pISSN:2349-5707 Volume:13,Issue 2, February -2026 eISSN:2349-5715

METHODOLOGY FOR SOLVING PROBLEMS RELATED TO TYPES OF RADIOACTIVE DECAY

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Annotation: Radioactive decay is one of the fundamental processes studied in nuclear physics and plays an important role in fields such as nuclear energy, medicine, geology, and environmental science. Understanding the mechanisms of radioactive decay and the ability to solve related quantitative problems are essential skills for students studying physics and related disciplines. This article examines the methodological approaches used in solving problems related to various types of radioactive decay. Particular attention is given to alpha decay, beta decay, and gamma decay processes. For each decay type, example problems are presented and solved step by step to demonstrate practical calculation methods based on established physical laws. The research relies on theoretical principles of nuclear physics and methodological recommendations used in physics education. The findings highlight effective strategies for teaching students how to analyze radioactive decay equations, apply conservation laws, and calculate decay parameters such as half-life and energy release.

Keywords: Radioactive decay, alpha decay, beta decay, gamma radiation, nuclear physics, half-life, nuclear reactions, problem-solving methodology

Introduction

Radioactive decay refers to the spontaneous transformation of unstable atomic nuclei into more stable configurations through the emission of particles or electromagnetic radiation. This phenomenon was first discovered by **Henri Becquerel in 1896**, and later studied extensively by **Marie and Pierre Curie**, leading to the development of modern nuclear physics [1].

Radioactive decay processes are governed by well-established physical laws and are characterized by specific decay modes. The most common types include **alpha decay, beta decay, and gamma decay**. These processes differ in the particles emitted and the resulting changes in the atomic nucleus.

The study of radioactive decay is important for understanding nuclear reactions, radiation safety, nuclear energy production, and medical diagnostics such as radiotherapy and nuclear imaging [2]. In physics education, solving problems related to radioactive decay helps students develop analytical skills and apply theoretical knowledge to quantitative calculations.

This article focuses on the methodology for solving problems related to different types of radioactive decay. Each decay type is analyzed through theoretical explanation and illustrative examples that demonstrate practical calculation procedures.

Methodology

The methodology used in solving radioactive decay problems is based on several fundamental principles of nuclear physics. These principles include the **law of conservation of mass number (A)** and **atomic number (Z)**, as well as the mathematical law governing radioactive decay.

The general radioactive decay law is expressed as:

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

where:

pISSN:2349-5707 Volume:13,Issue 2, February -2026 eISSN:2349-5715

N – number of undecayed nuclei after time t
N_0 – initial number of nuclei
λ – decay constant
t – time

The half-life of a radioactive isotope is related to the decay constant through the expression:

$$T_{1/2}=\frac{\ln 2}{\lambda}$$

These equations form the basis for most quantitative problems related to radioactive decay [3].

In solving decay problems, the following methodological steps are typically applied:

First, identify the type of radioactive decay occurring in the nucleus.

Second, write the nuclear reaction equation according to conservation laws.

Third, determine the unknown quantities such as mass number, atomic number, energy released, or remaining nuclei.

Fourth, apply the appropriate physical formula and perform calculations.

The methodology presented in this article includes practical examples illustrating these steps.

Results

Alpha Decay Problem Example

Alpha decay occurs when an unstable nucleus emits an **alpha particle**, which is equivalent to a helium nucleus consisting of two protons and two neutrons.

Example problem:

Uranium-238 undergoes alpha decay. Determine the daughter nucleus produced after the decay.

Solution:

The alpha particle is represented as:

$${}_{2}^{4}He$$

The nuclear reaction is written as:

$${}_{92}^{238}U\rightarrow{}_{90}^{234}Th+{}_{2}^{4}He$$

Explanation:

Mass number:

238 = 234 + 4

Atomic number:

92 = 90 + 2

Thus, uranium-238 transforms into **thorium-234** after alpha decay [4].

Beta Decay Problem Example

Beta decay occurs when a neutron in the nucleus converts into a proton while emitting an electron (beta particle) and an antineutrino.

Example problem:

Carbon-14 undergoes beta decay. Determine the resulting nucleus.

Solution:

The reaction equation is:

$${}_{6}^{14}C\rightarrow{}_{7}^{14}N+e^{-}+\bar{\nu}$$

Explanation:

Mass number remains unchanged:

14 = 14

Atomic number increases by 1:

6 → 7

Therefore, carbon-14 decays into **nitrogen-14** [5].

Gamma Decay Problem Example

Gamma decay occurs when an excited nucleus releases excess energy in the form of gamma radiation without changing its atomic or mass numbers.

Example problem:

pISSN:2349-5707 Volume:13,Issue 2, February -2026 eISSN:2349-5715

A nucleus of cobalt-60 emits gamma radiation after beta decay. Determine what changes occur in the nucleus.

Solution:

Gamma radiation does not change the atomic number or mass number. It only releases energy from the excited nucleus.

Reaction form:

$$^{60}_{27}Co^{*} \rightarrow ^{60}_{27}Co + \gamma$$

Explanation:

Mass number remains the same: 60

Atomic number remains the same: 27

Thus, gamma emission results only in a lower energy state of the same nucleus [6].

Analysis and Discussion

The study of radioactive decay and the methodology used to solve related problems occupy an important place in nuclear physics education. Radioactive transformations represent fundamental nuclear processes that obey strict physical laws, including the conservation of mass number and atomic number, as well as statistical decay laws. Understanding these processes not only contributes to theoretical physics knowledge but also develops students' analytical and quantitative reasoning skills. Therefore, the analysis of problem-solving methodologies related to radioactive decay types—alpha decay, beta decay, and gamma decay—provides valuable insights into both scientific understanding and pedagogical practice.

One of the most important aspects of solving radioactive decay problems is the correct identification of the decay type involved. Each decay mechanism produces specific changes in the nucleus and follows well-established nuclear reaction patterns. Misidentifying the decay process can lead to incorrect calculations and misunderstanding of nuclear transformations. Consequently, the first step in any methodological approach to solving decay problems involves analyzing the nuclear equation and determining which particle or radiation is emitted.

Alpha decay is typically observed in heavy nuclei with large atomic numbers, such as uranium, radium, and polonium. These nuclei contain a relatively high number of protons and neutrons, making them energetically unstable. The emission of an alpha particle, which consists of two protons and two neutrons, reduces both the atomic number and the mass number of the nucleus. As a result, the daughter nucleus moves closer to the region of nuclear stability [7].

From a problem-solving perspective, alpha decay problems are often considered the most straightforward because the emitted particle has well-defined mass and atomic numbers. When writing the nuclear reaction equation, the conservation laws must always be satisfied. The mass number decreases by four units, and the atomic number decreases by two units. For example, in the decay of uranium-238, the emission of an alpha particle produces thorium-234. This transformation illustrates how alpha decay contributes to the formation of natural radioactive decay chains, which are sequences of nuclear transformations occurring in heavy elements [4].

An important analytical point when teaching alpha decay problems is the relationship between nuclear stability and the emission of alpha particles. The energy released during alpha decay is associated with the difference in nuclear binding energy between the parent and daughter nuclei. This energy release explains why the decay occurs spontaneously in certain isotopes. Students often benefit from visualizing this process using nuclear binding energy diagrams, which illustrate the relative stability of different nuclei.

Another significant aspect of alpha decay analysis involves the concept of half-life. The half-life represents the time required for half of the radioactive nuclei in a sample to decay. Many quantitative problems require calculating the remaining number of nuclei after a certain period of time or determining the decay constant from the half-life value. Applying the exponential decay law helps students understand the statistical nature of radioactive processes [3].

pISSN:2349-5707 Volume:13,Issue 2, February -2026 eISSN:2349-5715

In contrast to alpha decay, beta decay involves the transformation of a neutron into a proton or a proton into a neutron inside the nucleus. As a result, the atomic number changes while the mass number remains constant. There are two primary types of beta decay: beta minus decay and beta plus decay. Beta minus decay occurs when a neutron converts into a proton, emitting an electron and an antineutrino. Beta plus decay occurs when a proton converts into a neutron, emitting a positron and a neutrino [8].

When solving beta decay problems, students must carefully analyze how the nuclear composition changes. In beta minus decay, the atomic number increases by one unit because a neutron is converted into a proton. The mass number remains unchanged because the total number of nucleons stays the same. This process explains why carbon-14 decays into nitrogen-14 during radiocarbon dating. Such examples are frequently used in physics and chemistry education to illustrate the practical importance of radioactive decay.

From a methodological standpoint, beta decay problems are slightly more complex than alpha decay problems because they involve internal transformations within the nucleus rather than the emission of a large particle. Students must remember that electrons emitted during beta decay originate from the nuclear transformation process rather than from the atomic electron cloud. Clarifying this distinction helps prevent conceptual misunderstandings.

Another interesting analytical aspect of beta decay is its role in nuclear stability. Nuclei with an imbalance between neutrons and protons tend to undergo beta decay to achieve a more stable neutron-to-proton ratio. This principle is often illustrated using the nuclear stability curve, which shows how stable nuclei are distributed according to their neutron and proton numbers. Understanding this concept allows students to predict the direction of beta decay transformations in many problem-solving situations.

Gamma decay represents a different category of radioactive transformation because it does not change the number of protons or neutrons in the nucleus. Instead, it occurs when an excited nucleus releases excess energy in the form of high-energy electromagnetic radiation. This radiation is known as gamma radiation and has very short wavelengths and high frequencies [9].

From a theoretical perspective, gamma decay can be compared to the emission of photons by excited atoms. Just as electrons in atoms can transition between energy levels by emitting photons, nuclei can release energy when transitioning from an excited state to a lower energy state. This analogy is often useful in educational contexts because it helps students relate nuclear processes to concepts they have already encountered in atomic physics.

When solving gamma decay problems, the main challenge is recognizing that the nuclear identity remains unchanged. Both the mass number and atomic number remain the same before and after the emission of gamma radiation. The only change occurs in the energy state of the nucleus. Consequently, gamma decay problems often involve calculating energy differences or understanding how gamma radiation accompanies other decay processes.

In many cases, gamma emission occurs after alpha or beta decay when the daughter nucleus is left in an excited state. The nucleus subsequently releases energy through gamma radiation to reach a stable energy configuration. This sequential decay process is commonly observed in radioactive isotopes used in medical diagnostics and industrial applications.

From an educational standpoint, integrating gamma decay examples into problem-solving exercises helps students appreciate the diversity of nuclear transformations. It also reinforces the concept that nuclear reactions must satisfy conservation laws while allowing for changes in nuclear energy levels.

Another important analytical component in the methodology of solving radioactive decay problems is the application of the radioactive decay law. This law describes the exponential decrease in the number of radioactive nuclei over time. The mathematical expression of this law enables students to calculate quantities such as remaining nuclei, decay rates, and activity levels.

The activity of a radioactive sample is defined as the number of decay events occurring per unit time. It is directly proportional to the number of radioactive nuclei present in the sample.

pISSN:2349-5707 Volume:13,Issue 2, February -2026 eISSN:2349-5715

Understanding this relationship is crucial in many practical applications, including radiation measurement and nuclear medicine.

When solving problems related to radioactive decay kinetics, students must often combine exponential decay equations with half-life relationships. For example, determining how much of a radioactive substance remains after several half-lives requires repeated application of the decay formula. Teaching students to approach these calculations systematically improves both accuracy and conceptual understanding.

In addition to theoretical knowledge, effective learning of radioactive decay problem solving requires clear methodological instruction. Students frequently encounter difficulties when interpreting nuclear equations or applying conservation principles. Therefore, structured problem-solving frameworks are essential for guiding them through each step of the calculation process.

One widely used educational strategy involves breaking the solution process into sequential stages. The first stage involves identifying the known and unknown quantities in the problem. The second stage requires writing the appropriate nuclear reaction equation. The third stage involves applying conservation laws and mathematical formulas. Finally, the result is interpreted in the context of nuclear physics principles.

Another effective teaching method involves using graphical representations such as nuclear charts and decay schemes. These visual tools help students track nuclear transformations and understand how isotopes evolve through successive decay processes. Visual learning techniques have been shown to improve comprehension of complex scientific concepts [10].

Modern technology also provides new opportunities for enhancing the teaching of radioactive decay. Computer simulations and digital modeling tools allow students to observe nuclear transformations in a virtual environment. These simulations demonstrate how radioactive nuclei decay randomly over time while still following statistical laws. Observing such processes visually helps students grasp the probabilistic nature of radioactive decay.

Simulation software can also illustrate the formation of radioactive decay chains, showing how unstable isotopes transform into stable elements through multiple decay stages. These tools are particularly valuable in helping students understand long and complex decay sequences that may be difficult to analyze using only equations.

Furthermore, integrating interdisciplinary perspectives into the study of radioactive decay can enrich the learning experience. For example, discussing the applications of radioactive isotopes in medicine, archaeology, and environmental science helps students see the practical relevance of nuclear physics. Radiocarbon dating, radiation therapy, and nuclear power generation all rely on the principles of radioactive decay.

Conclusion

Radioactive decay is a fundamental phenomenon in nuclear physics with significant applications in science, technology, and medicine. Understanding the mechanisms of alpha, beta, and gamma decay is essential for students studying nuclear processes.

This study examined methodological approaches for solving problems related to different types of radioactive decay. By applying conservation laws and the mathematical law of radioactive decay, students can systematically analyze nuclear reactions and determine resulting nuclei and radiation types.

The presented examples demonstrate that structured problem-solving methods improve comprehension of nuclear transformations and strengthen analytical skills. Effective teaching strategies should combine theoretical explanation, mathematical modeling, and practical exercises to facilitate deeper understanding of radioactive decay processes.

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