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Short note

Measurement of the lifetime of the first 2^+ state in ^{124}Ba

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Abstract. The lifetime of the first 2^+ state in the nucleus ^{124}Ba has been measured by γ-γ coincidence recoil-distance Doppler shift method. The ^{109}Ag(^{19}F, $4n$)^{124}Ba reaction at a beam energy of 75 MeV was employed to populate excited states in ^{124}Ba. The mean lifetime was determined to be 275(12) ps using the differential decay curve method. The value of $B(\mathrm{E2}; 0_1^+ \to 2_1^+)$ for ^{124}Ba deduced from the lifetime is in reasonable agreement with the prediction of the proton-neutron interacting boson model(IBM-2) without Pauli blocking effect.

PACS. 21.10.Tg Lifetimes – 23.20.-g Electromagnetic transitions – 27.60.+j $90 \leq A \leq 149$

The experimental values of $B(\mathrm{E2}; 0_1^+ \to 2_1^+)$ for the first 2^+ states(2_1^+ states) in the neutron-deficient Xe and Ba nuclei with even mass numbers gradually increase as the neutron number decreases [1,2]. Although the increase was qualitatively described by the proton-neutron interacting boson model(IBM-2), earlier experimental B(E2) values for midshell nuclei were smaller than those of the theoretical predictions, and it was suggested that the Pauli blocking effect had to be taken into account to explain the experimental data [1,3]. Recently, however, Walpe et al. have performed a new measurement of the lifetime of the 2_1^+ state in ^{120}Xe, and reported that the experimental B(E2) values are well reproduced by IBM-2 without Pauli blocking effect [4].

As regards Ba isotopes, Morikawa et al. reported the experimental B(E2) value of 1.35±0.12 e^{2}b^2 for the 2_1^+ state in ^{124}Ba using β-γ delayed coincidence method [3]. However, Raman et al. pointed out that the B(E2) value was largely discrepant with the value of 1.99±0.08 e^{2}b^2 obtained by Sala [2,5]. In order to resolve the discrepancy of the experimental B(E2) values, the lifetime measurement of the 2_1^+ state in ^{124}Ba has been performed by means of γ-γ coincidence recoil-distance Doppler-shift(RDDS) method.

The excited states of the nucleus ^{124}Ba were produced through the ^{109}Ag(^{19}F,$4n$)^{124}Ba reaction at a bombarding energy of 75 MeV. The ^{19}F beam was provided by the 12UD tandem accelerator at the University of Tsukuba. Gamma rays were detected with seven Compton-suppressed HPGe detectors. Four detectors were placed at an angle of 116.5°; two detectors were mounted at 63.5°; and one of the detectors was set at 0° with respect to the beam. The relative efficiencies and energy resolutions for all Ge detectors were around 40 % with respect to $3^{\mathrm{in}} \times 3^{\mathrm{in}}$ NaI and 2.0 keV at 1333 keV, respectively. The energy scale of the γ-ray detectors was calibrated with standard sources of ^{60}Co and ^{152}Eu. The ^{109}Ag target was a 0.5 mg/cm^2 thick stretched self-supporting foil prepared by vacuum evaporation. The enrichment of ^{109}Ag was as high as 99.4 %. A stretched natural Pb foil of 57 mg/cm^2 in thickness was used for the stopper. The target and the stopper were mounted in a plunger. The recoiled nuclei and the incident beam were stopped in the stopper. Gamma-gamma coincidence spectra were observed at six target-to-stopper distances between 427 and 1427 μm. The mean velocity of recoiled nuclei was evaluated to be $v/c = 1.35(3)$ % from the energy separation between the Doppler-shifted and unshifted peaks of the 230 keV γ ray of $2_1^+ \to 0_1^+$ transition observed with the detector at 0°.

The analysis of the RDDS γ-γ coincidence spectra was performed for the lowest cascade in ^{124}Ba. The energy of the upper $4_1^+ \to 2_1^+$ transition is 421 keV, while that of the lower $2_1^+ \to 0_1^+$(ground state) is 230 keV. The differential decay curve method(DDCM)[6] was employed to determine the lifetime of the 2_1^+ state. The mean lifetime of the 2_1^+ state can be obtained from the following relation;

$$\tau = \frac{I_{u,s}(x)}{I_{s,s}(x+\Delta x) - I_{s,s}(x-\Delta x)} \frac{2\Delta x}{v}, \qquad (1)$$

where x stands for the distance between the target and the stopper, Δx is a small displacement from x, v is the veloc-

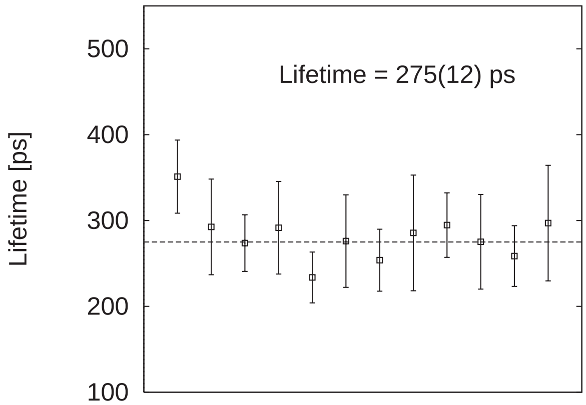

Fig. 1. The results of the DDCM analysis. The abscissa does not express any physical quantity, but just corresponds to the combination of x and Δx in (1) in the text

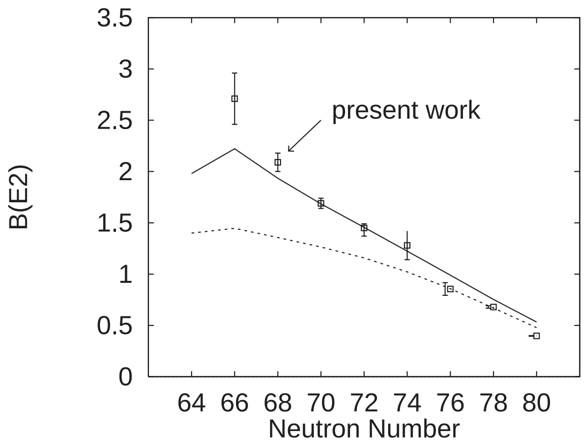

Fig. 2. $B(\mathrm{E2};0_1^+ \to 2_1^+)$ values for Ba isotopes. The IBM-2 calculations without and with the Pauli blocking effect are shown by *solid* and *dotted line*, respectively. The data other than ^{124}Ba are taken from [3,9,10,12,13]

ity of recoiled nuclei, $I_{u,s}(x)$ in the numerator is the intensity of the Doppler-unshifted γ ray for the $2_1^+ \to 0_1^+$ transition observed in coincidence with the Doppler-shifted component of the $4_1^+ \to 2_1^+$ transition, and $I_{s,s}$ in the denominator are the coincidence yields for Doppler-shifted components in both $4_1^+ \to 2_1^+$ and $2_1^+ \to 0_1^+$ transitions. In the present experiment, six detectors placed at 63.5° and 116.5° resolved the Doppler-shifted peak from unshifted peak for the $4^+ \to 2^+$ transition(ΔE_γ=2.5 keV for 421 keV), but not for the $2^+ \to 0^+$ transition(ΔE_γ=1.4 keV for 230 keV). Thus, coincidence matrices produced between the 0° detector and other six detectors were used to obtain the yields $I_{u,s}$ and $I_{s,s}$ in (1).

The 230 keV photopeak of the $2_1^+ \to 0_1^+$ transition may be contaminated with the high-lying 231 keV $6^- \to 5^-$ transition. However, the intensity is less than 3.4 % of the lowest 230 keV transition [7]. The 6^- state is located at an excitation energy of 2497 keV, and it is not reported as an isomeric state. If the lifetime of the 6^- state is shorter than 100 ps, the unshifted peak of the 231 keV cannot be observed over the whole range of the present target-to-stopper distances. Therefore, the contamination of the 231 keV $6^- \to 5^-$ transition was ignored.

The mean lifetimes obtained from the DDCM analysis for various combinations of the target-to-stopper distances is shown in Fig. 1. The weighted mean values was calculated to be $\tau = 275(12)$ ps. For comparison with theoretical calculations, the $B(\mathrm{E2};0_1^+ \to 2_1^+)\uparrow$ was deduced from the following formula;

$$B(\mathrm{E2};0_1^+ \to 2_1^+)\uparrow = \frac{40.81\times10^{13}}{(1+\alpha)(E_\gamma[\mathrm{keV}])^5\,\tau[\mathrm{ps}]} \quad [\mathrm{e}^2\mathrm{b}^2]. \tag{2}$$

Using a calculated value of internal-conversion coefficient $\alpha = 0.109$, the value of $B(\mathrm{E2};0_1^+ \to 2_1^+)\uparrow$ was obtained to be 2.09(9) [e^{2}b^2]. This value is in good agreement with B(E2) obtained by Sala [5].

The discrepancy between the present B(E2) value and that obtained by the β-γ delayed coincidence method could be discussed in the following way. The parent nucleus ^{124}La decays not only from a low-spin β-unstable state but from a high-spin β-unstable state with $I^\pi = (7^-$ or $8^-)$ [8]. The branching ratio of the β decay from the high-spin state is 82 %, so that many states in ^{124}Ba with spins higher than $2\hbar$ are populated. Since the energy selection for β^+ rays was not made in the delayed coincidence in [3], the coincidence yield involved large contribution from decay paths other than $\beta^+ \to 2_1^+ \to 0_1^+$. In this experimental condition, a proper correction for the lifetimes of high-lying states would be very difficult.

The experimental $B(\mathrm{E2};\,0_1^+ \to 2_1^+)$ values for Ba isotopes are plotted as a function of the neutron number in Fig. 2. Here the B(E2) values calculated with the IBM-2 code NPBOS[11] are compared with the data. We used the same values of the parameters as those in [1] except the quadrupole force strength $\kappa_0 = -0.3$ MeV. Fig. 2 shows that the experimental B(E2) values except for ^{122}Ba are in reasonable agreement with the calculations without Pauli blocking effect.

In summary, the lifetime of the 2_1^+ state in ^{124}Ba was measured by RDDS method. The systematic trend of $B(\mathrm{E2};0_1^+ \to 2_1^+)$ values for even Ba isotopes from ^{124}Ba to ^{136}Ba is well reproduced by the IBM-2 calculations without Pauli blocking effect.

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