FUNDAMENTALS OF NUCLEAR PHYSICS

Ritesh Kohale
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Bentham Books

Fundamentals of Nuclear Physics

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Fundamentals of Nuclear Physics

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CONTENTS

FOREWORD

I welcome the publication of the book ‘Fundamentals of Nuclear Physics.’ It is an introductory text for scientists, teachers, engineers and students written by Dr. Ritesh Kohale, Dr. Sanjay J. Dhoble and Dr. Vibha Chopra. ‘Fundamentals of Nuclear Physics is an ultimate textbook for courses at the undergraduate level in nuclear physics. Moreover, it is a significant basis for scientists and those who initiated working with nuclei, particle physicists, astrophysicists and anyone willing to learn more about novel trends in this field. Its importance on phenomenology and discussions of the theory are covered with the suitable examples that clarify and put on the theoretical formulism, differentiating this book from all other books available. The text is well organized to deliver the fundamentals of content for students with a little mathematical background, providing more distinguished material in each section.

This textbook is competent because it includes the discovery of the neutron and other modern advances, providing readers with widespread coverage of the elementary models of each topic in particle physics for the first time. Physics emphasizes mathematical precision, making the material handy to students with no prior knowledge of elementary nuclear physics. The theory and mathematical expressions are linked together in a very sophisticated manner, helping students understand how key ideas were developed. The content on nuclei, mass defect, packing fraction, particle accelerator and detectors, the discovery of a neutron, a nuclear chain reaction, liquid drop model and the shell model of a nucleus, nuclear fission and fusion, and radioactivity has been completely revised to familiarize the students to what lies beyond. The easily understandable figures and equations with problems inspire students to apply the theory themselves.

I am pleased to authenticate this book as an advanced phase in this ongoing quest, and I hope this book will be a valuable addition to the bare literature on the subject matter.

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India

PREFACE

This textbook clears the cavity between the elementary and the highly progressive volumes that are commonly accessible on the subject. It offers a brief but widespread outline of a number of topics, like fundamental ideas and characteristics of the nucleus, fission and fusion, general relativity, and radioactivity which are otherwise only accessible with much more detail. Providing a general introduction to the underlying concepts allows individuals who read to improve their knowledge of what these two research fields actually encompass. The book uses real-world examples to make the subject more attractive and inspire the use of mathematical formulations. Anticipated essentially for students of scientific disciplines such as physics and chemistry who want to learn about the subject and/or the associated techniques, it is also useful to high school teachers wanting to rejuvenate or modernize their understanding and to fascinated non-experts. This textbook gives an elementary understanding of nuclear and particle physics, offering an overview of theoretical as well as the experimental grounds, providing students with a profound understanding of the ideas about the nucleus, particle detectors, accelerators, radioactivity, and elementary particles, fundamental forces and recent applications of radioactivity. Each chapter provides the fundamental theoretical and experimental knowledge for students to strengthen their concepts regarding nuclear physics.

It is an appropriate textbook for undergraduate courses in nuclear and particle physics as well as more innovative courses; the book includes sophisticated and newly constructed figures as well as thoroughly solved equations that create the interest amongst undergraduate students to renovate the content of their course. It could be a vital textbook for students framing their future study or a profession in the field who needs a concrete understanding of nuclear and particle physics together. It provides a concise, thorough, and accessible treatment of the fundamental aspects of nuclear physics. Reorganized figures, resolved equations, rearranged contents and appendices make it easier to use for entire users. Indeed this book is unique because it makes important connections to other fields such as elementary particle physics and astrophysics. Moreover, its presentation is student-friendly and bridges nuclear physics as an essential part of modern physics with a comprehensive scientific and historical context. We trust that it may be advantageous for graduate students, or more commonly scientists, in various fields. In the first three chapters, we present the "extract," *i.e.*, we give the basic concepts essential to improve the rest. Chapter 1 deals with the introduction to nuclei and basic concepts in nuclear physics. In chapter 2, we describe nuclear fission and fusion. Chapter 3 is dedicated to the nuclear structure and properties of nuclei. Chapter 4 goes a step further. It deals with particle detectors. We shall see that it is conceivable to give a reasonably modest but comprehensive explanation of the major development in particle physics and fundamental dealings made since the late 1960s. In chapters 5 and 6, we turn to the important practical applications of nuclear physics, *i.e.*, particle accelerators and nuclear reactors. In chapters 7 and 8, we intend to understand the origin and applications of radioactivity with some contemporary illustrations of how radioactivity originated and was used, be it in medicine, in the food industry or in engineering. Chapters 9 and 10 are subjected to nuclear astrophysics, stellar structure and evolution and nuclear cosmology and elementary particles. To conclude, we present an introduction to present ideas about nuclear astrophysics in chapter 10.

We want to extend our sincere thanks to all our collogues who constantly provided us with ideas before initiating this project. We are obliged to our co-workers for their irreplaceable help and recommendation throughout the years. We are also grateful to all who directly or indirectly contributed to illuminating discussions on various aspects of nuclear physics.

This book has been kept on track and seen through to completion with the support and encouragement of numerous people, including our well-wishers, our friends, as well as various institutions and laboratories. At the end of this book, it is a pleasant task to express our thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for us to write this book.

ACKNOWLEDGEMENTS

Authors express their sincere thanks to Dr. Subhash Chaudhari, Vice Chancellor , Rashtrasant Tukadoji Maharaj Nagpur University, MH, India for his kind co-operation and we owe a great deal of appreciation and gratitude towards Dr. Sanjay Dudhe, Pro-Vice Chancellor, Rashtrasant Tukadoji Maharaj Nagpur University, MH, India for all the help extended by them during the completion of this book. At this moment of accomplishment we would like to express our cordial and honest gratitude to Dr.Arti Moglewar, Principal, Sant Gadge Maharaj Mahavidyalaya, Hingna, MH, India for her guidance, support and constant encouragement. We are also thankful to Dr. Rajesh Kumar, Principal, AV College, Amritsar, India for his valuable advice, constructive criticism and his extensive discussions around this work.

We extend our sincere thanks to all of them who directly and indirectly supported willingly and selflessly for our experiments and all of them who also stayed with us in the process. We are indebted to our many young and dynamic friends for always providing a stimulating and fun filled environment whenever we go into this process.

We can see the good shape of present book because of the enough size of our research group. We remember our communication and coordination with each other, we had interesting and cheerful discussions started from search to research. We enjoyed the same with tea and snacks during the entire process of this book project.

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CHAPTER 1

Fundamentals of Nuclear Physics

Abstract: The present chapter is an introduction to various scientific and technological fields. It is a beginning step to trail further study in this book. The first chapter specifies the contemporary idea and fundamental understandings of nuclear physics, which is necessary to develop the rest of the studies in this domain. The present chapter deals with an introduction to nuclei, constituents of the nucleus and its properties, mass defects and binding energy, nuclear reactions, the Q-value of nuclear reactions, and the discovery of the neutron and nuclear chain reactions.

Keywords: Chain Reaction, Mass Defect, Neutron, Proton.

1. INTRODUCTION TO NUCLEI

Nuclear physics aims to improve the knowledge of all nuclei and understand astrophysical nucleosynthesis. There are similarities between the electronic structure of atoms and nuclear structure. In nuclei, protons and neutrons are two groups of similar particles [1].

1.1. Constituents of the Nucleus and its Properties

1.1.1. Proton

It is one of the major and significant constituents of the nucleus. Its positive charge and mass are 1.673×10^{-27} kg ≈ 1u.

1.1.2. Neutron

- Zero charge
- Mass 1.675×10^{-27} kg ≈ 1u
- Mass of neutron ≈ mass of proton + mass of an electron

1.1.3. Nucleon

In chemistry and physics, a nucleon is either a proton or a neutron, considered in its role as a component of an atomic nucleus. (*e.g.*, neutron or proton).

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

1.1.4. Nomenclature

- A - Number of nucleons (atomic mass number)
- Z - Number of protons
- N - Number of neutrons
- A = Z + N
- The symbol for the nucleus of chemical element X.

1.1.5. Atomic Mass Unit, (U)

A convenient unit for measuring nuclear mass. Usually, nuclear mass is expressed in terms of a unit known as the *atomic mass unit,* denoted by the letter *u.* One atomic mass unit is defined as one-twelfth the mass of a carbon atom (*i.e.*, the most abundant isotope of Carbon),

viz., ^{12}C, If Mass of ^{12}C = 12 u, then,

$$1\ u = \frac{1}{12} \text{ x mass of one carbon atom}$$

$$= \frac{1}{12} \text{ x } \frac{12}{6.0\text{x } 10^{23}}$$

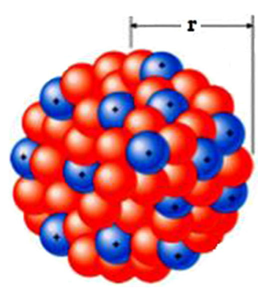
$$1u = 1.66 \text{ x } 10^{-27} \text{ kg}$$

In terms of the above units,

Mass of a proton, m_p = 1.00727 u

Mass of a neutron, m_n = 1.00866 u

1.1.6. Nuclear Size and Density

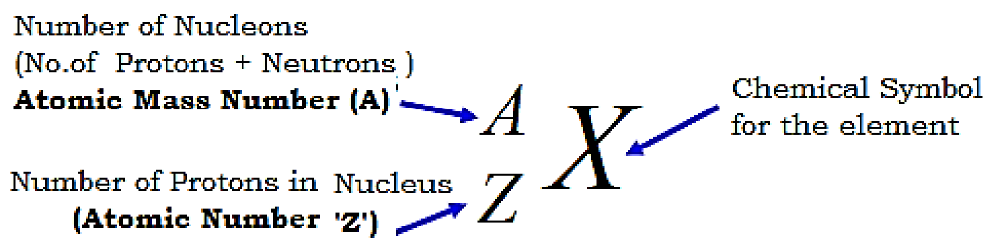


- It has Close-packed structure
- Constant density
- Volume proportional to atomic number (A)
- Since $V = 4/3\ \pi r^3$, A proportional to r^3
- r is proportional $A^{1/3}$
- $r \approx (1.2 \times 10^{-15}\ m)\ A^{1/3} = 1.2\ fm\ A^{1/3}$
- Density of neutron star = 100 million tons/cm^3

1.1.7. Nuclei

Nuclei are composed of protons and neutrons. The number of protons is atomic number Z, the number of neutrons is N, and the mass number A is approximately the total number of nucleons (*i.e.*, protons and neutrons, A = (Z + N,)

Therefore the number of neutrons is N = A-Z



Hydrogen Nucleus: ${}^{1}_{1}H$

Example: Carbon ${}^{12}_{6}C$ Helium: ${}^{4}_{2}He$

6 Protons + 6 Neutrons

Neutron: ${}^{1}_{0}n$

Electron: ${}^{0}_{-1}e$

Aluminium: ${}^{27}_{13}Al \equiv {}^{27}Al$

1.2. Mass Defect and Binding Energy

1.2.1. Mass Defect

The constituents of a nucleus are neutrons and protons, collectively known as nucleons. The mass of a nucleus is always less than the sum of the masses of its constituent nucleons (*i.e.*, protons and neutrons); the difference between the total mass of nucleons and the actual mass of the nucleus is called **the mass defect** denoted by **Δm** and given by [2].

$$\Delta m = [Zm_p + (A\text{-}Z)\ m_n] - M$$

CHAPTER 2

Nuclear Fission and Fusion

Abstract: The present chapter deals with the analysis and relationship of significant features of theoretical nuclear physics. It is perhaps the most widely adopted chapter on the subject. The authors' line of understanding is subjected to "the theoretical perceptions, approaches, and deliberations formulated to infer the investigational matter and spread our aptitude to calculate and govern nuclear occurrences." The present chapter elaborates on the features of conjectural nuclear physics. Its attention is classified agreeing to occurrences concerning nuclear fission, transition state (saddle point) and scission point, photo−fission, fissile materials and fertile materials, moderation and thermalization of the neutron, neutron transport in the matter, nuclear fusion and basic reaction for energy generation in the sun by fusion.

Keywords: Fission, Fusion, Neutron Transport, Photo−fission.

1. INTRODUCTION

Energy from the nucleus draws attention to the two central approaches to generating energy from the nucleus: fission and fusion. In the present approach, the eminence of existing and upcoming reactors advanced security provisions and the eco-friendly effect of electrical energy generation from nuclear fission. The sections in the chapter proceeding with nuclear fusion address both inertial and magnetic confinement fusion.

The significant aspect of fission is photo-fission was discovered in 1940 by a small team of engineers and scientists functioning the Westinghouse Atom Smasher at the company's Research Laboratories in Forest Hills, Pennsylvania [1]. They used a 5 MeV proton beam to bombard fluorine and produce high-energy photons, which were then exposed to samples of uranium and thorium [2]. In the low tens of MeV, Gamma radiation of modest energies can induce fission in conventionally fissile essentials such as the actinides thorium, uranium [3], plutonium, and neptunium [4]. Experiments have been conducted with much higher energy gamma rays, finding that the photo fission cross-section varies little within ranges in the low GeV range.

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

Fission is a system of nuclear transformation because the consequential fragments (or daughter atoms) are not the identical constituent as the unique parent atom. The two (or more) nuclei formed are most regularly of similar but somewhat different sizes, characteristically with a mass ratio of products of about 3 to 2 for common fissile isotopes. Most fissions are binary (generating two charged fragments), but sometimes (2 to 4 times per 1000 events), three positively charged fragments are formed in a ternary separation. The tiniest of these fragments in ternary developments sorts in size from a proton to an argon nucleus.

In 1920, Arthur Eddington recommended that hydrogen-helium fusion could be the principal basis of cosmological energy. Quantum channelling was revealed by Friedrich Hund in 1929, and soon after, Robert Atkinson and Fritz Houtermans used the measured masses of light components to show that large extents of energy could be released by combining small nuclei. Building on the early experiments in simulated nuclear transformation by Patrick Blackett, a laboratory with an emerging and effective fusion inside a fusion container or reactor has continued since the Berkeley cyclotron get up in the 1940s, but the expertise and equipment for fusion are still in their improvement stage. The objective of this section in the book is to recognize by what means definite arrangements of N neutrons and Z protons produce certain states. The ample nuclear classes encompass additional neutrons or protons; thus, they are β-unstable. Many dense nuclei degenerate by giving out of α-particle or by additional arrangements of allowed fission into lighter components. The further purpose of the present chapter is to recognize why definite nuclei are steady compared to these degenerations and anything that regulates the leading decay approaches of unstable cores of nuclei.

1.1. Nuclear Fission Basics

Nuclear fission is the process of splitting the nucleus of a heavy atom (target nucleus) into two or more lighter atoms (fission products) when a neutron bombards the heavy atom.

Fission releases a large amount of energy along with two or more neutrons due to the sum of the masses of the fission products being less than the original mass of the heavy atom.

Otto-Hann and Stresemann bombarded ^{235}U with thermal neutrons and observed that the Uranium nucleus splits into two nuclei, ^{141}Ba and ^{92} Kr, with the emission of 3 neutrons, and hence, a great extent of energy is liberated. The basic nuclear fission of ^{235}U can be given as,

$$^{235}U + {}^{1}n \rightarrow {}^{236}U \rightarrow {}^{141}Ba + {}^{92}Kr + 3\ {}^{1}n + \text{energy}$$

The products formed during nuclear fission are called fission fragments. ^{141}Ba and ^{92}Kr are the fission fragments from the ^{235}U nucleus, see Fig. (**2.1**).

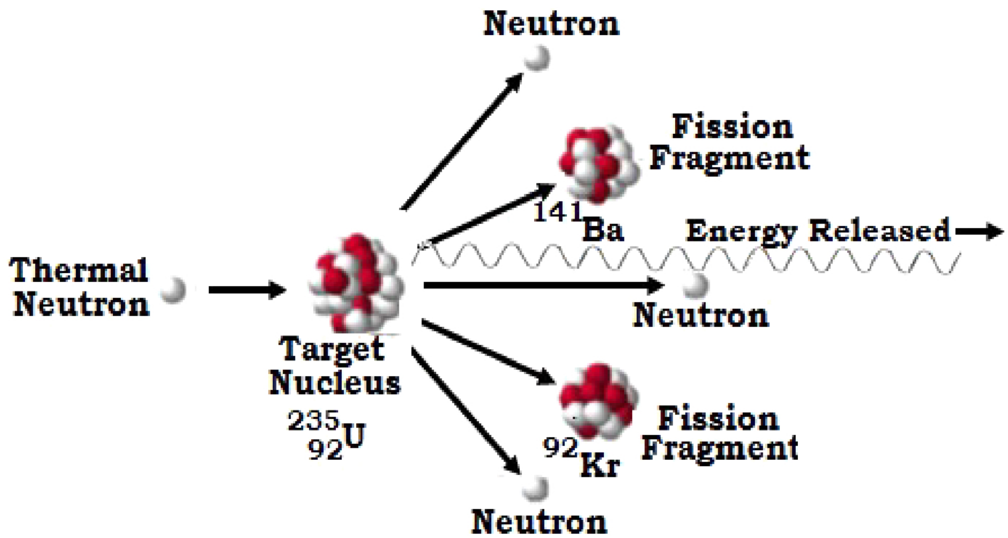


Fig. (2.1). Nuclear Fission Mechanism.

1.1.1. Nuclear Fission Energy

Nuclear energy is taken out by exothermic nuclear reactions; fission and fusion are the two main categories. Obviously, we ought to evoke that radioactivity discharges an enormous amount of energy in this particular situation, as Henri Becquerel and Pierre Curie first expected. For example, the decay of ^{238}U,

$$^{238}U \rightarrow {}^{234}Th\ \alpha$$

$$t_{1/2} = 4.468 \times 10^{9}\ \text{Yr}$$

$$Q_{\alpha} = 4.262\ \text{MeV}$$

Releases the amount of power,

$$P = \frac{N_A}{238}\frac{Q_{\alpha} I_n 2}{t_{1/2}} = 8 \times 10^{-9} Wg^{-1}$$

CHAPTER 3

Nuclear Structure and Properties of Nuclei

Abstract: An atom's nucleus comprises neutrons and protons, which in turn are the appearance of more fundamental particles, called quarks, that are seized in a relationship by the strong nuclear force in certain stable arrangements of hadrons, called baryons. The strong nuclear force encompasses far enough from each baryon to drag the neutrons and protons together beside the repulsive electrical force between the positively charged protons. The present chapter deals with investigating and correlating key features of the nuclear structure and its properties as understanding the structure of the atomic nucleus is one of the central challenges in nuclear physics. The line of understanding in this chapter is subjected to the structure of nuclei, atomic models, Rutherford model of the atom, nuclear composition, nuclear properties, determination of mass and determination of the charge.

Keywords: Charge, Mass, Nuclear Properties, Nuclear Structure, Nuclear Structure.

1. INTRODUCTION

When discussing the atomic nucleus, it is very important to know about the history of the atom. An 'Atom' is the smallest particle of a substance that can exist by itself. Each atom consists of a nucleus with a positive charge and a set of electrons that move around the nucleus. The atom in its normal state is always found to be electrically neutral so that the number of protons and electrons must be exactly equal.

The nucleus was revealed in 1911 due to Ernest Rutherford's determinations to test Thomson's "plum pudding model" of the atom [1]. J.J. Thomson had previously revealed the electron and deliberated that atoms are electrically neutral; he hypothesized that there must also be a positive charge. In his desirable pudding model, Thomson recommended that an atom comprised of negative electrons is arbitrarily dispersed inside a sphere of positive charge. Ernest Rutherford later developed experimentation with his research mate Hans Geiger and with the help of Ernest Marsden, which elaborated the deflection of alpha particles (helium nuclei) focused on a thin sheet of metal foil. He well-structured that if J.J Thomson's model were accurate, the positively charged alpha particles would certainly pass through the foil with very slight deviance in their paths, as the foil

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

should act as electrically impartial if the negative and positive charges are so confidentially mixed as to make it perform neutral. To his disclosure, many particles were deflected at great angles. Because the mass of an alpha particle is about 8000 times that of an electron, it became obvious that a very strong force must exist if it could deflect the enormous and fast-moving alpha particles. He recognized that the desirable pudding model could not be precise and that the deflections of the alpha particles could only be clarified if the positive and negative charges were disconnected from each other and that the atom's mass was a concentrated point positive charge. This warranted the idea of a nuclear atom with a dense center of positive charge and mass.

The term nucleus is from the Latin word nucleus, a tiny part of nux ('nut'), which signifies the grain (*i.e.*, the 'small nut') within a damp type of fruit (like a peach). In 1844, Michael Faraday recycled the term to denote the "central point of an atom." The modern atomic significance was projected by Ernest Rutherford in 1912 [2]. Nevertheless, the assumption of the term "nucleus" in atomic theory was not instantaneous. In 1916, for example, Gilbert N. Lewis stated, in his well-known piece of writing "The Atom and the Molecule," illuminating the concept that "the atom is composed of the grain and an outer atom or shell" [3].

1.1. Atomic Models

Different models were proposed to explain an atom. In 1808, John Dalton published his theory suggesting that the atom is the smallest unit of matter. It can neither be created nor be destroyed. Later in 1897, the 'Plum Pudding model' or 'watermelon model' was put forward by Sir J.J. Thomson. It was suggested that the atom consisted of a positive electric fluid distributed over a whole body of atoms, and negative electrons are embedded in it like seeds in watermelon (Fig **3.1**).

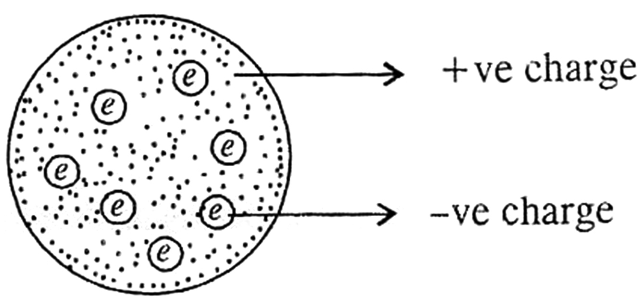


Fig. (3.1). Schematics of an atom as the smallest unit of matter.

1.1.1. Rutherford Model of the Atom

J.J. Thomson's model of the atom was static. Later this static model was transformed into a dynamic 'Planetary Model' in 1911 by Rutherford as the static model of the atom failed to explain the α-scattering experiment performed by Rutherford [4]. The schematic diagram of Rutherford's experimental setup is shown in Fig. (**3.2)**.

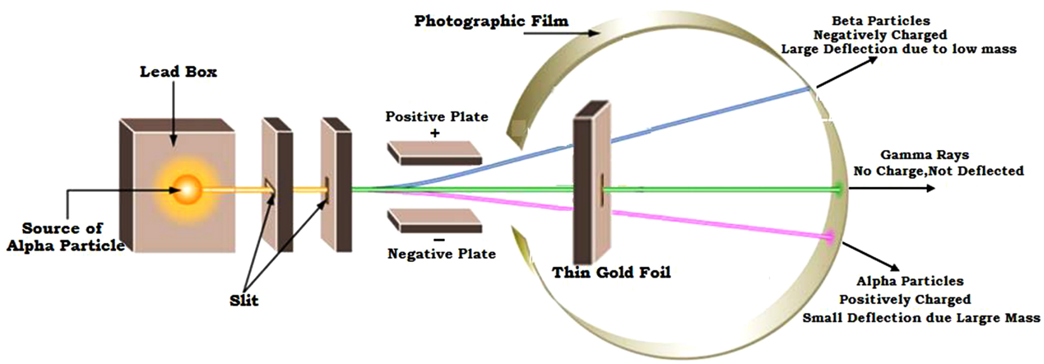


Fig. (3.2). Rutherford's gold foil experiment. (Source Credit: Britannica).

A beam of ∝-particles from the Radium source was made to strike a thin gold foil. A fluorescent screen detected the scattered s-particles. Rutherford observed that many ∝-particles went straight through the foil or were deflected at very small angles. However, few of the ∝-particles were deflected through very large angles, and few were scattered back. J.J. Thomson's model of the atom could not explain the deflections. So, to explain the deflections, Rutherford assumed that the positive massive part of the atom was concentrated in a very small volume at the centre of the atom called the nucleus. This nucleus is surrounded by an electron cloud, making the entire atom electrically neutral.

An ∝-particle is scattered at the larger angle because an ∝-particle approaching the centre of the atom experiences an increasingly large Coulomb repulsion. So, the nucleus was assumed to have a negative charge. Most ∝-particles do not go sufficiently close to the nucleus, so they pass through the foil with practically no deviation, so the atom was assumed to have a lot of empty space. Further, it was assumed that there were enough electrons outside the positive nucleus to provide a balance of positive and negative charges.

Despite all this, this model also failed. The atoms did not stabilize through electrostatic forces alone since the extranuclear electrons were stationary. This created a problem even if the electrons were assumed to revolve around the

CHAPTER 4

Particle Detectors

Abstract: Many of the particle detectors developed are gaseous based on ionization. The semiconductor and scintillation detectors are the most typical and cast-off, but other, entirely diverse ideologies have also been functional, like Cerenkov light and transition radiation. Recent detectors in particle physics pool numerous elements in layers much like an onion. The present chapter is aimed to deliberate the significant aspects of G. M. Counter (Geiger-Muller Counters), Wilson cloud chamber, Scintillation counter and a semiconductor detector.

Keywords: Counter, Detector, G. M, Particle, Wilson Cloud.

1. INTRODUCTION TO PARTICLE DETECTORS

A particle detector is an instrument that is used to identify the ionizing particles and their track produced by reactions in a particle accelerator, nuclear decay and cosmic radiation. Detectors can also measure particle energy and other characteristics such as particle type, charge, momentum, spin *etc.* They can also be used to record the particle's presence and are also known as a radiation detector. In investigational and practical nuclear physics, particle physics and nuclear engineering, a particle detector, also recognized as a radiation detector [1], and is a systematic structure recycled to detect, track, and/or classify ionizing particles, such as those produced by nuclear decay, cosmic radiation, or responses in a particle accelerator. Detectors can quantity the particle energy and supplementary characteristics such as particle type, spin, momentum, and charge in accretion to simply classify the particle's existence [2].

Detectors aimed for contemporary accelerators are massive in magnitude and price. The term counter is regularly used as an alternative of detector when the detector computes the particles but does not determine their energy or ionization. Particle detectors can also characteristically track -energy photons or detectable photons (light), known as ionizing radiation. If their primary purpose is radiation measurement, they are entitled radiation detectors, but as photons are also (massless) particles, the term particle detector is quite precise. The following

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

types of particle detectors are commonly used in particle and nuclear physics for radiation protection in the nuclear, medical and environmental fields [3].

1.1. G. M. Counter (Geiger-Muller Counters)

Germany, in 1928, Geiger and Muller settled a ‘Particle detector’ for determining ‘ionizing radiation.’ They titled it ‘Geiger Muller Counter.’ It has been one of the supreme and extensively used nuclear detectors in the initial generations of nuclear physics. It is a gas-occupied counter that functions in the Geiger region. Basically, the G.M. counter is a radiation detector.

A Geiger counter is an apparatus cast-off for spotting and calculating ionizing radiation, and it is comprehensively used in solicitations such as radiological protection, radiation dosimetry, investigational physics, and nuclear engineering. It notices ionizing radiation such as alpha particles, beta particles, and gamma rays using the ionization effect produced in a Geiger–Müller tube, which provides its name to the instrument [4]. It is conceivably one of the world's best-known radiation detection devices in wide and noticeable use as a hand-held radiation investigation device.

The unique detection principle was recognized in 1908 at the University of Manchester [5], but it was not in anticipation of the development of the Geiger–Müller tube in 1928 that the Geiger counter could be manufactured as a practical instrument. Since then, it has been widespread due to its strong sensing component and low cost. Nevertheless, there are restrictions in calculating high radiation rates and the energy of incident radiation [6].

1.1.1. Principle, Construction and Working

Principle

Radioactive rays ionize the gas they pass and yield a small number of ions. In definite conditions, when the applied voltage is adequate, these ions yield a secondary avalanche, and a small voltage drop is recorded through the load. This voltage is intensified so the counter can record it [7]. The Schematics of G. M. Counter are shown in Fig. (**4.1**).

Construction

- The G. M. tube entails a high-pitched metal cylinder performing as a cathode.
- A wire of tungsten drives from side to side to the axis of the tube, which performs as an anode.
- Cathode (-) and anode (+) is disjointed by the insulator (ebonite plugs).

- Together the cathode and anode are coupled with a high voltage DC battery (1000 – 2000 Volts), and load R_L is connected in series with maximum resistance.
- At the one end, a skinny mica window is settled to permit the admittance of radiation in thtube-initiated radioactive source.
- The tube is emptied (vacuum) and then packed with a gaseous mixture *i.e.*, 90% Argon and 10% ethyl alcohol vapours at preferred low pressure.

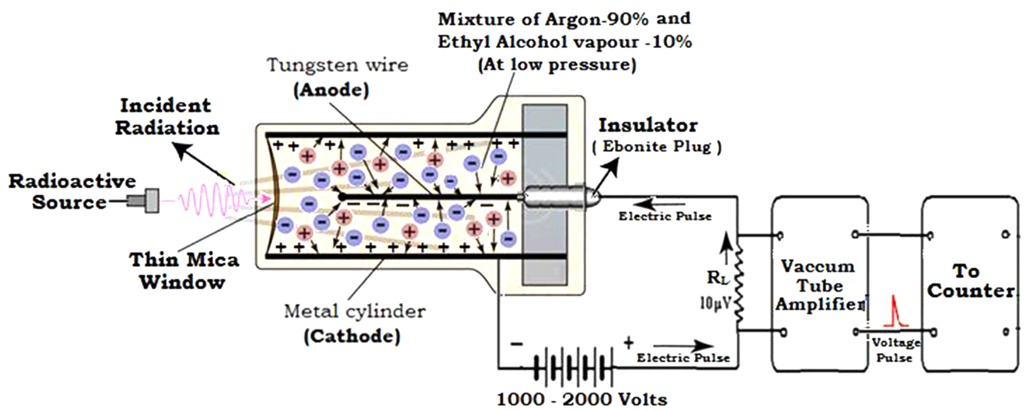


Fig. (4.1). Schematics of G. M. Counter.

The simplified G.M. counter circuit and block diagram are as shown in Fig. (**4.2**).

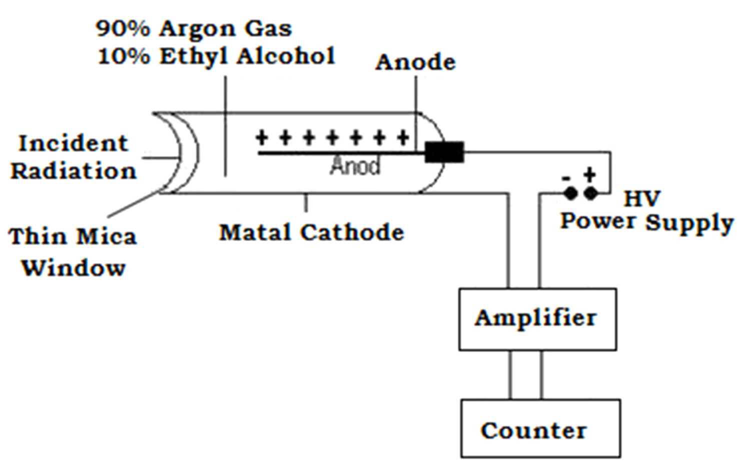


Fig. (4.2). Block diagram of G. M. Counter.

CHAPTER 5

Particle Accelerators

Abstract: Particle accelerators are devices that increase the speed of elementary particles like electrons or protons. Such particles are accelerated to enormously elevated energies and yield an energetic stream of beams recycled for appreciative identifications about the forces that act upon them (elemental and nuclear behaviour) and fundamental structure wedges of natural surroundings. The present chapter is dedicated to understandings of Linear accelerators along with construction working, calculation of the length of drift tubes, and calculation of particle energy. It also focuses on the cyclotron, its principle, construction, working and applications.

Keywords: Beams, Cyclotron, Linear Accelerator, Particle Physics.

1. INTRODUCTION

On an elementary ground, particle accelerators harvest shaft of rays (beam) using exciting elements that can be recycled for multiple investigations and scientific determinations. It gives an idea about accepting the configuration and dynamic forces acting on the materials and their belongings (chemistry, natural science, nuclear physics, medicinal applications). Stream of accelerated particles can be used to yield beams of secondary particles such as:

- Photons (gamma-rays, x-rays, observable light) are generated from beams of electrons.
- Neutrons are produced beginning from beams of protons by using the spallation neutron source.
- Such kind of subordinate particle streams of beams are used to investigate the materials and their properties in the form of probes [1].

Massive accelerators are used for elementary examination in particle physics. The leading accelerator is LHC, operated by the CERN, the Large Hadron Collider situated in Switzerland, nearby Geneva. It is an accelerator that works on the principle of particle collision, which can speed up the dual-stream of protons beam to an energy of 6.5 TeV and allow them to strike directly, generating centre

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

of mass energies of 13 TeV. Accelerators are also used as synchrotron light sources for learning reduced masses and condensed matter behaviour in physics. Compact particle accelerators are used in multiple applications, together with particle analysis. At the moment, around 30,000 accelerators are under usage and advancement all over the globe [2]. There are dual elementary divisions of accelerators: electrostatic and electrodynamic accelerators [3]. Electrostatic accelerators use static electric fields to speed up particles. The most communal categories are the Van de Graaff and Cockcroft–Walton generators. A moderate pattern of this class that gives a precise determination of the motion of a particle with pictorial representation is the CRT (cathode ray tube). The possible kinematic energy for elementary entities in these approaches is resolute by increasing the accelerating voltage, which is restricted and pulled down by electrical intermission. Additionally, electrodynamic accelerators use varying electromagnetic fields (*viz*., oscillating radio frequency fields) to speed up and fast-track the particles. Such kinds of particles can penetrate through the corresponding accelerating field with the highest frequency; the production energy is not restricted by the influence of the field with an increase in velocity. This kind of accelerator was primarily recognized in the twentieth century near 1920 and is the base for the most all-encompassing accelerators.

Gustav Ising, Max Steenbeck and Ernest Lawrence are well-thought-out inventors of this arena, recognizing and constructing the initial and practically working LINAC (linear particle accelerator) [4], the cyclotron and the betatron.

1.1. Significant Categories of Particle Accelerator

A widespread selection of particle accelerators is in use these days. The categories of technologies and accelerators are remarkably identified by the speed of particles that are augmented and sped up by the mass of particles conveyed. It has been observed that accelerators for electrons commonly ‘appeared’ not equivalent to accelerators for bulky or heavy ions and the positively charged protons. The three basic types of particle accelerator are,

1. *Linear accelerator* - Particle acquires energy while moving in a straight line.

2. *Cyclic accelerator* - Particle acquires energy while moving in a circular path.

3. *Static accelerator* - Particle acquires energy while moving in a static path.

1.2. In What Manner Does a Particle Accelerator Performs

Particle accelerators consume electrically powered fields to expedite (accelerate) and intensify the energy of particle beams, which remain strongly directed and focused by magnetic fields. The source makes the elementary particles, such as negatively charged electrons or positively charged protons that are to be speeded. The stream of particles (beam) moves within the evacuated compartment in the metallic beam cylinder. Such evacuation is critical to upholding a midair and any environment without contamination for the particles to move on freely. The directions and focusing of the beam of particles are maintained by precisely maintained electromagnets while it moves through the evacuated cylinder. Electric fields space out all over the place around the accelerator that switches from positive to negative potential at a specified rate of recurrence by maintaining the radio frequency that speeds up the particles in groups. Particles can be focused at an immovable objective, such as a minute unit of metal foil, or dual beams of particles can be struck. Particle detectors disclose as well as record the particles. Moreover, it can also give significant information about radiation formed by the collision between a particle beam and the target.

2. LINEAR ACCELERATOR (LINAC)

(LINAC) A linear particle accelerator is a category of particle accelerator that significantly raises the kinematic energy of subatomic stimulating particles or ions by exposing the charged particles to a succession of oscillating electric potentials laterally along a linear beamline; this technique of speeding up for elementary particles was developed by Leo Szilard.

In linear accelerators, where the fields with increased speed are equivalent to the speed of the particle, the accelerating arrangement is deliberated such that the periodic (phase) velocity of the wave is identical to the velocity of the elementary particles that are to be accelerated.

In 1924 Gustav Ising projected the significant ideologies for such apparatuses [5], while the initial instrument that worked was assembled by Rolf Wideroe in 1928 [6] at the University of Aachen. LINACs ensure numerous solicitations: they produce high-energy electrons and X-rays for medicinal determinations, work as particle incubators for higher-energy accelerators, and are cast off cooperatively to attain the utmost kinematic energy for the elementary particles like positrons and electrons with some other light particles [7].

The line of outbreak and focusing of a LINAC can be influenced by the category of particle pertaining to their nature, the charge, the mass and the spin that is not similar to electrons, protons or any other fundamental ions. LINACs ranges in magnitude, shape and size. One can believe the practical applications from a cathode ray tube (which is a type of LINAC) to the 3.2-kilometre-long (2.0 mi) LINAC [8].

CHAPTER 6

Nuclear Reactors

Abstract: The present chapter is thoroughly dedicated to nuclear power reactors to understand its fundamental conceptions. It also envelops the ancient background and constructed nuclear fission reactors, important components of nuclear reactors, thermal reactors, heavy water, moderator reactors, graphite-gas moderator reactors, and accelerator-driven subcritical reactors (ADSR). The Oklo ancient nuclear reactor is the foundation of natural fission reactors.

Keywords: ADSR, Fission, Moderator, Nuclear Reactors, Thermal Reactors.

1. INTRODUCTION

A nuclear reactor uses a controlled chain reaction, *i.e.*, nuclear fission, to generate power. The energy eliminated away in nuclear reactors may be used for the constructive cause and the production of electricity. In 1939, during their experiments on fission reactions, scientists Hahn and Strassman came across the rare-earth elements in uranium after irradiating it with neutrons. O. Frisch and L. Meitner afterward acknowledged this advent as being due to neutron-induced fission of uranium. This finding was scrutinized, monitored and modified with a few more suggestions. Considering that, on December 2, 1942, Enrico Fermi aimed a chain reaction in a device that consisted of a periodic chimney of herbal uranium separated by graphite moderators. Therefore, Fermi confirmed experimentally the idea of the unique length of the chimney to confirm a sequence reaction. This was performed with a very insignificant collective power of the device, ~ 1W. Contemporary electricity reactors accomplish powers of ~ 3 GW. The rise in electricity in fission reactions was in distinction with managed fusion structures.

Steam generated in nuclear reactors finds application in commercial heating or industrial purposes. A few reactors find their application in the production of isotopes for industrial and scientific usage or weapons-grade plutonium. As per

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

the early 2019 records of IAEA [1], there are 226 nuclear studies reactors and 454 nuclear power reactors being used worldwide [2, 3].

1.1. Principle of Operation

The fundamental Nuclear reactors exchange the energy generated by controlled nuclear fission into thermal energy for further conversion to electrical or mechanical systems similar to thermal power stations that produce electricity from burning fossil fuels.

1.2. Fission

Nuclear fission proceeds when a huge fissile nucleus with uranium (235U) or plutonium (239Pu) captivates a neutron. A bulky nucleus splits into two or extra lighter nuclei during a fission reaction emitting gamma radiation, kinetic energy and free neutrons. The ratio of these neutrons may get consumed by other fissile atoms, which results in the acceleration of additional fission reactions, due to which additional neutrons are released, termed as a nuclear chain reaction. The nucleus of a uranium (^{235}U) atom absorbs a neutron and liberates free neutrons and fast-transferring lighter elements called fission products. However, reactors and nuclear weapons both proceed through a nuclear chain reaction; the rate of reactions in a reactor is more than in a bomb. An illustration of an induced nuclear fission occurrence is shown in Fig. (**6.1**).

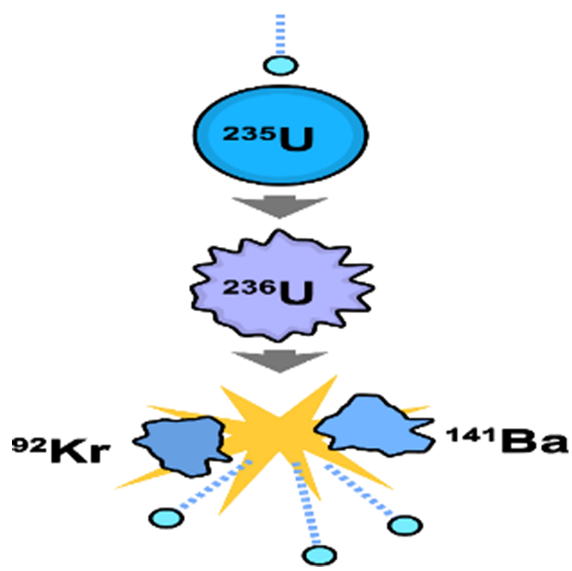


Fig. (6.1). An illustration of an induced nuclear fission event. Courtesy: "Wikimedia Commons." Originally created by Fast fission in Illustrator. Source: https://commons.wikimedia.org/w/index.php?curid=486924.

To regulate such a nuclear chain reaction, control rods encompassing neutron moderators and neutron contagions can modify the percentage of neutrons that will cause additional fission [4]. If monitoring or instrumentation suffers from unsafe conditions, nuclear reactors normally have spontaneous and physical systems to close the fission reaction [5].

1.3. Generation of Heat

There are several techniques to generate heat in the reactor core: Thermal energy is transformed from the kinetic energy of fission products when nearby atoms strike these nuclei. Some of the gamma rays produced are absorbed by the reactor during fission and transformed this energy into heat. The formation of heat occurs by the radioactive decay of fission products and materials activated by neutron absorption. This decay source will subsequently continue for some time, even if the reactor is shut down [6, 7].

1.4. Fission Reactions Rate Mechanism

The fission reaction rate within a reactor center can be adjusted by regulating the quantity of neutrons capable of setting off additional fission movements. Nuclear reactors have diverse strategies to regulate the neutron flow and hence can regulate the reactor's power output. The control rods aid in regulating the rate of the neutron-induced fission reaction. Control rods act as neutron poisons and consequently engross neutrons. When a control rod is inserted deeper into the reactor, it absorbs extra neutrons than the material it transfers (the moderator). Due to this, few neutrons are accessible to cause further fission reactions. On the other hand, if the control rods are completely removed or pushed upwards, the rate of fission reaction will increase, and hence a large amount of power will be generated.

1.5. Cooling System

Most commonly, the coolants in a nuclear reactor are water and sometimes a gas or liquid sodium or lead (liquid metallic) or molten salt. This coolant runs through the reactor core to captivate the heat generated in the reactor. The heat generated from the reactor is used to generate steam.

Most reactor systems use a cooling system alienated from the water that will be boiled to generate pressurized steam to run the turbines. Although, just like traditional boiling water reactors, in nuclear reactors, the water for the steam turbines is boiled openly by the reactor core [8].

CHAPTER 7

Radioactivity

Abstract: Radioactivity, also known as nuclear decay, radioactivity, radioactive disintegration or nuclear disintegration, is the progression by which an unstable atomic nucleus drops energy by radiation. A material comprising unbalanced nuclei is considered radioactive. Three of the most common types of decay are alpha decay (α - decay), beta decay (β-decay), and gamma decay (γ-decay). The present chapter envelops the fundamental understanding of radioactivity. It progresses through the introduction to radioactivity, alpha decay, magnetic spectrometer, determination of energy of α (Alpha) particle, Gamow's Theory of Alpha decay, beta decay, measurement of energy of beta particle and Neutrino Theory of Beta decay: (Pauli's Neutrino Hypothesis, Fermi theory of Beta decay, Gamma Decay, Measurement of Gamma γ-Ray Energies.

Keywords: Alpha Decay, Beta Decay, Gamma Decay, Radioactivity.

1. INTRODUCTION TO RADIOACTIVITY

Some nuclei are unstable and decay. These nuclei are radioactive. A nucleus can emit an alpha ray, beta ray, or a gamma-ray during its decay. Ernest Rutherford and others started studying the radiation emitted by these elements. He found three distinct forms of radiation, originally divided up based on their ability to pass through certain materials and deflection in magnetic fields. Radioactivity is a random process at the level of distinct atoms. The quantum theory proves that it is difficult to predict when a specific atom will decay, irrespective of how long the atom has been existent [1]. Nevertheless, for a majority of identical atoms, the whole decay rate can be stated as half-life or as a decay constant. The half-lives of radioactive atoms have an enormous array, from nearly instantaneous to far longer than the stage of development of the universe [2]. Radioactive decay (also known as nuclear decay, radioactivity, radioactive disintegration or nuclear disintegration) is the process by which an unbalanced atomic nucleus drops energy by particle emission. The decaying nucleus is called the parental radionuclide, and the process produces at least one daughter nuclide. Excluding gamma decay or internal conversion from a excited nuclear state, the decay is a nuclear transformation ensuing in a daughter containing an altered number of proton or

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

neutrons (or both). When the number of protons changes, an atom of a different chemical constituent is generated [3].

A material encompassing unbalanced nuclei is deliberated radioactive. Three of the most communal categories of decay are alpha decay (α -decay), beta decay (β-decay), and gamma decay (γ-decay), all of which include releasing one or more particles or photons. The weak force is the mechanism accountable for beta decay, while the other two are ruled by the usual electromagnetic and tough forces [4].

1.1. Alpha (α) Rays

They could barely pass through a single sheet of paper. Deflected in a magnetic field as they are positively charged particles.

1.2. Beta (β) Rays

They can pass through about 3mm of aluminium metal sheet. Deflected in the magnetic field as they are negatively charged particles.

1.3. Gamma (γ) Rays

They can pass through several centimetres of lead or concrete walls. They do not deflect in a magnetic field as they are charge-less particles.

Following Fig. (**7.1**) gives a general idea about their existence and nature.

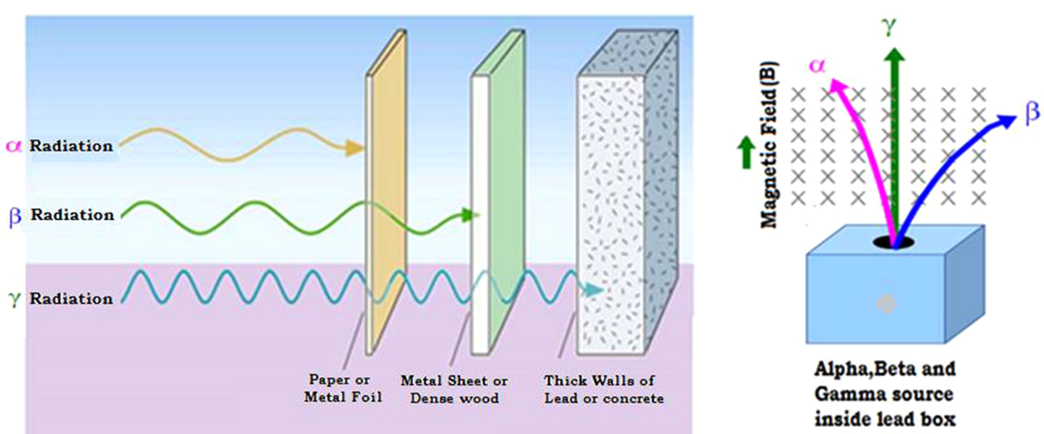


Fig. (7.1). Schematics of Alpha, Beta and Gamma rays.

2. ALPHA, BETA AND GAMMA DECAY

2.1. Origin of Alpha Decay

In alpha decay, an energetic helium ion (alpha particle) is ejected, leaving a daughter nucleus of an atomic number less than two by the parent (Z-2) and of an atomic mass number less than four by the parent (A-4). Alpha rays have been identified as helium nuclei (^4_2He). Fig. (**7.2**) indicates the basic mechanism of Alpha decay.

The reaction for alpha decay is,

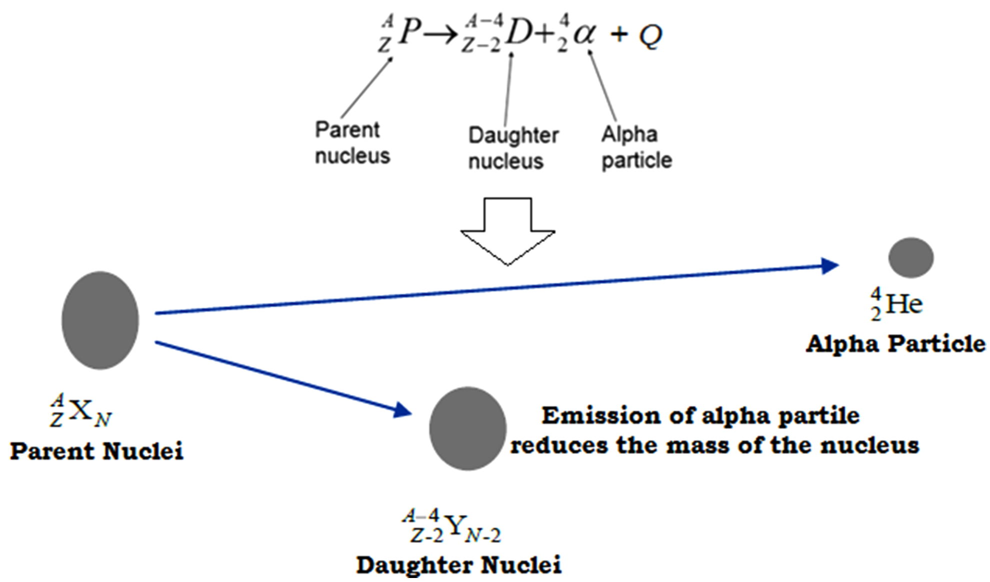


Fig. (7.2). Alpha decay.

In the process of alpha decay, the total mass of the daughter nucleus plus the alpha particle is less than the mass of the original parent nucleus.

$$\mathbf{M}_{\text{Parent}} > \mathbf{M}_{\text{Alpha}} > \mathbf{M}_{\text{Daughter}}$$

The "missing" mass is not really missing. But it has been converted into energy as per Einstein's mass-energy correlation $E = mc^2$.

The energy is found (mostly) in the kinetic energy of the alpha particle and daughter nucleus moving away from each other.

CHAPTER 8

Origin and Applications of Radioactivity

Abstract: A brief introduction to radioisotopes, radiation sources, types of radiation, their applications, effects and occupational protection has been presented in this chapter. The sources of radiation (whether natural or artificial) have been discussed. However, special emphasis has been given to natural radioactive decay series and artificial radioisotopes. Applications of ionizing radiations have significantly improved the quality of human life. The contribution and application of radioisotopes in various spheres of life, *viz.* tracing, radiography, food preservation and sterilization, eradication of insects and pests, medical diagnosis and therapy and new varieties of crops in the agricultural field, have been presented briefly. In this chapter, we have first discussed the natural origin of radioactivity and the production of radioactive elements in neutron and charged-particle streams, then exchanged the data and facts to see how high-energy particles lose energy during their interaction with matter. Finally, fossil radioactivity, artificial radioactivity, applications of radioactivity in medicinal and pharmaceutical extent, and nuclear dating followed by some wide-range applications of radioactivity have been discussed.

Keywords: Artificial Radioactivity, Artificial Radioactivity, Fossil Radioactivity, Radioactivity.

1. INTRODUCTION

Radioactivity or Radioactive decay (sometimes known as radioactive disintegration, nuclear disintegration or occasionally nuclear decay) is a process by which an unstable atomic nucleus loses its energy by radiation to be more stable. A material consisting of unstable nuclei is regarded as radioactive material. The most common types of decays are alpha decay (α-decay), beta decay (β-decay), and gamma decay (γ-decay), all of which either radiate one or more particles or photons. The mechanism responsible for beta decay is the weak force, while the other two decays are attributed to the usual electromagnetic and strong forces, respectively [1]. Radioactive decay is a random process at the single atomic level. According to quantum theory, it is difficult to guess when a specific atom will decay, irrespective of the long-time existence of the atom [2]. Conversely, for a noteworthy number of indistinguishable atoms, the complete decay rate can be expressed as decay constant or half-life. The half-lives of radio-

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

active atoms have an enormous range that can vary from almost instantaneously to far longer than the age of the universe [3].

The decaying nucleus is termed the parent radionuclide, and this process produces at least one daughter nuclide. Excluding internal conversion or gamma decay from an excited nuclear state, the decay is a nuclear transformation ensuing in a daughter nuclide consisting of a different number of protons or neutrons (or both). An atom of a different chemical element is produced when the number of protons changes [4].

1.1. Origin of Radioactivity

Radioactive indigenous nuclides found on the Earth are deposits from the earliest supernova events that occurred before the development of the solar system. They are the elements of radionuclides that continued from that time, through the formation of the ancient solar nebula, planet mass, and up to the present. The expected short-lived radiogenic radionuclides found in today's rocks are the daughter nuclides of those primordial radioactive nuclides. Another minor source of naturally occurring radioactive nuclides is cosmogenic nuclides, formed by the attack of cosmic rays on the material in the Earth's atmosphere or shell. The decay of the radionuclides in rocks of the Earth's mantle and crust contributes to Earth's interior heat budget significantly.

Taking into account the Big Bang theory, stable isotopes of the lightest five elements (H, He, and traces of Li, Be, and B) were formed very shortly at the very beginning of the formation of the universe in a progression called Big Bang nucleosynthesis. These lightest stable nuclides such as including deuterium, still exist to date, but any radioactive isotopes of the light elements created in the Big Bang, such as tritium, have long subsequent decay. Isotopes of elements that were denser than boron were not formed at all in the Big Bang explosion, and these first five light elements do not have any long-lived radioisotopes. Therefore, all radioactive nuclei are relatively newer than the birth of the universe, having formed far along in numerous other types of nucleosynthesis in stars like supernovae, and also in the course of ongoing exchanges amongst stable isotopes and energetic particles. For example, carbon-14, a radioactive nuclide with a half-life of only 5,730 years, is continuously produced in Earth's upper atmosphere due to interactions between cosmic rays and nitrogen [5]. Nuclides formed by radioactive decay are termed radiogenic nuclides, ignoring whether they are stable or not. Stable radiogenic nuclides formed from short-lived and died-out radionuclides in the initial solar system [6]. The occurrence of other additional stable radiogenic nuclides such as xenon-129 from extinct iodine-129 in contrast to the background of stable elemental nuclides can be concluded by numerous resources.

The term radioactivity was invented by Marie Curie, who, together with her husband Pierre, began examining the occurrence in recent times revealed by Becquerel. Marie Curie and Pierre Curie removed uranium from minerals and surprisingly found that the remaining minerals exhibit more activity than the pure ones. They determined that the ore enclosed other radioactive elements. This paved the way to discover the other two elements, polonium and radium. It took four more years of treating tons of ore to segregate each constituent adequately to conclude their radioactive properties.

1.2. Fossil Radioactivity

1.2.1. Radioactive Dating of Fossils

Fossils are composed of rocks that come from identical layers. These models are widely classified and examined with a mass spectrometer. The mass spectrometer is competent in giving statistics about the nature and quantity of isotopes established in the rock. Researchers discover the proportion of parent to daughter isotope, and by associating this proportion with the parent isotope's half-life logarithmic measure, they can reveal the age of the rock or fossils.

1.2.2. Isotopes Used for Dating

A large number of joint radioactive isotopes are available, which are recycled for the dating of rocks, objects and fossils. The most common is U-235 which originated in several rocks, soil and residue. U-235 decays to Pb-207 with a half-life of 704 million years. Owing to its extended half-life, U-235 is the finest isotope for radioactive dating, predominantly of older fossils and rocks. C-14 is an alternative radioactive isotope that decays to C-12. This isotope is found in all living entities. When an animal or plant dies, the C-14 initiates decay. The half-life of C-14 is only 5,730 years. Because of its shorter half-life, the number of C-14 isotopes in a sample becomes insignificant after nearly 50,000 years, making it difficult to use for dating older samples. C-14 is used frequently in dating objects from a human being.

Maximum elements on Earth have been summarized from an astronomical mist around 4.5×10^9 years ago. This mist is typically comprised of "elemental" Hydrogen (^1H) and Helium (^4He) formed in the just first minutes after the "Big Bang." Moreover, the surrounding cloud compressed the elements produced in past generations of stars and isolated them into the intergalactic medium through numerous developments. The most radioactive nuclei were formed in supernovae,

CHAPTER 9

Nuclear Cosmology and Elementary Particles

Abstract: Physical cosmology is a branch of cosmology concerned with studying cosmological models. An astrophysical model, or merely cosmology, explains the largest-scale assemblies and dynamics of the universe and allows the study of necessary inquiries about its beginning, configuration, progress and conclusive fortune. In the present chapter, we tried to envelop the fundamental conceptions of Nuclear Cosmology and Elementary Particles encompassing primary and secondary Cosmic Rays (CR), the composition of CRs in the solar system and the Galaxy, elementary particles and their entire characteristics, matter and antimatter, generations of matter and fundamental forces with necessary schematics and illustrations.

Keywords: Elementary Particles, Fundamental Forces, Nuclear Cosmology, Solar System.

1. INTRODUCTION TO NUCLEAR COSMOLOGY AND ELEMENTARY PARTICLES

Cosmology is a science initiated with the Copernican principle, which suggests that heavenly bodies follow indistinguishable physical laws from those on Earth. Newtonian mechanics first permitted those physical laws to be implicit. Physical cosmology, as it is now assumed, initiated with the progress in 1915 of Albert Einstein's general theory of relativity, trailed by chief observational findings in the 1920s: first, Edwin Hubble exposed that the universe comprises an enormous number of exterior galaxies away from the Milky Way; then, work by Vesto Slipher and others presented that the universe is increasing [1]. These improvements made it conceivable to take a chance at the beginning of the universe and permitted the creation of the Big Bang theory by Georges Lemaître as the principal astrophysical model. Rare investigators still support a few unconventional cosmologies [2]; however, most cosmologists understand that the Big Bang theory gives the best details of these observations.

In nuclear particle physics and cosmology, it has been revealed that we are investigating the facts from the tiniest particles and nuclei up to the infinite universe. Moreover, fascinating enough, the study of the microscopic world, such

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

as particles and nuclei, is associated with the study of the macroscopic world, such as the universe. Both studies harmonize each other. It is whispered that the universe just after the big bang has incredible energy concentration and marinas novel particles unidentified to manhood. Considering the preliminary void, the existing universe has many components. If we revise the nuclear properties, we can recognize how and where these components were made in the universe. To appreciate passionate occurrences such as supernova outbursts, we need those nuclear belongings. The development and growth of galaxies can also be assumed with numerical simulation. In short, cosmology and nuclear particle physics attempt to make a widespread understanding of the history and contemporary singularities of the universe through the learning of the microscopic realm of particles and nuclei [3].

Cosmology draws profoundly on the work of numerous distinct areas of investigation in theoretical and practical physics. Areas applicable to cosmology involve particle physics research, theory, hypothetical, observational astrophysics, general relativity, quantum mechanics, and plasma physics [4].

Particle physics (similarly identified as high energy physics) is a branch of physics that reviews the natural surroundings and the particles that are set up with matter and radiation. Even though the word particle can talk about countless categories of very small entities (*e.g.*, protons, gas particles, or even domestic dust), particle physics typically examines the irreducibly tiniest noticeable particles and the essential interactions essential to designate their activities.

In particle physics, an elementary particle is a subatomic particle with no substructure, *i.e.*, it is not composed of other particles [5]. Particles at present supposed to be elementary encompass the basic fermions (quarks, leptons, antiquarks, and antileptons), which commonly are "matter particles" and "antimatter particles," as well as the gauge bosons and the Higgs boson, which normally are "force particles" that intermediate interfaces among fermions [5]. A particle encompassing two or more elementary particles is called a composite particle. In present consideration, the elementary particles are excitations of the quantum fields that similarly govern their impacts. At the moment, elementary theory clarifying these dynamic fields and particles, along with their dynamic forces, is called the Standard Model [6]. Consequently, existing particle physics examines the Standard Model and its various conceivable postponements, *e.g.*, to the latest "known" particle, the Higgs boson, or even from the past known force field, gravity [7].

1.1. Cosmic Rays (CR)

They are the artifact of cosmological reactions and breakdowns: the foremost foundations of CRs up to the knees are enormous solar radiations. In 1900: electroscopes discharged even far from normal radioactivity sources stimulated using a pole, and the ionization was dignified from the degree to which the abundances got collected due to outflow currents related to ionization. Hess 1912 (1936 Nobel prize) and Kolhörster 1914 functioned hot-air balloon which climbs up to 5-9 km and perceived that the average ionization intensifies with elevation 'A radiation of precisely extraordinary penetrating power comes into our troposphere from above.'

Thereafter Cosmic Rays were entitled by Millikan (1925) that restrained subaquatic ionization domains (he witnessed the more probing 'muon' element, not the electromagnetic as in the sky). After 1929 it was understood they are made of charged particles getting at the Earth in clusters, *i.e.*, atmospheric cascades [8].

Remarkable balloons above the height of sea level, rockets, and satellites are cast-off to scrutinize the CRs in the solar system. In forming these 'primary' CRs at the borderline of the Earth's atmosphere (>40 km), there is a constituent of the cosmological source, but then again, the main constituent overhead 1 GeV directly reaches us from the stellar space. There are decent explanations to accept as true that CRs are molded in the Galaxy apart from those with E > 1017 eV (but their impact on the energy concentration and change is insignificant).

The direct extent of cosmic rays, particularly at lower energies, has been probable since the introduction of the first satellites in the late 1950s. Particle detectors comparable to those recycled in nuclear and high-energy physics are used on satellites and interstellar investigations for research into cosmic rays. Data from the Fermi Space Telescope (2013) [9] have been inferred as confirmation that a noteworthy portion of primary cosmic rays originates from the supernova outbursts of stars [10]. Grounded on clarifications of gamma rays and neutrinos from blazar TXS 0506+056 in 2018, energetic and enormous nuclei also give the idea to produce cosmic rays [11].

Showers of high-energy particles arise when energetic cosmic rays attack the top of the Earth's troposphere. Utmost cosmic rays are atomic nuclei: most are hydrogen nuclei, some are helium nuclei, and the rest heavier elements. Even though many of the low-energy cosmic rays originate from the Sun, the backgrounds of the highest energy cosmic rays leftovers are unidentified and a matter of ample exploration. Fig. (**9.1**) illustrates air showers from very high-energy cosmic rays.

CHAPTER 10

Nuclear Astrophysics

Abstract: Nuclear Astrophysics is a field at the joining of nuclear physics and astrophysics that try to find and recognize how nuclear processes shape the universe. In essence, we look in the present chapter for the connection between the properties of atomic nuclei and the properties of planets, stars, and galaxies. The present chapter encloses astrophysics of the universe, theories on the creation of the universe, formation of a star, thermonuclear reactions in stars, nucleosynthesis, a process for the production of elements, death of a star and the age of our Galaxy.

Keywords: Galaxy, Nuclear Astrophysics, Nucleosynthesis, Star, Universe.

1. INTRODUCTION

Nuclear astrophysics is an interdisciplinary part of both nuclear physics and astrophysics, containing a close relationship between investigators in numerous subfields of each field. This comprises, particularly, nuclear reactions and their proportions as they take place in cosmic surroundings, and demonstrating of cosmological entities where these nuclear reactions may take place, but also deliberations of cosmic advancement of isotopic and chemical evolution to identify the fundamental structures. Limitations from interpretations include multiple messengers, all across the electromagnetic spectrum (nuclear gamma-rays, X-rays, optical, and radio/sub-mm astronomy), as well as isotopic dimensions of solar-system constituents such as meteorites and their stardust presences, cosmic rays, material deposits on Earth and Moon). Nuclear physics experiments address stability (*i.e.*, lifetimes and masses) for atomic nuclei well outside the system of stable nuclides into the territory of unstable or radioactive nuclei, practically to the parameters of certain nuclei, and below up to neutron star matter and high temperatures plasma up to 10^9 K [1].

Models and their principles are vital in this domain, as cosmic nuclear reaction surroundings cannot be understood but, at finest, moderately moved toward by experiments. In overall expressions, nuclear astrophysics purposes of recognizing the foundation of the isotopes and chemical components, and the role of nuclear energy generation, in cosmic foundations such as stars, novae, supernovae, and intense binary-star connections.

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

Nuclear astrophysics leftovers are a difficult mystery to solve in science [2]. The existing agreement on the origins of isotopes and elements is that only helium and hydrogen (and traces of lithium, beryllium, and boron) can be molded in an identical Big Bang, while all other isotopes and elements there are twisted in cosmic matters that formed far ahead, such as in stars and their explosions. Even though the grounds of nuclear astrophysics give a conceivable and clear idea, many problems remain unanswered. One example from nuclear reaction physics is helium fusion (specifically the ^{12}C (α, γ) ^{16}O reaction(s)) [3]; others are the cosmological site of the r-process, irregular lithium abundances in Residents III stars, and the bang mechanism in core-collapse supernovae and the originators of thermonuclear supernovae. Contemporary explanations of the cosmic progression of fundamental abundances are approximately reliable to those detected in the galaxy and Solar System, whose distribution duration is one trillion in twelve orders of magnitude.

1.1. Astrophysics of the Universe

Astrophysics is a science that employs the approaches and main beliefs of physics in studying astrophysical entities and singularities [4, 5]. In the middle of the subjects studied are the galaxies, the Sun, extrasolar planets, the interstellar medium, other stars and the cosmic microwave background [6]. Emissions from these entities are scrutinized across all parts of the electromagnetic spectrum, and the properties examined contain chemical composition, temperature and luminosity. Because astrophysics is a very comprehensive subject, astrophysicists relate concepts and methods from numerous disciplines of physics, including electromagnetism, statistical mechanics, classical mechanics, quantum mechanics, relativity, thermodynamics, nuclear and particle physics, and atomic and molecular physics [7].

The Universe is vast, far bigger than we can imagine or comprehend. It is enormous and includes Earth and the remainder of space, the sun, the moon, other planets, stars and galaxies. The Greece Philosopher Aristotle, in 300s B.C., reasoned that a perfectly spherical earth had to be at the center of the Universe. Later, Ptolemy summed up that Earth was at the center, and all the other heavenly bodies revolve around it. Later Copernicus put forward his idea that the motion of heavenly bodies could be better explained if the sun and nor earth were at the centre of things. The later development of the telescope proved the concept that the sun was just one of many stars. Earth was not the centre of the Universe, nor the sun, nor even the Milky Way. It became apparent that our Milky Way galaxy was one of the many galaxies. Now the problem was to measure the distance of those off Galaxies. Edwin Hubble proposed that, since the founder galaxies had the larger redshifts, the velocity at which they receded was proportional to their distance. It had a deep meaning that the Universe was expanding. Further, it implied that if the galaxies were receding, they must have been concentrated into a small region of space at some time, meaning that the Universe must have a definite age. This can simply be expressed by Hubble's law. It relates the galaxy's distance to its recession velocity *via* a value known as Hubble's constant. The Hubble's constant was considered to be a direct measure of the universe's age if it is expanding at a constant rate. But the problem is that measuring Hubble's constants was not straightforward, which eventually led to the discovery of some other theories to explain the creation of the universe.

1.2. Theories on the Creation of the Universe

There are three well-known theories explaining the creation of the universe. These are the Big Bang Theory, the Oscillation Theory and the Steady-State Theory. None of these theories can completely explain the phenomena of creation, evolution and the death of the universe.

1.2.1. The Big Bang Theory

According to *George Gamow,* the universe came into existence nearly 15 billion years ago from a sudden explosion and the phenomenon is known as Big Bang. In this phenomenon, the entire matter, energy, space and time were created simultaneously. It is believed that all of a sudden, in one in a million fractions of section (10^{-12}s), the universe expanded to a size equal to the present size of our solar system. At that stage, the universe had a temperature of 10^{13} K. The basic concept of the Big Bang theory is that from the beginning of the creation of the universe, it expanded continuously and correspondingly cooled down [8].

The Big Bang theory explains the evolution of the Universe through different stages. It is theoretically assumed that from the beginning of time until 10^{-43}s, known as Planck time, all the four fundamental forces, namely Gravitational Force, Electromagnetic force, Nuclear Strong force and Weak force, jointly acted as a single unified force. At the end of the 10^{-43}s, the Gravitation force separated from the other forces. At that time, the temperature of the Universe was 10^{32} K. This Universe then suddenly expanded and thereby cooled down. At that time, there was not even a single particle of matter present in the Universe; it was all energy. When the Universe was 10^{-35} sec old, its temperature reduced to 10^{28} K due to cooling, and the Strong Nuclear force started separating from the remaining other forces. Further, when the age of the Universe was between 10^{-35}s and 10^{-32}s, the size of the universe got doubled and the temperature reduced to 10^{20} K; the strong nuclear forces and electromagnetic forces got separated from each other [9]. Further, there was fluxation of particles, especially quarks, antiquarks, photons and electrons, from the vast energy reserve of the Universe. When the age

CONCLUSION

This textbook gives an elementary understanding of nuclear and particle physics, offering an overview of theoretical and experimental grounds, providing students with a profound understanding of the ideas about the nucleus, particle detectors, accelerators, radioactivity, and elementary particles. Each chapter provides the fundamental theoretical and experimental knowledge for students to strengthen their concepts regarding nuclear physics. The present form of the textbook is appropriate for undergraduate courses in nuclear and particle physics as well as more innovative courses; the book includes sophisticated and newly constructed figures as well as thoroughly solved equations that create the interest amongst undergraduate students to renovate the content to their course. It could be a vital textbook for students framing their future study or a profession in the field who needs a concrete understanding of nuclear and particle physics together. It provides a concise, thorough, and accessible treatment of the fundamental aspects of nuclear physics. Reorganized figures, resolved equations, rearranged contents and appendices make it easier to use for entire users.

It is an adequate and systematically up–to–date textbook on nuclear and particle physics. Indeed the concepts in this book are unique because it makes important connections to other fields such as elementary particle physics and astrophysics. Moreover, its way of presentation is student-friendly, and it bridges nuclear physics as an essential part of modern physics with a comprehensive scientific and historical context.

The book is intended to focus on the following:

1. Elements of Nuclear Physics is an ultimate textbook for courses at the undergraduate level in nuclear physics. Moreover, it is a significant basis for scientists and those who initiated working with nuclei, particle physicists, astrophysicists and anyone willing to learn more about novel trends in this field.

2. Its importance on phenomenology and discussions of the theory are covered with the suitable examples which clarify and put on the theoretical formulism differentiate this book from all other textbooks available.

3. The text is well organized to deliver the fundamentals of content for students with a small mathematical background that provides more distinguished material in each section.

4. This textbook is competent because it includes the discovery of the neutron and other modern advances, providing undergraduate students with widespread coverage of the elementary models of each topic in particle physics for the first time. Physics emphasizes mathematical precision, making the material handy to students with no earlier knowledge of elementary nuclear physics. The theory and mathematical expressions are linked together in a very sophisticated manner, helping students to understand how key ideas were developed.

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

5. The content on nuclei, mass defect, packing fraction, particle accelerator and detectors, Discovery of Neutron, Nuclear Chain Reaction, Liquid Drop Model and Shell Model of Nucleus, Nuclear fission and fusion, and radioactivity has been completely revised to familiarize the students to what lies beyond. The easily understandable figures and equations with over 50 problems inspire students to apply the theory themselves.

SUBJECT INDEX

A

B

C

Ritesh Kohale, Sanjay J. Dhoble & Vibha Chopra

D

E

F

G

H

I

K

L

M

N

S

T

U

V

W

X