STUDY ON NUCLEAR ISOMERS IN ODD-EVEN $^{69-79}$As, $^{71-83}$Br, AND $^{83-89}$Rb ISOTOPES

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To my lovely parents,

Drs. Hj. Mohamed Abdul Ghani b. Haji Ibrahim and Hjh Che Siti Nor bt Che Sulaiman

To my brothers and sisters

N. Azleena

N.Muhammad Asyraaf

N. Muhammad Aslaam

N. Muhammad Asnawi

N. Afeefah

N. Muhammad Hazwan

To all my best friends, you know who you are

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ABSTRACT

Study on nuclear isomers is one of the way to understand the structure of certain nucleus. The odd-even $^{67-79}$As, $^{79-83}$Br and $^{83-89}$Rb isomers excited around ^{68}Ni had been confirmed as sub-shell closure based on the research conducted by Broda and his group in 1995. The odd-even $^{67-79}$As, $^{79-83}$Br and $^{83-89}$Rb were selected in this work to investigate the theoretical isomerism of nuclei. The odd-even populated nuclei of $^{67-79}$As, $^{79-83}$Br, and $^{83-89}$Rb were considered in this work by using Deep-Inelastic Collisions reaction of ^{76}Ge (635MeV) + ^{198}Pt. The theoretical calculations were carried out to investigate the characteristics of isomeric level, magnetic reduced transition probabilities B(M2), binding energy (B.E), mean-lifetime (τ), width of isomeric level (Γ_γ), hindrance factor (F_w), fragments energy (PLF) and Coulomb barrier for the isotopes. The Nuclear Reaction Video was used to determine the fragments energy of the isomers. Odd-even $^{67-79}$As, $^{79-83}$Br and $^{83-89}$Rb isomers were populated as a single particle excited states near to the shell closure Z=28 and N=40 of ^{68}Ni. The isomers were assigned to B(M2) transition and compared with the experimental data taken from Nuclear Data Sheets. The results were in good agreement with the experimental data within the experimental error. The calculated value of binding energy, width of isomeric level, hindrance factor and fragment energy were plotted as a function of mass number in order to observe the characteristic of the isomers.

ABSTRAK

Kajian tentang nuklear isomer adalah salah satu cara untuk memahami tentang struktur nukleus tertentu. Isomer ganjil-genap $^{67\text{-}79}$As, $^{79\text{-}83}$Br dan $^{83\text{-}89}$Rb teruja sekitar ^{68}Ni telah dipastikan sub-petala penutupannya berdasarkan kajian yang telah dijalankan oleh Broda dan kumpulannya pada tahun 1995. Isomer ganjil-genap $^{67\text{-}79}$As, $^{79\text{-}83}$Br dan $^{83\text{-}89}$Rb telah dipilih dalam kajian ini bagi menyiasat tentang teori isomer nukleus. Populasi nukleus ganjil-genap $^{67\text{-}79}$As, $^{79\text{-}83}$Br dan $^{83\text{-}89}$Rb telah diambilkira dengan menggunakan proses perlanggaran dalam tak kenyal iaitu ^{76}Ge (635MeV) + ^{198}Pt. Pengiraan secara teori telah dilakukan untuk mengkaji ciri aras isomer, kebarangkalian peralihan pengurangan magnetik B(M2), tenaga ikatan (BE), min-hayat (τ), lebar aras isomer (Γ_γ), faktor halangan (F_w), tenaga serpihan (PLF), dan Sawar Coulomb bagi suatu isotop. Video Tindak Balas Nuklear telah digunakan untuk menentukan tenaga serpihan isomer. Isomer ganjil-genap $^{67\text{-}79}$As, $^{79\text{-}83}$Br dan $^{83\text{-}89}$Rb telah teruja dalam bentuk zarah tunggal berdekatan dengan penutupan petala Z=28 dan N=40 dalam ^{68}Ni. Isomer tersebut telah ditentukan kepada peralihan B(M2) dan dibandingkan dengan data eksperimen yang diambil daripada *Nuclear Data Sheet*. Hasil yang diperoleh adalah sesuai dengan data eksperimen dalam julat ralat eksperimen. Nilai tenaga ikatan, lebar aras isomer, faktor halangan dan tenaga serpihan yang telah dihitung telah diplotkan terhadap nombor jisim untuk mencerap ciri isomer tersebut.

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LIST OF SYMBOLS

γ	-	Gamma
$T_{1/2}$	-	Half-life
τ	-	Meanlife
Γ	-	Width of isomeric level
F_w	-	Hindrance factor
B(M2)	-	Magnetic Reduced Transitiom Probability
B(E3)	-	Electric Reduced Transition Probability
π_g	-	Proton at g level
ν_p	-	Neutron at p level
φ	-	Wavefunction
n	-	Quantum number
ℓ	-	Orbital Quantum Number
V(r)	-	Potential
ω	-	Frequency of angular Oscillator
m	-	Mass of atom
N	-	Number of Quantum Harmonic Oscillator
S	-	Spin Angular Momentum
ℓ	-	Orbital Angular momentum
L	-	Total Orbital Angular Momentum
j	-	Spin
λ	-	Transition Gamma Decay
μ	-	Magnetic moment
e	-	Electron charge
P	-	Transition Probability

L	-	Multipolarity
σ	-	Electric/Magnetic Transition
M	-	Transition Operator
w.u	-	Weiskopf unit
Z	-	Proton Number
A	-	Mass number
m_p	-	Mass of Proton
m_e	-	Mass of electron
m_n	-	Mass of neutron
α	-	Internal conversion
E_γ	-	Gamma ray energy
h	-	Plank Constant
Q	-	Q-value
ns	-	Nanosecond
μs	-	Microsecond
ms	-	Millisecond

LIST OF ABREVIATIONS

DIC	-	Deep Inelastic Collision
JAERI	-	Japan Agency Energy Research Institute
Ge	-	Germanium
Si	-	Silicon
Ni	-	Nickel
As	-	Arsenic
Br	-	Bromine
Rb	-	Rubidium
Pt	-	Platinum
Zr	-	Zirconium
Pd	-	Polodium
PLF	-	Projectile Like Fragment
TLF	-	Target Like Fragment
DNS	-	Double Nuclear System
NRV	-	Nuclear Reaction Video
keV	-	KiloelectronVolt
ev	-	Electron Volt
BE	-	Binding Energy

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CHAPTER 1

INTRODUCTION

1.0 Introduction of Nuclear Isomer

Isomers are known as a long-lived excited state of nuclei where the nucleon is at higher energy state. It usually belongs to shell closure or magic number [1]. Studies of nuclear structure are important to understand the formation of nuclear isomers along with its application in nuclear physics. A study of excited states and their decay pattern for odd-even and even-odd nuclei gives the information of single particle state of nuclear structure. The transition of nuclear isomer is governed by single particle when the nuclear excitation is due to only one nucleon.

Isomers can be characterized through one of the nuclear model called Shell Model. Shell Model approach is one of the nuclear models. It is an ideal method to explore the nuclear structure in details. This Shell Model is able to describe magic number of nuclei as well as explaining about the nuclear spins of the odd-mass nuclei near to double-magic nuclei. It obeys the Pauli Exclusion Principle where the nucleons are restricted to only limited number of allowed orbits. Commonly, the isomer-related orbitals are coupled to produce higher-spin states than other couplings at similar energy. Concurrently, the isomer decay necessitates the emission of high-spin or low-energy radiation, resulting in their long half-lives. In odd-even nuclei there is only one unpaired nucleons so the tendency to lead to excited states is higher than paired nucleon. Stability of nucleus can be achieved when the nucleus reach closed shell of nucleons [2]. Odd-even nuclei stabilized by their even numbers of paired neutrons. For any atom with close shell, the electrons are paired off and so no valence electrons are existed.

1.1 Background of Study

Neutron rich nuclei are particularly interesting since they have the ability to reveal nuclear structure associated with excess of neutrons. Nuclear shell model has the explanation on the properties of nuclear isomers in the vicinity of the closed shells exited near to magic numbers. It is known that single particle nuclear transition is governed when the nuclear excitation is due to only one nucleon [3]. Sub-shell closure in ^{90}Zr for Z=40 already observed [4]. Therefore, finding the shell closure for N=40 would be an interesting task. Broda and his group has discovered sub-shell closure in ^{68}Ni which is N=40 experimentally [5]. Nuclei with magic numbers of proton or neutron have their first 2^+ excited states at higher energies than neighboring nuclei. In usual, 2^+ levels of all double magic nuclei have high energy.

Stability of an atomic nucleus comprises of nucleon that is bound together with a strong force interaction that governs the behavior of the nucleus. It is expected that there is a small energy difference and large angular momentum different between $\pi_g^{9/2}$ and $\pi_p^{1/2}$ which makes isomerism happened in the area of ^{68}Ni and ^{78}Ni. Proton-rich isomers with N≈50, 40 < Z < 50 have also been investigated by Broda et.al [6]. Usually large proton-proton repulsion tries to break the nuclei apart hence, more neutrons are added which is neutron-neutron attraction to the nuclei which becomes stable nuclei. The yrast states up to $I^\pi = 8^+$ in N=48 isotones were found two-hole states $\nu g_{9/2}^{-2}$ configurations for the N=50 closed shell. The appearance of nuclear structure of $\nu_{9/2}n$ configurations indicates to find structure of the valance mirror nuclei $\pi g_{9/2}n$ configurations [7-9]. Where n indicate number of particles outside the closed shell. A lot of experimental properties of isomers were studied around ^{68}Ni and ^{90}Zr [10-11].

A study of E2 transition in neutron-rich nuclei has been made by using shell model calculation. It shows that proton motion and neutron motion are collective for a quadrupole transition [12]. In this case, shell model is playing an important role to find the information about the characteristic of nuclei and isomer-spin base on selection rule. The nuclei with proton numbers Z=33, 35, 37 plus with even neutron number could give the single particle excited state and those nuclei are excited around ^{68}Ni. Therefore, the aims of this research are to find the theoretical information for the isomers around ^{68}Ni hence to compare with the previous work.

The nucleus ^{68}Ni lies far from the stability line on the neutron rich side. Productions of neutron-rich nuclei around ^{68}Ni are very difficult by standard nuclear reaction [13]. Thus it is difficult to determine the high-spin state in neutron-rich nuclei ^{68}Ni. In order to produce neutron-rich nuclei widely, Deep Inelastic Collision (DIC) is an efficient method to be adapted for use since the fusion reaction cannot be an efficient way to produce neutron-rich nuclei. Reaction of 635MeV ^{76}Ge projectile nuclei towards ^{198}Pt target is measured at Japan Atomic Energy Research Institute, Tokai Mura and Ibaraki [14-15]. This experiment utilized a new instrument called isomer-scope. An isomer-scope consists of Ge detector and Si detector which can identify the isomers which are near to closed shells. This instrument also gives the information about the single-particle of nuclear excitation [14-15].

1.2 Statement of Problem

The investigation of nuclear isomer through experimental studies has been viral, given that it can reveal the properties of nuclear structure of the nuclei. As there are a lot of experimental researches, the theoretical investigation should also be considered. The detailed studies of theoretical investigation of nuclear isomer especially for magic number of nuclei however, have not been studied yet. The odd-even As, Br, and Rb isotopes are the new nuclei which never been analyzed theoretically. The reduced transition probabilities, mean-life, width of energy level for the isomeric transition, hindrance factor, coulomb barrier, binding energy and fragment energy have been calculated for nuclei with Z=33,35,37 plus with even number of neutrons which are excited around ^{68}Ni. These properties have not been studied yet in odd-even As, Br, and Rb isotopes. Calculation of fragments energy and its comparison with previous experimental values in deep-inelastic collisions ^{76}Ge (635 MeV) + 198Pt would give the information about nuclear reaction that produces neutron rich nuclei.

1.3 Purpose of Research

This study is focusing on systematic reduced transition probabilities B(M2) of odd-even As, Br, and Rb isotopes. Those nuclei are excited around ^{68}Ni based on the experiment to find the sub-shell closure [5]. This research will present in details the properties of isomers such as mean lives, reduced transition probabilities, width of isomeric levels and Weisskopf hindrance factors in odd-even As, Br, and Rb isotopes which never investigated theoretically.

1.4 Objectives

1) To calculate the magnetic reduced transition probabilities B(M2) from $\pi(g_{9/2}^{+})^n$ to $\pi(f_{5/2}^{-})^n$ transitions for nuclei As, Br and Rb with even neutron N=34 to 52.

2) To calculate the mean life, width of the isomeric level, hindrance factor, and binding energy of $^{67\text{-}69}$As, $^{79\text{-}83}$Br and $^{83\text{-}89}$Rb isotopes.
3) To calculate the fragment energy, coulomb barrier and dynamic properties of deep inelastic collisions ^{76}Ge (635 MeV) + ^{198}Pt.
4) To compare the calculated data with the experimental values.

1.5 Significance of Research

This theoretical study could reveal the isomeric properties around ^{68}Ni nucleus which has shell closure is Z=28 and N=40. On other hand, the systematic studies could lead in finding the strength of shell closure N=40. The results of theoretical calculations give a lot of information of the isomers nuclear structure which are useful for compiling to the nuclear data table.

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