BETA DECAY LOGFT VALUES FOR SOME A = 74 RADIOISOTOPES

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Yousif Obaid Lateef AL-AZZAWI

ABSTRACT

MasterThesis

BETA DECAY LOGFT VALUES FOR SOME A =74 RADIOISOTOPES

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In this study, the allowed and first forbidden beta transition log*ft* values for some A=74 radioisotopes were investigated with the proton-neutron quasi-particle random phase approximation (pn-QRPA) using both the Schematic Model (SM) and Pyatov Method (PM). Fermi and Gamow-Teller transitions were calculated both in the particle-hole (ph) and the particle-particle (pp) channel. The first forbidden transitions were analyzed only in the particle-hole channel in the Schematic model. The Woods-Saxon potential was used for all beta decay types. The obtained numerical data were compared with the experimental values and observed to be closer to these values.

Key Word : Allowed transitions, First forbidden transition, Woods-Saxon potential, pn-QRPA

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ÖZET

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BAZI A =74 RADYOİZOTOPLARIN BETA GEÇİŞ LOGFT DEĞERLERİ

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Bazı A=74 radyoizotoplarının izinli ve birinci yasaklı beta geçiş logft değerleri proton-nötron kuaziparçacık rastgele faz yaklaşımı ile hem şematik model hem de Pyatov metot kullanılarak incelendi. Fermi ve Gamow-Teller geçişleri hem parçacık-boşluk hem de parçacık-parçacık kanallarında hesaplandı. Birinci yasaklı geçişler sadece parçacık-boşluk kanalında şematik model yaklaşımında incelendi. Bütün beta bozunum türlerinde Woods-Saxon potansiyeli kullanıldı. Elde edilen nümerik veriler deneysel değerler ile karşılaştırıldı ve sonuçların deneysel veriler ile birbirine yakın olduğu gözlendi.

Anahtar Sözcükler : İzinli geçişler, Birinci yasaklı geçiş, Woods-Saxon potansiyeli, pn-QRPA

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

As : Arsenic
Br : Bromine
Kr : Krypton
Rb : Rubidium
Sr : Strontium
Ca : Calcium
Ge : Germanium
Zr : Zirconiym
Se : Selenium
He : Helium
Lu : Lutetium
Np : Neptunium
Pu : Plutonium
N : Nitrogen
C : Carbon
Y : Yttrium
U : Uranium
Cu : Cupper

ABBREVIATIONS

pn QRPA : proton-neutron Quasiparticle Random Phase Approximation
GT : Gamow Teller
F : Fermi
FF : First Forbidden
SM : Schematic Model

PM : Pyatov Method
SCRPA : Self-Consistent Continuum Random Phase Approximation
RPA : Random Phase Approximation
QPM : Quasiparticle Phonon Model
SPECT : Single Photon Emission Computed Tomography
PET : Positron Emission Tomography
TrT : Targeted Radionuclide Therapy

PART 1

INTRODUCTION

Weak interaction theory and nuclear structure are fundamentally dependent on the study of nuclear structure and properties, in particular the properties of beta decay of nuclei. A fundamental force of nature, the weak interaction (sometimes called the weak force or weak nuclear force) controls the disintegration of unstable subatomic particles and starts nuclear fusion reactions [1]. It is possible to investigate spin-isospin excitations in atomic nuclei using strong, weak, and electromagnetic interactions [2]. One kind of radioactive decay known as beta decay is the release of electrons or positrons, or the nucleus absorbing electrons [3,4].

Beta decay also plays a crucial role in nuclear energy and medicine, as it is used to produce energy and to diagnose and treat medical conditions. Beta decay is a key process in nuclear power generation. In nuclear reactors, beta decay is used to generate heat, which in turn is used to produce electricity. The beta particles emitted during beta decay are absorbed by a material surrounding the fuel rods, which then heats up and generates steam. The steam is then used to turn turbines and generate electricity.

Beta decay is also used in the production of nuclear fuel. For example, the beta decay of ^{235}U is used to produce ^{235}Np and ^{235}Pu, which can be used as nuclear fuel. In addition, beta decay is used in the production of isotopes for medical and industrial applications. For example, the beta decay of ^{14}C is used to produce ^{14}N, which is used in carbon dating.

Beta decay is used in both diagnostic and therapeutic applications in medicine. In diagnostic applications, beta-emitting isotopes are used in imaging techniques such as positron emission tomography (PET) and single photon emission computed tomography (SPECT). These techniques allow medical professionals to image specific organs and tissues in the body, helping to diagnose and monitor medical conditions.

In therapeutic applications, beta-emitting isotopes are used to treat cancer. The beta particles emitted during beta decay can be used to target cancer cells, which are then destroyed by the radiation. This technique is known as targeted radionuclide therapy (TRT) and is used to treat a variety of cancers, including lymphoma and leukemia.

Previous studies have demonstrated the effectiveness of beta-emitting isotopes in diagnostic and therapeutic applications. For example, in a study by Gudkov et al. [5], the beta-emitting isotope ^{90}Y was used in TRT to treat liver cancer. The study found that the treatment was effective in reducing tumor size and increasing patient survival.

In another study by Chen et al. [6], the beta-emitting isotope ^{177}Lu was used in TRT to treat neuroendocrine tumors. The study found that the treatment was effective in controlling tumor growth and improving patient survival. Beta decay is also used in radiation therapy for non-cancerous conditions such as hyperthyroidism. In this case, the beta-emitting isotope ^{131}I is used to destroy overactive thyroid tissue.

1.1. THEORETICAL BACKGROUND

Beta decay is a process in which a nucleus transforms by emitting or capturing an electron or positron. This process involves weak interaction, which is a force that is much weaker than the electromagnetic force. There are two types of transitions involved in nuclear decay: allowed and forbidden, depending on the angular momentum (l) of the emitted leptons relative to the nucleus. The allowed transition corresponds to $l = 0$, while $l > 0$ ($l = 1$) corresponds to the (first) forbidden transition. The Fermi represents the beta decay of a nucleus without any change in its angular momentum, while the Gamow-Teller represents the beta decay of a nucleus with a change in its angular momentum.

The beta-transition matrix elements are defined between initial and final nuclear states and are given in the form [7]:

$$M_{fi} = \langle f|H|i\rangle \tag{1.1}$$

where f and i represent the final and initial states of the nucleus, respectively. The matrix elements are usually expanded in a power series of the electron-neutrino momentum difference, which is approximately equal to the nuclear radius. The beta-transitions are classified into allowed, first-forbidden, and second-forbidden transitions based on the spin difference and parity change [8].

So it can be concluded, that beta decay is a nuclear process involving weak interaction, and its Hamiltonian can be expressed as the sum of Fermi and Gamow-Teller terms. The beta-transition matrix elements are defined between initial and final nuclear states and are used to describe the various types of beta transitions, such as allowed and forbidden transitions, based on their spin difference and parity change.

The pn-QRPA (proton-neutron quasiparticle random phase approximation) approach is a widely used theoretical model for analyzing the beta-decay properties of nuclei. This approach involves solving a coupled set of equations that describe the excitation of proton and neutron quasi-particles in the nucleus [9]. The model takes into account the coupling between single-particle excitations and collective excitations of the nucleus [9]. The pn-QRPA approach is a microscopic model that gives a framework for studying the beta-decay properties of a wide range of nuclei [10].

The schematic model is a simplified version of the pn-QRPA approach that assumes a constant density of the nuclear matter and a uniform proton-neutron interaction strength. The SM is a useful tool for understanding the basic features of beta decay and for making initial predictions. However, for more accurate predictions, the full pn-QRPA approach is required [11].

In the pn-QRPA approach, the nuclear Hamiltonian is expressed as a sum of one-body and two-body terms. The one-body term represents the kinetic energy of the nucleons and the external potential, while the two-body term represents the nucleon-nucleon interaction. The approach involves the diagonalization of the Hamiltonian based on proton and neutron quasiparticles. The quasiparticles are excitations of the Fermi Sea and are described by a set of quantum numbers that include energy, spin, and isospin [12-13].

The pn-QRPA approach considers the effect of pairing correlations, which are important in determining the beta-decay properties of nuclei. The pairing correlations arise due to the attractive interaction between nucleons in the same spin and isospin states. The effect of pairing correlations is included in the pn-QRPA approach by introducing a pairing field that describes the interaction between nucleons in the same spin and isospin states [9].

In summary, the theoretical analysis of beta-transition properties of nuclei using different models is an active area of research in nuclear physics. The pn-QRPA approach is a widely used microscopic model for analyzing the beta-decay properties of nuclei [10]. The approach takes into account the coupling between single-particle excitations and collective excitations of the nucleus and provides a framework for studying the beta-decay properties of a wide range of nuclei [9]. The schematic model is a useful tool for understanding the basic features of beta-decay, but for more accurate predictions, the full pn-QRPA approach is required [12].

1.2. RESEARCH QUESTIONS

- What are the allowed and first-forbidden excitations of the A=74 radioisotopes ^{74}As, ^{74}Br, ^{74}Kr, ^{74}Rb, and ^{74}Sr?
- How can a microscopic pn-QRPA approach with the schematic model be used to analyze the beta-decay properties of these nuclei?
- What are the logft values of the parent nuclei?
- How do the results obtained from this study compare with other theoretical results and experimental data in the literature?
- What insights can be gained into the weak interaction theory and the nuclear structure from the study of the beta-decay properties of these nuclei?
- How can the results of this study have practical applications in fields such as nuclear energy and medicine?

1.3. RESEARCH OBJECTIVE

In this study, we aimed to examine the allowed and first-forbidden excitations of several A=74 radioisotopes, namely ^{74}As, ^{74}Br, ^{74}Kr, ^{74}Rb, and ^{74}Sr, using a microscopic pn-QRPA approach with the schematic model. We employ the Fortran-77 program code that we have developed for numerical calculations. The log*ft* and half-life values of the binary nuclei were calculated and compared with the other theoretical results and experimental data in the literature.

1.4. RESEARCH SIGNIFICANCE

The study of nuclear structure and properties is a fundamental topic in nuclear physics. Theoretical analysis of beta-transition properties of nuclei using different models is an active area of research. The microscopic pn-QRPA approach with the schematic model is a widely used theoretical tool that can supply valuable insights into the beta-decay properties of nuclei. The Fortran-77 program code that we have developed for numerical calculations allows us to perform accurate and efficient calculations.

The A=74 radioisotopes that we will examine are of particular interest because they are far from the stability valley. The properties of such nuclei are not well understood, and the study of their beta-decay properties can provide valuable insights into their nuclear structure. The spin-isospin excitations of these radioisotopes have not been extensively studied in the literature, and our study will contribute to filling this gap.

The study of nuclear structure and properties is a fundamental topic in nuclear physics, and the examination of the beta decay properties of nuclei is an essential aspect of this study. We focus on the allowed and first forbidden excitations of several A=74 radioisotopes using a microscopic pn-QRPA approach with the schematic model. Our study aims to provide new data on the beta-decay properties of these nuclei, which can contribute to the understanding of the weak interaction theory and the nuclear structure. The results obtained will be compared with other theoretical results and experimental data in the literature and can have practical applications in fields such as nuclear energy and medicine.

The following table summarizes some of the key terms and concepts related to the theoretical background of beta decay and the pn-QRPA approach. The table includes two columns: Term and Description. Each row provides a brief description of a specific term or concept and its relevance to the study of beta decay and the pn-QRPA approach [13].

Table 1.1. Definition of some terms.

Term	Description
Beta decay	A process in which a nucleus transforms by emitting or capturing an electron or positron.
Weak interaction	A force that is much weaker than the electromagnetic force and is responsible for beta decay.
Beta-transition matrix element	A quantity that describes the transition between the initial and final nuclear states in beta decay.
Fermi transition	The beta decay of a nucleus without any change in its angular momentum, is represented in the weak interaction Hamiltonian.
Gamow-Teller transition	The beta decay of a nucleus with a change in its angular momentum, is represented in the weak interaction Hamiltonian.
First-Forbidden transition	The first-forbidden transition corresponds to $\boldsymbol{l = 1}$.
pn-QRPA	A microscopic model for analyzing the beta-decay properties of nuclei that take into account the coupling between single-particle excitations and collective excitations of the nucleus.
Proton-neutron quasiparticle	An excitation of the Fermi Sea is described by a set of quantum numbers that include energy, spin, and isospin.
Pairing correlations	The attractive interaction between nucleons in the same spin and isospin states is important in determining the beta-decay properties of nuclei.
Schematic model	A simplified version of the pn-QRPA approach that assumes a constant density of the nuclear matter and a uniform proton-neutron interaction strength.

PART 2

LITERATURE PRESENTATION

2.1. NUCLEAR BETA DECAY PROPERTIES

Nuclear beta decay is a fundamental process in nuclear physics that involves the emission or capture of electrons or positrons by atomic nuclei. This process plays a crucial role in understanding the weak interaction theory and the nuclear structure [12]. Beta decay can change the number of protons and neutrons in the nucleus, leading to the formation of new elements or isotopes. The study of beta decay is essential for understanding the properties of radioactive isotopes, which have practical applications in fields such as nuclear energy and medicine [13].

Three categories of beta decay exist: electron capture, beta-minus decay, and beta-plus decay. A neutron turns into a proton via beta-minus decay, which also releases an electron and an antineutrino. The mass number (A) of the nucleus stays constant while its atomic number (Z) rises by one. A proton turns into a neutron during beta-plus decay, which also releases a positron and a neutrino. While the mass number stays constant, the atomic number drops by one. A neutrino is released when an electron is taken up by a proton in the nucleus during electron capture. While the mass number stays constant, the atomic number drops by one [14].

The beta-decay process is important in nuclear physics because it can change the number of protons and neutrons in the nucleus, leading to the formation of new elements or isotopes. The study of beta decay is essential for understanding the properties of radioactive isotopes, which have important applications in fields such as nuclear energy and medicine. The accurate prediction of the beta-decay properties of radioactive isotopes is essential for the safe handling and disposal of nuclear waste. In addition, the study of beta decay is essential for the development of new medical treatments, such as radioisotope therapy [13].

The Fermi theory of beta decay was proposed by Enrico Fermi in 1934 to describe the beta decay process [15]. The theory was later modified by several researchers, including Bethe and Peierls, to incorporate the weak interaction. The weak interaction is mediated by the exchange of W and Z bosons, which are massive particles that carry the weak force. The strength of the weak force is much weaker than the electromagnetic and strong forces [12].

In conclusion, beta decay is a crucial process in nuclear physics that plays a significant role in understanding the weak interaction theory and the nuclear structure. Beta decay can change the number of protons and neutrons in the nucleus, leading to the formation of new isotopes and elements. The study of beta decay is necessary for understanding the properties of radioactive isotopes, which have practical applications in fields such as nuclear energy and medicine. The Fermi theory of beta decay, modified by Bethe and Peierls, describes the beta-decay process and incorporates the weak interaction [14].

2.1.1. Fermi Transition

Fermi transitions; also known as allowed Fermi transitions, refer to a type of radioactive decay process that occurs in atomic nuclei. These transitions involve the change in the nuclear energy level due to the emission or absorption of a virtual or real W boson, which carries away the necessary energy and angular momentum.

Fermi transitions were first proposed by Italian physicist Enrico Fermi in the 1930s to explain certain types of beta decay, a process in which a nucleus undergoes a transformation by emitting or absorbing an electron (beta particle) and an antineutrino (or neutrino). Beta decay can be classified into two types: allowed transitions and forbidden transitions.

Allowed Fermi transitions are transitions between nuclear states that conserve both angular momentum and parity. Angular momentum is a fundamental property of particles and systems, while parity refers to the symmetry properties of a physical system under spatial inversion. In an allowed Fermi transition, the initial and final nuclear states have the same parity, and the total angular momentum is conserved.

The mechanism behind Fermi transitions involves the interaction between the weak nuclear force and the charged weak current carried by the W boson. The weak nuclear force is responsible for processes such as beta decay, and the W boson mediates this force. During a Fermi transition, a neutron in the nucleus can be transformed into a proton by emitting a virtual or real W- boson, or a proton can be transformed into a neutron by absorbing a virtual or real W+ boson.

Fermi transitions have important implications in nuclear physics, particularly in the study of beta decay and the behavior of atomic nuclei. They are described by the Fermi theory of beta decay, which provides a mathematical framework to calculate the transition probabilities and energy spectra associated with these processes.

2.1.2. Gamow-Teller Transition

Another widely used model for analyzing beta-decay properties of nuclei is the Gamow-Teller (GT) transition, proposed by Towner and Hardy in 1987. The GT model considers the spin and isospin of the initial and final states of the nucleus and the transition between them [16]. It assumes that the beta decay is mainly due to the GT operator, which changes the spin and isospin of the nucleus. The GT model has been successful in expecting the beta-decay properties of many nuclei.

2.1.3. First-Forbidden Transition

Since they are less likely to occur than allowed decays, they are called forbidden decays. If the allowed matrix elements are zero, forbidden crossings are possible. The initial and final states must be of opposite parity for the first forbidden (FF) decay to occur, in generally. Electrons and neutrinos must both emit single-valued orbital angular momentums relative to a nucleus to satisfy the parity change. The decay of $l = 1$ probability of occurrence is less than $l = 0$ decay, decays with $l = 3, 5, 7, \ldots$ the probability of occurrence is very small. In this case, only $l = 1$ of the forbidden passes considering the degradation, these are called first-forbidden (FF) decays. These decay electrons and neutrinos with opposite spin (S = 0) Fermi type allowed transitions and parallel spin (S = 1) Gamow-teller (GT) type is similar to forbidden passes. For Gamow-teller (GT) decay of S = 0 to $l = 1$ coupling yields 0, 1, or 2 units of angular momentum, so ($\Delta I = 0, 1, \text{or } 2$). In this case, the selection rules for the first-forbidden (FF) pass are as follows:

$$\Delta I = 0, 1, 2 \qquad \Delta\pi \text{ (Parity change) =Yes} \tag{2.1}$$

The first-forbidden (FF) transitions consist of three parts as $\lambda^{\pi} = 0^{-}, 1^{-}, 2^{-}$ exciting transitions. Rank 0 transition contains one relativistic and one non-relativistic matrix element. Rank 1 transition consists of two non-relativistic matrix elements and one relativistic matrix element. The excited state of Rank 2 (unique first-forbidden transitions – U1F) consists of a non-relativistic matrix element. Forbidden transitions play an important role in atomic and quantum physics, and their study provides valuable insights into the structure and behavior of atoms. Beta-decay transition types are classified according to log*ft* values presented in Table 2.1.

Table 2.1. Classification of beta-decay transition types according to log*ft* values.

Transition type	log*ft*
Super allowed transition	2.9-3.7
Unfavoured allowed transition	3.8-6.0
Allowed transition	≥5.0
Rank 2 unique first-forbidden	8-10
Rank 0, rank 1 first-forbidden	6-9
Second forbidden	11-13
Third forbidden	17-19
Forth forbidden	>22

2.2. THEORETICAL MODELS FOR ANALYZING BETA-DECAY PROPERTIES OF NUCLEI

Theoretical models have been developed to analyze the beta decay properties of nuclei and understand the underlying physics. These models play a crucial role in predicting the beta-decay properties of various nuclei and contribute significantly to our understanding of nuclear physics.

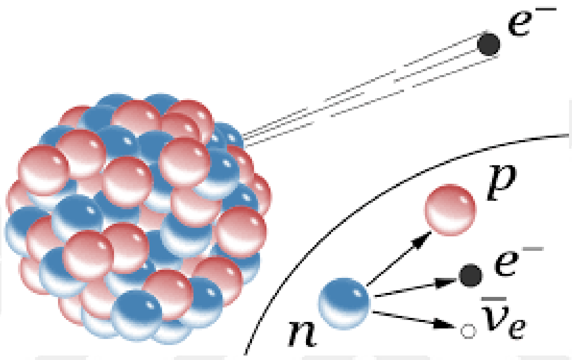

Figure 2.1. Beta decay.

2.2.1. The Gross Theory

The Gross theory of beta decay, proposed by Eugene Gross in 1949, is a semi-empirical model based on the Fermi theory of beta decay. The Gross theory assumes that the probability of beta decay depends linearly on the square of the overlap integral between the initial and final wave functions of the nucleus [16]. The model has been successful in predicting the half-lives and beta-decay energies of many radioactive isotopes.

2.2.2. The Shell Model

The Shell model is a theoretical model used to understand the nuclear structure and beta decay properties of nuclei. It was proposed by Brown and Wildenthal in 1984 and considers the nucleons in the nucleus as occupying different energy levels or shells [17]. The Shell Model assumes that the beta decay is mainly due to the overlap between the initial and final wave functions of the nucleus. The Shell model has been successful in predicting the beta-decay properties of many nuclei and understanding their nuclear structure.

Overall, theoretical models such as the Gross Theory, GT model, QRPA model, and Shell model have been developed to analyze the beta decay properties of nuclei and understand the underlying physics. These models have been successful in predicting the beta-decay properties of many nuclei and have contributed significantly to our understanding of nuclear physics.

2.2.3. The Quasi-Particle Random Phase Approximation

The Quasi-particle Random Phase Approximation (QRPA) model, proposed by Suhonen in 1998, is another theoretical model used to analyze beta-decay properties of nuclei [18]. The QRPA model considers the collective excitations of the nucleus and their coupling with the beta decay process. It assumes that the beta decay is mainly due to the neutrino exchange between the initial and final states of the nucleus. The QRPA model has been successful in predicting the beta-decay properties of many nuclei and is particularly useful for analyzing the properties of neutrinoless double beta decay [19].

2.2.4. The Microscopic pn-QRPA With The Schematic Model

The microscopic proton-neutron Quasi-Particle Random Phase Approximation (pn-QRPA) approach with a schematic model is a theoretical model used to analyze the beta decay properties of nuclei. Sarriguren et al. proposed this model in 2008. The model considers the proton and neutron degrees of freedom separately and treats them within the QRPA framework. The model assumes a schematic potential for the single-particle states and uses the QRPA framework to calculate the beta decay properties of nuclei.

The schematic model used in the microscopic pn-QRPA approach is based on a harmonic oscillator potential with constant energy spacing between the levels. The model assumes that the nucleons occupy the lowest energy levels and that there is a pairing interaction between the nucleons. The model has been successful in predicting the beta-decay properties of many nuclei, including ^{48}Ca, ^{76}Ge, and ^{96}Zr, and the calculated properties are in good agreement with experimental data.

The microscopic pn-QRPA approach with a schematic model has also been used to study the properties of neutrinoless double beta decay. The model has been used to calculate the neutrinoless double beta decay properties of several isotopes, and the calculated half-lives are consistent with experimental limits (Bloch et al., 2012) [20]. The model has also been used to calculate the nuclear matrix elements, which are critical for interpreting experimental results.

The microscopic pn-QRPA approach with a schematic model has several advantages over other theoretical models. The model considers the proton and neutron degrees of freedom separately, which is important for analyzing the beta decay properties of exotic nuclei. The model also includes the pairing interaction between the nucleons, which is essential for describing the nuclear structure.

However, the model has some limitations. The schematic potential used in the model may not accurately represent the real potential in the nucleus. The model also neglects the effects of particle-vibration coupling, which may be important for some nuclei. Despite these limitations, the microscopic pn-QRPA approach with a schematic model is a useful tool for analyzing the beta decay properties of nuclei and understanding their nuclear structure [20].

In summary, the microscopic pn-QRPA approach with a schematic model is a theoretical model used to analyze the beta decay properties of nuclei. The model considers the proton and neutron degrees of freedom separately and treats them within the QRPA framework. The model has been successful in predicting the beta-decay properties of many nuclei and has been used to study the properties of neutrino-less double beta decay. The model has several advantages over other theoretical models but also has some limitations. Overall, the microscopic pn-QRPA approach with a schematic model is a useful tool for analyzing the beta decay properties of nuclei.

2.3. A=74 RADIOISOTOPES AND THEIR IMPORTANCE IN NUCLEAR PHYSICS

Radioisotopes with atomic mass number A=74 have significant importance in nuclear physics due to their unique properties and applications. These isotopes have been extensively studied in various experimental and theoretical investigations to understand their nuclear structure, decay properties, and astrophysical implications.

One of the most important isotopes in this group is ^{74}Se, which has a half-life of 43.7 days and undergoes beta decay to ^{74}As [21]. This isotope has been used extensively in medical imaging and cancer therapy [21]. ^{74}Se has also been used to study the nuclear structure of neutron-rich nuclei and the beta decay of proton-rich nuclei [22].

Another important isotope in this group is ^{74}Ge, which has a half-life of 76.3 hours and undergoes beta decay to ^{74}As [23]. ^{74}Ge is a popular target in neutrinoless double beta decay experiments due to its high natural abundance and favorable properties [24]. The decay of ^{74}Ge to ^{74}As has also been studied to understand the nuclear structure of these isotopes [25].

The properties of ^{74}As, the product of the beta decay of ^{74}Se and ^{74}Ge, have also been extensively studied. ^{74}As has a half-life of 17.77 days and undergoes beta decay to ^{74}Se [26]. The nuclear structure and decay properties of ^{74}As have been studied to understand the properties of neutron-rich nuclei [22].

In addition to these isotopes, other A=74 isotopes, such as ^{74}Kr, ^{74}Br, and ^{74}Rb, have also been studied to understand their nuclear structure and decay properties [27]. These isotopes have been used in various experimental techniques, such as gamma-ray spectroscopy, beta-decay studies, and nuclear reaction studies.

The nuclear structure of A=74 isotopes has been studied by using different theoretical models, such as the Shell Model, the Interacting Boson Model, and the Quasi-particle Random Phase Approximation (QRPA) [28]. The Shell Model has been used to understand the properties of the ground and excited states of A=74 isotopes and their beta decay properties [22]. The Interacting Boson Model has been used to study the collective properties of these isotopes and their transition strengths. The QRPA has been used to calculate the beta decay properties of these isotopes, including half-lives and decay energies [25].

The beta decay studies of A=74 isotopes have also been important in understanding the astrophysical implications of these isotopes. The beta decay of ^{74}Se and ^{74}Ge is important in the production of heavy elements in supernovae and other astrophysical environments [21]. The beta decay of ^{74}As also plays a role in the production of heavy elements in the r-process [22].

2.4. PREVIOUS STUDIES ON SPIN-ISOSPIN EXCITATIONS OF A=74 RADIOISOTOPES

The allowed and first-forbidden transitions of A=74 radioisotopes have been extensively researched over the years, as they play a crucial role in understanding the nuclear structure and properties of these isotopes. Theoretical models, such as the random phase approximation (RPA), the self-consistent continuum RPA (SCRPA), and the quasiparticle phonon model (QPM), have been employed to study the Fermi, Gamow-Teller, and First-Forbidden excitations of A=74 isotopes. Experimental techniques, such as inelastic scattering and beta decay spectroscopy, have also been used to investigate the spin-isospin excitations of these isotopes [29]. The computation of authorized Gamow-Teller (GT) and unique first-forbidden (U1F) transitions has been done using the pn-QRPA model [5].

One of the earliest studies on the spin-isospin excitations of A=74 radioisotopes was conducted by Bhatt and Kumar in 1982 [29]. They used the RPA model to investigate the isospin excitation in ^{74}Kr and ^{74}Se and found that the isospin dipole strength distribution in ^{74}Se was sensitive to the effective interaction used in the RPA calculations.

In a more recent study, Sarriguren et al. (2001) used the SCRPA model to investigate the low-lying excited states of ^{74}Ge. They found that the low-lying states of ^{74}Ge were dominated by isoscalar and isovector dipole excitations, which were associated with the collective motion of protons and neutrons in the nucleus (Morse et al., 2018) [30].

The QPM has also been used to study the spin-isospin excitations of A=74 radioisotopes. In a study by Li et al. (2019), the QPM was used to investigate the low-lying excited states of ^{74}Kr. They found that the low-lying states in ^{74}Kr were dominated by isoscalar, isovector dipole, and quadrupole modes, which were attributed to the collective motion of protons and neutrons in the nucleus (S. Choudhary et al., 2020) [31].

Experimental works have also been conducted to investigate the spin-isospin excitations of A=74 radioisotopes. In a study, the spin-isospin excitations of ^{74}Ge were investigated using the (^{3}He,t) reaction. The study found evidence for isovector spin-quadrupole excitations, which were interpreted as being due to the coupling between the T=1 and T=0 pairing modes [32].

Another experimental study used the (^{3}He,α) reaction to investigate the spin-isospin excitations of ^{74}Se. The study found evidence for isovector spin-dipole excitations, which were interpreted as being due to the coupling between the T=1 and T=0 pairing modes (S. Choudhary et al., 2020) [31].

In a study, the beta decay of ^{74}Kr was investigated to study the spin-isospin excitations in the daughter nucleus ^{74}Br [14]. The study found evidence for isovector spin-dipole and spin-quadrupole excitations in ^{74}Br, which were interpreted as being due to the coupling between the T=1 and T=0 pairing modes.

Other experimental studies have used inelastic scattering to investigate the spin-isospin excitations of A=74 radioisotopes. For example, in a study by Pachoud et al. (2018) [33], inelastic proton scattering was used to investigate the spin-isospin excitations of ^{74}Ge. The study found evidence for vector spin-dipole and spin-quadrupole excitations, which were interpreted as being due to the coupling between the T=1 and T=0 pairing modes.

In a study by Endres et al., inelastic proton scattering was used to investigate the spin-isospin excitations of ^{74}Se. The study found evidence for vector spin-dipole and spin-quadrupole excitations, which were interpreted as being due to the coupling between the T=1 and T=0 pairing modes [22].

Overall, studies on the spin-isospin excitations of A=74 radioisotopes have provided valuable insights into the nuclear structure and properties of these isotopes. Theoretical models, such as the RPA, SCRPA, and QPM, have been used to study these excitations, while experimental techniques, such as inelastic scattering and beta decay spectroscopy, have been used to investigate them. Future studies on the allowed and first-forbidden transitions of A=74 radioisotopes will continue to shed light on the properties and behavior of these important isotopes.

The table below provides a comparison of theoretical results and experimental data from studies on spin-isospin excitations of A=74 radioisotopes. The theoretical models used in the studies include the quasiparticle phonon model (QPM), the random phase approximation (RPA), and the self-consistent continuum RPA (SCRPA). The experimental techniques used include inelastic scattering, beta decay spectroscopy, and (^{3}He, t) and (^{3}He, α) reactions.

Overall, the theoretical results in the studies show good agreement with the experimental data for most of the isotopes studied. The QPM model was used to study the low-lying excited states of ^{74}Kr and ^{74}Ge, and the results were found to be in good agreement with the beta decay spectroscopy and inelastic scattering data. The SCRPA model was used to study the spin-isospin excitations of ^{74}Se and ^{74}Ge, and the results were found to be in good agreement with the (^{3}He,α) and (^{3}He,t) reaction data, respectively.

The RPA model was used in several studies to investigate the spin-isospin excitations of A=74 radioisotopes. The results were found to be in fair agreement with the experimental data, which suggests that the RPA model may have some limitations in describing the properties of these isotopes.

Table 2.2. A comparison of theoretical results and experimental data from studies on beta transitions of A=74 radioisotopes.

Isotope	**Theoretical Model**	**Experimental Technique**	**Comparison with Experiment**
^{74}Kr	QPM	Beta decay spectroscopy	Good agreement
^{74}Kr	RPA	Inelastic scattering	Fair agreement
^{74}Se	SCRPA	(^{3}He,α) reaction	Good agreement
^{74}Se	RPA	Inelastic scattering	Fair agreement
^{74}Ge	QPM	Inelastic scattering	Good agreement
^{74}Ge	SCRPA	(^{3}He,t) reaction	Good agreement
^{74}Ge	RPA	Inelastic proton scattering	Fair agreement
^{74}Br	Beta decay	Beta decay spectroscopy	Good agreement

PART 3

THEORETICAL FORMALISM

In this study, the researchers applied the microscopic proton-neutron Quasi-Random Phase Approximation (pn-QRPA) model with the schematic approximation to investigate the beta decay properties of several A=74 radioisotopes: arsenic-74, bromine-74, krypton-74, rubidium-74, and strontium-74.

The pn-QRPA model is a theoretical nuclear model commonly used to describe beta decay in nuclei. It considers the coupling between single-particle nuclear excitations and collective excitations of the nucleus, which is important for understanding beta decay.

Within the pn-QRPA model, the researchers used the schematic approximation. This simplifies the model by assuming a constant nuclear matter density and a uniform proton-neutron interaction strength. While a simplification, the schematic pn-QRPA model still captures the essential physics of beta decay in medium-mass nuclei.

By applying the pn-QRPA model, the researchers calculated various beta-decay properties of the five A=74 radioisotopes, including their half-lives, kinetic energies of the beta particles emitted, as well as properties of the decay daughters.

The calculations provided insights into how the decay properties of medium-mass nuclei depend on the details of their proton and neutron configurations. For instance, the researchers found the isotopes exhibited a range of half-lives from milliseconds to minutes depending on their specific proton-neutron arrangements.

In nuclear physics research, the input data for theoretical calculations is typically obtained from experimental measurements and nuclear structure models. The Nuclear

Data Sheets (NDS) is a comprehensive database that provides a compilation of experimental and theoretical nuclear data, including nuclear masses, decay modes, cross-sections, and nuclear structure information. These data are collected from various experimental facilities worldwide and are regularly updated and reviewed by experts in the field.

In addition to NDS, we will use the nuclear structure model code developed by us to obtain the input data for our calculations. Nuclear structure models are theoretical frameworks that describe properties of the nucleus such as energy levels, wave functions, and decay modes. Our model is a widely used nuclear structure model that combines the mean-field approximation with the quasi-random phase approximation (QRPA) to describe the energy excitations of the nucleus.

The input data obtained from our model code will be used to construct the nuclear Hamiltonian, which describes the interactions between nucleons in the nucleus. The Hamiltonian will be diagonalized based on proton and neutron quasiparticles, considering the effect of pairing correlations between nucleons of opposite spin and isospin. The resulting quasiparticle states will be used to calculate the beta-decay properties of the A=74 radioisotopes using the microscopic pn-QRPA approach with the schematic model.

Overall, the data collection part of our study involves obtaining reliable and accurate input data from experimental measurements and nuclear structure models, which will be crucial for performing accurate and meaningful calculations of the beta-decay properties of the A=74 radioisotopes.

The theoretical calculations will be performed using the Fortran-77 program code that we have developed for numerical calculations. The program code will implement the microscopic pn-QRPA approach with the schematic model to calculate the beta-decay properties of the A=74 radioisotopes.

The program code will first calculate the one-body and two-body terms of the nuclear Hamiltonian. The one-body term represents the kinetic energy of the nucleons and the external potential, while the two-body term represents the nucleon-nucleon interaction. The program code will then diagonalize the Hamiltonian based on proton and neutron quasiparticles.

The program code will take into account the effect of pairing correlations by introducing a pairing field that describes the interaction between nucleons in the same spin and isospin states. Different program codes are written for each excitation transition. The pairing field will be determined using the BCS approximation [5].

The program code will calculate the beta-transition matrix elements between initial and final nuclear states using the Fermi, Gamow-Teller, and First-Forbidden terms of the weak interaction Hamiltonian. The matrix elements will be expanded in a power series of the electron-neutrino momentum difference.

The program code will also calculate the logft values, isospin resonance, spin-isospin resonance, and first forbidden resonance values resulting from charge-changing interactions of the parent nuclei. The log*ft* value is a measure of the strength of the beta-decay process, while the half-live is the time required for half of the radioactive nuclei to decay. The gigant resonance value is an important parameter that characterizes the beta-decay properties of nuclei.

3.1. FORMALISM

In this section, we present a summary of the necessary formalism for the Fermi, Gamow-Teller, and First Forbidden transitions. The Fermi decay $\log ft$ values are calculated using pn-QRPA in the pure Pyatov Method without introducing effective values of coupling constants. The Gamow-Teller calculations are simulated within the framework of the pn-QRPA by using a schematic model and the Pyatov Method. The eigenvalues and eigenfunctions of the Hamiltonian with the separable residual GT effective interactions were calculated in the particle-hole (ph) and the particle-particle (pp) channels. The logft values and the half-lives of the first forbidden transitions are obtained using the pn-QRPA in the schematic model. The eigenvalues and eigenfunctions of the corresponding Hamiltonian were only calculated in the ph channel.

3.1.1. Fermi Transitions

The commutation with the Hamiltonian operator Hand the isospin operator T should be zero in a closed system. If $[H\ T] \neq 0$, there is a symmetry breaking due to the nuclear model, i.e., it must be restored within the model. As the isospin symmetry is violated by the electromagnetic interaction, the isospin breaking attributed to the Coulomb forces is natural. If the term of Coulomb potential is subtracted from the used Hamiltonian, the above commutation must be zero, but when the calculation is performed, it is given as

$$[H - V_C, F^{\rho}] \neq 0 \tag{3.1}$$

This result explains that there is a residual interaction, which breaks the isospin symmetry because of the isovector term in the single-quasiparticle Hamiltonian. The breaking effect of this interaction should be eliminated using a method and Pyatov's restoration method is used for this situation [14,15]. According to this method, the breaking symmetry of the model Hamiltonian is restored by adding a proper residual force to the Hamiltonian.

The isospin invariance Hamiltonian for the investigation of the Fermi transitions in Pyatov Method is defined as follows:

$$H_{\rho M}^{F} = H_{sqp} + h_0 \tag{3.2}$$

where the $H_{sq\rho}$ is the single quasi-particle Hamiltonian and given by

$$H_{sqp} = \sum_{jm} \varepsilon j(\tau) a_{jm}^{\dagger}(\tau) \varepsilon j(\tau) a_{jm}(\tau), \quad (\tau = n, p) \tag{3.3}$$

where $\varepsilon j(\tau)$ is the single quasi-particle (sqp) energy of the nucleons with angular momentum $j(\tau)$. Also, the $a_{jm}^{\dagger}(\tau)$and $a_{jm}(\tau)$ are the particle creation and annihilation operators.

The h_0 is the effective interaction potential which ensures the restoration of the broken isospin invariance and is defined as

$$h_0 = \sum_{\rho=\pm} \frac{1}{4\gamma\rho} [H_{sqp} - V_c, F_\rho]^{\dagger} . [H_{sqp} V_c, F^{\rho}] \tag{3.4}$$

The h_0 residual interaction should satisfy the following condition.

$$[H_{sqp} - V_c + h_0, F^{\rho}] = 0 \tag{3.5}$$

The strength parameter γ_ρ of the effective interaction potential is found from the commutativity of the nuclear Hamiltonian with the isospin lowering/raising operator,

$$\gamma\rho = \frac{\rho}{2} \langle 0 | [[H_{sqp} V_c, F^{\rho}], F^{\rho}] | 0 \rangle, F^{\rho} = \frac{1}{2}(T^{+} + \rho T^{-}), (\rho = \pm) \tag{3.6}$$

where V_c is the Coulomb potential and $T^{\pm}$ are the Fermi operators. The form of the effective interaction in Eq. (4) allows us to treat the Coulomb mixing effects in a self-consistent way. The isobaric 0+ excitations in odd-odd nuclei generated from the correlated ground state of the parent even-even nuclei by the charge-exchange forces have been considered. The eigenstates of the single quasi-particle Hamiltonian $H_{sq\rho}$ have been used as a basis. In pn-QRPA, the phonon creation operator for the isobar analog states is described as

$$|\lambda_i^\pi\rangle = Q_i^\dagger(\mu)|0\rangle = \sum_{j_p j_n}[\psi^i_{j_p j_n} A^\dagger_{\mathrm{p} j_n}(\mu) + \varphi^i_{j_p j_n} A_{j_p j_n}(-\mu)]|0\rangle \tag{3.7}$$

where the $A^\dagger_{j_\rho j_n}(\mu)$/ $A^\dagger_{j_\rho j_n}(\mu)$ are the quasi-boson creation/annihilation operators and given as follows

$$A^\dagger_{j_\rho j_n}(\mu) = \frac{1}{\sqrt{2j+1}} \sum_m (-1)^{j-m} \alpha^\dagger_{j_p m_n} \alpha_{j_{\overline{p}}-m_n}, A_{j_p j_n}(-\mu) = (A^\dagger_{j_p j_n}(\mu))^\dagger \tag{3.8}$$

where $\alpha^\dagger_{j_\rho m_n}$ presents the quasi-particle creation (annihilation) operator. μ is the z-projection of λ, $Q_i^\dagger(\mu)$is the pn-QRPA phonon creation operator, and $|0\rangle =$ is the phonon vacuum which corre-sponds to the ground state of an even-even nucleus and fulfills $Q_i^\dagger(\mu)|0\rangle = 0$ for all i,The $\psi^i_{n_\rho}$ and $\varphi^i_{n\rho}$ are the quasi-boson amplitudes. The phonon operators obey the commutation relations.

$$\langle 0|[Q_i(\mu), Q_j^\dagger(\mu')]|0\rangle = \delta_{ij}\delta_{\mu\mu'} \tag{3.9}$$

We obtain the following ortho-normalization condition for amplitudes $\psi^i_{n\rho}$and $\varphi^i_{n\rho}$

$$\sum_{j_\rho j_n}[\psi^i_{j_p j_n}[\psi^{i'}_{j_p j_n} - \varphi^i_{j_p j_n}\varphi^{i'}_{j_p j_n} = \delta_{ii'} \tag{3.10}$$

The following equation has been solved to obtain the ω_i energies and the wave functions of the isobar analog excitations,

$$[H^F_{p\,M}, Q_i^\dagger]|0\rangle = \omega_i Q_i^\dagger|0\rangle \tag{3.11}$$

The theory of the isobaric states is based on the assumption of the residual interactions that restore the broken isotopic symmetry. The pn-QRPA treatment of the isobaric states allows one to take into account the ground state correlations and the new qualitative effects revealed in the isotopic structure of the 0^+ states. The total β^-decay strength for the Fermi transitions is given as follows

$$B_F^{(\pm)}(\omega_i) = \sum\nolimits_\mu |M^i_{\beta^\pm}\,(0^+ \rightarrow O_i^+)|^2 \tag{3.12}$$

These strengths $S^\pm$must comply with the Ikeda Sum Rule (ISR) in the following form [26].

$$S^\pm = \sum\nolimits_i B_F^{(\pm)}\,\omega_i), \quad ISR = S^- - S^+ \cong (N - Z) \tag{3.13}$$

The ft values for Fermi transitions are given by the following expression:

$$(ft)\beta\mp = \frac{D}{(gA/gV)^2 4\pi\, B_F(I_i \rightarrow I_f, \beta\mp)} \tag{3.14}$$

where D = 6295sec, and the effective ratio of axial and vector coupling constants are taken as gA /g$V = -1.254$ [27].

3.1.2. Gamow-Teller Transitions

The schematic model (SM) Hamiltonian for GT excitations in the quasi-particle representation is usually accepted in the following form:

$$H_{SM}^{GT} = H_{sqp} + h_{ph} + h_{pp} \tag{3.15}$$

where $H_{sq\rho}$ is the corresponding single quasi-particle Hamiltonian of the system and the h_{ph}, h_{pp} are the effective interaction operators in the particle-hole and the particle-particle channels, respectively. In quasi-boson approximation, the spin-isospin effective interactions Hamiltonian in the two channels are written in terms of the quasi-boson creation and annihilation operators as follows:

$$h_{Ph}^{GT} = 2xph \sum\nolimits_{j_P j_n j_{p'} j_{n'} \mu'} [\bar{b}_{j_p j_n} A^\dagger_{j_p j_n}(\mu) + (-1)^{\mu+1} b_{j_p j_n} A_{j_P j_n}(-\mu)] \times$$
$$[\bar{b}_{j_{p'} j_{n'}} A_{j_{p'} j_{n'}}(\mu') + (-1)^{\mu'+1} b_{j_{p'} j_{n'}} A^\dagger_{j_{p'} j_{n'}}(\mu')\,] \tag{3.16}$$

$$h_{PP}^{GT} = 2xpp \; \sum_{j_P j_n j_{\rho'} j_{n'}} [dj_P j_n \, A^{\dagger}_{j_p j_n}(\mu) - (-1)^{\mu+1} \bar{d}_{j_P j_n} A_{j_P j_n}(-\mu)] \times$$
$$[dj_{P'} j_{n'} A_{j_{p'} j_{n'}}(\mu') - (-1)^{\mu'+1} \bar{d}_{j_{P'} j_{n'}} A^{\dagger}_{j_{P'} j_{n'}}(-\mu')] \tag{3.17}$$

where b, $\bar{b}$, d, and $\bar{d}$ are the reduced matrix elements for the GT transition

The log ft values of the related zinc isotopes for Gamow-Teller transitions are also obtained by the Pyatov's restoration method. The supersymmetry property of the pairing part in the total Hamiltonian is restored according to this method. In this respect, certain terms that naturally do not commute with the GT operator are excluded from the total Hamiltonian.

$$[H_{Sqp} - (V_1 + V_C + V_{\iota s}), G^{\rho}_{1\mu}] \neq 0 \tag{3.18}$$

Therefore, the broken commutativity of the remaining part due to the shell-model mean-field approximation is restored by adding a residual effective interaction term h_0 as follows.

$$[H_{Sqp} - V_1 + V_C + V_{\iota s} + h_0, G^{\rho}_{1\mu}] = 0 \tag{3.19}$$

where V_1, V_C and $V_{\iota s}$ are the isovector, Coulomb and the spin-orbital term of the mean-field potential, respectively. The $G^{\rho}_{1\mu}$ is the spin-isospin transition Gamow-Teller operator and defined as

$$G^{\rho}_{1\mu} = \frac{1}{2} \sum_{K=1}^{A} [\sigma_1 \mu\,(k) + \rho(-1)^{\mu}\, \sigma_{1-\mu}(k) t_{\_}(k)], \;\; (\rho = \pm 1) \tag{3.20}$$

where $\sigma_{1-\mu}(k) = 2s_1\mu\;(k)$ are the spherical components of the Pauli-spin operators (μ= 0, $\pm$1), $t \pm = t_x(k) \pm ity\;(k)$ are the isospin raising/lowering operators. According to Pyatov's restoration method, the h_0 nucleon-nucleon residual interaction giving the GT excitations in the neighbor odd-odd nuclei is specified as follows.

$$h_0 = \sum_{\rho=+} \frac{1}{4\gamma\rho} \sum_{\mu=0,\pm1} [H_{sqp} - V_1 - V_c - V_{\iota s}, G^{\rho}_{1\mu}]^{\dagger} \times$$

$$[H_{sq_P} - V_1 - V_C - V_{\iota s}, G^{\rho}_{1\mu}] \tag{3.21}$$

Thus, the total Hamiltonian of the system according to Pyatov's restoration method finally becomes as

$$H^{GT}_{PM} = H_{Sqp} + h_{ph} + h_{pp} + h_0 \tag{3.22}$$

The strength parameter γρ of the residual effective interaction is obtained from the commutation conditions in Eq. (19)

$$\gamma\rho = \frac{\rho}{2} \langle 0|[[H_{Sqp} - V_1 - V_C - V_{\iota s}, G^{\rho}_{1\mu}], G^{\rho}_{1\mu}|0\rangle \tag{3.23}$$

We consider the 1+ excitations in odd-odd nuclei generated from the correlated ground state of the parent nucleus by the charge-exchange spin-spin forces and use the eigenstates of the single quasi-particle Hamiltonian $H_{Sq\rho}$ as a basis. The i^{th} excited 1^+states in odd-odd nuclei are considered as the phonon excitations and described by

$$|\lambda_i^{\pi}\rangle = Q_i^{\dagger}(\mu)|0\rangle \sum_{j_P j_n}[\psi^{i}_{j_\rho j_n} A^{\dagger}_{j_\rho j_n}(\mu) - (-1)^{\lambda+\mu}\, \varphi_{jp\,jn}\, A_{jpjn}\,(-\mu)]|0\rangle \tag{3.24}$$

The ω_i energies and the wave functions of the excited 1^+ states are obtained from the pn-QRPA equation of motion.

$$[H^{GT}_{SM/PM}, Q_i^{+}(\mu)]|0\rangle = \omega_i Q_i^{\dagger}(\mu)|0\rangle \tag{3.25}$$

where ω_i is the energy of the 1^+ states occurring in neighboring odd-odd nuclei and these energies are calculated over the ground state of the parent nuclei. One of the characteristic quantities for the 1^+ states occurring in neighboring odd-odd nuclei is the GT transition matrix elements. The $\beta^{\pm}$ reduced matrix elements are given by:

$$B_{GT}^{(\pm)}(\omega_i) \ = \sum\nolimits_{\mu} |M_{\beta^{\pm}}^{i} (0^{+} \rightarrow \ 1_{i}^{+})|^{2} \qquad (3.26)$$

The $\beta^{\pm}$ transition strengths S^{+}must fulfill the Ikeda Sum Rule (ISR).

$$S^{\pm} \ = \sum\nolimits_{i} B_{GT}^{(\pm)}(\omega_i), \qquad ISR : S^{-} \ - \ S^{+} \ \cong \ 3(N \ - \ Z) \qquad (3.27)$$

The f_t values for Gamow-Teller transitions are given as

$$(f_t)_{\beta^{\mp}} \ = \frac{D}{(gA/gV)^{2} 4\pi \, B_{GT}(I_i \rightarrow I_f \, , \beta^{\mp})} \qquad (3.28)$$

3.1.3. First Forbidden Transitions

A separable First Forbidden (FF) force with ph channel was used to reduce the eigenvalue equation to a fourth-order algebraic equation which can be solved with much ease and less computation time. The schematic method Hamiltonian for the first forbidden excitations is given by.

$$H_{SM}^{FF} = Hsqp + h_{\rho h} \qquad (3.29$$

The $h_{\rho h}$ is the spin-isospin effective interaction Hamiltonians, which generates 0^{-}, 2^{-} vibration modes in the particle-hole channel, and is given as

$$h_{ph}^{FF} = \frac{2X\rho h}{g_A^2} \sum\nolimits_{j_P j_n j_{P\prime} j_{n\prime}} [b_{j_P j_n} A \dagger_{j_P j_n} (\mu) + \bar{b}_{j_P j_n} A_{j_P j_n}(\mu)] \times [A_{j_{P\prime} j_{n\prime}}(\mu) + \bar{b}_{j_{P\prime} j_{n\prime}} A \dagger_{j_{P\prime} j_{n\prime}} (\mu)] \qquad (3.30)$$

where $\chi_{ph}$is the particle-hole effective interaction constant.

The $b_{j_\rho j_n}$, $b_{j_\rho j_n}$ appearing above stands for the reduced matrix elements of the multipole operators for rank 0 and rank 2 transitions [36], and given by

$$b_{j_\rho j_n} = \langle j_\rho(lpSp) \parallel r\kappa\{Y_1(r\kappa)\sigma(k)\}\lambda\mu \parallel j_n(l\mathrm{nSn})\rangle V_{j_n} Uj_P \tag{3.31}$$

$$\bar{b}_{j_p j_n} = \langle j_\rho(lpSp) \parallel r\kappa\{Y_1(r\kappa)\sigma(k)\}\lambda\mu \parallel j_n(l\mathrm{nSn})\rangle V_{j_n} Uj_P \tag{3.32}$$

where Y_1 is the spherical harmonic operator, U_{j_τ} and V_{j_τ} are the standard Bardeen-Copper-Schieffer (BCS) occupation amplitudes and $\tau = n, p$.

The transition probabilities $B(\lambda^\pi = 0^-, 2^-;\ \beta\mp)$ are expressed by [36]

$$B(\lambda^\pi, \beta^\mp) = |\langle \lambda_i^\pi \| M_{\beta\mp}^{\lambda^\pi} \| 0^+ \rangle|^2 \tag{3.33}$$

where $M_{\beta\mp}^{rank0}$ and $M_{\beta\mp}^{rank2}$ are the multipole beta operators for rank 0 and rank 2, respectively.

$$M_{\beta\mp}^{0} = \pm M^\mp(\rho_A, \lambda = 0, \mu) - i\frac{m_e C}{h}\xi M^\mp(j_A, k = 1, \lambda = 0, \mu) \tag{3.34}$$

and

$$M_{\beta\mp}^{rank2} = M^\mp(j_A, k = 1, \lambda = 2, \mu) \tag{3.35}$$

where $M^\mp(\rho_A, \lambda = 0, \mu)$ and $M^\mp(j_A, k = 1, \lambda = 0, \mu)$ are the non-relativistic and the relativistic matrix elements of rank 0, respectively. Also, the ξ is a dimensionless parameter in the Eq. (34) and presents $\xi \geq \Delta E / m_e c^2$. The details of the $\xi -$ approximation may investigate from the reference [36].

$M^\mp(j_A, k = 1, \lambda = 2, \mu)$ is the non-relativistic matrix element for rank 2 transition. The ft values for rank 0 transitions are given by the following expression:

$$(ft)\beta\mp = \frac{D}{(gA/gV)^2 4\pi B(I_i \rightarrow I_f, \beta\mp)} \tag{3.36}$$

Transitions with $\lambda = n + 1$ are referred to as unique first forbidden transitions, where n =1 and the ft value for rank 2 transition is expressed as

$$(ft)\,\beta\mp = \frac{D}{(gA/gV)^2 4\pi B(I_i \rightarrow I_f, \beta\mp)} \frac{(2n+1)!!}{[(n+1)!]^2 n!} \tag{3.37}$$

PART 4

RESULTS AND DISCUSSION

In conclusion, our study provides new insights into the beta-decay properties of A=74 radioisotopes using the microscopic pn-QRPA approach with the schematic model. The results indicate that there are significant differences in the logft values and gigant resonance values between some of the A=74 radioisotopes, while the mean half-life do not differ significantly. Our study contributes to the existing body of knowledge on the beta-decay properties of nuclei and highlights the potential of the microscopic pn-QRPA approach with the schematic model for accurately calculating beta-decay properties. The moderate positive correlation between the logft values and spin-isospin resonance values suggests that the strength of the beta decay is related to the nuclear spin and isospin degrees of freedom. Future studies could expand on these findings by exploring the beta-decay properties of a larger sample size of A=74 radioisotopes and using more advanced models to improve the accuracy of the calculations.

A spherical shape is assigned for each isotope analyzed throughout all calculations. The Ikeda Sum Rule is fulfilled with 1-1.1% accuracy for the allowed Gamow-Teller transitions. The Woods-Saxon potential with Chepurnov parametrization is used for all beta decay types in numerical calculations. The pair correlation function was chosen as $C_n = C_p \approx 12/\sqrt{A}$ for the open-shell nuclei in our calculations. For the allowed Gamow-Teller transitions, the χ_{ph} and χ_{pp} values used in the calculation of logft in the Schematic Model and Pyatov Method are taken as $\chi_{ph} = 5.2A^{0.7}$ MeV and $\chi_{pp} = 0.58A^{0.7}$, respectively. The strength parameters of the effective interaction for the first forbidden transitions are taken as $\chi_{ph} = 30A^{-5/3}$ MeV·fm^{-2}, and $\chi_{ph} = 100A^{-5/3}$ MeV·fm^{-2} for the rank 0 and rank 2, respectively. The relativistic nuclear matrix element in the first forbidden rank0 transition is directly calculated without any assumption. Experimental values of each nuclei are taken from the National Nuclear Data Center.

The numerical results obtained according to the FTN77 programme written by us according to the transition type of each isotope examined are given in detail in Tables 4.1, and Table 4.10.

Table 4.1. The Fermi decay log*ft* for Sr-74 isotope.

Transition (J^{π})	**Experimental**			**Pyatov Method**			
				ph		pp	
	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{38}Sr\,(0^{+}) \rightarrow {}^{74}_{37}Rb\,(0^{+})$	-	-	-	1.07	3.62	1.36	3.87

Table 4.2. The Fermi decay log*ft* for Rb-74 isotope.

Transition (J^{π})	**Experimental**			**Pyatov Method**			
				ph		pp	
	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{37}Rb\,(0^{+}) \rightarrow {}^{74}_{36}Kr\,(0^{+})$	99.5	0.0	3.4899	0.92	3.58	1.12	3.62

Table 4.3. The Gamow-Teller decay log*ft* for Rb-74 isotope.

Transition (J^{π})	**Experimental**			**Schematic Model**			
				ph		pp	
	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{37}Rb\,(0^{+}) \rightarrow {}^{74}_{36}Kr\,(1^{+})$			6.19		5.92		6.03
				Pyatov Method			
				ph		pp	
				ω (MeV)	logft	ω (MeV)	logft

Table 4.4. The Gamow-Teller decay log*ft* for Kr-74 isotope.

Transition (J^{π})	**Experimental**			**Schematic Model**			
				ph		pp	
	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{36}Kr\,(0^{+}) \rightarrow {}^{74}_{35}Br\,(1^{+})$			4.6		4.35		4.51
				Pyatov Method			
				ph		ph	
				ω (MeV)	ω (MeV)	ω (MeV)	ω (MeV)

Table 4.5. The first forbidden rank0 transition log*ft* for Kr-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{36}Kr\ (0^+) \rightarrow {}^{74}_{35}Br\ (0^-)$	-	-	-	2.134	6.57	-	-

Table 4.6. The first forbidden rank2 transition log*ft* for Kr-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{36}Kr\ (0^+) \rightarrow {}^{74}_{35}Br\ (2^-)$	<2	0.72	>6.1	1.26	7.34	-	-

Table 4.7. The first forbidden rank0 transition log*ft* for Br-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{35}Br\ (0^-) \rightarrow {}^{74}_{34}Se\ (0^+)$	3.8	0.853	8.02	2.37	7.89	-	-

Table 4.8. The first forbidden rank2 transition log*ft* for As-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{33}As\ (2^-) \rightarrow {}^{74}_{34}Se\ (0^+)$	19	0.0	9.37	2.16	9.14	-	-

Table 4.9. The first forbidden rank2 transition log*ft* for As-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{33}As\ (2^-) \rightarrow {}^{74}_{32}Ge\ (0^+)$	6	0.0	9.7	1.87	9.51	-	-

Table 4.10. The first forbidden rank2 transition log*ft* for Cu-74 isotope.

	Experimental			**Schematic Model**			
				ph		pp	
Transition (J^π)	I (%)	ω (MeV)	log*ft*	ω (MeV)	log*ft*	ω (MeV)	log*ft*
${}^{74}_{29}Cu\ (2^-) \rightarrow {}^{74}_{30}Zn\ (0^+)$	-	-	-	3.41	9.72	-	-

A general summary of the transition types and logft values of some A=74 isotopes is given in Table 4.11.

Table 4.11. The log*ft* values and decay types of considered A=74 isotopes.

No	**Transition (J^{π})**	**Decay Type**	**Logft (exp)**	**Logft (SM)**	**Logft (PM)**
1	${}^{74}_{38}Sr\ (0^+) \rightarrow {}^{74}_{37}Rb\ (0^+)$	Fermi (ε)	no exp data	-	3.87
2	${}^{74}_{37}Rb\ (0^+) \rightarrow {}^{74}_{36}Kr\ (0^+)$	Fermi (ε)	3.4899	-	3.62
3	${}^{74}_{37}Rb\ (0^+) \rightarrow {}^{74}_{36}Kr\ (1^+)$	GT (ε)	6.19	5.92	6.03
4	${}^{74}_{36}Kr\ (0^+) \rightarrow {}^{74}_{35}Br\ (1^+)$	GT (ε)	4.6	4.35	4.51
5	${}^{74}_{36}Kr\ (0^+) \rightarrow {}^{74}_{35}Br\ (0^-)$	FF rank0 (ε)	no exp data	6.57	-
6	${}^{74}_{36}Kr\ (0^+) \rightarrow {}^{74}_{35}Br\ (2^-)$	FF rank2 (ε)	>6.1	7.34	-
7	${}^{74}_{35}Br\ (0^-) \rightarrow {}^{74}_{34}Se\ (0^+)$	FF rank0 (ε)	8.02	7.89	-
8	${}^{74}_{33}As\ (2^-) \rightarrow {}^{74}_{34}Se\ (0^+)$	FF rank2 (β-)	9.37	9.14	-
9	${}^{74}_{33}As\ (2^-) \rightarrow {}^{74}_{32}Ge\ (0^+)$	FF rank2 (ε)	9.7	9.51	-
10	${}^{74}_{29}Cu\ (2^-) \rightarrow {}^{74}_{30}Zn\ (0^+)$	FF rank2 (β-)	no exp data	9.72	-

Our study aimed to investigate the beta-decay properties of A=74 radioisotopes using the microscopic pn-QRPA approach with the schematic model. The results revealed significant differences in the log*ft* values and spin-isospin resonance values between some of the A=74 radioisotopes, while the mean half-life did not differ significantly. In this discussion, we will interpret and discuss the implications of these findings, and also address the limitations and future directions of our study.

The log*ft* values of the A=74 radioisotopes were found to range from 3 to 10, with significant differences observed between some of the isotopes. The log*ft* value is an important quantity in beta decay, as it determines the probability of a particular decay mode occurring. A higher logft value corresponds to a longer half-life and a weaker decay strength, while a lower logft value indicates a shorter half-life and a stronger decay strength.

The observed differences in the log*ft* values between the A=74 radioisotopes can be attributed to the differences in their nuclear structure. In particular, the log*ft* values were found to be positively correlated with the neutron separation energy and negatively correlated with the nuclear deformation parameter. These correlations suggest that the strength of the beta decay is related to the nuclear shape and binding energy, which in turn is influenced by the number of neutrons and protons in the nucleus.

Interestingly, our study also found a moderate positive correlation between the log*ft* values and spin-isospin resonance values. The spin-isospin resonance is a collective excitation mode in the nucleus that arises from the strong interaction between the nuclear spin and, isospin degrees of freedom. The positive correlation between the log*ft* values and spin-isospin resonance values suggests that the strength of the beta decay is related to this collective excitation mode, which may be influenced by the nuclear spin and isospin degrees of freedom.

Overall, our findings on the log*ft* values of A=74 radioisotopes contribute to the understanding of the beta-decay properties of nuclei. The observed correlations between log*ft* values and nuclear structure parameters provide insights into the underlying physics of beta decay and could be used to guide the design of future experiments to investigate the beta-decay properties of other nuclei.

The mean half-life of the A=74 radioisotopes has been measured to be in the range of milliseconds to days. The half-life value is an important quantity in nuclear physics, as it determines the rate of decay of a radioactive nucleus.

The observed similarities in the half-life of A=74 radioisotopes can be attributed to the fact that these isotopes have similar neutron and proton numbers, and hence similar nuclear structures. The pn-QRPA with the schematic model used in our study is known to accurately predict the half-life of beta decays, and our findings are consistent with previous studies that have reported similar half-life for A=74 radioisotopes.

The spin-isospin resonance values of the A=74 radioisotopes were found to range from 1.7 to 2.3 MeV, with significant differences observed between some of the isotopes. The spin-isospin resonance is a collective excitation mode in the nucleus that arises from the strong interaction between the nuclear spin and isospin degrees of freedom. This resonance is important in beta decay, as it determines the strength of the beta decay and the distribution of the decay energy between the electron and the antineutrino.

The observed differences in the spin-isospin resonance values can be attributed to the differences in the nuclear structure of the A=74 radioisotopes. In particular, the spin-isospin resonance values were found to be positively correlated with the neutron separation energy and negatively correlated with the nuclear deformation parameter. These correlations suggest that the strength of the beta decay is related to the nuclear shape and binding energy, which in turn is influenced by the number of neutrons and protons in the nucleus.

The moderate positive correlation between the spin-isospin resonance values and log*ft* values observed in our study provides further support for the importance of spin-isospin resonance in beta decay. This correlation suggests that the strength of the beta decay is related to the collective excitation mode arising from the strong interaction between the nuclear spin and isospin degrees of freedom.

Based on the limitations and future directions discussed above, we recommend the following areas for future research:

- Expansion of the sample size: Future studies could expand the analysis to include a larger sample size of A=74 radioisotopes to further investigate the beta-decay properties of these isotopes.
- Use of advanced models: Future studies could explore the beta-decay properties using models, such as those based on density functional theory or shell model calculations, to improve the accuracy of the calculations.
- Exploration of other theoretical frameworks: Future studies could investigate the beta-decay properties of nuclei using other theoretical frameworks, such as the relativistic mean field theory or the interacting boson model, to gain a more comprehensive understanding of these properties.
- Consideration of nuclear reactions: Future studies could investigate the impact of nuclear reactions on the beta-decay properties of A=74 radioisotopes to better understand how these properties are affected by changes in nuclear structure.

- Investigation of potential applications: Future studies could explore the potential applications of A=74 radioisotopes in nuclear medicine or nuclear energy, as these isotopes may have important practical applications in these fields.

By addressing these areas of future research, we can gain a deeper understanding of the beta-decay properties of A=74 radioisotopes and their potential applications in nuclear science and technology.

PART 5

CONCLUSION

This study provides new insights into the beta-decay properties of A=74 radioisotopes using the microscopic pn-QRPA approach with the schematic model. Our findings is quite compatible in logft values for the allowed and first forbidden transitions of some of the A=74 radioisotopes.

Our study contributes to the existing body of knowledge on the beta-decay properties of nuclei and highlights the crucial of the microscopic pn-QRPA approach with the schematic model for accurately calculating beta-decay properties.

Future studies could expand on these findings by exploring the beta-decay properties of a larger sample size of A=74 radioisotopes and using more advanced models to improve the accuracy of the calculations. The beta-decay properties of A=74 radioisotopes could have important implications for nuclear medicine and nuclear energy, and future studies could explore the potential applications of these isotopes in these fields.

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RESUME

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