Studies of $\pi g_{9/2}^{+}$ Isomers in Odd $^{67\text{-}79}$as Nuclei by Deep-inelastic Collisions

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Abstract

In this paper, we report systematic studies of single particle $\pi g_{9/2}^{+}$ isomers in odd $^{67\text{-}79}$As nuclei. We have calculated the energies of projectile-like fragments of odd $^{67\text{-}79}$As in ^{76}Ge (635 MeV) + ^{198}Pt reactions. The theoretical calculations of projectile like fragments (PLFs) energies are compared with the experimental values. The mean lives, reduced transition probabilities, width of isomeric levels, and Weisskopf hindrance factors in odd $^{67\text{-}79}$As nuclei are calculated. The excitation levels of $9/2^{+}$ and $5/2^{-}$ state as a function of mass number from odd ^{67}As to ^{79}As nuclei indicate maximum deformation at N=42. The systematic reduced transition probabilities B(M2) of odd $^{67\text{-}79}$As nuclei are also investigated. The angular distributions of fragments energies of ^{79}As and its counterpart as a function of scattering angles are investigated.

Keywords: $\pi g_{9/2}^{+}$ isomers; odd $^{67\text{-}79}$as nuclei; deep-inelastic collisions; reduced transition probabilities; projectile like fragments width of isomeric levels; hindrance factors

1. INTRODUCTION

The nuclear isomers in the vicinity of the closed shells were one of the first phenomena naturally explained by the nuclear shell model. In the odd As nuclei, the atomic number is Z=33 and neutron number is even. The odd number of protons governs the ground state spin $2P_{3/2}$ level or $1f_{5/2}$ level according to shell model. However, the observed ground state spin was $5/2^-$ for ^{67,69,71}As and $3/2^-$ for ^{73,75,77,79}As because of the pairing effect [1-3].

The decay pattern of odd As nuclei with even neutron number from N = 34-46 in the intermediate mass region is a challenging theoretical and experimental task. Broda et al. found sub-shell closure N=40 experimentally [4]. It is an interesting to investigate whether the numbers of N = 40, 50 as well as Z = 28 keep the magicity in neutron-rich nuclei. It was found that the quadrupole de-excitation of single particle plays an important role in this region. The M2 transitions between the $9/2^+$ and $5/2^-$ states, were observed earlier in the odd As isotopes with A = 67-79 [2,5]. The systematic mean lives, reduced transition probabilities, width of isomeric levels, and Weisskopf hindrance factors in odd $^{67-79}$As nuclei are not calculated in details [6]. In this paper, we have presented systematically the details properties of isomers ^{67,69,71,73,75,77,79}As and dynamic features in deep-inelastic collisions.

2. THEORETICAL CALCULATIONS

The formula for the calculation of reduced transition probabilities B(M2) are described in section 2.1. Section 2.2 is devoted to the calculation of the projectiles like fragments (PLFs). The formula for the calculation of Mean-life, width of isomeric level and hindrance factors are described in section 2.3.

2.1 Reduced Transition Probability B (M2)

The reduced transition probabilities B (M2) are defined for γ-ray transitions with certain multi-polarity as follows,

$$B(M_2; I_i \rightarrow I_f) = 7.381 \times 10^{-8} E_\gamma^{-5} P_\gamma (M_2; I_i \rightarrow I_f) \qquad (1)$$

Experimentally, the partial γ-ray transition probability $P_\gamma(M\lambda)$ can be obtained from the total transition probability of the level, by

$$P_\gamma(^M_E \lambda) = P(level)\frac{I_\gamma(^M_E \lambda)}{I_{total}} \qquad (2)$$

P (level) = 1/τ(level), and τ(level) is the measured mean-life of the level of interest.

2.2 Projectile Like Fragments (PLFs)

The theoretical values of PLFs could be calculated by using equation (3)

$$E_y = Q - E_Y + E_x \quad (3)$$

Where; E_y: Energy of Projectile like fragment
E_Y: Energy of Target like fragment
E_x: Energy of Projectile (Elastic energy of ^{76}Ge)
Q: Q-value

2.3 Mean-life and Width of Isomeric Level and Hindrance Factors

2.3.1 Mean Life

Mean life τ, in radioactivity, average lifetime of all the nuclei of a particular unstable atomic species.

$$\tau = \frac{T_{1/2}}{0.693} \quad (4)$$

Where; $T_{1/2}$ = Half life

2.3.2 Width of the Level

Width of the level indicates the spread in energy of an unstable state.

$$1/\tau = \Gamma / \hbar \quad (5)$$

Where; τ=Mean life
Γ = Width of the level
$\hbar = h/2\pi$, h is Planck constant

2.3.3 Hindrance Factor, F_w

The hindrance factors F_w indicate relative to the theoretical single-particle Weisskopf estimate. The Weisskopf estimate is especially useful when an estimate of the order of magnitude is of interest. The Weisskopf estimate would be expected to agree with experiment in the extreme single-particle case. It does not intend to produce experimental data, but will be used as a scale [7]. A transition is often characterized by its transition probability in units of the Weisskopf estimate,

$$F_w = \frac{B\begin{pmatrix} M \\ E \end{pmatrix}\lambda\Big) w}{B\begin{pmatrix} M \\ E \end{pmatrix}\lambda\Big) \exp eriment} \quad (6)$$

Where; $B\left(\begin{smallmatrix} M \\ E \end{smallmatrix}\lambda\right)w = 1.65\,A^{2/3}$, A = mass number

3. RESULTS AND DISCUSSION

The isomeric levels, M2 gamma transition between $9/2^+$ to $5/2^-$, half-lives, mean life, reduced transition probabilities, hindrance factors and width of isomeric levels of odd $^{67\text{-}79}$As are summarized in table 1, which was presented at the conference [8]. The theoretical calculation of projectile-like fragments are compared with those of experimental values produced in ^{76}Ge (635 MeV) incident on target ^{198}Pt.

Table 1: Systematic properties of isomers in ^{67,69,71,73,75,77,79}As.

Nucl.	$9/2^+$ E_{level} (keV)	$5/2^-$ E_{level} (keV)	E_γ ($9/2^+ \rightarrow 5/2^-$) (keV)	*$T_{1/2}$ (Half-life)	τ Sec Cal.	*B(M2) W.u exp.	B(M2) W.u Cal.	Γ (eV) Cal.	F_w (Cal.)	*PLF energy $(MeV)_{exp}$	PLF energy $(MeV)_{Cal.}$	*Ref.
^{67}As	1422	0	1422	12 (2) ns	1.7316×10^{-8}		0.027	3.81×10^{2}	37.29		330.19	9
^{69}As	1307	0	1307	1.35 (4)ns	1.9481×10^{-9}		0.356	3.38×10^{3}	1.70		342.59	10
^{71}As	1000	0	1000	91.8 (3) ns	1.3247×10^{-7}	0.091(1)	0.090	49.82	50.99		352.48	11
^{73}As	428	67	361	5.7 (2)μs	8.225×10^{-6}	0.050(2)	0.050	0.80	19.51	386(10)	357.86	12
^{75}As	304	279.4	24.6	17.72 (23) ms	2.560×10^{-2}	0.043(1)	0.045	2.58×10^{-4}	203.07		361.58	13
^{77}As	475	264	211	114.0 (25) μs	1.6450×10^{-4}		0.036	0.04	27.98		364.13	14
^{79}As	773	231	542	0.87 (6) μs	1.1703×10^{-6}	0.036(3)	0.044	5.64	22.63	466(10)	365.32	15

3.1 Isomeric Levels

Figure 1 shows the single particle levels $9/2^+$ and $5/2^-$ which are plotted as a function of odd mass number of Arsenic isotopes. It is shown that isomeric levels of $\pi 9/2^+$ decreases from A = 67 to 75, and then increases towards A=79. The single particle level of $\pi 5/2^-$ increases from A = 67 to 75, and then decreases towards A = 79. The maximum deformation is found at N = 42 for ^{75}As and then excitation of isomeric level increases with mass number.

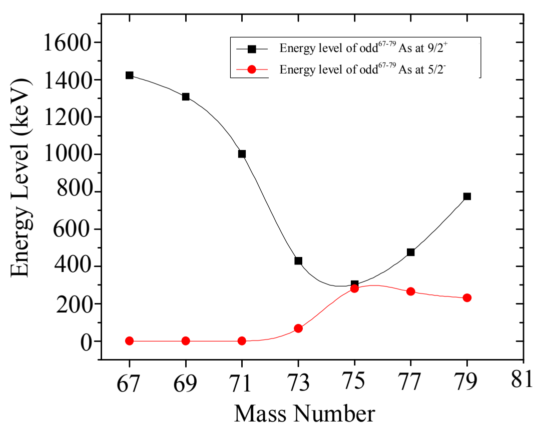

Figure 1: Single particle levels ($9/2^+$ and $5/2^-$) versus mass number of odd $^{67\text{-}79}$As.

3.2 Systematic Reduced Transition Probabilities

The transition energies between states $9/2^+$ to $5/2^-$ with those of reduced transition probabilities, one can safely assign the M2-type transition based on selection rules [16]. Fig. 2 shows electric quadrupole reduced transition probabilities in Weisskopf unit (W.u.) as a function of mass number of odd arsenic from 67 to 79. The calculated B(M2) values are compared with experimental values [11-15]. It is shown that calculated values are in good agreement with experimental values. The B(M2) values of odd $^{67\text{-}79}$As are very close to each other except ^{69}As. The maximum electric quadrupole reduced transition probability is 0.356 W.u. in ^{69}As. The nuclear structure in ^{69}As isotopes is complex and configuration mixing of ^{69}As is different those from ^{67,71,73,75,77,79}As. The dynamics is weakly driven by the proton-neutron interaction from the valence nucleons filling spin-orbit partner orbitals in ^{67,71,73,75,77,79}As .

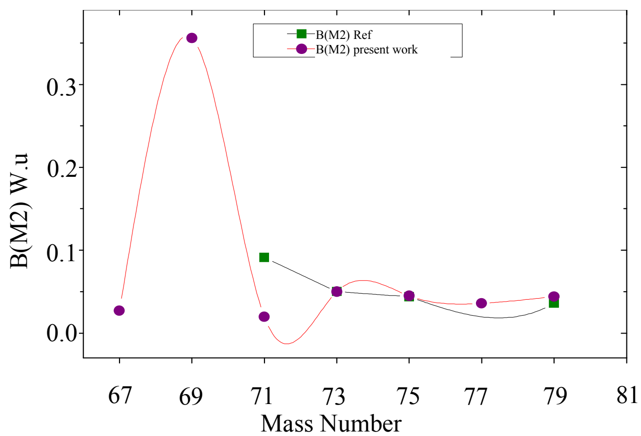

Figure 2: B(M2) values in W.u. versus mass number of odd $^{67\text{-}79}$As

3.3 Fragments Energies and Angular Distribution

The individual projectile-like fragments energies (E_y) were calculated using equation (3). The energies of target-like fragments (E_Y) were calculated by considering experimental elastic energy 520 MeV of ^{76}Ge [17]. The theoretical angular distribution of projectile like fragments (PLFs) ^{79}As and target like fragments (TLFs) ^{195}Ir in deep-inelastic collisions ^{76}Ge (635) + ^{198}Pt are indicated in Fig.3. This figure shows how the energy of PLFs and their counterpart are correlated with scattering angle. The two body natures of DICs show two large fragments are only produced in the output channel of the reaction. It is shown that the fragment energy of PLFs and TLFs are decreases as a function of angle increases and their momentum are in opposite directions.

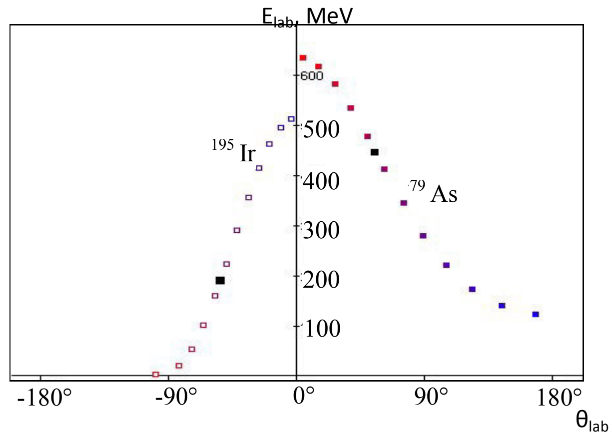

Figure 3: Fragments energies as a function of angle.

4. CONCLUSION

The systematic isomeric levels, reduced transition probabilities B(M2), width of isomeric level, hindrance factor are calculated in odd $^{67-79}$As. The theoretical calculation of energies of projectile-like fragments and reduced transition probabilities are in well agreement with experimental results. The systematic de-excitation of isomeric levels indicate maximum deformation occurs at the neutron number N=42 in As nuclei. The B(M2) values of ^{69}As is very strong and indicates different configuration mixing comparer to ^{67,71,73,75,77,79}As.

Acknowledgements

The author thanks to the Research Management Centre (RMC), Universiti Teknologi Malaysia and Ministry of Higher Education (MOHE) for the grant Gup vote #(Q.J130000.2626.00J64).

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