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Lifetime Measurements of the yrast states in ^{86}Zr

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Abstract

The existing experimental values of the ratios $B_{4/2}$=B(E2:$4_1^+ \rightarrow 2_1^+$) / B(E2:$2_1^+ \rightarrow 0_1^+$) and $B_{6/4}$ = B(E2:$6_1^+ \rightarrow 4_1^+$) / B(E2:$4_1^+ \rightarrow 2_1^+$) in ^{86}Zr are less than unity. From the point of view of the collective models, this is an anomaly. However, the existing lifetimes of the yrast 2^+, 4^+ and 6^+ states in ^{86}Zr were measured with plunger experiments performed in singles, therefore it can be suspected that they represent only some effective values. Moreover, for the 8^+ state from the same plunger experiments two values are reported that differ by about 50% (lifetimes of 62 and 90 ps, respectively). We propose to re-measure, more precisely, the lifetimes of these yrast states with both the Differential Decay curve plunger technique and the fast-timing technique, using the ROSHPERE array, and thus solve the puzzle of the (apparently) unusual B(E2) values in this nucleus.

1. Introduction

The situation with the ^{86}Zr nucleus is similar to that of ^{134}Ce, for which a proposal of experiment to re-measure the lifetimes of the yrast 2^+, 4^+ and 6^+ states was submitted to this committee in 2012 (the experiment was performed and the data are being evaluated) [1,2]. There are two independent experimental measurements of the lifetimes of the yrast 2^+, 4^+ , 6^+ and 8^+ states in ^{86}Zr [3,4], and the ENSDF adopted B(E2) values are the following [4]: B(E2:$2_1^+ \rightarrow 0_1^+$) = 13(3) W.u.; B(E2:$4_1^+ \rightarrow 2_1^+$) = 8(4) W.u.; B(E2:$6_1^+ \rightarrow 4_1^+$) = 2.9(12) W.u.; B(E2:$8_1^+ \rightarrow 6_1^+$) = 5.5(7) W.u. Thus, we obtain for this nucleus the following ratios: $B_{4/2}$ ≡ B(E2:$4_1^+ \rightarrow 2_1^+$) / B(E2:$2_1^+ \rightarrow 0_1^+$) = 0.62(34) and $B_{6/2}$ ≡ B(E2:$6_1^+ \rightarrow 4_1^+$) / B(E2:$2_1^+ \rightarrow 0_1^+$) = 0.22(10). Notwithstanding the large errors of the B(E2) values and of the resulting B(E2) ratios, it is striking that both $B_{4/2}$ and $B_{6/2}$ values are smaller than 1. As observed in [1,2] this is rather unexpected for a nucleus which is not so close to magic numbers:

Table 1: Yrast B(E2) ratios for various models (from [1])

	Harm Vib.	U(5)$^{a)}$	O(6)$^{a)}$	Rotor	SU(3)$^{a)}$	E(5)	X(5)
$B_{4/2}$	2	1.71	1.34	1.43	1.37	1.67	1.60
$B_{6/2}$	3	2.14	1.41	1.56	1.39	2.21	1.98

$^{a)}$ N_B = 7, corresponding to ^{86}Zr is used for these three IBA predictions

With a ratio R(4/2)=E(4_1^+)/E(2_1^+) = 2.22, our nucleus appears as close to the vibrator limit. Indeed, it is known that decreasing the neutron number from 50 towards 40, the Zr nuclei become transitional and the N=Z nucleus ^{80}Zr reaches a value of 2.86, close to the value for the X(5) critical point of the U(5) to SU(3) transition. Therefore, the anomaly $B_{4/2}$<1 has to be examined with much care, and, first of all, by new experimental measurements, as it is of utmost importance to understand how the collectivity develops in this isotopic chain. Figure 1 (taken from [1] and slightly adapted) shows the systematics of B(E2) values for the 2^+ and 4^+ states of all even-even nuclei for 40≤Z≤80 (except N=50 and 82). This figure highlights a small set of nuclei with $B_{4/2}$ < 1. Most of these nuclei have a P=factor (P= N_pN_n / (N_p+N_n)) larger than 2, therefore are collective nuclei. As commented in [1], for three nuclei, ^{98}Ru, ^{180}Pt and ^{144}Nd, for which until recently the $B_{4/2}$ value was smaller than 1, this value moved above 1 after recent measurements (the red symbols above 1). Also, our plunger measurements for ^{134}Ce (preliminary results [6]) move this nucleus into the 'normal' region $B_{4/2} > 1$ [2].

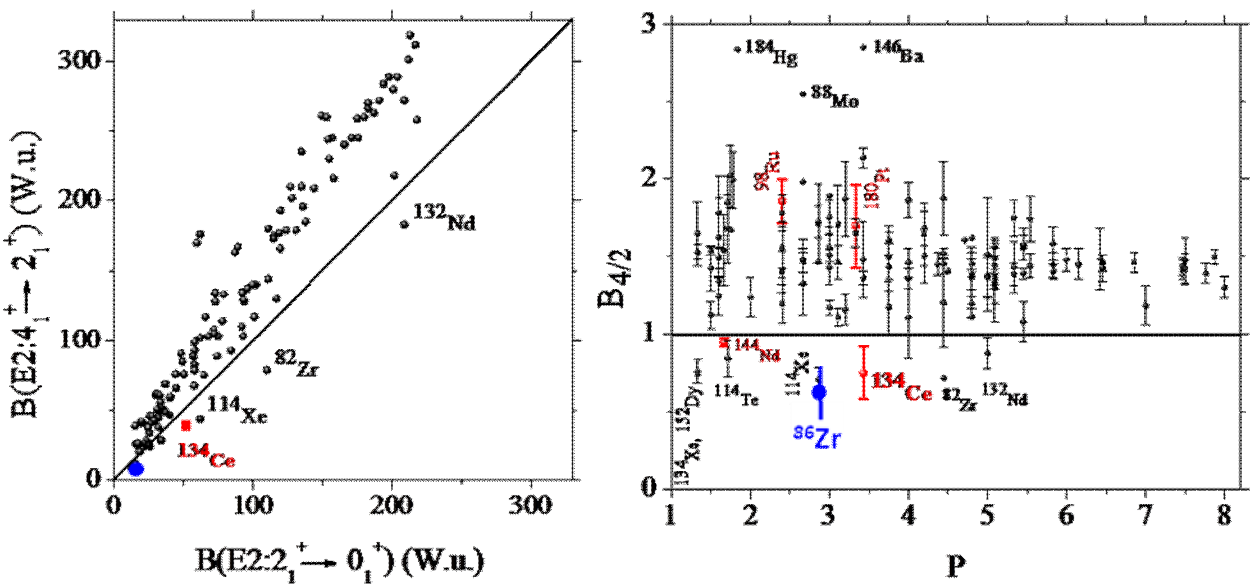

Figure 1 : Left: $B(E2{:}4_1^+ \rightarrow 2_1^+)$ as a function of $B(E2{:}\ 2_1^+ \rightarrow 0_1^+)$ for $40 \leq Z \leq 80$ (except for magic nuclei) [1,2,5]. The diagonal line corresponds to $B_{4/2} = B(E2{:}4_1^+ \rightarrow 2_1^+) / B(E2{:}\ 2_1^+ \rightarrow 0_1^+) = 1$. Right: $B_{4/2}$ against the P factor. ^{86}Zr is shown with blue symbol. The nucleus ^{134}Ce is still shown with $B_{4/2} < 1$, but the recent Bucharest measurements move it above 1 [2], as it is also the situation with the nuclei ^{98}Ru, ^{180}Pt and ^{144}Nd, which moved up in $B_{4/2}$ values with more recent B(E2) measurements (also shown in red).

Figure 1 shows that ^{86}Zr is left as one of the very few anomalous cases. This situation may look strange for a nucleus with a relatively large number of valence nucleons (10 proton holes and 4 neutron holes). On the other hand, this nucleus may be one with a weakly collective structure based on shell-model excitations at low energies, as suggested in Ref. [4]. The present proposal of experiment aims at solving this puzzle.

A critical overview of the previous experiments [6] in which the lifetimes of these yrast states (up to 8^+) were measured: there are two such experiments, our experiment in 1978 [3], and in 1998 [4], both with the recoil distance (plunger) technique. The reported half-lives are shown in Table 2. A third plunger experiment [7] reports lifetimes for higher spin states, including the 8^+ state, for which a lifetime consistent with that of ref. [3] is given.

Table 2. Half-lives $T_{1/2}$ (in ps) from the previous (singles) plunger experiments [3,4]

State	Ref. [3]	Ref. [4]
2^+	7.3(14)	7.8(19)
4^+	6.0(27)	5.4(24)
6^+	8(4)	8.5(34)
8^+	62(6)	46(6)

Within the (large) errors, the values from the two experiments up to the 6^+ state agree with each other. One should emphasize, nevertheless, that *both experiments are singles experiments*, therefore subject to large errors and sensitive to the side feeding lifetimes. The difference between the two measurements for the 8^+ state value is more important. In ref. [4] it is stated that omission of distances larger than 2 mm gives a half-life of about 65 ps ! (in our experiment (ref. [3]) the largest measured distance was 1.6 mm , while in [7] it was 0.4 mm).

In the proposed experiment, the plunger measurements will be made in the coincidence mode, that is, we will apply the DD-RDM (differential decay RD method) [8], therefore the determined lifetimes will be more exact, as the feeding problems will be avoided. Second, as we use ROSPHERE, with 14 HPGe detectors in the backward and forward rings, and 11 $LaBr_3{:}Ce$ detectors around the 90^{o} ring, the lifetime of the 8^+ state will be independently measured with the fast-timing method [9].

2. Proposed experiment

The experiment will use the ROSPHERE array and the Bucharest Köln-type plunger device, therefore *both the DD-RDM and fast-timing methods will be used to determine the lifetimes of the yrast states in ^{86}Zr*. We will use, as in ref. [3], the fusion-evaporation reaction ^{73}Ge(^{16}O,3n)^{86}Zr reaction at 52 MeV. The target will be 73Ge of about 0.5 mg/cm^2, evaporated on ~ 2mg/cm^2 Ta or Au backing.

The experiment will be run at 52 MeV (see the CASCADE predictions for the cross section in Fig. 3). At this energy, the velocity of the recoil nuclei will be around 0.0137c [3].

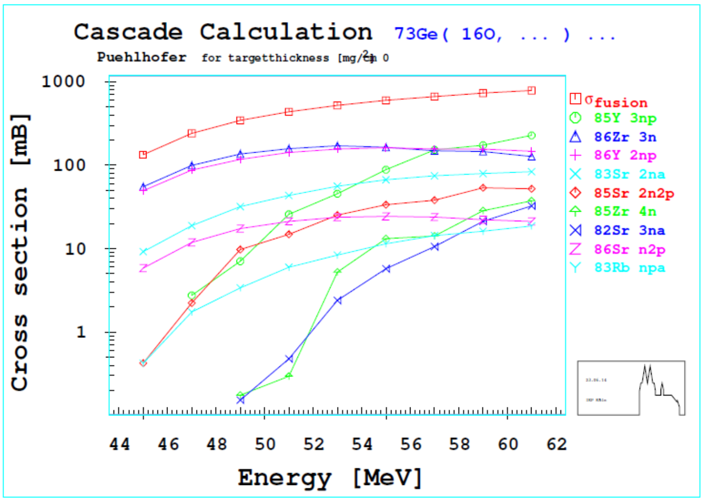

Figure 3 : Cross section results from the Cascade program for ^{16}O beam and ^{73}Ge target.

The level scheme with the states of interest is shown in Fig. 4. Some other lifetimes measured in Refs. [4,7] can also be verified through the DD-RDM approach.

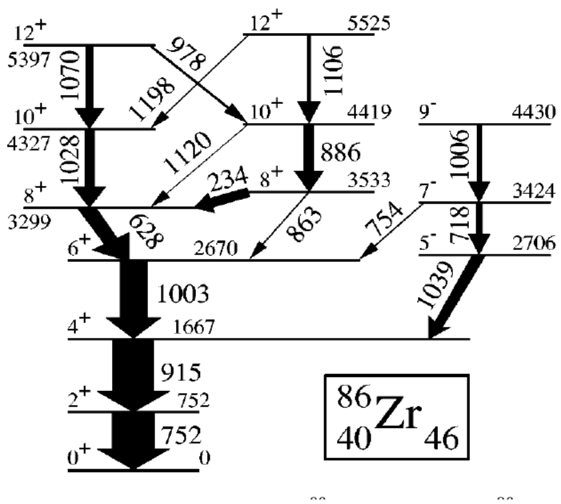

Figure 4 : The level scheme of interest for the present experiment [3,4,6,7].

3. Beam time request

The Differential Decay curve recoil distance method [8] implies setting gates on the shifted component of transitions populating the level of interest, thus requiring a high level of statistics for each distance. With a 0.5 mg/cm2 target, a 2 pnA beam of ^{16}O, and a production cross section of 100 mb (Fig. 2), we produce about 5000 ^{86}Zr nuclei per second. With a typical efficiency of the HPGe detectors of ~1% for the gamma rays of interest (Fig. 4), we will get around 2000 counts per hour for a two gamma-ray cascade, therefore we estimate that good statistics γ-γ coincidence spectra for one distance can be obtained in runs of about 20 hours. As we need to measure 10 distances between 0 and 150 µm, we ask for **9 days of beam time.** This should also provide enough statistics for the fast-timing measurement of the lifetime of the 8$^+$ state.

In conclusion, this experiment is proposed to confirm or revise what we now think may be an anomaly in the B(E2) values of the yrast 2^+, 4^+ and 6^+ states of ^{86}Zr. This will be achieved by performing plunger measurements in the γ-γ coincidence mode. Use of the fast-timing technique in the same experiment will allow to independently measure a precise value for the lifetime of the 8^+ yrast state.

As a by-product, some lifetimes of excited states in ^{86}Y [10,11] may be measured for the first time.

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