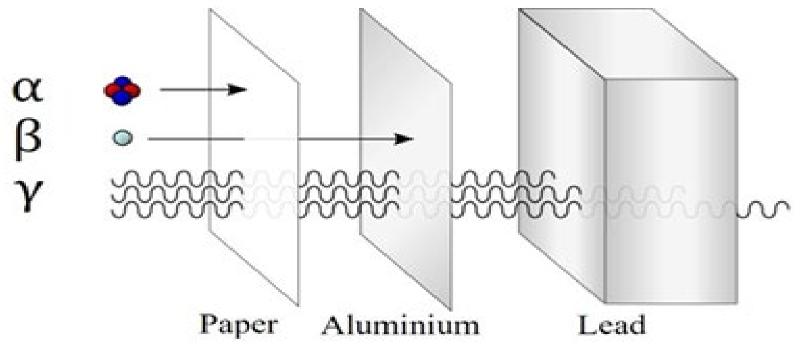

Figure 2.6: Examples of materials which will stop alpha beta and gamma radiation1 **[15]**

Alpha Particles

Alpha particles are the slowest of the different types of radiation. They can travel only a few inches in the air, losing their energy almost as soon as they collide with anything. They can easily be shielded with a sheet of paper or the outer layer of a person's skin. An alpha particle has a large mass and two protons and no electrons. Because it has two protons and no electrons, it is positively charged. When emitted from the nucleus, the positive charge causes the alpha particle to strip electrons from nearby atoms as it passes.

The alpha decay of U-238 is

$$ {}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th \qquad \textbf{(2.2)} $$

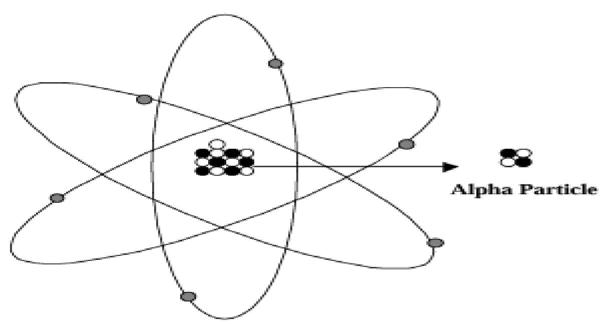

Figure 2.7: Alpha Radiation **[15]**

Alpha particles are extremely hazardous to fire fighters because they can be inhaled and deposited in body tissues, where they can cause severe long term health effects. Positive pressure SCBA is effective protection against inhaling alpha particles. These agents can affect the cells of the body in various ways, and each can destroy cells.

Alpha decay: When an alpha particle emits its nucleus, the process is called alpha decay. The formula for alpha decay is given as:

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}X + {}^{4}_{2}\alpha \qquad \textbf{(2.3)} $$

Where, ${}^{A}_{Z}X$is the parent nucleus (the original nucleus before decay). ${}^{A-4}_{Z-2}X$ is the daughter nucleus (the resulting nucleus after emitting the alpha particle). ${}^{4}_{2}\alpha$ is the emitted alpha particle. Z is the atomic number (number of protons). In this equation: A is the mass number (total number of protons and neutrons). This process decreases the mass number by 4 and the atomic number by 2.

Beta Particles: Beta particles are more energetic than alpha particles. They travel in the air for a distance of a few feet. Beta particles can pass through a sheet of paper but may be stopped by a sheet of aluminum foil or glass. A beta particle has a small mass and is usually negatively charged. It is emitted from the nucleus of an atom with a charge of minus one. Beta radiation causes ionization by interfering with electrons in their orbits. Both have a negative charge, so the electrons are repelled when the beta particle passes.

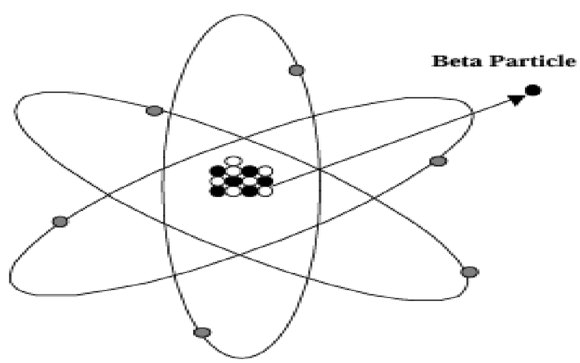

Figure 2.8: Beta Radiation [15]

Therefore, the nuclear symbol representing an electron (beta particle) is ${}^{0}\beta_{-1}$. Thorium-234 is a nucleus that undergoes beta decay. Here is the nuclear equation for this beta decay.

$$ {}^{234}_{90}Th \rightarrow {}^{0}_{-1}e + {}^{234}_{91}Pa \qquad \textbf{(2.4)} $$

As well as some nuclei decay via beta emission as below:

$$ {}^{32}_{15}P \rightarrow {}^{32}_{16}S + {}^{0}_{-1}e \qquad \textbf{(2.5)} $$

Beta particles can damage the skin or tissues of the eye. Internally, they can be extremely damaging if they concentrate on specific tissues.

Beta Decay: A beta particle is often referred to as an electron, but it can also be a position. If the reaction involves electrons, the nucleus sheds out neutrons one by one. Even the proton number increases accordingly. A beta decay process is beta minus (β-) and beta plus (β+). In beta minus (β-) a neutron is transformed into a proton, emitting an electron and an antineutrino. The atomic number increases by one. In beta plus (β+) a proton is transformed into a neutron, emitting a positron and a neutrino. The atomic number decreases by one.

Gamma Rays: Gamma rays (unlike alpha or beta particles) are waves of pure energy; they have no mass. They are emitted from the nucleus of an atom and travel at the speed of light (186,000 miles per second). Gamma radiation can be very penetrating and requires concrete, lead or steel to stop it.

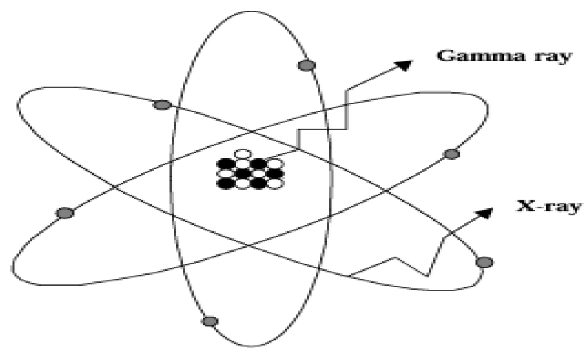

Figure 2.9: Gamma and X radiation **[15]**

Gamma Decay: The nucleus has orbiting electrons, which indeed have some energy, and when an electron jumps from a level of high energy to a level of low energy, there is an emission of a photon. The same thing happens in the nucleus: whenever it rearranges into a lower energy level, a high-energy photon is shooted out, which is known as a gamma ray. In the alpha decay of U-238, two gamma rays of different energies are emitted in addition to the alpha particle.

$$ {}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + 2{}^{0}_{0}\gamma \qquad \textbf{(2.6)} $$

Neutron Particles: Neutrons are particles normally contained in the nucleus of an atom. The can be released through certain manufacturing processes, such as nuclear fission (splitting an atomic nucleus).

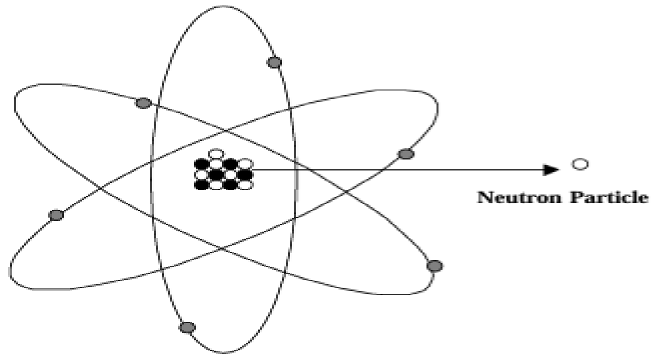

Figure 2.10: Neutron Radiation **[15]**

Neutrons are considerably larger than beta particles but have only one-fourth the mass of an alpha particle. Because they can penetrate even thick lead shields, they can be extremely damaging to humans. However, neutron radiation is very rare since it is generally emitted only when atomic weapons are detonated.

2.4 Radioactive Materials Parameters and Methods

2.4.1 Half-Life ($t_{1/2}$)

Rutherford in 1904 introduced a constant known half-life period of the radio element for evaluating its radioactivity or for comparing its radioactivity with the activities of other radio elements. The half-life period of a radio element is defined as the time required by a given amount of the element to decay to one-half of its initial value. In other words, half-life is the time taken for the radioactivity of a substance to reduce to half its initial value. The half-life of radioactive materials is calculated using the formula: Mathematically,

$$t_{1/2} = \frac{\ln 2}{\lambda} \qquad \textbf{(2.7)}$$

Where, $t_{1/2}$ is the half-life, λ is the decay constant, which represents the probability of decay per unit time. Ln (2) is the natural logarithm of 2 (approximately 0.693). This formula allows you to determine how long it takes for half of a given quantity of a radioactive substance to decay. The half-life periods or the half-lives of different radioelements vary widely, ranging from a fraction of a second to millions of years. Let the initial amount of a radioactive substance be N_0. After one half-life period $t_{1/2}$ it becomes = $N_0/2$.

After two half-life periods ($2t_{1/2}$) it becomes = $N_0/4$. After three half-life periods ($3t_{1/2}$) it becomes = $N_0/8$. After n half-life periods ($nt_{1/2}$) it becomes = $(\frac{1}{2})^n N_0$. Number of radioactive substances left after n half-life periods $N = (\frac{1}{2})^n N_0$ and Total time $T = n \times t_{1/2}$. Where n is a whole number.

2.4.2 Average-life period (T)

Since the total decay period of any element is infinity, it is meaningless to use the term total decay period (total life period) for radio elements. Thus, the term **average life** is used which the following relation determines.

$$\text{Average life (T)} = \frac{\text{Sum of lives of the nucle}}{\text{Total number of nuclei}} \qquad \textbf{(2.8)}$$

Relation between average life and half-life: Average life (T) of an element is the inverse of its decay constant, i. e., T= 1/λ, Substituting the value of λ in the equation **(2.8)**,

$$\boldsymbol{T = \frac{t_{1/2}}{\ln 2} = \frac{t_{1/2}}{0.693} = 1.44\ t_{1/2}} \qquad \textbf{(2.9)}$$

Thus, **Average life (T)** = 1.44 × Half-life ($T_{1/2}$) = $\sqrt{2}\, t_{1/2}$.

Thus, the average life period of a radioisotope is approximately under-root two times its half-life period. This is because the greater the value of λ , i.e., faster is the disintegration, the smaller is the average life (T).

2.4.3 Activity

The activity of a radioactive material is a measure of the decay rate, typically expressed in becquerels (Bq) or curies (Ci). Activity **A** can be calculated using the formula

$$A = \lambda\, \text{N} = 0.693 \frac{\text{N}}{t_{1/2}} \qquad \textbf{(2.10)}$$

where $\boldsymbol{\lambda}$ is the decay constant and ***N*** is the number of radioactive nuclei.

The activity A(t) of a radioactive material change over time as it decays. The relationship can be described using the exponential decay formula:

$$A\,(t) = \text{A}_0 \text{e}^{-\lambda\, t} \qquad \textbf{(2.11)}$$

Where, A (t) is the activity at time t, A_0 is the initial activity, λ is a decay constant, t is a time elapsed, and e is the base of the natural logarithm (2.71828).

2.5 Radioactive Materials Applications

Radioactive materials are used in producing many of the products we use every day: plastic wrap, radial tires, coffee filters, and smoke detectors. Many medical facilities contain radioactive hazards (medical isotopes are used for diagnosis and treatment of many diseases). Radioactive materials are used for diagnostic radiology, radiation medicine, and radiopharmaceuticals. Radiation hazards also exist wherever radioactive materials are stored, or radioactive waste products are discarded. Radioactive materials are used in industry (e.g., radiography), research and nuclear energy, health and environmental effects, short-term and long-term exposure risks and case studies of accidents or contamination.

Chapter 3: Materials and Methods

The study of radioactive materials, focusing on Iodine-131, Carbon-14, and Cobalt-60, along with the materials and methods for calculating key parameters. Usually, samples are collected and prepared for analysis in case of experimental work, ensuring safety protocols for handling radioactive materials. In this work, we apply decay equations to calculate half-lives and, activity of, Iodine-131, Carbon-14, and Cobalt-60.

3.1 Materials

A brief description of the radioactive materials used in this study such as iodine-131, carbon-14 and cobalt-60. Iodine-131 has an atomic number of 53, mass of 131and half-life (about 8 days). Carbon-14 has an atomic number of 6, mass of 14 and half-life (about 5,730 years). Cobalt-60 has an atomic number 27, mass of 60 and half-life (about 5.27 years)

3.2 Methods of Radioactive Materials Parameters Calculations

3.2.1 The Activity of Iodine-131 Changes over Time

For the activity A(t) of Iodine-131 over time due to radioactive decay, you can use the following exponential decay formula, $A\,(t) = A_0 e^{-\lambda\, t}$ in equation (2.11). The activity decreases exponentially over time due to the radioactive decay of Iodine-131. Each value is calculated using the formula $A(t)=100\cdot e^{-0.115t}$. For the activity A (t) of Iodine-131 changes over time (t) in 10 days, the time intervals (e.g., 0, 1, 2,3, 4, 5, 6, 7, 8, 9, 10 days), due to its radioactive decay, initial activity A_0=100 mCi, the calculated value of decay constant is (λ=0.115 $days^{-1}$).

Table 3.1: Parameters for Iodine-131

Time t (days)	Decay constant, λ ($days^{-1}$)	initial activity $A_{0,}$ mCi
0	0.115	100
1	0.115	100
2	0.115	100
3	0.115	100
4	0.115	100
5	0.115	100
6	0.115	100
7	0.115	100
8	0.115	100
9	0.115	100
10	0.115	100

3.2.2 The Activity of Carbon-14 Changes over Time

For the activity A(t) of carbon-14 over time due to radioactive decay, you can use the following exponential decay formula, $A\,(t) = A_0 e^{-\lambda\, t}$ in equation (2.11). The activity decreases exponentially over time due to the radioactive decay of carbon-14. Each value is calculated using the formula $A(t)=100\cdot e^{-0.115t}$. For Carbon-14, the half-life $t_{1/2}$ is approximately 5730 years. Thus, you can calculate λ and then use it to find A(t) at any time t. For the activity A (t) of carbon-14 changes over time (t) in 1000 years, the time intervals (e.g., 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 years), due to its radioactive decay, initial activity A_0=100 Bq, the calculated decay constant is ($\lambda=1.21\times10^{-4}$ $years^{-1}$).

Table 3.2: Parameters for **Carbon-14**

Time t (years)	Decay constant, λ ($years^{-1}$)	Initial Activity $A_{0,}$ Bq
0	1.21×10^{-4}	100
100	1.21×10^{-4}	100
200	1.21×10^{-4}	100
300	1.21×10^{-4}	100
400	1.21×10^{-4}	100
500	1.21×10^{-4}	100
600	1.21×10^{-4}	100
700	1.21×10^{-4}	100
800	1.21×10^{-4}	100
900	1.21×10^{-4}	100
1000	1.21×10^{-4}	100

3.2.3 The Activity of Cobalt-60 Changes over Time

For the activity A(t) of cobalt-60 over time due to radioactive decay, you can use the following exponential decay formula, $A\,(t) = A_0 e^{-\lambda\, t}$ in equation (2.11). The activity decreases exponentially over time due to the radioactive decay of cobalt-60. Each value is calculated using the formula $A(t)=100\cdot e^{-0.131\ t}$. For cobalt-60, the half-life is approximately 5.27 years. For the activity A (t) of cobalt-60 changes over time (t) in 1000 years, the time intervals (e.g., 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 years), due to its radioactive decay, initial activity A_0=100 Bq, decay constant (λ=0.131 years^{-1}).

Table 3.3: Parameters for Cobalt-60

Time t (years)	Decay constant, λ (years $^{-1}$)	Initial Activity A_0, Bq
0	0.131	100
100	0.131	100
200	0.131	100
300	0.131	100
400	0.131	100
500	0.131	100
600	0.131	100
700	0.131	100
800	0.131	100
900	0.131	100
1000	0.131	100

Chapter 4: Results, Discussion, and Conclusion

4.1 Results and Discussion

4.1.1 The Activity of Iodine-131

Here's the completed table 4.1 with the calculated activity values for Iodine-131 over 10 days. The physical half-life of iodine-131 is approximately 8.02 days. This duration is the time required for half of the radioactive substance to decay through radioactive processes, independent of biological factors. Iodine-131 exhibits the fastest decay rate due to its short half-life, which makes it useful in medical applications (e.g., thyroid treatment). The rapid decay of iodine-131 means that it must be administered quickly in medical treatments, as its effectiveness diminishes rapidly.

Table 4.1: the activity A (t) of Iodine-131 changes over time (t)

Time, t (days)	Activity A(t), mCi
0	100.00
1	87.24
2	76.73
3	67.35
4	59.09
5	51.03
6	43.15
7	35.46
8	27.95
9	20.61
10	13.43

In Figure 4.1, at time t = 0 days, the activity is 100 mCi. The activity decreases steadily over time, indicating a typical radioactive decay pattern. The half-life of Iodine-131 is approximately 8 days. By observing the data, we notice that after 8 days, the activity is approximately 27.95 mCi, which is close to half of the initial 100 mCi.

The activity shows a significant decline in the first few days, particularly from 100 mCi to 87.24 mCi (day 1). The activity decreases from 87.24 mCi to 76.73 mCi on day 2. This pattern continues, with each day showing a decrease until reaching 13.43 mCi at day 10.

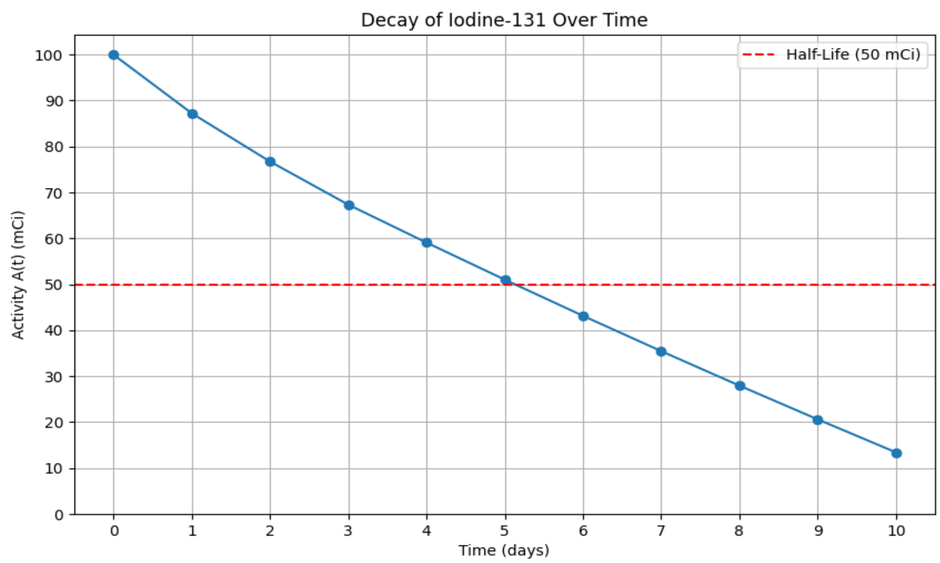

Figure 4.1: the activity A (t) of Iodine-131 changes over time (t)

4.1.2 The Activity of Carbon-14

Table 4.2 shows the activity A (t) of **Carbon-14** changes over time (t). Carbon-14's long half-life allows for its application in radiocarbon dating, providing a means to date ancient organic materials. Carbon-14's stability allows it to remain useful for thousands of years, but it limits the range of materials that can be dated with precision. The activity decreases gradually, indicating a typical exponential decay pattern characteristic of radioactive substances. Each interval shows a small decrease in activity.

Table 4.2: the activity A (t) of **Carbon-14** changes over time (t)

Time, t (years)	Activity A(t), Bq
0	100.00
100	98.79
200	97.58
300	96.39
400	95.20
500	94.02
600	92.84
700	91.67
800	90.51
900	89.35
1000	88.20

Figure 4.2 shows a graph of A(t) of **Carbon-14** versus time would show an exponential decay curve. For instance, from 0 to 100 years [(100- 98.79)/100] % is 1.21%. This trend continues with diminishing returns as time progresses. The half-life of Carbon-14 is about 5,730 years, which means it takes this long for the activity to reduce to half its original value. The gradual decline suggests that after thousands of years, the activity will approach zero but will never quite reach it, consistent with the nature of exponential decay.

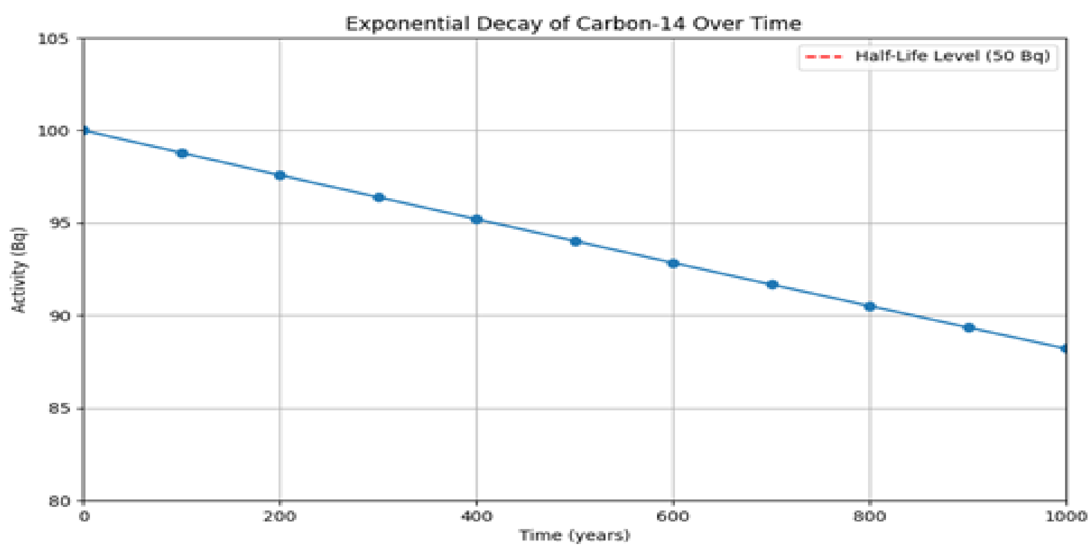

Figure 4.2: the activity A (t) of Carbon-14 changes over time (t)

4.1.3 The Activity of Cobalt-60

Table 4.3 shows the activity A (t) of **Cobalt-60** changes over time (t). Cobalt-60, with a moderate half-life, is widely used in radiation therapy and industrial applications. The activity of Cobalt-60 changes over time due to its radioactive decay. Cobalt-60's decay characteristics make it suitable for medical and industrial uses, though facilities must manage its short-term hazards.

Table 4.3: the activity A (t) of **Cobalt-60** changes over time (t)

Time, t (years)	Activity A(t), Bq
0	100.00
100	36.77
200	13.52
300	4.96
400	1.82
500	0.67
600	0.25
700	0.09
800	0.03
900	0.01
1000	0.00

Figure 4.3 shows a graph of A(t) of Cobalt-60 versus time would show an exponential decay curve. To analyze the decay pattern of Cobalt-60 over time based on the activity data provided, we can observe the following key points: At time t = 0 years, the activity is 100 Bq. The activity decreases significantly over 100 years, dropping to about 36.77 Bq at t=100years. After 200 years, the activity is approximately 13.52 Bq. By 500 years, it further decreases to about 0.67 Bq. After 1000 years, the activity approaches 0 Bq, indicating the material has decayed significantly. The activity decreases significantly over time, demonstrating a classic exponential decay pattern.

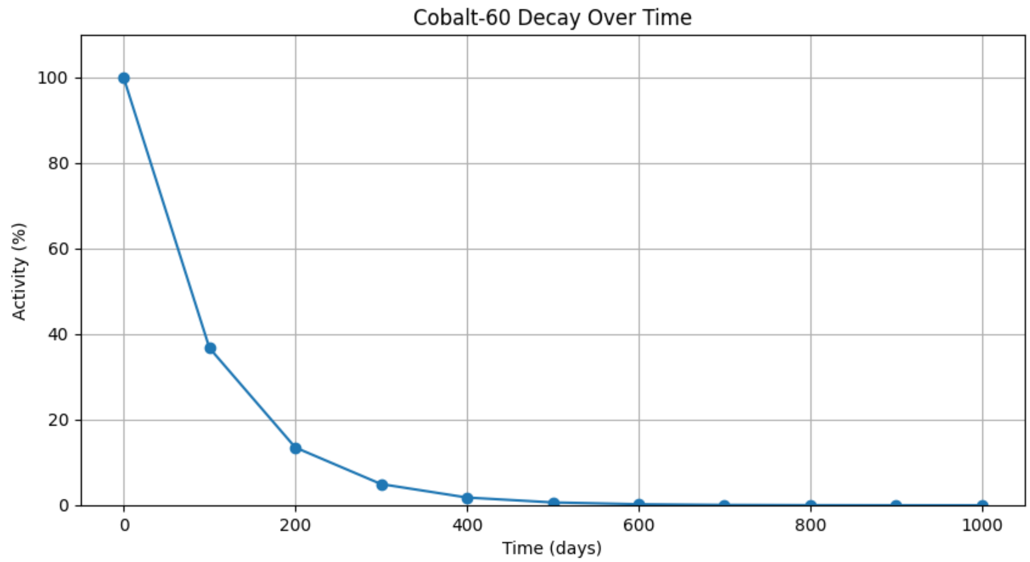

Figure 4.3: the activity A (t) of Cobalt-60 changes over time (t)

4.2 Conclusion

The activity **of iodine-131** decreases exponentially, with a significant drop in the first few days. This information is crucial for applications in medicine where precise timing and dosage are necessary for effective treatment. The decline of carbon-14 activity over time is a crucial aspect of radiocarbon dating, providing insights into the age of artifacts and the history of life on Earth. Understanding this decay process and its implications is fundamental in fields that rely on dating ancient materials. **Cobalt-60** has a half-life of about 5.27 years, which explains the rapid decline in activity. By the end of 1000 years, the activity is negligible, illustrating the effectiveness of radioactive decay in reducing the presence of radioactive isotopes over time. By 1000 years, the activity is effectively negligible, indicating that Cobalt-60 becomes much less hazardous over time. This data illustrates the importance of understanding radioactive decay in safety assessments and long-term storage considerations. Studying radioactive materials is not just about understanding science; it’s about making meaningful contributions to society, improving healthcare, advancing technology, and addressing critical global issues. The potential to make a difference can be a powerful motivator for any student or professional in the field.

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