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Full Length Research Paper

Calculation of gamma-ray spectroscopy of $\pi g_{9/2}^{+}$ isomers in ^{69,71,73,75,77,79}As nuclei

I. Hossain[1,3]*, J. Islam[3], N. N. A. M. A. Ghani[1], M. E. Hoque[4], K. K. Viswanathan[2], H. Y. Abdullah[1,6], M. A. Saeed[1], M. H. Al-Monthery[1] and I. M. Ahmed[5]

[1]Department of Physics, University Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
[2]Department of Mathematics, University Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
[3]Department of Physics, Shah Jalal University of Science and Technology, Sylhet 3114, Bangladesh
[4]Department of Physics, Jahangirnagar University, Dhaka 3114, Bangladesh.
[5]Department of Physics, College of Education, Mosul University, Koya, Erbil, Iraq.
[6]Department of Physics, College of Science Education, Salahaddin University, Erbil, Krg, Iraq.

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We have calculated binding energy, reduced transition probabilities and deformation parameter in ^{69,71,73,75,77,79}As nuclei. The energies of projectile-like fragments and Q-value in ^{76}Ge (635 MeV) + ^{198}Pt reactions are also calculated. The theoretical calculations of projectile like fragments (PLFs) energies are compared with the experimental values. The systematic energies for $9/2^{+} \rightarrow 5/2^{-}$ de-excitation of those nuclei indicate maximum deformation at N=42. The decrease in excitation level of the $9/2^{+}$ state from ^{69}As to ^{79}As provides some evidence for decreasing quadruple "softness" towards the closed neutron shell at N = 40. We have reported single and coincidence γ-ray spectroscopy of ^{79}As by deep-inelastic collision ^{76}Ge (635 MeV) + ^{198}Pt. The systematic isomeric level and reduced transition probabilities of ^{69,71,73,75,77,79}As nuclei have been investigated.

Key words: Q-value, reduced transition probabilities, projectile like fragments.

INTRODUCTION

A study of excited states and their decay pattern for odd As nuclei with even neutron number from N = 36 to 46 in the intermediate mass region is a challenging theoretical and experimental task. The in-beam techniques reach their limits; β-decay studies are even more difficult. Both the techniques have to overcome experimental difficulties connected with low production cross-sections and isotope identification. On the other hand, there is a need to study such exotic nuclei for a better understanding of nuclear properties far from the stability line. The existence of the N = 40 sub-shell closure was suggested experimentally (Broda et al., 1995). The regular appearance of nuclear isomers in the vicinity of the closed shells was one of the first phenomena naturally explained by the shell model. It was well established that the quadpole 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 = 69-79 (Jones et al., 1980; Fireston et al., 1996; Hossain et al., (1998, 1999). The life-time of $\pi g_{9/2}^{+}$ isomer in ^{79}As was reported by in-beam gamma rays spectroscopy group (Hossain et al., 1998). Now it is very interesting to study systematically the details properties of isomers such as levels, reduced transition probabilities, binding energy, Q-value, and deformation parameter in ^{69,71,73,75,77,79}As isomers.

THEORETICAL CALCULATIONS

Binding energy (B.E)

The binding energy is the energy required to break apart the nucleus of the atom into each component part. This

*Corresponding author. E-mail: imamhossain@utm.my

PACS number(s): 23.20.lv, 25.75.-q, 29.30.kv, 27.50. +e can be calculated using:

Binding energy = Δm $[\frac{931.5MeV}{1amu}]$ (1)

Δm (mass defect) = $[Z (m_p+m_e) + (A-Z)m_n] - m_{atom}$

Q-value

The Q-value indicates the analytical relationship between the energy of the projectile and the energy of the particles outgoing from the reaction.The Q-value of the reaction was calculated by using Formula (2):

$$Q = m(a) + m(b) - [m(A) + m(B)]c^2 \quad (2)$$

Where, m (a) = mass of projectile like fragment, m (b) = mass of TLF, m (A) = mass of projectile, m (B) = mass of target, C = velocity of light.

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, Q: Q-value.

Reduced transition probability B (M2)

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

$$B(M_2; I_i \rightarrow I_f) = 7.381 \times 10^{-8} E_\gamma^{-5} P_\gamma (M_2; I_i \rightarrow I_f) \quad (4)$$

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

$$P_\gamma(^M_E\lambda) = P(level)\frac{I_\gamma(^M_E\lambda)}{I_{total}} \quad (5)$$

P (level) = 1/ττ(level), and τ(level) is the measured mean-life of the level of interest. The upward transition probability $B(M2)\uparrow$ is related to this value (Abdullah et al., 2011):

$$B(M2, J_i \rightarrow J_f)\downarrow = B(M2, J_f \rightarrow J_i)\uparrow x\ g \quad (6)$$

With $g = \frac{(2J_f+1)}{(2J_i+1)}$ (7)

Deformation parameter

The quadruple deformation parameter β is very similar to related to the formula (Abdullah et al., 2011):

$$\beta = [B(M2)\uparrow]^{\frac{1}{2}}[3ZR_o^2/4\pi]^{-1} \quad (8)$$

Where R_0 is the average radius of the nucleus, and (Raman et al., 2001):

$$R_o^2 = 0.0144\ A^{2/3}\ b \quad (9)$$

EXPERIMENTS

The experiments were carried out at Japan Atomic Energy Agency (JAEA) Tokai, Ibaraki to excite As nuclei around ^{68}Ni using the bombardment of ^{76}Ge with 635 MeV incidents on the target ^{198}Pt. The beam current was 0.2 particle nA. The scattering angles from 21 to 35° along beam direction. This was sufficient for a detailed γ-ray spectroscopy of isomers in ^{79}As by means of PLF-γ–γ coincidence and analysis of the time correlations. The details of experiments and data analysis were presented (Hossain et al., 1998; Asai et al., 2000; Makishima et al., 1999; Ishii et al., 2008, 2002; 1997). For the γ-decay studies, there was a set of five high-efficiency germanium detectors mounted around the implanted silicon-detector telescope. The full-energy-peak efficiency as a function of photon energy was determined with standard calibration sources and reached for whole detection system ε= 10% of maximum at 100 keV and amounted to ε =2.8% at 1 MeV. Five time-amplitude converters were used to measure the time between a heavy-ion signal from the first telescope detector (ΔE1) and a γ-ray signal from any germanium detectors allowing half-life measurements of isomeric states, but also providing a relative timing between the γ detectors.

RESULTS AND DISCUSSION

PLF-γ spectra

The energy spectra of 542 keV in coincidence with projectile like fragment (PLF) ^{79}As were measured by Ge detector. These spectra were sorted out by setting the gate on a region of interest in the energy spectrum of PLF. The discrimination of energy-dumped PLF from elastically scattered projectiles permitted us to intensify the γ-rays from the isomer of PLF. The measured energy spectrum of the γ radiation correlated with ^{79}As within 2 µs range is presented in Figure 1. The peak 542 keV spectrum was fitted by the least-squares method, with an analytic line shape consisting essentially of a skewed Gaussian plus exponential functions to represent the low-energy tails on the peaks. The main purpose of this procedure was to determine the magnitude of the back-ground under inelastic peaks due to the low-energy

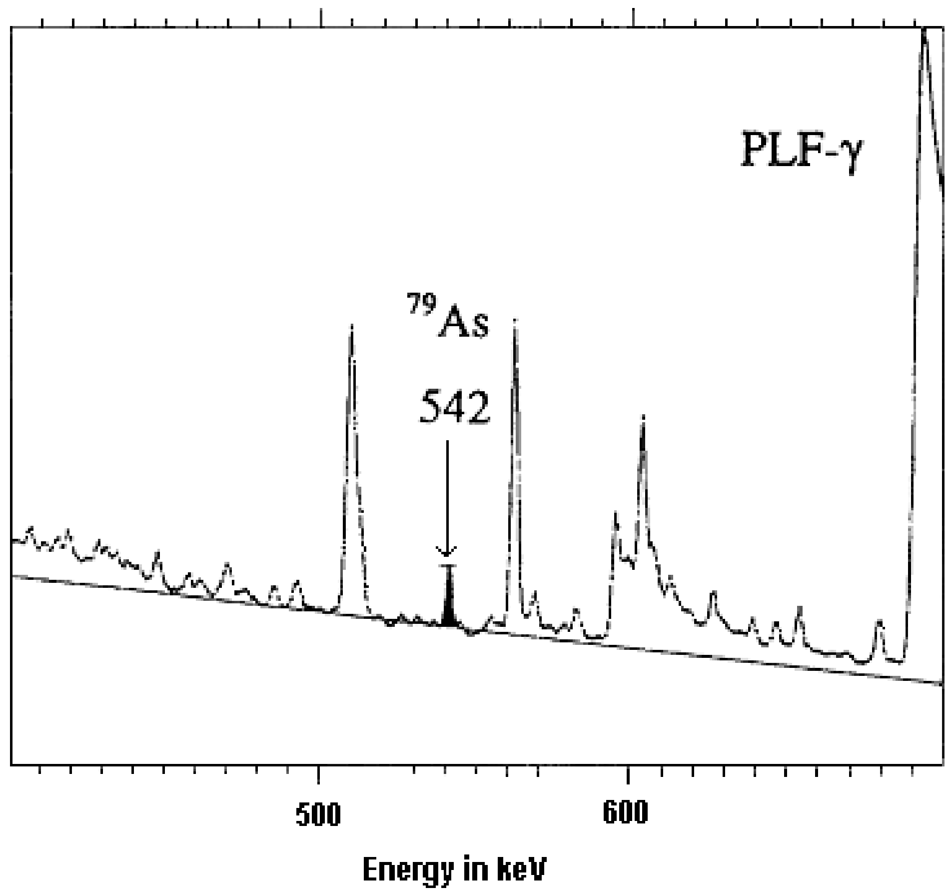

Figure 1. Single γ-ray of 542 keV in coincidence with projectile like fragments ^{79}As.

tails of high-energy peaks. The net peak-area was then used after subtraction of the estimated background level.

4.2 γγ spectra of ^{79}As

The isomeric level schemes of the product nuclei were built from γ-γ coincidence data with the help of intensity, energy balance and branching ratio arguments. The γ-γ matrices were made with the set on the region of interested fragment spectrum and on delayed or prompt region of the PLF-γ time spectrum. The γ-γ coincidence spectra of ^{79}As isomer with the gate set on 542 keV ($9/2^+ \rightarrow 5/2^-$) and 231 keV ($5/2^- \rightarrow 3/2^-$) are shown in Figure 2 (a) and (b) respectively. In Figure 2, it is shown that the γ-ray spectrum is very clear as there are no random coincidence events with background radiation.

We have calculated binding energy, projectile-like fragments energy, Q-value, isomeric level, gamma-ray transition between $9/2^+$ to $5/2^-$ levels, systematic B(M2)↑ and B(M2)↓ values of ^{69,71,73,75,77,79}As, which are presented in Table 1. The calculation of transition energies with those of reduced transition probabilities, one can safely assign the M2-type for isomeric transitions based on selection rules. The competition between in single particle and collective quadruple modes of nuclear excitations demonstrate the attractive particular attention.

M2 transition energy vs. neutron number

In Figure 3 the isomeric M2 transitions between $9/2^+$ and $5/2^-$ states are plotted as a function of neutron number in odd $^{69-79}$As nuclei. The transition energies are calculated from $9/2^+ \rightarrow 5/2^-$ level. The energy from $9/2^+ \rightarrow 5/2^-$ are known as M2 transition decreases from N = 36 to 42, and then the energy increases with the increasing neutron number.

There is a tendency for the experimental M2 strength to decrease as the neutron number increases towards the closed N = 40 shell. This feature, along with the decrease in excitation level of the $9/2^+$ state from odd ^{69}As to ^{75}As provides some evidence for decreasing quadruple "softness" towards the closed neutron shell at N=40. The maximum deformation occurs at the neutron number N = 42 in ^{75}As nuclei.

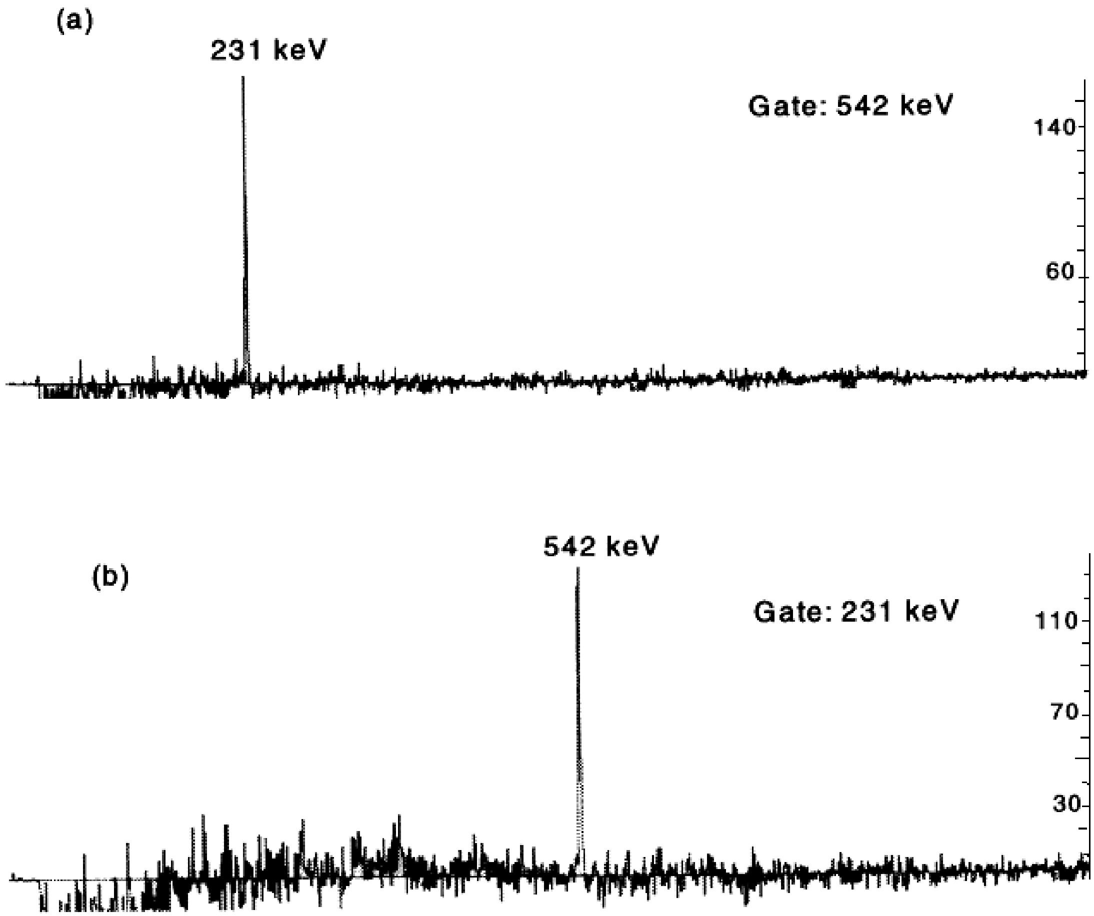

Figure 2. $\gamma\gamma$ coincidence spectra in ^{79}As. 231 keV gamma ray observed by setting the gate 542 and 542 keV gamma ray observed by setting the gate at 231 keV.

Single particle M2 transitions in odd $^{69-79}$As nuclei

In the case of odd As nuclei, the atomic number is Z = 33 and neutron number is even. The odd number of proton governs the ground state spin. After the shell closure of the 1f $_{7/2}$ orbit at Z=28, 5 protons are left. Out of these, 4 should go to the $2P_{3/2}$ level and one proton to the 1f $_{5/2}$ level that would give a spin of $5/2^-$ for the ground state of As nuclei. However, the observed spin is $5/2^-$ for ^{69,71}As and $3/2^-$ for ^{73,75,77,79}As. Therefore, in later cases the higher level $1f_{5/2}$ might be filled with 2 protons or 4 protons (an even number); while the remaining 3 or 1 (an odd number) go to the $2P_{3/2}^-$ level. This happens because of the pairing effect. Due to this, the presence of the even number of nucleons in the upper level pushes down the energy of this level so much that the 1f $_{5/2}$ level lies below the $2P_{3/2}$ level. The isomeric M2 transitions between $9/2^+$ and $5/2^-$ states shows that the $5/2^-$ levels are ground states in ^{69,71}As, but turn to excited states in $^{73-79}$As. Figure 4 shows single particle transition from $1g_{9/2}$ to $1f_{5/2}$ in ^{69,71,73,75,77,79}As. In Table 1 the B (M2) values are large in ^{69,71}As, because $5/2^-$ levels are almost empty with proton as shown in Figure 4. Therefore the transition probability from $9/2^+$ to $5/2^-$ is large. So B (M2) values in ^{69,71}As are large. On the other hand B (M2) values are very small and remain constant in $^{73-79}$As, because $5/2^-$ levels is relatively filled with protons. Therefore the transition probabilities from $9/2^+$ to $5/2^-$ are weak in odd $^{73-79}$As.

Conclusion

We have studied the in-beam gamma ray spectroscopy of ^{79}As. The systematic isomeric levels, reduced transition probabilities B (M2), deformation parameter, Q-value and binding energy are quite useful to compiling nuclear data table in odd $^{69-79}$As nuclei. The theoretical calculation of energies of projectile like fragments is well agreement with experimental results. The systematic de-excitation indicate maximum deformation occurs at the neutron number N=42 in As nuclei. We note that the spectroscopy results demonstrate that the excitation level of the $9/2^+$ state from ^{69}As to ^{79}As provides some evidence

Table 1. M2 transition from $9/2^+$ to $5/2^-$ states in $^{69,71,73,75,77,79}As$.

Nucleus	B.E. (MeV)	Q value(MeV)	PLFs energy (MeV)		Isomeric level $9/2^+$ in KeV	γ in KeV ($9/2^+ \rightarrow 5/2^-$)	**$B(M2)_{Ex}$ in e^2fm^4	β
			Calculation	*Experiment				
^{69}As	594.19	-33.18	424.37		1307	1307	8.65(35)	
^{71}As	615.14	-19.81	434.00		1000	1000	3.97(23)	0.008
^{73}As	634.36	-11.79	439.11	386(10)	428	361	1.93(17)	0.026
^{75}As	652.56	-5.69	442.55		304	24	1.82(11)	
^{77}As	669.6	-0.94	444.82	520(8)	475	211	1.62(25)	
^{79}As	685.45	2.19	445.73	466(8)	773	542	1.97(13)	0.036

*(Hossain et al., 1998; Ishii et al., 1997). **Reference: (Fireston et al., 1996; Hossain et al., 1998).

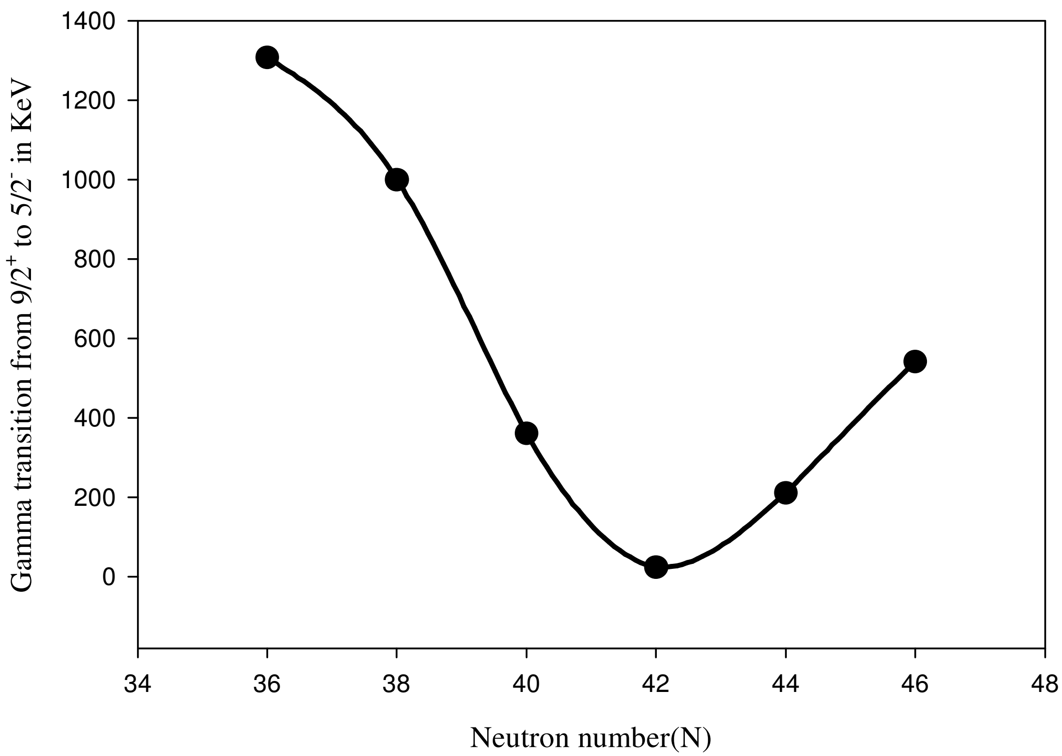

Figure 3. Energy (keV) versus neutron number of $^{69,71,73,75,77,79}As$ nuclei.

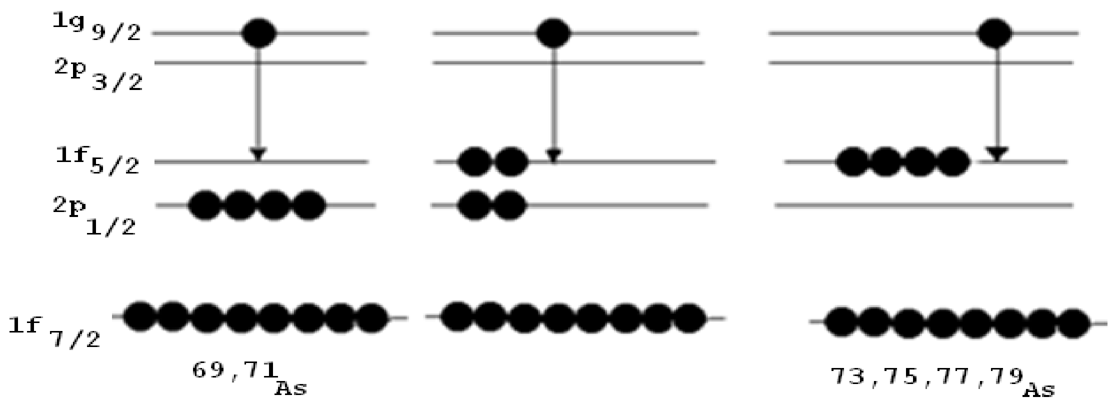

Figure 4. Single particle M2 transitions between $9/2^+$ and $5/2^-$ in odd $^{69\text{-}79}$As.

for decreasing quadruple “softness” towards the closed neutron shell at N=40.

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