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MAGNETIC MOMENTS AND SHAPE COEXISTENCE NEAR THE N=38 SHELL GAP. MAGNETIC MOMENT OF THE 151 KEV, $J^{\Pi}=5/2^{-}$ LEVEL IN ^{73}SE

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Abstract. The magnetic moment of the 151 keV, $J^{\pi} = 5/2^{-}$ level in N = 39 nucleus ^{73}Se has been measured by time–integral perturbed angular distribution technique. Has been found a value of $\mu = -(0.472\pm0.094)\ \mu_N$. The measured value shows that the $5/2^{-}$ level is not a member of the band based on $3/2^{-}$ isomer. Our analysis indicate that the collective band based on $5/2^{-}$ level has a substantial prolate deformation,. The ^{73}Se nucleus exhibit shape coexistence at low spins, similar with its neighbor ^{72}Se.

Key words: Magnetic moments, shape coexistence, shell gap, ^{73} Se, excited levels

1. INTRODUCTION

Extensive investigations of the structure of neutron deficient A≈60–80, N≈Z=33–40 nuclei has revealed many interesting features. Drastic changes of properties appears for nuclei with Z≥33when going from nuclei with 50 neutrons to nuclei with 36–40 neutrons [1,2]. Large quadrupole deformations (β≈0.4) and strong collectivity are seen. Furthermore, evidence for shape coexistence at low spins found for the first time in ^{72}Se [3] has generated a special interest in studies of the region. A striking feature is the strong variation of the shape as a function of particle number, excitation energy and spin.

The microscopic structure of the nuclei from A≈60–80 mass region is essentially determined by the $2p_{1/2}$, $1f_{5/2}$, $2p_{3/2}$ and $1g_{9/2}$ orbitals. The strong shape variation and the shape coexistence effects may be interpreted as resulting from the competition of the stabilizing energy gaps of the deformed single-particle field. Calculations based on the generalized Woods-Saxon potential [4] predict competing deformed gaps at nucleon numbers 34 and 36 for β≈–0.26 and β≈–0.40 and at nucleon numbers 34 and 38 for β≈0.26 and β≈0.40. A pronounced shell gap also exist at a nucleon number 40 for a spherical shape. The single-particle level density in the A≈60–80 nuclei is by a factor of two lower than in deformed heavy nuclei; so, the single-particle deformed energy gaps which appear at similar nucleon numbers (N,Z=34–38) manifest themselves in a comparatively dramatic way. Adding or removing a few nucleons can hence have a dramatic effect on the nuclear shape. Competing prolate, oblate and spherical shapes are even expected to coexist in the same nucleus. This is particularly true for the neutron-deficient selenium (Z=34) and krypton (Z=36) isotopes, where the protons appear to prefer an oblate shape but where neutron numbers of 38–42 favors a strongly deformed (β≈0.4) prolate shape. The shape coexistence in ^{72}Se has been explained as arising from the oblate polarizing influence of the shell gap at nucleon number 34 and the strong prolate driving influence of the gap at nucleon number 38.

In recent years, nuclei near the strongly deformed shell gaps at N=Z=36 and N=Z=38 for large oblate and large prolate deformation, respectively have been investigated in much detail. The recently discovered $J^{\pi}=0^{+}$ shape isomers in ^{74}Kr and, for the first time, in the N=Z nucleus ^{72}Kr reinforced the evidence of the importance of both shell gaps [5]. So, the detailed spectroscopy near the N=38 deformed shell gap is still an interesting research subject.

The study of N=39 nucleus ^{73}Se is fairly interesting, the odd neutron proving the quadrupole deformation and the coexistence of different shapes of the even–even core. The excited states of ^{73}Se have already been investigated using both the β decay of ^{73}Br [6,7] and in-beam gamma-ray spectroscopy with reactions induced by α particles and heavy ions [8–15]. These investigations established the existence of a collective decoupled band built on $J^{\pi}=9/2^{+}$ ground state to spin $33/2^{+}$ as well as other positive-parity sequences of states. In addition to the positive-parity states a collective band built on a low-lying isomeric level $J^{\pi}=3/2^{-}$ at 27.2 keV was also established. This band was interpreted as a strongly coupled band built on $[301]3/2^{-}$ Nilsson orbital. Similar bands occur in heavier odd Se and Kr isotopes. Both the recent evidence of the anomalous behavior of the electromagnetic transition probabilities in ^{75}Kr [16] and the measured magnetic moments in odd and odd–odd Br isotopes $^{72-77}$Br [17] have emphasized shape variation and shape coexistence in Z=35,36 nuclei in the neighborhood of N=38. In order to test the assumption that the collective negative-parity band built on the $3/2^{-}$ level has the Nilsson configuration $[301]3/2^{-}$ and to further investigate shape coexistence in ^{73}Se we measured the magnetic moment of the 151 keV, $J^{\pi}=5/2^{-}$ level using time-integral perturbed angular distribution technique.

2. EXPERIMENTAL METHOD AND DATA ANALYSIS

The experiment was performed at the 8.5 MV Van de Graaff Tandem accelerator of NIPNE. The excited states in ^{73}Se were populated using ^{56}Fe(^{19}F,pn)^{73}Se reaction at 60 MeV bombarding energy. The magnetic moment of the 151 keV, $J^{\pi}=5/2^{-}$ level was measured by means of the time-integral perturbed angular distribution method. The experimental set-up includes a special reaction chamber centered on an angular correlation turntable . In order to have the residual nuclei in an ferromagnetic environment a thick (14 μm) natural iron foil was used as a target and implantation medium. The iron foil was placed between the poles of a small electromagnet to saturate the internal hyperfine field. The gamma rays were detected by two large volume intrinsic Ge detectors, having resolutions of about 2.5–2.7keV at 1.33 MeV. One of the detectors was placed at 270° and used as a monitor; the second one was placed successively at seven angles between 0° and 90°. Two measurements were performed:

- an angular distribution measurement without polarizing magnetic field.
- an measurement with the moving detector placed seven angles between 0° and 90° for up and down directions of the polarizing magnetic field.

The measured gamma ray spectra were quite complex. A relevant region of a measured spectrum is presented in Fig. 1.

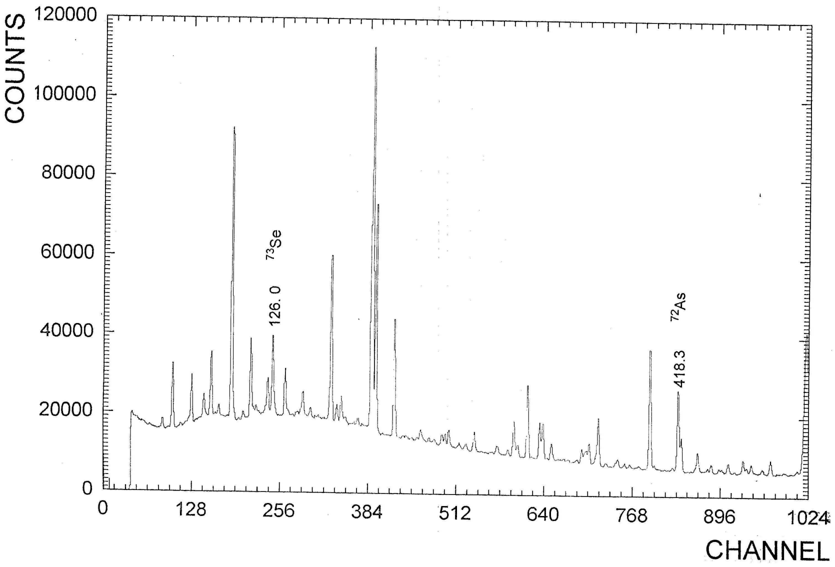

Fig. 1

The spectra analysis was carried out using the interactive code LEONE [18]. For normalization we used both the intensities of some strong transitions measured with the monitor detector and the intensity of the strong isotropic 398 keV transition from ^{69}Ge, measured with the moving detector. In Fig. 2 we present the measured angular distribution for 125 keV transition deexciting the 151 keV, $J^{\pi}=5/2^{-}$ level and the result of a fit with Legendre polynomials. The extracted coefficients were:

$$A_2=-0.236\pm0.005 \qquad A_4=0.006\pm0.007$$

The transition is a pure dipole. The rather large A_2 coefficient show a substantial alignment of the $5/2^{-}$ level.

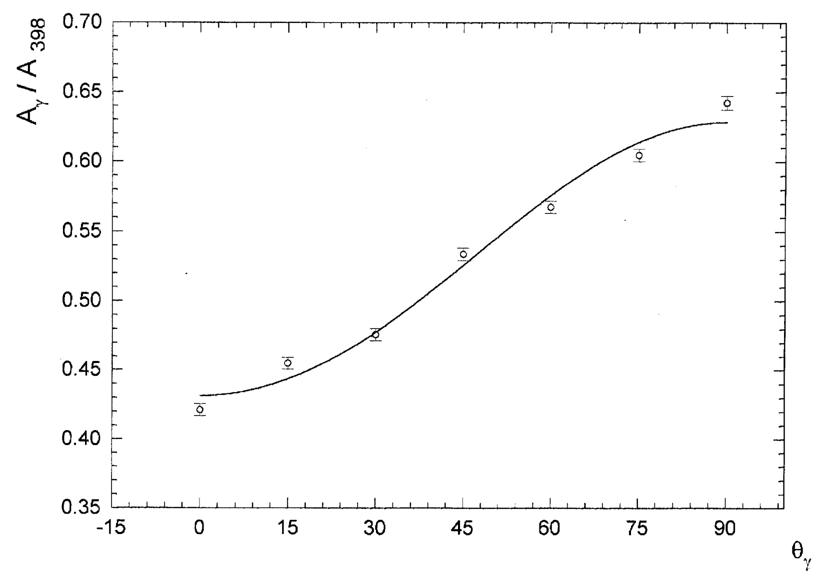

Fig. 2

The perturbed angular distribution in a static magnetic field is given by:

$$W(\theta,\pm H)=1+b_2\cos[2(\theta\mp\Delta\theta_2)]+b_4\cos[4(\theta\mp\Delta\theta_4)] \qquad (1)$$

For a pure dipole transition we have:

$$W(\theta,\pm H)=1+b_2\cos[2(\theta\mp\Delta\theta)] \qquad (2)$$

where $\Delta\theta$ is the mean rotation angle:

$$tg(\Delta\theta)=2\omega\tau$$

The b_2 coefficient is related to A_2 coefficient by the relation:

$$b_2=\frac{3/4A_2}{1+1/4A_2}$$

For $\theta=45^o$ forming the ratio

$$R=\frac{W(45^o,+H)-W(45^o,-H)}{W(45^o,+H)+W(45^o,-H)}$$

we obtain:

$$\sin 2\Delta\theta=R/b_2$$

Hence:

$$2\Delta\theta = \arcsin R/b_2$$

The Larmor frequency is obtained using

$$2\omega\tau = \mathrm{tg}\, 2\Delta\theta$$

Finally, the gyromagnetic factor is related to the Larmor frequency and to the value of the hyperfine magnetic field by:

$$\omega = -g\mu_N H/h$$

The hyperfine field for Se nuclei in Fe was measured by nuclear magnetic resonance in oriented nuclei [19,20]. A value of H(Se/Fe)=(716±81) kG and H(Se/Fe)=(690±50) kG was obtained, respectively. Using for the lifetime of the level the value τ=320±47 psec [11] we obtained from the data analysis the results presented in Table 1.

Table 1

Nucleus	E_x(keV)	J^{Π}	A_2	b_2	R	$\Delta\theta$	g
^{73}Se	151	$5/2^-$	–0.236(5)	–0.178(7)	0.067(2)	11.1(2)	–0.189(38)

Using the g factor we obtained for the magnetic moment :

$$\mu = -(0.472\pm0.094)\ \mu_N$$

3. DISCUSSIONS AND CONCLUSIONS

The ^{73}Se nucleus is situated in A≈70 mass region, where the coexistence of different shapes at low spin is a quite well established phenomenon. As was already mentioned in the Introduction, the potential energy surface gives for ^{72}Se two minima: one at a oblate deformation $\beta\approx-0.25$ which correspond to the ground state and another one at a prolate deformation $\beta\approx0.32$ which correspond to the first 0^+ excited state at 937 keV. The effect of an odd nucleon added to a shape coexistent even–even core is not well understood. In some cases, such as in ^{73}Br the odd nucleon has been found to polarize the core, thus stabilizing one of the shapes and quenching the coexistence. A relevant portion of the level scheme of ^{73}Se is presented in Fig. 3.

In ^{73}Se the negative parity sequence built on $3/2^-$ isomer displays a regular rotational sequence. The experimental evidence indicate a quite large axially symmetric quadrupole deformation. For a prolate deformation $\beta\approx0.3$–0.4 the odd neutron may occupy the $[422]5/2^+$ Nilsson orbital and, at a higher energy, the $[301]3/2^-$ Nilsson orbital. However, while in the isotone nucleus ^{75}Kr a strongly coupled rotational band based on the $5/2^+$ ground state was established, in ^{73}Se the decoupled band based on the 9/2+ ground state point to an oblate deformation.

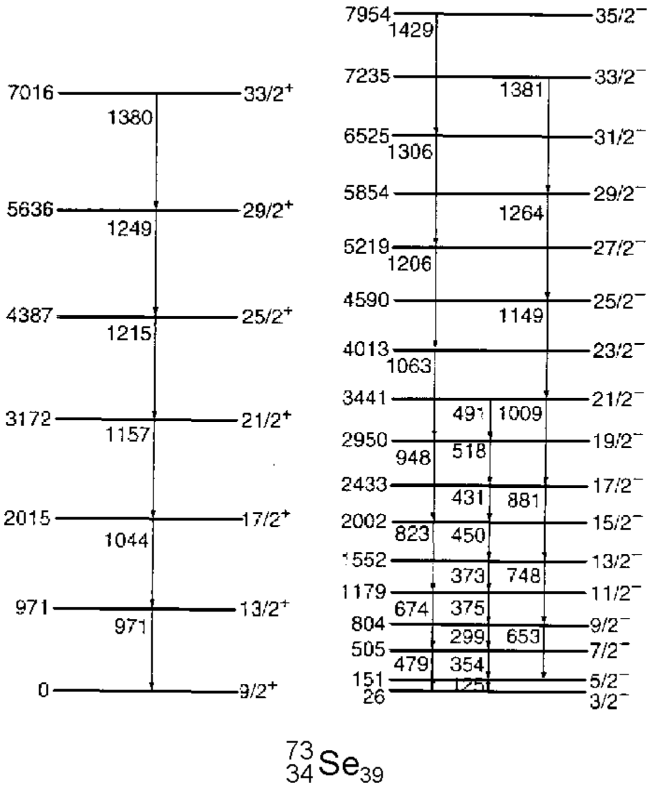

Fig. 3

Positive mixing ratio δ has been measured for the $11/2^+ \rightarrow 9/2^+$ transition, which may also point to an oblate deformation. Indeed, by using the relation $\mathrm{sign}\delta = \mathrm{sign}((g_K - g_R)/Q_0)$ and, taking into account that $g_K - g_R < 0$ holds for gyromagnetic factors of the $g_{9/2}$ configuration of the valence neutron, a negative value result for Q_0. The band based on the $3/2^-$ level was interpreted in the literature as a strongly coupled band based on $[301]3/2^-$ Nilsson orbital [12]. In order to test this configuration assignment we calculated the magnetic dipole moment of the $5/2^-$ level for different deformations, using Nilsson wave functions. The results are presented in Table 2.

Table 2

$^{73}_{34}Se_{39}$

$[301]3/2^-$		$g_R = Z/A$		$g_S = 0.65(g_S)_{free}$		
β	–0.3	–0.2	–0.1	0.1	0.2	0.3
$\mu(\mu_N)$	0.560	0.679	0.897	1.607	0.417	0.327

The experimental value is in disagreement with theoretical results. In Fig. 4 we present the $3/2^-$ band from ^{73}Se and the analogous negative parity bands from ^{75}Se and ^{75}Kr. The similar behavior of the negative-parity bands in ^{73}Se and ^{75}Se at spin 5/2 suggest that in ^{73}Se the $5/2^-$ level is not a member of the band based on the $3/2^-$ level. It is known from the measured spectroscopic factor in one-nucleon transfer that in ^{75}Se the $5/2^-$ level is the Nilsson level $[303]5/2^-$. This suggest that the 151 keV, $5/2^-$ level in ^{73}Se is the band head of a band based on $[303]5/2^-$ Nilsson orbital.

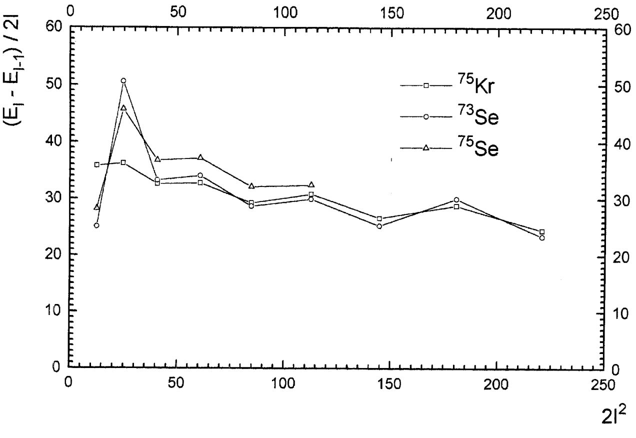

Fig. 4

We calculated the magnetic moment for the $5/2^-$ level for few oblate and prolate deformations. The results are presented in Table 3.

Table 3

$^{73}_{34}Se_{39}$

$[303]5/2^-$ $g_R=Z/A$ $g_S=0.65(g_S)_{free}$

β	−0.3	−0.2	−0.1	0.1	0.2	0.3
$\mu(\mu_N)$	0.155	0.510	0.795	1.060	1.112	1.142

The experimental value cannot be reproduced. In order to extract the deformation in the negative-parity band we used the relations:

$$\mu=g_R I+(g_K-g_R)K^2/I+1$$

$$B(M1)=3/4\pi(g_K-g_R)^2K^2(I_iK10|I_fK)^2$$

$$\frac{g_K-g_R}{Q_0}=0.934\frac{E_\gamma(MeV)}{\delta}\frac{1}{\sqrt{I^2-1}}$$

valid for a strongly coupled rotational band, with $K=5/2$, $I_i=7/2$, $I_f=5/2$, $I=5/2$.

If we use for $B(M1;7/2^-\rightarrow5/2^-)$ the value reported in [12] and for $\mu_{5/2}$ our measured value, we obtain:

$$g_R=0.454 \quad g_K=-0.434$$

The mixing ratios δ reported for the negative parity band in ^{73}Se are negative [12]. If we take $\delta=-0.38$ measured for the $7/2^-\rightarrow5/2^-$ transition, we obtain $Q_0=+3.47$ barn. The corresponding deformation is $\beta\approx+0.45$. This value is in quite good agreement with the values $Q_0=3.04$barn and $Q_0=3.19$ barn extracted from the measured B(E2) for $11/2^-\rightarrow7/2^-$ and $15/2^-\rightarrow11/2^-$ transitions. So, ^{73}Se present shape coexistence at low spin, similar with the core nucleus ^{72}Se: the ground state has an oblate deformation, while in the rotational band based on 151 keV, $5/2^-$ level the deformation is prolate. However, the structure of the $K^\pi=5/2^-$ band is not fully understood.

REFERENCES

1. J.H.HAMILTON, *Treatise on Heavy-Ion Science vol.8*, ed. D.A.Bromley, Plenum – New York, 1989, p3
2. *Nuclear Structure of the Zirconium Region*, eds. J.Eberth, R.A.Mayer and K.Sistemich, Springer Verlag – Berlin, 1988
3. J.H.HAMILTON, et al., Phys. Rev. Lett. **32**, p239, 1974
4. W.NAZAREWICZ, et al ., Nucl. Phys. **A435**, p397, 1985
5. E.BOUCHEZ, et al., Phys. Rev. Lett. **90**, p082502, 2003
6. G.MURRAY, et al., Nucl. Phys. **A142**, p21, 1970
7. K.HEIGUCHI, et al., Nucl. Phys. **A474**, p484, 1987
8. M.BEHAR, et al., Nucl. Phys. **A261**, p317, 1976
9. K.O.ZELL, et al., Z. Phys. **A279**, p373, 1976
10. LI GUANGSHENG, et al., Chin. J. Nucl. Phys. **5**, p217, 1983
11. A.DEWALD, et al., Z. Phys. **A326**, p509, 1987
12. F.SEIFFERT, et al., Z. Phys. **A340**, p141, 1991
13. M.S.KAPLAN, et al., Phys. Rev. **C44**, p668, 1991
14. G.MUKHERJEE, et al., Z. Phys. **A359**, p111, 1997
15. R.LORITZ, et al., Eur. Phys. J. **A6**, p257, 1999
16. S.SKODA, et al., Z. Phys. **A336**, p391, 1990; Nucl. Phys. **A633**, p565, 1998
17. G.AUSTYN, et al., Phys. Rev. **C46**, p2228, 1992
18. S.ALBERS, et al., *The interactive peak fitting code LEONE*, Verhandlungen der DPG(VI) **23**, 1988, p227
19. K.NISHIMURA, et al., J. Phys. Soc. Japan **56**, p3512, 1987
20. P.T.CALLAGHAN, et al., Phys. Rev. **B10**, p1075, 1974