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PROTON INDUCED COULOMB EXCITATION STUDY OF ^{93}Nb

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The low-lying levels of ^{93}Nb nucleus were excited with 2.7–4.3 MeV proton beam. The de-excited gamma-rays from this nucleus were identified in the singles spectra recorded with a 70 cm^3 HpGe detector. The reduced quadrupole transition probabilities of the low-lying levels have been measured via coulomb excitation technique using safe bombarding energy of 3.5 MeV proton beam. The angular distributions have been used to assign the spin of 1082.9 keV level and obtained the multipole mixing ratios of the various transitions. The present results on B(E2) have been compared with the reported measurements and model calculations.

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1. Introduction

The low-lying levels of ^{93}Nb have been investigated experimentally via the decay of isomer $21/2^+$ state ^{93m}Mo ($T_{1/2}$ =6.85 h) [1], various nuclear reactions [2-6], (n,n') and $(n,n'\gamma)$ reactions [7–11] and coulomb excitation technique [12–14]. The low-lying levels studied by coulomb excitation are considered to be as weak-coupled states to the first excited 2^+ state of the ^{92}Zr core. These experiments [12–14] reported the sum of B(E2) of the first five states from the ground state as 794 e^2 fm^4 [12], 743 e^2 fm^4 [13] and 753 e^2 fm^4 [14] which are equal to the first 2^+ state of ^{92}Zr within experimental errors. Also the centre of gravity of these five levels equals to the energy of the first 2^+ state of ^{92}Zr. All these facts support the weak-coupled nature of these excited states. But Kent *et al.* [5] studied these states and reported the absence of such weak coupling states. On the other hand, this nucleus has also been studied theoretically using different models [9,10,12] and reported transition probabilities. The aim of the present experiment

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was to measure the B(E2) values of the low-lying levels and to obtain the angular distribution results on spin assignments and multipole mixing ratios of the various transitions.

2. Experimental procedure and data analysis

A self-supporting 0.55 mg/cm^2 thick metal foil of natural spectroscopically pure ^{93}Nb was bombarded with proton beam of 2.7–4.3 MeV energy available from the Variable Energy Cyclotron at Panjab University, Chandigarh. The target was placed at an angle of 45° with respect to the beam direction and was thick enough to stop incident protons. The angular distributions were measured at 0°, 30°, 45°, 55°, 75° and 90°. The γ-rays were detected with a 70 cm^3 coaxial HPGe detector with a resolution of 1.9 keV for the 1332 keV γ-ray of ^{60}Co. The detector was placed at a distance of 10 cm from the target and a graded filter consisting of Pb, Cu and Al was placed in front of the detector to suppress the high flux of X-rays and very low energy gamma-rays. A $5'' \times 5''$ NaI(Tl) detector was placed at $-90°$ to act as a monitor for the angular distribution measurements. The target with an electron suppresser acted as a faraday cup. The signals from HPGe detector were stored using a Multichannel Pulse-Height Analyser. Electronic drift in the amplifier gain, if any, was monitored using background photopeaks at 440, 1461, 1779.1 and 2614.1 keV. At each angle a number of spectra were recorded and the drift in the gain was found to be negligible. The excitation functions of various γ-rays have been measured at 55° with respect to the beam direction at 2.7, 3.0, 3.5, 4.0 and 4.3 MeV beam energies to ascertain that the coulomb excitation at 3.5 MeV is dominant as compared to nuclear reaction. The details of the experiments are given in our previous publications [15,16].

The gamma ray spectra were analysed using the computer code PEAKFIT [17]. The origin of the observed gamma-rays was assigned by taking into account the background spectrum with the machine on. The excitation functions of all observed gamma-rays were analysed carefully as a function of energy and those from $(p, n\gamma)$ reaction were easily identified with a characterstic rise above their threshold energy. From the observed spectra at various proton energies, the gamma-ray energies and the branching ratios were obtained. The experimental thick-target yields per incident proton for the excited levels were obtained at all bombarding energies. The theoretical yields for compound nucleus formation and coulomb excitation [19] were compared and it was found that the contribution from compound nucleus formation to the total yield was less than 5% at 3.5 MeV proton beam. The theoretical yields were calculated from the cross sections corresponding to compound nucleus formation calculated with the help of code CINDY [18].

The reduced transition probabilities were determined from the comparison of theoretical and experimental gamma-ray yields using coulomb excitation theory of Alder *et al.* [19]. The Table I shows the branching ratios and the reduced transition probabilities $B(\mathrm{E2})\uparrow$ while the comparison of $B(\mathrm{E2})$ values with the previous results is shown in Table II for the excited levels of ^{93}Nb. The comparison of experimental and theoretical reduced quadrupole transition probabilities along with the mixing ratios (δ) for the various transitions are given in Table III. From the angular distribution data, the typical χ^2-fitting curves using various possible spins for two transitions from the levels at 979.4 and 1082.9 keV are shown in Fig 1. The 0.1% confidence limit was used to exclude the unacceptable spins and delta values.

TABLE I

Branching ratios and $B(\mathrm{E2})\uparrow$ values for the levels of ^{93}Nb

Level (keV)	Transition (keV)	γ-ray (keV)	Branching ratios (%)	$B(\mathrm{E2})\uparrow$ $\mathrm{e^2fm^4}$
744.1	744.1 → 0	744.1	100	168 ± 10
802.2	802.2 → 0	808.2	100	155 ± 10
949.4	949.4 → 0	949.4	100	265 ± 15
978.4	978.4 → 0	978.4	100	175 ± 15
1082.9	1082.9 → 0	1082.9	22.5 ± 3.0	20 ± 3
	1082.9 → 744.1	338.8	77.5 ± 2.0	–

TABLE II

Comparison of $B(\mathrm{E2})\uparrow$ values with the previous results in ^{93}Nb

Level (keV)	Spin-parity J^π	Measured $B(\mathrm{E2})\uparrow$ ($\mathrm{e^2fm^4}$) Present	Ref. [12]	Ref. [13]	Ref. [14]
744.1	$7/2^+$	168 ± 10	188 ± 10	180 ± 13	168 ± 8
808.2	$5/2^+$	155 ± 10	153 ± 8	167 ± 12	157 ± 8
949.4	$13/2^+$	265 ± 15	236 ± 13	247 ± 17	230 ± 11
979.4	$9/2^+$	175 ± 15	186 ± 10	127 ± 11	172 ± 9
1082.9	$9/2^+$	20 ± 3	30.6 ± 2.1	21.9 ± 2.6	26 ± 2

TABLE III

Properties of the excited states of ^{93}Nb

Level (keV)	J^π	Transition $J_i^\pi \to J_f^\pi$	$B(\mathrm{E2})\downarrow$ $\mathrm{e^2fm^4}$	B(E2)↓/B(E2)w.u. Present Expt.	Ref [12] Expt.	Ref [12] Weak coupl.	Mixing ratios(δ)
744.1	$7/2^+$	$7/2^+ \to 9/2^+$	210 ± 13	8.4	9.4	6.4	0.14 ± 0.12
808.2	$5/2^+$	$5/2^+ \to 9/2^+$	258 ± 13	10.3	10.2	6.3	$E2$
949.4	$13/2^+$	$13/2^+ \to 9/2^+$	189 ± 11	7.6	6.8	6.3	$E2$
979.4	$9/2^+$	$9/2^+ \to 9/2^+$	175 ± 15	7.0	6.2	6.3	2.1 ± 0.3 −0.4 ± 0.3
1082.9	$9/2^+$	$9/2^+ \to 9/2^+$	20 ± 3	0.8	1.2	6.4	−0.21 −2.47

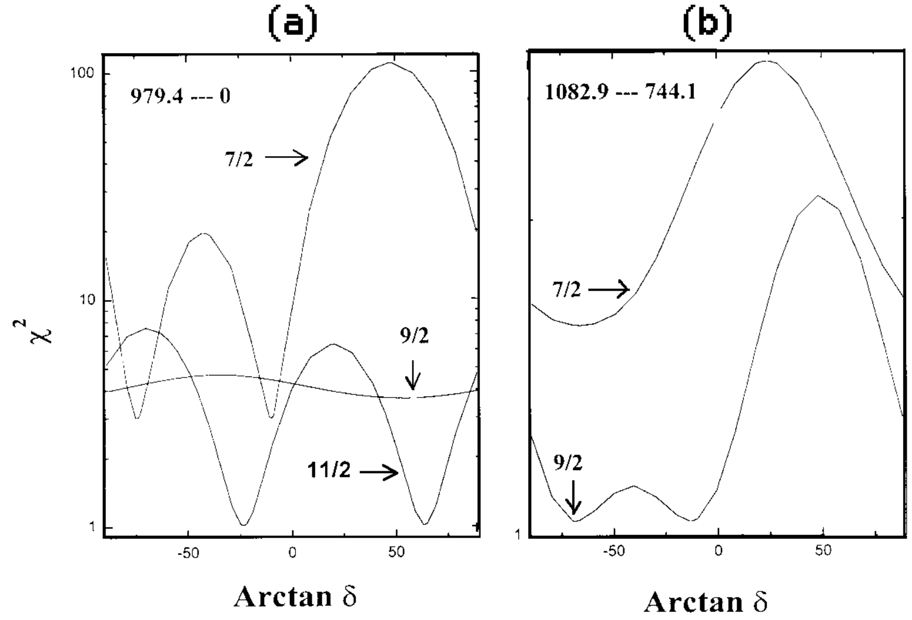

Fig. 1. Values of χ^2 as a function of mixing ratios for various spin values for (A) 979.4 keV and (B) 338.8 keV transitions.

3. Results and discussion

The first five levels at 744.1, 808.2, 949.4, 979.4 and 1082.9 keV were excited in the present experiment and the branching ratios, reduced transition probabilities for the excited levels, multipole mixing ratios for various transitions and spin values were obtained. The $B(E2)\uparrow$ values measured in the present work are shown in Table I. A comparison of present $B(E2)\uparrow$ values with the reported experimental values [12–14] are given in Table II. The Table III shows the comparison of experimental and theoretical $B(\mathrm{E2})\downarrow/B(\mathrm{E2})$w.u. values along with the mixing ratios of various transitions in ^{93}Nb. Our measured values of the reduced quadrupole transition probabilities $B(\mathrm{E2})\uparrow$ are in close agreement with the values of Stelson et al [14] for the levels at 744.1, 808.2 and 979.4 keV while the values of Kregar and Seaman [13] are matching with ours within experimental errors for the 949.4 and 1082.9 keV levels. The results of Yoshizawa et al [12] slightly differ from ours for 949.4 and 1082.6 keV levels. The B(E2) values in terms of w.u. are in close agreement with the weak coupling model calculations[12] except for the level at 1082.9 keV.

Our angular distribution data have confirmed the existing spins of the levels. Yoshizawa *et al.* [12] have predicted the spin of 979.2 keV level on the basis of experimental lifetimes [14] of this level. From the analysis of the present data in terms of χ^2-fitting, the spin of this levels is found to be 11/2 as shown in Fig 1. The spin of 1082.9 keV level was not uniquely assigned in coulomb excitation experiment [12] but it was adopted as 9/2. In the present experiment the χ^2-fitting of stronger transition (338.8 keV) $1082.9 \rightarrow 744.1$ has assigned the spin to this level as 9/2. Hence the values of multipole mixing ratios (δ) extracted in the present experiment from the χ^2-fitting of angular distribution data may be more reliable in comparison to the previously reported values.

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