Evidence for inversion of 0^+ phonon states and γ softness in ^{134}Ba†

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The γ-ray spectra of ^{134}La have been studied by γ-singles and γ-γ Ge(Li) spectroscopy. The γ-ray decay of the low lying 0^+ levels has been used to suggest that, because of softness toward γ deformation, the lowest 0^+ excited state in ^{134}Ba, with $B(E2; 0^+ \to 2_2^+/0^+ \to 2_1^+) = 28$, arises from the $N = 3$ phonon state. This is shown to be qualitatively consistent with calculations of transitional nuclei.

[RADIOACTIVITY $^{134}Ce \to {}^{134}La$, mass-separated, equilibrium sources, measured E_γ, I_γ, deduced ^{134}Ba levels.]

A number of recent papers have employed the use of the triaxial rotor-particle (TRP) coupling model, to account for the negative parity levels observed in nuclei such as ^{133}La.[1,2] In doing so, the required values of the parameters have suggested a large degree of γ softness ($\gamma \approx 28°$). If this is true, then the core nucleus (in the La case, the barium nuclei) ought to exhibit properties that are concomitant with γ softness. Few tests to prove this are possible; however, one of them is the requirement that the 0^+ state from the third phonon ($N = 3$) drops below the 0^+ state from the second phonon,[3,4] as illustrated in Fig. 1. The γ-ray decay of such a state would be expected to predominately populate the second phonon 2^+ level instead of the first phonon 2^+ level.[5] Also, a relatively large

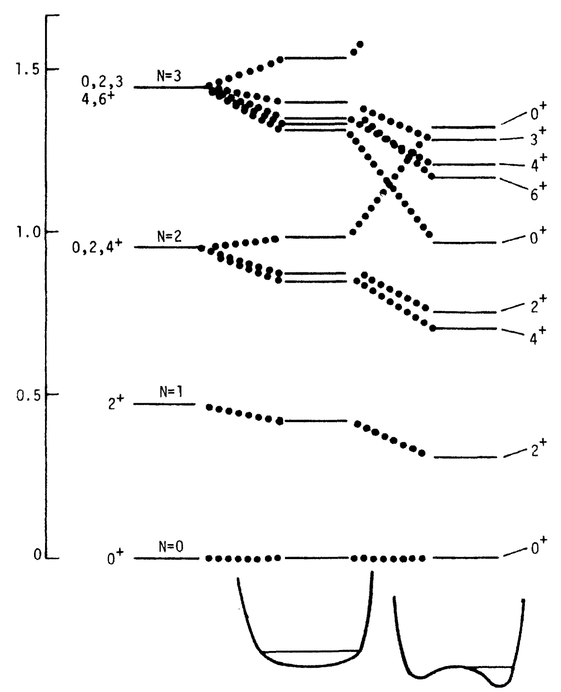

FIG. 1. Levels of even-even nuclei arising from (left to right) a spherical harmonic vibrator, a slightly anharmonic vibrator, and a γ-soft vibrator (these are taken from the results of Refs. 3 and 4).

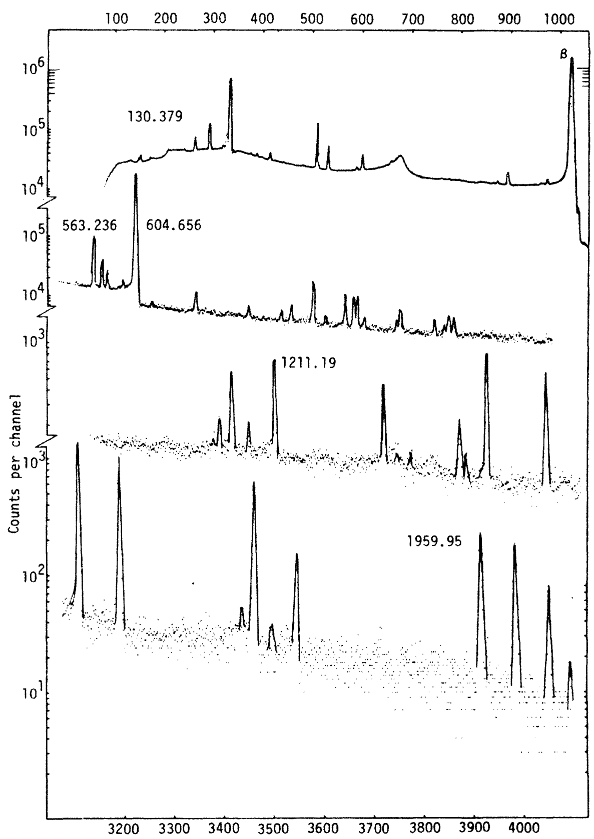

FIG. 2. Compton suppression spectra of a mass-separated $^{134}Ce \to {}^{134}La$ equilibrium source.

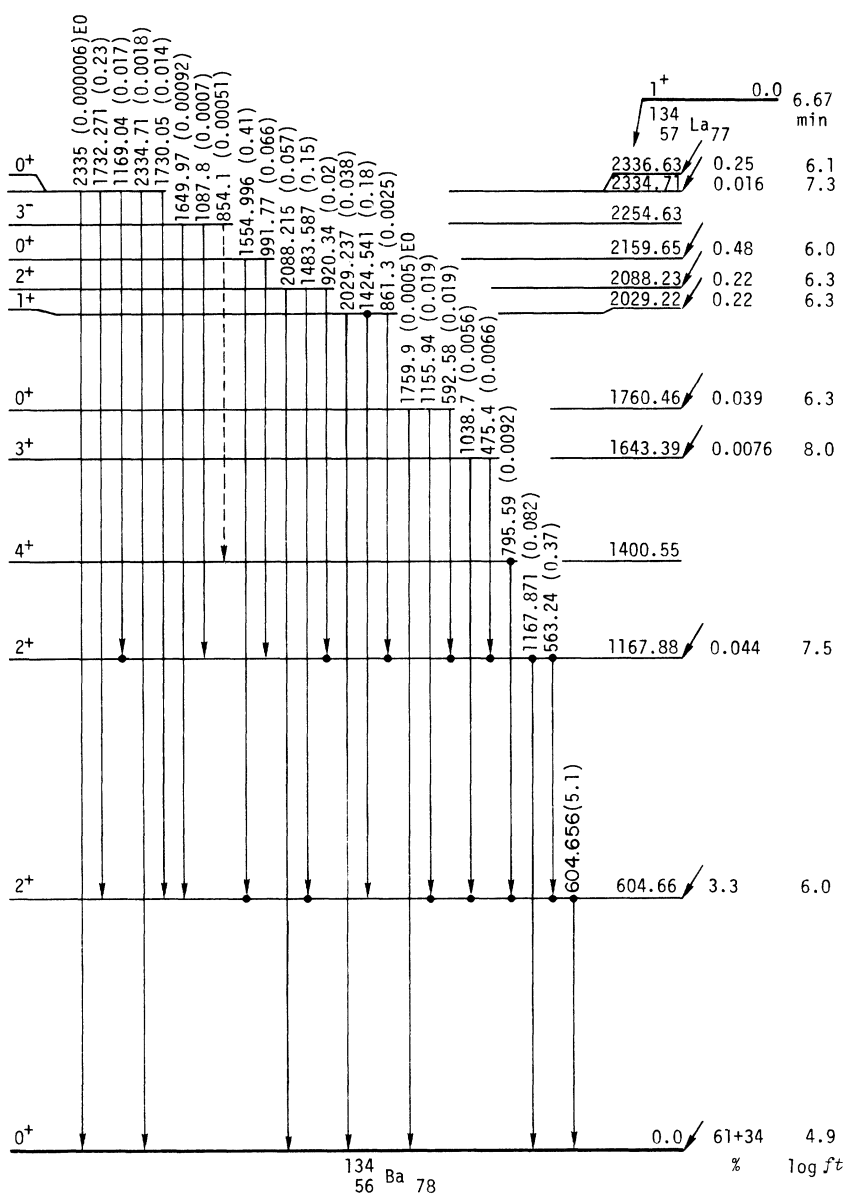

FIG. 3. Parital decay scheme of ^{134}La (see text; the numbers on the far right of the levels are the log*ft* values for the populations of the corresponding levels).

*E*0 transition to the ground state might be expected, since this state in a permanently deformed nucleus becomes the β bandhead, which has the property of a large, *E*0 ground-state, deexcitation mode. However, no such state has been identified in the even-even barium nuclei to date. Here, we wish to identify the 1760-keV level in ^{134}Ba as such a state.

In their conversion electron studies, Alexsandrov *et al.*[6] identified an *E*0 transition in the decay of ^{134}La at 1760 keV. In addition, they placed a 1156-keV γ ray as decaying to the 604-keV level. This was used to identify a 0^+ level at 1760 keV. In our γ-ray studies, we have shown that a 592.58-keV γ ray is in direct coincidence with the 1167- and 563-keV γ rays that depopulate the known 2^+ level at 1167.88 keV. These data were reported in preliminary form,[7] and the consequences of the 592.58-keV γ-ray placement were discussed earlier.[8] Our complete γ-ray data are available elsewhere.[9]

The ^{134}La sources were prepared by the ^{134}Ba$(\alpha, 4n)^{134}$Ce reaction on enriched ^{134}Ba targets. After bombardment in the 223.5-cm cyclotron

(Lawrence Berkeley Laboratory), the targets were chemically processed and the cerium fraction was mass-separated at the isotope separation facility of the Radiochemistry Division at the Lawrence Livermore Laboratory. The ^{134}Ce sources with a 74 h half-life provided equilibrium sources of 6.67-min ^{134}La. The sources were measured on a variety of Ge(Li) detectors, including a Compton suppression spectrometer (spectra are shown in Fig. 2). One of the sources was transported by air freight to the University of Maryland, where γ-γ coincidence spectroscopy was performed.

The results of our studies are shown in Fig. 3. Filled circles at the bottom of the arrows represent placement of the γ ray by coincidence relationship. Filled circles at the top of the arrows signify that a coincidence gate has been set at that energy. The γ-ray intensities, as well as the β intensities to the right of a level, are given per 100 decays of ^{134}La. The amount of ground-state feeding was taken from *Nuclear Data Sheets*.[9]

We have compared the decay properties of the ^{134}Ba levels populated in ^{134}Cs decay elsewhere.[10] They agree well with the calculations of Rohozinski, Srebrny, and Horbaczewska.[5] In addition, we concluded that the 1969-keV level was not their (0 3 4) state. Instead, it was predominately the two quasineutron $(d_{3/2}d_{5/2})$ configuration.

We suggest that the lowest 0^+ excited level at 1760 keV in ^{134}Ba is consistent with the calculations of Gneuss, Mosel, and Greiner,[3,4] in that the lowest 0^+ level expected in a γ-soft nucleus arises from the third phonon rather than from the traditionally expected second phonon. The relative transition probability ratio of $B(E2)[0_1^+ \to 2_2^+]/B(E2)[0_1^+ \to 2_1^+] = 28$ for the γ-ray decay of the 1760-keV 0^+ level is consistent with such a description.

We conclude that, in general, the properties of the collective levels of ^{134}Ba are consistent with the nucleus being soft toward γ deformation, and that the properties of the lowest lying 0^+ excited state qualitatively agree with this description. However, detailed calculations that allow the mixing of β and γ degrees of freedom are necessary, before any quantitative agreement can be expected. The calculations of Rohozinski *et al.*[5] do not agree too well with the experimental values for this level.[10] However, they do not allow mixing of the β and γ degrees of freedom, which is to be expected. Further, as mentioned earlier, this state is expected to have some properties of a quasi-β band. The 0^+ level arising from the $N = 2$ phonon is difficult to identify, since it is expected to rise in energy above the pairing gap. It should possess a relatively large $E0$ ground-state transition. The only other low lying 0^+ levels that have been identified are at 2159 and 2336 keV. The former has no observable ground-state $E0$ transition that depopulates it, while the latter has a very low intensity $E0$ transition to the ground state.

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