

THE LEVEL SCHEME OF ^{134}Ba

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Abstract: The gamma-ray spectrum associated with the beta decay of ^{134}Cs has been studied with curved-crystal and Ge(Li) spectrometers. The data provide energy and intensity measurements of 11 gamma rays. Coincidence spectra were taken using a Ge(Li)-NaI(Tl) combination. The data fail to support the previously proposed levels at 1570 and 1773 keV.

E

RADIOACTIVITY ^{134}Cs [from $^{133}\text{Cs}(n, \gamma)$]; measured E_γ , I_γ , $\gamma\gamma$ -coin.
 ^{134}Ba deduced levels. Natural target.

1. Introduction

Although the beta decay of ^{134}Cs has been studied extensively ¹⁻²⁶, there are several discrepancies in the ^{134}Ba level schemes proposed by the various authors.

In the past curved-crystal spectrometer studies have demonstrated their value by resolving low-energy transitions not readily seen with standard spectroscopy techniques – a feature which can be used to good advantage in searches for “missing” low-energy members of incomplete cascades. Since several of these cases occur in the proposed level schemes for ^{134}Ba it was felt that a curved-crystal spectrometer study would be desirable. Such a study has not been presented in the literature. Also, coincidence work using a NaI(Tl)-Ge(Li) combination has not been previously reported. It was felt that this combination of detectors could provide better coincidence data than previously available from NaI(Tl)-NaI(Tl) combinations and possibly lead to a better understanding of the ^{134}Ba level scheme.

2. Experimental arrangements

All energy measurements reported in this paper were taken on the University of Michigan 2m curved-crystal spectrometer utilizing the Ge(022) planes as diffraction planes. This spectrometer and the experimental techniques associated with it have been described previously ²⁷⁻²⁹. The curved-crystal spectrometer source was a CsCl-epoxy mixture irradiated for a period of 36 weeks in the University of Michigan Ford Nuclear Reactor (thermal neutron flux $\approx 3 \times 10^{13}$ neutrons/sec \cdot cm²). The activity of the sample was about 0.4 Ci. The energy resolution of the spectrometer

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using this particular source was $\Delta E(\text{FWHM}) = (2.7 \times 10^{-5})(E^2/n)$ keV, where n is the order of reflection and E the gamma-ray energy in keV. Measurements were made in reflection orders appropriate to the intensity of the line measured. This varied from first-order for the weak 243 and 327 keV lines to fourth-order for the strong 605 keV line; to separate the 796, 802 keV doublet it was necessary to go to fifth order. Each reported energy value is the average of at least three measurements.

The Ge(Li) detector used for the intensity measurements was an Ortec $4 \text{ cm}^2 \times 5$ mm. The associated electronics consisted of a Tennelec TC130 pre-amplifier, a Tennelec TC200 amplifier and a Scipp 1600-channel analyser. The resolution (FWHM) of this system was about 3.4 keV at 605 keV. A description of the efficiency calibration of the system is to be published³⁰). The source used in the present intensity measurements was prepared in the same manner as those used in the efficiency calibration; a small drop of radioactive CsCl in HCl solution (obtained from Oak Ridge National Laboratory) was allowed to dry on a lucite disk. The disk was then mounted in a lucite holder which permitted the source-detector distance to be varied. To check on possible summing in the singles spectrum, eight runs were taken at source-detector distances varying from 1 cm to 65 cm.

The total spectrum channel of the coincidence system consisted of an Ortec $8 \text{ cm}^2 \times 5$ mm Ge(Li) detector coupled to a Tennelec TC130 pre-amplifier and a Tennelec TC200 amplifier. The gate channel consisted of a Harshaw $7.6 \text{ cm} \times 7.6 \text{ cm}$ NaI(Tl) crystal (integral mount) connected directly to a Sturupp 1410 amplifier. The resolution of the Ge(Li) channel was 5 keV at 796 keV; the resolution of the NaI(Tl) channel was 67 keV at 796 keV. The remainder of the coincidence system consisted of Sturupp 1435 timing single-channel analysers and a Sturupp 1441 fast coincidence unit. The spectra were recorded on a Nuclear Data 1024-channel analyser. Data were taken in the cross-over timing mode. Double delay line shaped pulses were used for timing. These pulses were obtained from the Sturupp 1410 amplifier and, by a suitable arrangement, from the Tennelec TC200 amplifier. Due to the high count rate, double differentiated pulses were sent to the multi-channel analyser. Resolving curves using a ^{22}Na source were run for resolving times of 1 μsec and 50 nsec. Both curves were flat-topped and the same height, implying that the coincidence efficiency was constant over a wide range of resolving times. Since no quantitative measurements were anticipated, we made no attempt to determine the absolute coincidence efficiency of the system, although we estimate it to be greater than 90% for a resolving time of 50 nsec. All coincidence runs reported in this paper were taken at a resolving time of 50 nsec. Using this coincidence arrangement and gating a 10% energy region with the NaI(Tl) detector there was less than 5 nsec shift in the resolving curve for a $15 \times$ gain change in the total spectrum channel. The source used in these runs was prepared in the same manner as the one used in the intensity measurements. The true-to-chance ratio using this source was greater than 20.

3. Results

The results of the energy and intensity measurements are presented in table 1. The intensity values were computed on the assumption that the sum of the intensities

TABLE 1
Energies and intensities of transitions in the decay $^{134}\text{Cs} \xrightarrow{\beta} ^{134}\text{Ba}$

Energy (keV)	Intensity (% of total decay) ^{a)}
242.694 ± 0.041	0.02 ± 0.01 ^{b)}
326.512 ± 0.095	0.02 ± 0.01 ^{b)}
475.355 ± 0.038	1.51 ± 0.16
563.325 ± 0.041	8.96 ± 0.84
569.371 ± 0.047	15.81 ± 1.1
604.744 ± 0.027	98.04
795.806 ± 0.050	87.79 ± 6.6
801.86 ± 0.28	8.94 ± 0.8
1038.61 ± 0.49	1.02 ± 0.08
1167.99 ± 0.39	1.96 ± 0.22
1365.08 ± 0.32	3.25 ± 0.32

^{a)} The intensity values reported were computed on the assumption that the sum of the intensities of the 605 keV and 1168 keV transitions is 100 %.

^{b)} Values obtained from the curved-crystal spectrometer work.

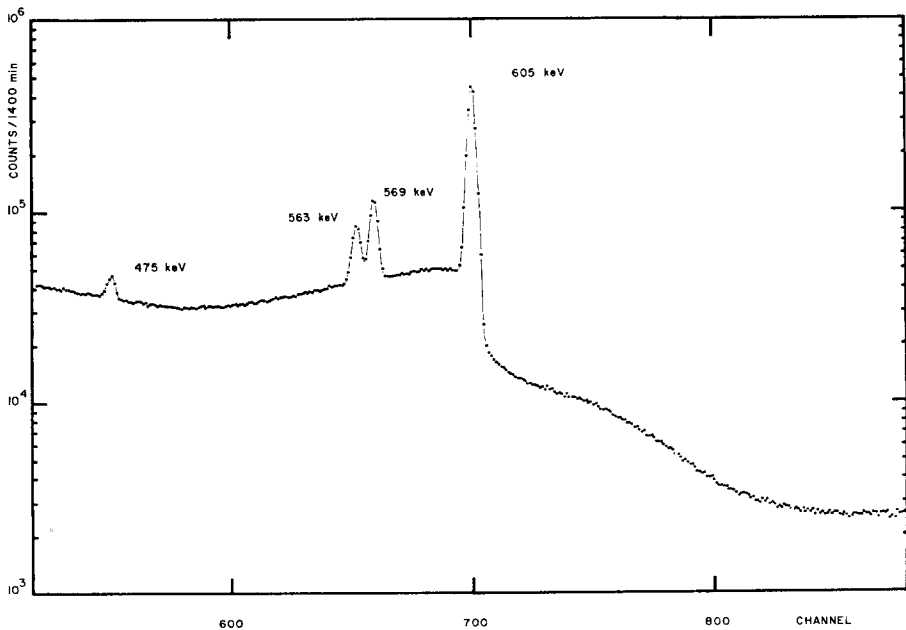


Fig. 1. (a) Gamma-ray spectrum of ^{134}Cs from 450 keV to 765 keV observed with a $4 \text{ cm}^2 \times 5 \text{ mm}$ Ge(Li) spectrometer.

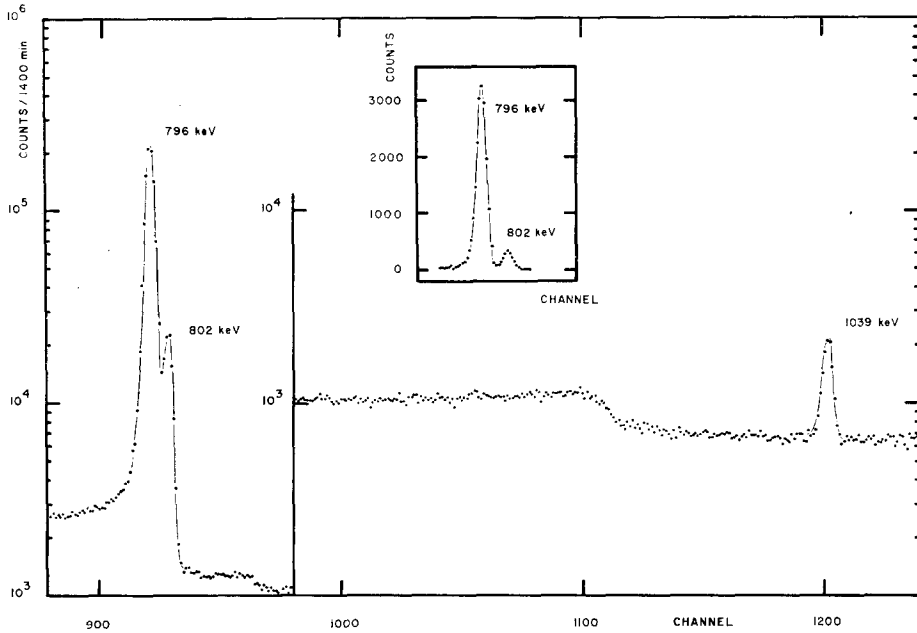


Fig. 1. (b) Gamma-ray spectrum of ^{134}Cs from 765 keV to 1070 keV. The inset shows the 800 keV region as observed with an $8\text{ cm}^2 \times 5\text{ mm}$ Ge(Li) detector.

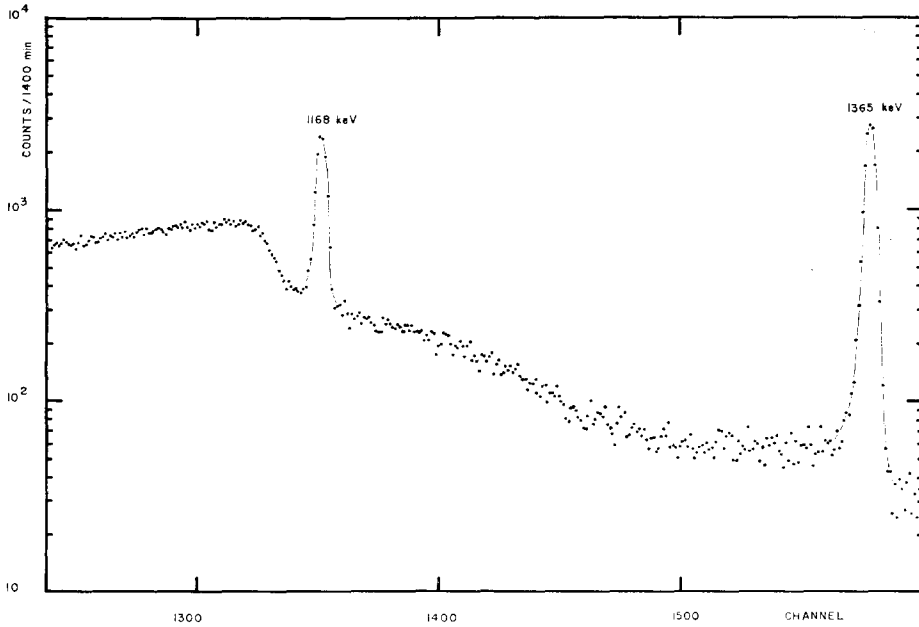


Fig. 1. (c) Gamma-ray spectrum of ^{134}Cs from 1070 keV to 1380 keV. The solid lines merely indicate the trend of the data points.

of the two ground state transitions 605 keV and 1168 keV is 100 %. There are no previous reports of beta feeding to the ground state; Van Wijngaarden and Connor ⁵⁾ place an upper limit of 0.005 % on beta branches having end-point energies in excess of 1400 keV. One of the Ge(Li) spectra used in the intensity determinations is shown in fig. 1. The inset in fig. 1b shows the 800 keV region observed with an $8 \text{ cm}^2 \times 5 \text{ mm}$ Ge(Li) detector.

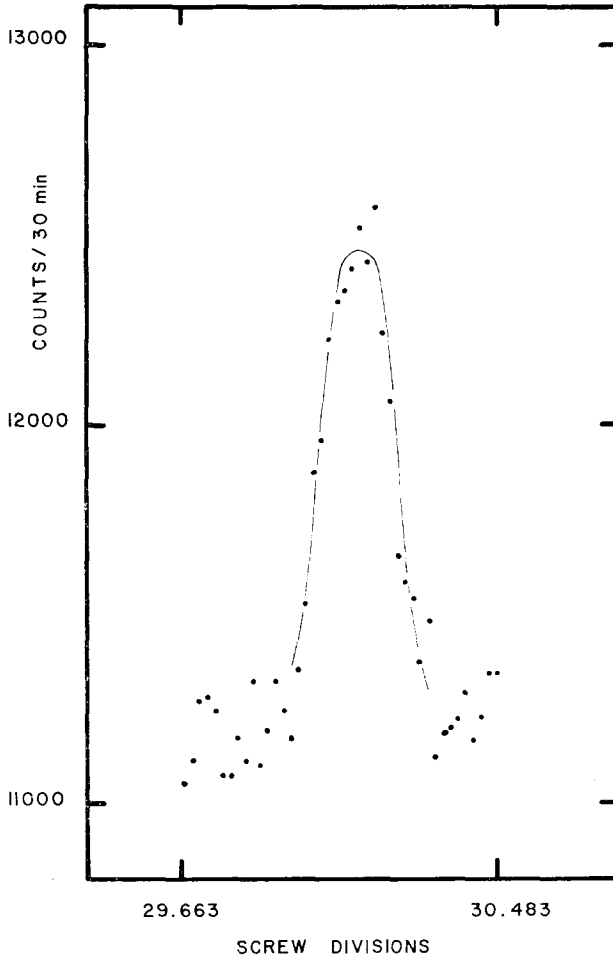


Fig. 2. (a) First-order diffraction profile of the 243 keV gamma ray occurring in the decay of ^{134}Cs observed with curved-crystal spectrometer.

Two transitions that do not appear in the work of recent investigators were observed with the curved-crystal spectrometer; their energies were measured as $242.694 \pm 0.041 \text{ keV}$ and $326.512 \pm 0.095 \text{ keV}$. The intensity of each of these lines is about 0.02 % of the total decay. This value was obtained by making a comparison corrected for NaI(Tl) efficiency and Ge(022) reflectivity ²⁹⁾ of the first-order peak heights of

the 243 and 327 keV transitions to the first-order peak height of the 475 keV transition. Fig. 2 shows the first-order diffraction profiles of these lines. It was established that both the 243 keV and 327 keV transitions originate from a long-lived isotope. Since they can be placed into that portion of the ^{134}Ba level scheme accepted by all recent investigators ²⁻⁸), we have assumed that they are associated with the de-excitation of ^{134}Ba . A probable transition at about 250 keV was reported previously ¹⁶) as was a possible transition ¹⁴) at about 320 keV.

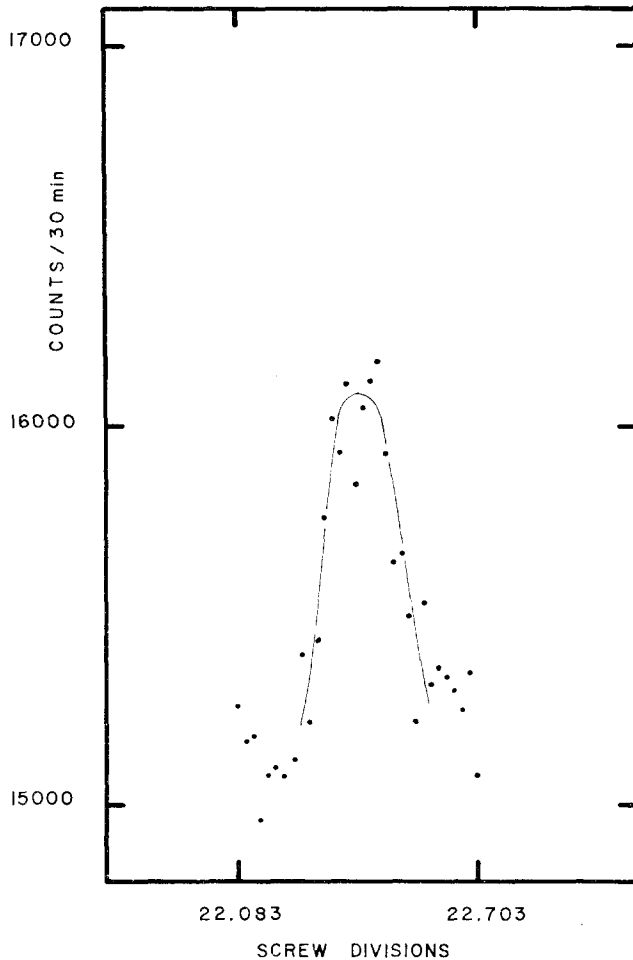


Fig. 2. (b) First-order diffraction profile of the 327 keV gamma ray. The solid lines merely indicate the trend of the data points.

Transitions in the 200 keV region have been reported previously ^{2,6,7,14,15,17,21}). A search of the region between 195 keV and 205 keV was made with the curved-crystal spectrometer. The only peaks evident in this search were those due to third-order reflections of the 605 keV gamma rays and fourth-order reflections of the 796

keV gamma rays. We estimate intensity upper limits as follows:

194.6–197.0 keV,	0.01 %,
197.0–197.7 keV,	0.03 %,
197.7–199.8 keV,	—
199.8–200.2 keV,	0.03 %,
200.2–202.3 keV,	—
202.3–203.0 keV,	0.03 %,
203.0–205.8 keV,	0.01 %,

where the dash indicates that no useful upper limit can be stated due to the presence of higher-order reflections.

Transitions at 960 keV and 1570 keV have also been reported previously ^{2, 3, 7, 12}). Our Ge(Li) spectra fail to show gamma rays of these energies, in agreement with the observations of Brown and Ewan ⁴), Van Wijngaarden and Connor ⁵) and Trehan *et al.* ⁶). We place upper limits on the intensities of such transitions at 0.1 % for the 960 keV transition and 0.02 % for the 1570 keV transition.

A study of the gamma radiations from ¹³⁴Cs by the external conversion method was reported recently by Bashandy and El-Haliem ²). These investigators give evidence for 29 gamma rays. Although they report several new transitions, the 243 keV and 327 keV transitions that were observed in our curved-crystal spectrometer work were not seen in their study. Moreover, the intensities of several of the new transitions reported by Bashandy and El-Haliem are in considerable disagreement with our Ge(Li) spectrometer results. For example, Bashandy and El-Haliem report gamma rays at 910 keV and 923 keV with intensities which are more than twice as great as the intensity which they assign to their 1038 keV transition. Such a situation is clearly not consistent with the fact that there is no evidence in fig. 1b for peaks in the 900 keV region. In addition, these authors assign an intensity value to a 962 keV transition which is more than ten times greater than the upper limit placed on the intensity of such a transition from the present work.

Fig. 3 shows a Ge(Li) coincidence spectrum which was taken with the NaI channel gating the 605 keV region. There is no evidence for a peak at 1168 keV. This indicates that a 1168-605 keV cascade must have an upper limit on its intensity of about 0.13 % of the total decay, which is not in agreement with the previous reports on such a cascade ^{3, 6}). The fact that this upper limit is lower than the reported intensities for a 1168-605 keV cascade places a 1773 keV level in doubt. Coincidence runs were also taken with the NaI channel gating the 1168 keV peak. These data clearly showed that the 475 keV and 802 keV gamma rays were in coincidence with the 1168 keV gamma ray. Another set of coincidence data was obtained with the NaI channel gating the 1365 keV peak. Some care was required in setting this gate, because of the nearness of the 605-796 summing peak at 1401 keV. In order to be sure that only the 605 keV gamma ray was in coincidence with the 1365 keV gamma ray, coincidence

runs were taken with the NaI gate on various portions of the 1300-1450 keV region. From these runs it was determined that of the prominent transitions only the 605 keV transition is in coincidence with the 1365 keV transition. An attempt was also made to verify the placing of the 327 keV transition observed in the curved-crystal

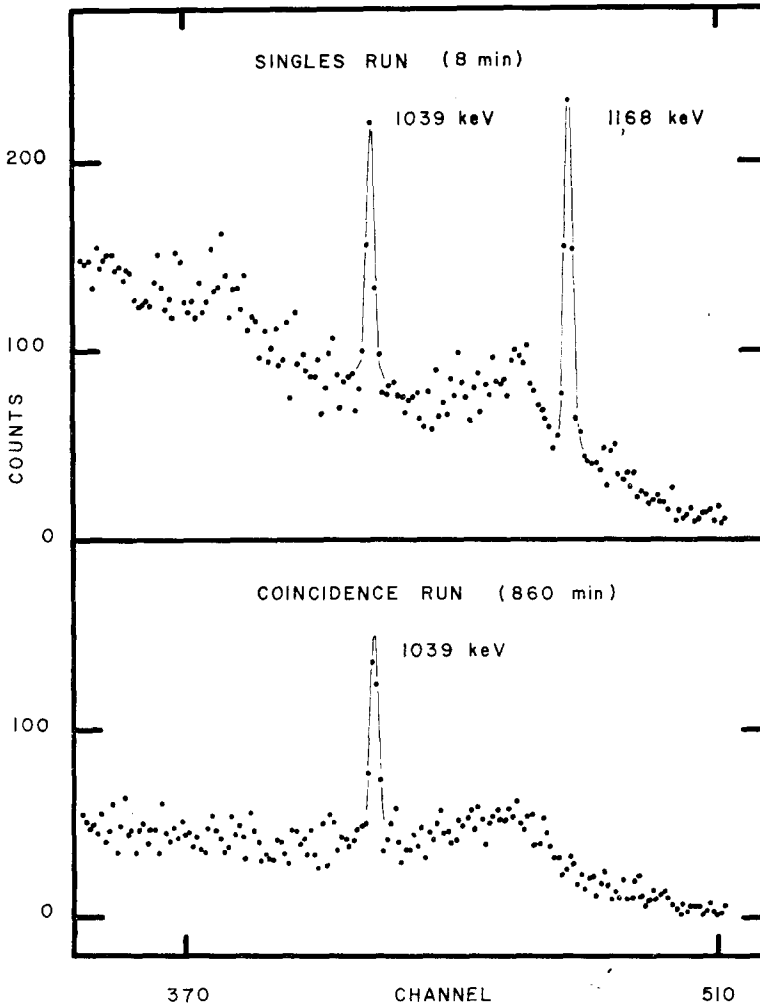


Fig. 3. The gamma-ray spectrum of ^{134}Cs in the region 850 to 1270 keV which is in coincidence with the 605 keV gamma ray as observed with an $8\text{ cm}^2 \times 5\text{ mm}$ Ge(Li) detector. The singles spectrum observed with the same system is shown for comparison. The solid lines merely indicate the trend of the data points.

spectrometer study. An energy fit indicates that it is in cascade with the 1039 keV transition. By gating the 1039 keV peak it was found that the 1039 keV gamma ray

is in coincidence with the 605 keV gamma ray, but the possible coincidence with the weak 327 keV gamma ray could not be established due to the statistical fluctuations associated with the large 605 keV Compton distribution.

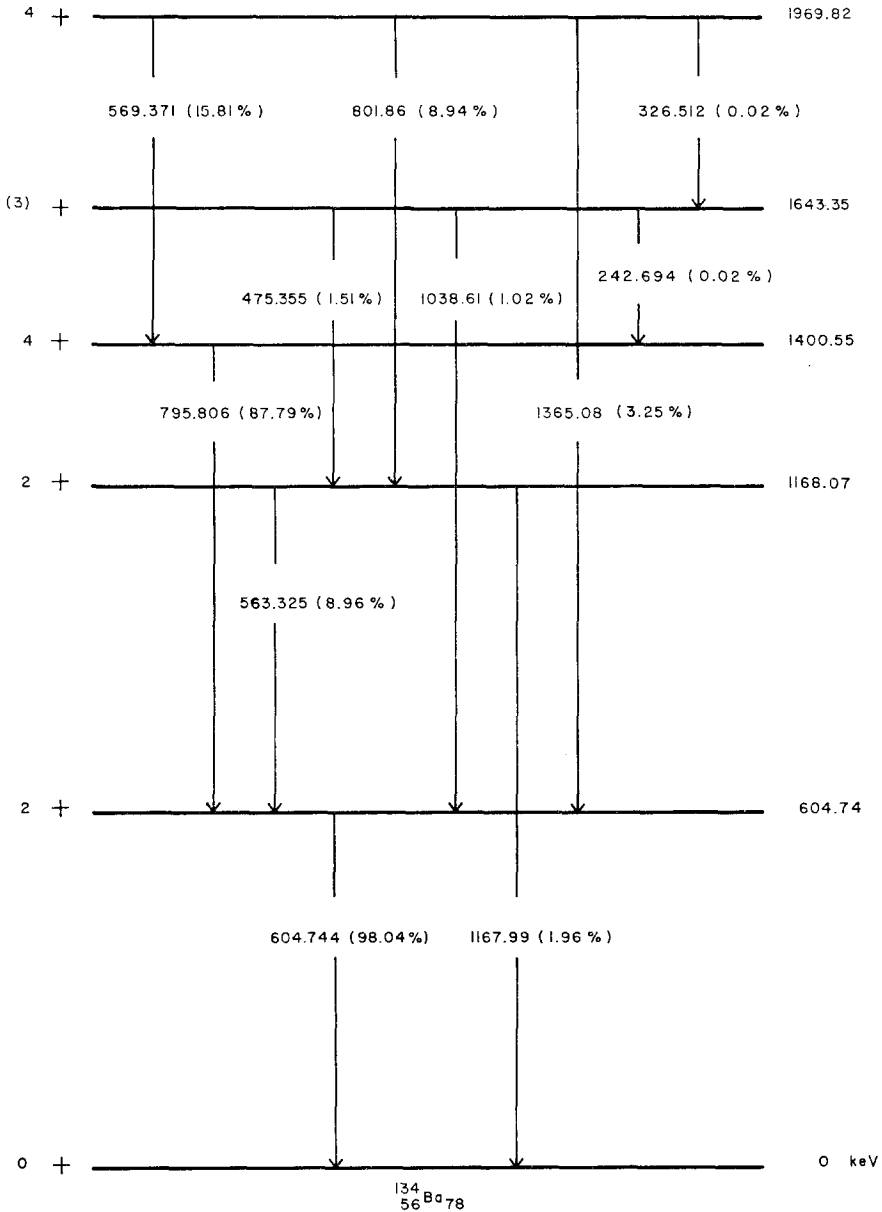


Fig. 4. The level scheme of ^{134}Ba populated in the beta decay of ^{134}Cs . Spins and parities are from ref.⁴).

4. Conclusion

The results of the present work verify the level scheme shown in fig. 4. This level scheme is in agreement with the one given in refs. ^{4,5,8}); it does not agree with the level schemes given in refs. ^{2,3,6,7,12}).

We have not attempted to carry out a detailed theoretical investigation of the level scheme of ^{134}Ba verified by the present work. Previous authors ^{2,3,7}) have discussed the applicability of various theories, in particular the asymmetric rotor theory of Davydov and Filippov ³¹) and Davydov and Chaban ³²) and a pairing plus long range forces coupling scheme presented by Ricci *et al.* ³³). The spin sequence predicted from the asymmetric rotor theory is 0, 2, 2, 0, 4, 3; whereas that predicted by Ricci *et al.* is 0, 2, 2, 4, 4, 4. Since the spin of the 1643 keV level in ^{134}Ba is in doubt, either spin sequence is entirely possible. A 0^+ state would not be populated to any extent in the decay of ^{134}Cs (4^+). Although Ricci *et al.* do predict more than one spin 4 state, their work is qualitative and no energies are given for the levels. Also, the predominant M1 character of the 569 keV transition which depopulates the 1970 keV (4^+) state indicates that it is probably not of the type predicted by Ricci *et al.* It appears, then, that neither theory can correctly describe the 1970 keV (4^+) state.

The level scheme of fig. 4 allows for the placing of one more low-energy transition between the 1168 and 1401 keV levels. A careful curved-crystal spectrometer search was made for a 232.5 keV gamma ray, but none was observed. An upper limit on the intensity of this transition is 0.01 %.

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