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The ^{73}Br Decay

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The $\gamma-\gamma$ coincidence and $\gamma-\gamma$ angular correlation measurements of ^{73}Br produced in ^{64}Zn(^{12}C, 2np)^{73}Br reaction have been performed. The energies and relative intensities of the 27 γ -rays are obtained, of which nine lines and three levels were not reported before. The level scheme of ^{73}Br is established. The spin of 90.4 keV level is inferred to be 3/2 or 5/2.

1. INTRODUCTION

It was already proved that a strongly deformed region of ground states exists at A = 70--80 mass range. Möller and Nix suggested that there could be a new strongly deformed region around $N = Z = 38$. There exists very interesting physics, such as the effect of shell gaps on nucleus deformation at N and $Z = 38$, the competition between oblate and prolate ellipsoidal shapes in nuclei in the region $N < 50$, the strong deformation induced in lighter nucleus due to an additional nucleon, etc. The most strongly oblate deformation should be at $Z = 35$, $N = 35$ and the most strongly prolate deformation should be at $Z = N = 38$, as first suggested by Hamilton and Bengtsson [1,2].

Determination of the low lying exited states of daughter nucleus ^{73}Se from ^{73}Br β decay will help us to understand the deformation tendency at $Z = 35$ and $Z = 38$. The previous decay scheme of ^{73}Br was established by Mürray et al. in 1970 with the measurement of γ-spectrum from the sample obtained by normal chemical separation. They did not do the $\gamma-\gamma$ coincidence measurement and the angular momenta of many levels were not assigned. The halflife of ^{73}Br and some γ-ray transitions were measured

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by us in 1983. And now we have measured the $\gamma-\gamma$ coincidence and the angular correlation. All of these samples were produced by a He-jet system in combination with a rapid chemical separation. With the speed-up of the transport and chemical separation, the increase of the detection efficiency and the improvement of the counting statistics, we expect more information and more complete decay scheme of ^{73}Br be obtained.

2. EXPERIMENT PROCEDURE

^{73}Br was produced in ^{64}Zn(^{12}C, 2pn) reaction, when the 72 MeV ^{12}C beam from the cyclotron of Institute of Modern Physics, whose energy was degenerated by the 3.6 mg/cm^2 Al foils, bombarded on the ^{64}Zn isotope target. ^{73}Br product recoiled out from the target was stopped and transported with He-gas plus AgCl additive agent from the target chamber into the rapid chemical separation apparatus. The capillary of polyethylene between the target chamber and the separation apparatus is 8 meters long. The He-gas pressure at the entrance of the target chamber is 1.3 atm. Finally only Br element was absorbed by a plastic sponge moistened by HDEHP + CCl_4 and this sponge is put inside the lucite tube (The wall is 1 mm thick). The He-jet system is shown in Fig.1. For detailed procedure of the chemical separation, see Ref.[4].

A Ge(Li) (140cm^3, FWHM 2.6 keV at 1332.5 keV) detector, a Ge HP (50 cm^3, FWHM 2.0 keV at 1332.5 keV) detector and a normal fast-slow coincidence system with 50 ns time resolution were used for $\gamma-\gamma$ coincidence measurement. The distance between the source and the detectors is 4.2 cm. The angle between those two detectors is 90° or 160°. The measuring time accumulated for each angle is 19 or 26 hours, respectively. The samples were measured one after another with 5 minutes for each one. The relative

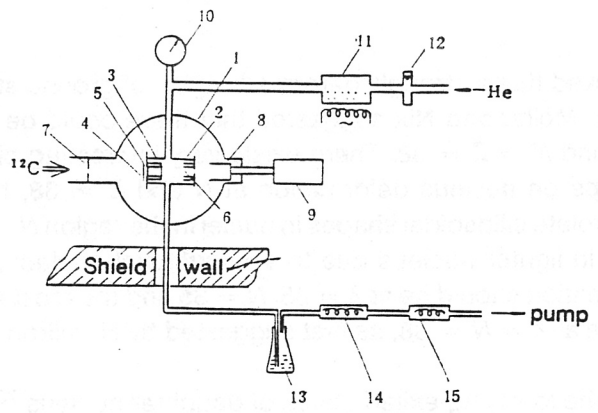

FIGURE1 Experiment equipment. 1. target chamber, 2. thermalized chamber, 3. target, 4. Al foil to degrade energy, 5. Ni window, 6. exit window, 7. collimator, 8. Farady cup, 9. beam integrator, 10. pressure meter, 11. AgCl additive agent, 12. flowmeter, 13. absorber (18 ml 10NHNO_3 + 10μg Br + 23 ml H_2O + 18 ml 0.5M $KBrO_3$), 14. plastic sponge moistened by 1 NH_2SO_4, 15. plastic sponge moistened by 80% HDEHP-CCl_4.

TABLE 1. γ-ray energy and relative intensity in ^{73}Br.

Energy (keV)		Relative intensity (%)		Energy (keV)		Relative intensity (%)	
This work	Reference	This work[1]	Reference[2]	This work	Reference[3]	This work[1]	Reference[2]
64.7±0.1	64.9±0.1	418.6±33.5	100	400.4±0.5	400.6±0.2	65.6±2.6	20±1
102.1±0.3		2.4±0.1		489.6±0.1	489.6±0.2	14.9±0.6	4±1
125.6±0.1	125.5±0.1	51.7±4.1	23±2	540.0±0.3	539.6±0.2	21.4±0.7	8±2
137.2±0.2		2.2±0.1		550.2±0.2	550.1±0.2	7.5±0.2	3±1
166.2±0.1		17.7±0.7		615.6±0.1	614.9±0.2	24.3±0.2	8±1
249.0±0.1		1.4±0.1		638.4±0.3	638.6±0.3	4.9±0.1	4±1
275.2±0.1	275.1±0.2	26.9±0.1	10±1	700.2±0.1	699.5±0.2	97.2±3.0	40±3
336.0±0.1	335.7±0.2	100	34±2	849.9±0.1	848.7±0.2	61.9±1.9	20±1
345.5±0.1		0.8±0.3		870.3±0.4	869.8±0.3	8.0±0.3	5±1
363.8±0.2		3.9±0.1		914.2±0.4	913.6±0.2	50.4±1.5	19±2
374.1±0.3	374.3±0.2	24.0±1.0	8±1	931.0±0.3	930.7±0.2	59.6±1.8	22±2
381.5±0.5		8.1±0.3		995.3±0.3	995.6±0.2	17.3±0.5	7±1
385.7±0.3		5.2±0.1		788.3±0.2	788.1±0.2	11.0±0.4	3±1
390.2±0.3		7.7±0.2					

1) The intensity of 336 keV γ ray is normalized to be 100 %.
2) The intensity of 64.9 keV γ ray is normalized to be 100 %.

efficiency was calibrated with the solution sources of $^{152+154}$Eu and ^{133}Ba. The shape and the wall of the solution container were almost the same with those of the container of ^{73}Br. Standard sources of ^{241}Am, ^{57}Co, ^{60}Co, ^{22}Na and ^{137}Cs were used for energy calibration. The 1024 × 1024 data were obtained with the Multi-20 data acquisition system. The data of $\gamma-\gamma$ coincidence were recorded in list mode on tapes. Because of the restriction of the beam time, we have only made the two coincidence spectra of 90° and 160°. 7.5 x 10^4 and 1.2 x 10^6 events were accumulated respectively. The data were analyzed off-line. The γ-ray spectra were analyzed on computer PDP 11/44 which included the programs of the abstraction of the correlation spectra, the background

TABLE 2. Coincidendce relationship between γ- transitions.

γ ray as gate-openning signal (keV)	γ ray with coincidence relation (keV)	γ ray as gate-openning signal (keV)	γ ray with coincidence relation (keV)
65	102,336,550,700,850,931	390	126,249,374
102	65,345,382	490	126
126	249,275,386,490,788,870	540	374
166	345,382	550	65
249	126,390,540	638	126
275	126,364	700	65
345	65,102,166	788	126
364	65,126,275,336,400	850	65
374	137,390,540	870	126
382	166	931	65

substraction, the peak area calculation, the decomposition of the complex peak, the spectrum drawing and so on. The area of peak was obtained by the program LEONE which employed the least square fit method.

3. RESULTS AND DISCUSSION

3.1 γ-Ray Energies and Their Relative Intensities

Four direct spectra were obtained during the coincidence measurement. 27 γ-rays are assigned to ^{73}Br based on the $\gamma-\gamma$ coincidence spectrum of this experiment and the halflife measurement of our previous result in 1983. The energies and the relative intensities of these γ-rays are shown in Table 1. Here the intensity of the 336.0 keV γ-ray is normalized as 100%. Errors of the intensities are 3--10%. The results of this work of the γ-ray energies and their relative intensities are in agreement with the previous work

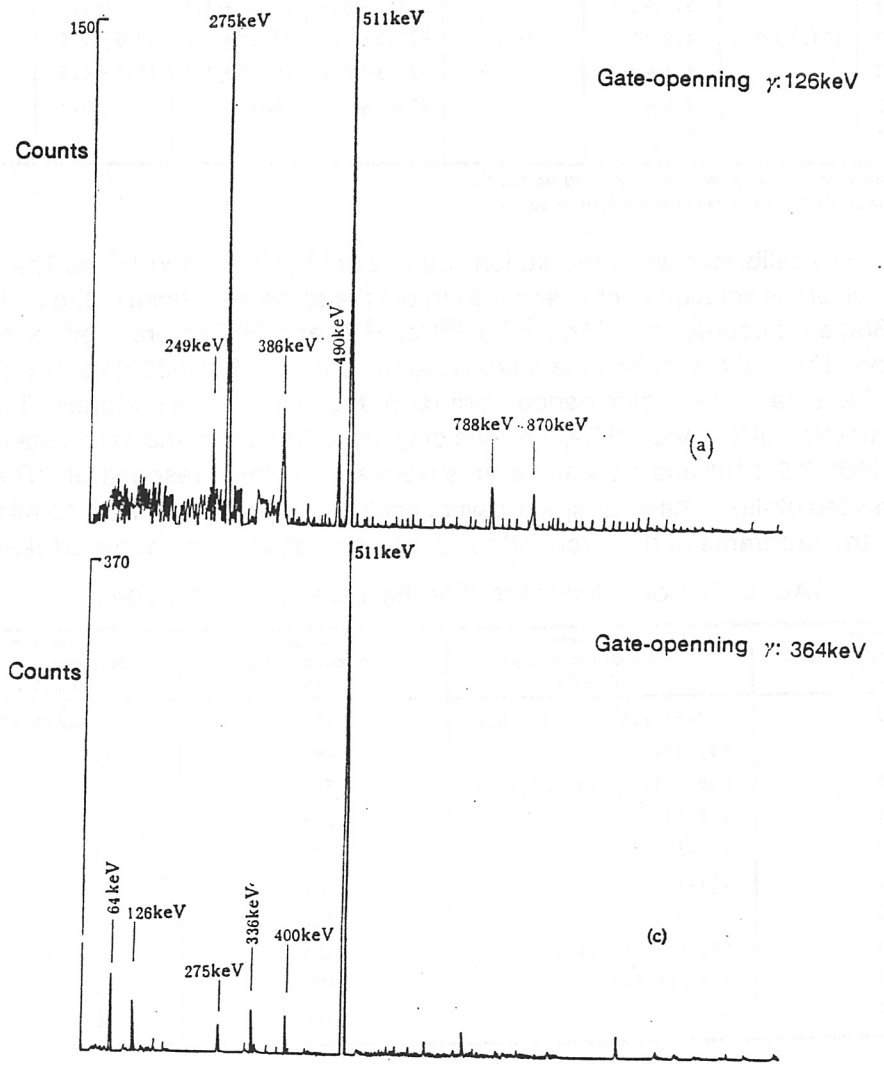

FIGURE 2 Typical coincidence spectra.

except for the 64.7 keV γ-ray. The intensity of the 64.7 keV γ-ray is obtained by subtracting the interference. The intensity of the 166.2 keV γ -ray is determined after subtracting the contribution from ^{67}Ge.

3.2 γ -Ray Transitions and Their Cascade Relationship

Based upon γ-rays energies, the intensities and their coincidence relationship, the level scheme of ^{73}Br is determined and shown in Fig.3. In this work the 25.7 keV transition could not be measured because it is attenuated by the wall of the ^{73}Br source container and because the sensitivity of the Ge(Li) detector for the low energy γ-ray is not high enough. The energy and the intensity of this transition, the spin and the parity of the 25.7 keV level are taken from Ref.[5].

The transitions and the levels measured for the first time in this work are the following:

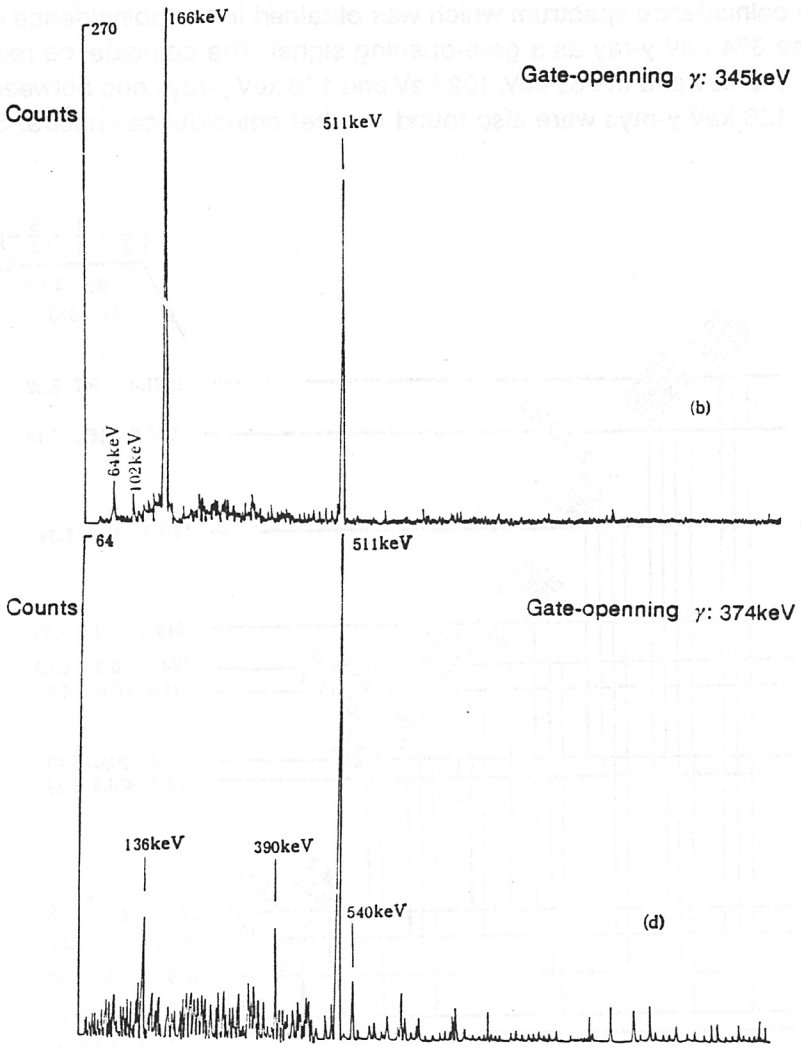

FIGURE 2 Continued.

The 102 keV and 166 keV transitions and 197.4 keV level: a cascade between the 102 keV and 65 keV transitions has apparently been found. The 166 keV transition appeared in this experiment, but a part of it came from the interference of ^{67}Ge (167 keV, 18.3 min), and the other part belonged to ^{73}Br. Its cascade relationship with the 345 keV and 382 keV transitions, which should not appear in ^{67}Ge, was observed in the coincidence spectra. When the part of 167 keV γ-ray from ^{67}Ge was subtracted from this peak, the halflife of the residual part was 3.0 ± 0.4 min. Therefore the 166.2 keV γ -transition does exist in ^{73}Br. Since a cascade between the 102 keV and 166 keV transitions has not been found and the 102 keV transition has a weak cascade relation with the 345 keV and 382 keV γ-rays, it seemed adequate that both the 102 keV and the 166 keV γ-transitions came from the 192.4 keV level.

The 137 keV, 345 keV, and 386 keV γ-rays and the 537.4 keV level: the 137 keV γ-ray exists in the coincidence spectrum which was obtained in the coincidence measurement with the 374 keV γ-ray as a gate-opening signal. The coincidence relationship between the 345 keV and the 65 keV, 102 keV and 166 keV γ-rays and between the 386 keV and the 126 keV γ-rays were also found in other coincidence spectra. Summing

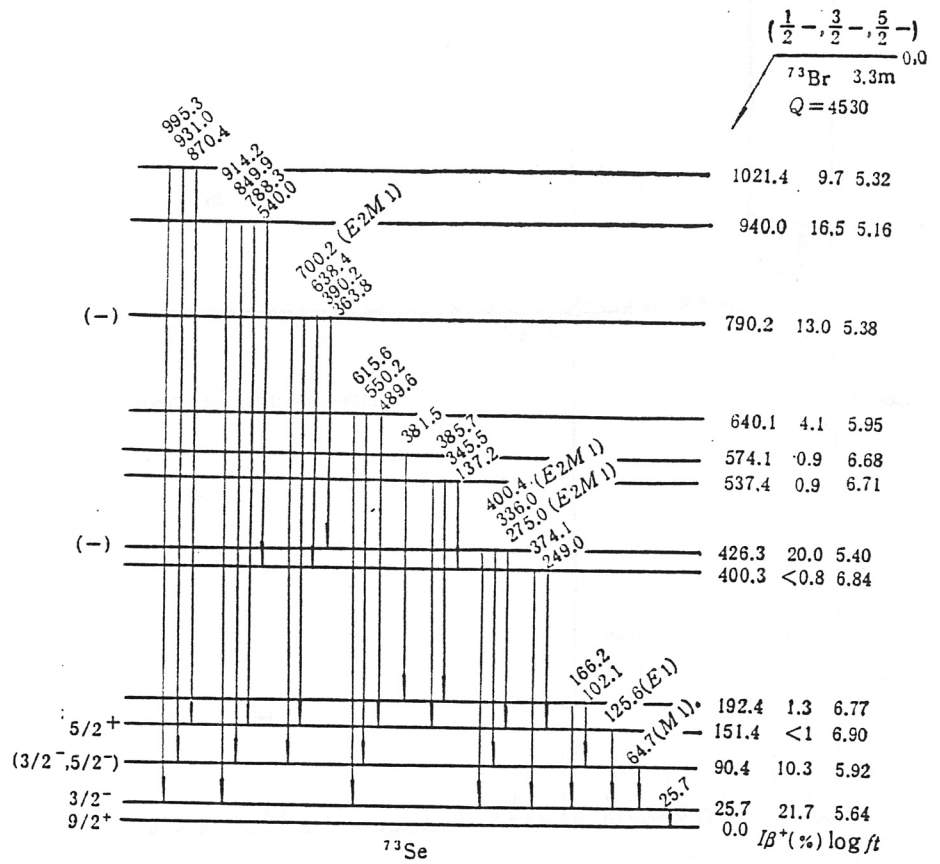

FIGURE 3 ^{73}Br decay scheme.

TABLE 3. β branching ratio and log ft value in ^{73}Br decay.

Level (keV)	$I\beta^+$(%)	log ft	Level (keV)	$I\beta^+$(%)	log ft
25.7	21.7	5.64	537.4	0.9	6.71
90.4	10.3	5.92	574.1	0.9	6.68
151.4	<1	6.90	640.1	4.1	5.95
192.4	1.3	6.77	790.2	13.0	5.38
400.3	<0.8	6.84	940.0	16.5	5.16
426.3	20.0	5.40	1021.4	9.7	5.32

up the corresponding energies, the 537.4 keV level was obtained. The halflife of the 386 keV γ-ray was 2.8 0.8 min.

The 249 keV γ-ray: the 249 keV γ -ray was found in the coincidence spectrum with the 126 keV γ-ray as a gate-opening signal and the 126 keV, 390 keV and 540 keV γ-rays were found in the coincidence spectrum with the 249 keV γ-ray as a gate-opening signal. Therefore the 249 keV transition was between the 400.3 keV and 151.4 keV levels.

The 364 keV and 390 keV γ-rays: The 364 keV and 390 keV transitions were found in the coincidence spectra with the 249 keV and 374 keV and with 275 keV and 336 keV γ-rays as gate-opening signals respectively. It was also found that the cascade relationship exists between the 364 keV and the 336 keV, 275 keV γ—rays and between the 390 keV and the 374 keV, 249 keV γ-rays. The halflives of the 364 keV and 390 keV γ-rays were 3.5 $\pm$ 0.4 min and 3.3 $\pm$ 0.6 min, respectively. Therefore the 364 keV γ-ray was a transition between the 790 keV and the 426 keV levels, and the 390 keV γ-ray was between the 790 keV and the 400 keV levels.

The 382 keV γ-ray and 574.1 keV level: The cascade relationship between the 382 keV and the 166 keV γ-transitions was obtained in the coincidence spectra, and there were 102 keV and 65 keV peaks in the spectrum with gate-opening by the 382 keV γ-ray, whereas there was no 382 keV γ-ray in ^{67}Ge. The halflife of the 382 keV γ-ray was 2.4 $\pm$ 1.0 min. Therefore the 574.1 keV level was established and the 382 keV γ -transition was assigned.

The 862 keV γ-ray: The 862 keV γ-ray was observed in this work. No cascade relation was found in the coincidence spectrum with gate-opening by the 382 keV γ-ray. Its halflife was 1.2 $\pm$ 0.1 min in the work of Ref.[4], and the halflife of ^{72}Br was 1.3 min[6]. There was ^{72}Br in the products of the nuclear reaction in this experiment and it couldn't be reduced by the chemical separation. Besides the intensity of the 862 keV γ-ray relative to those of the other γ-rays of ^{72}Br also match. Therefore it should belong to ^{72}Br. This is different from Mürrag's result in which it was assigned to ^{73}Br.

Nine γ-rays were observed for the first time in this work. Four of them (102 keV, 137 keV, 249 keV and 345 keV) were not measured for halflife due to low counts. They belong to ^{73}Br basically through coincidence relationship. In the three newly-determined levels, maybe the 192.4 keV and the 571.4 keV levels are the same with the 192.4

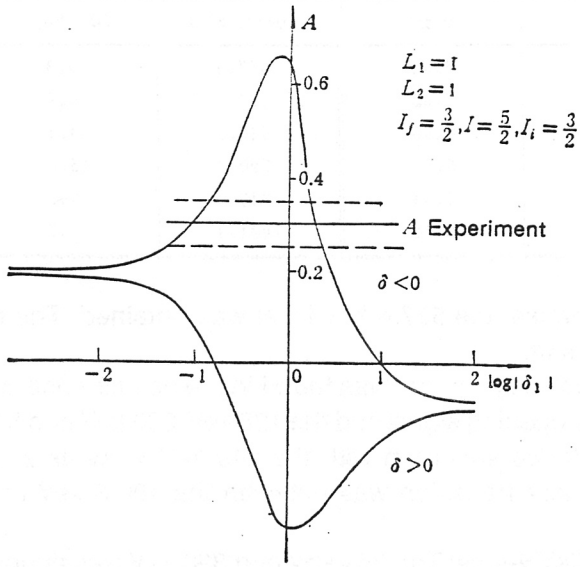

FIGURE 4 Theory A value vs δ curve compared with the experiment A value.

keV and 575.0 keV levels which were observed in the in-beam spectroscopy, but they were now measured in β decay spectroscopy for the first time in this work.

3.3 Q Value of ^{73}Br Calculated from the Mass Table

The Q value of ^{73}Br was calculated from the mass table. It was found to be 4530 keV. The populations of each level were calculated by the intensities of the γ-transitions, and then the β^+-branching ratios and log ft values were obtained with log f value taken from Ref.[8], see Table 3. Conversion factors were considered in the calculation of the population.

3.4 Measurement of Anisotropy A and Inference to the Angular Momenta of the Levels

The angular correlation factors between the 336 keV and the 65 keV, the 700 keV and the 65 keV, the 275 keV and the 126 keV transitions were measured and the anisotropy A-values were found to be 0.306 ± 0.056, 0.495 ± 0.158 and 0.630 ± 0.157 respectively. The angular correlations for other transitions could not give meaningful values because of their weak intensities, low statistics and big errors. It was found that only when $L_2 = 1$ and L_1 was a mixed transition in the cascade between the 336 keV and the 65 keV γ-rays, the experimentally measured A-value has a cross point with the theoretically calculated A vs. δ curve. The typical curve is shown in Fig.4. Therefore it is inferred that if the spin of the 25.7 keV level is 3/2, the spin of the 90.4 keV level seems to be 1/2, 3/2 or 5/2. When $I = 1/2$, the γ-ray will emit isotopically, the angular correlation function should be constant, the anisotropic factor $A = 0$, which is not consistent with the experiment result. Therefore the spin of the 90.4 keV level seems

to be 3/2 or 5/2. Because the ground state's parity of ^{73}Br is negative and log ft = 5.92 for the 90.4 keV level, the 65 keV γ -ray seems to be $M1$ transition. Due to the same reason, the parities of the 426 keV and 790 keV levels seem to be negative. Comparing the measured A-value of the experiment with the theoretical A vs. δ curve, the 336 keV and 700 keV γ-rays seem to be $E2$ + $M1$ mixing transition. Since log ft = 6.9 for the 151 keV levels, its parity seems to be positive, the 126 keV γ -ray seems to be $E1$ transition and the 275.0 keV γ-ray $E2$ + $M1$ mixing transition.

If we compare the low excited states of ^{73}Se with their neighboring isotopes, it is seen that their analogy is not apparent. Hence we hardly know the situation of its deformation. In theory, we know that the structure of the level is influenced by the proton shell more than by the neutron shell. All of the Z = 35 isotopes are of oblate ellipsoidal shape and all of the Z = 38 isotopes are of prolate ellipsoidal shape, but in isotopes with 35 or 38 neutrons they could be either oblate or prolate ellipsoid. ε_2 is calculated for ^{73}Se to be −0.23, therefore it is of oblate shape. However we are short of experimental data to justify this statement.

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