K-capture probability in the decay of ^{133}Ba from X-ray-gamma-ray summing in Ge(Li) detectors

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K-capture probability in the decay of ^{133}Ba from x-ray–gamma-ray summing in Ge(Li) detectors

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Abstract. A new technique has been developed in which a quantitative analysis of the sum-peaks observed with a high resolution Ge(Li) x-ray detector, yields P_K, the probability for K-electron capture to the two excited states $\frac{1}{2}^+$, 437·0 keV and $\frac{3}{2}^+$, 383·8 keV of ^{133}Cs in the decay of ^{133}Ba (10·4 yr). A total P_K has also been determined from the measurement of the gamma-ray and K x-ray intensities following the decay.

1. Introduction

A considerable amount of work has been done in the past to study the summing phenomenon in a single NaI(Tl) detector. The analysis of the above phenomenon led to the determination of the absolute source strength, the absolute photopeak efficiency, L/K electron capture ratio, etc, in a number of cases (Shapiro and Higgs 1957, Brinkman *et al* 1963, Gupta *et al* 1958).

It is expected that Ge(Li) detectors, because of their high energy resolution should yield more accurate and rich summing data, particularly for the nuclei with complicated decay schemes. In the literature, one finds very little use of such detectors to explore the above phenomenon (Luukko and Holmberg 1968, Verplanke 1971). The decay of ^{133}Ba offers a very convenient check on the utilization of the summing technique. The earlier work (Gupta *et al* 1958, Ramaswamy *et al* 1960, Thun *et al* 1966) gives a higher value for the L/K electron capture ratio for the $\frac{1}{2}^+$ highest excited state at 437·0 keV, while from the measurement of P_K (Schmidt-Ott and Fink 1972, Narang and Houtermans 1968) the L/K capture ratio is found to be considerably lower, which is also corroborated by Schulz (1967). Most of these works are based on the conventional coincidence technique. We, therefore, feel that a measurement of the above quantities involving an independent method is worthwhile.

In the present investigation a large number of sum-peaks are observed with a single Ge(Li) x-ray detector. The probability for K-electron capture, P_{K1}, to the 437·0 keV state can be independently measured from the three sum-peaks ($356·0+K_\alpha$) keV, ($276·3+K_\alpha$) keV and ($53·2+K_\alpha$) keV. Besides P_{K1}, we have determined P_{K2}, the probability for K-electron capture to the 383·8 keV state, from the sum-peaks ($302·8+K_\alpha$) keV and ($383·8+K_\alpha$) keV.

2. Experiment and results

2.1. Source and detector

The ^{133}Ba source in very pure form was obtained from Nuclear Chicago. In the investigation of the sum-peaks it is placed at about 2 mm from the Be window of a 4·88 mm deep, 10 mm diameter Ge(Li) detector. The spectra are recorded in a 4096 channel analyser (LABEN). A typical spectrum is shown in figure 1.

2.2. *Decay scheme*

For the determination of the P_K utilizing the present technique a detailed knowledge of the decay scheme is needed. For ^{133}Ba the decay scheme is fortunately well investigated (Bosch *et al* 1968). In the present investigation the relative intensities of the gamma rays are measured keeping the source at a distance of 5 cm from the detector so that the summing is practically nil. With the use of the total conversion coefficients of the gamma rays listed in table 1, the absolute intensity and the EC branchings as determined by us are shown in figure 2. The measured EC branchings agree well with the work of Schmidt-Ott and Fink (1972).

2.3. *Efficiency calibration of the detector*

The relative efficiency curve for the detector is determined using standard calibrating sources: ^{152}Eu (12·4 yr), ^{207}Bi (38 yr), ^{241}Am (458 yr) and ^{137}Cs (30 yr).

For the determination of the absolute photopeak efficiency for K x rays which enter into our calculations, the following method is adopted. It has been shown that for the gamma rays in the cascade the absolute photopeak efficiency can be determined from the analysis of their sum-peaks (Das Mahapatra and Mukherjee 1973). In the present work the absolute photopeak efficiency for the 81·0 keV gamma ray is obtained from the sum-peak: (356·0 + 81·0) keV. The area under the sum-peak can be expressed as

$$N^{\text{sum}}_{356\cdot0+81\cdot0} = N\frac{1}{1+\alpha_T^{356\cdot0}}\frac{1}{1+\alpha_T^{81\cdot0}}\epsilon_{356\cdot0}\epsilon_{81\cdot0} = N_{356\cdot0}\frac{1}{1+\alpha_T^{81\cdot0}}\epsilon_{81\cdot0} \qquad (1)$$

where N is the total number of 356·0 keV events, ϵ is the absolute photopeak efficiency and α_T is the total conversion coefficient of the gamma ray. $N_{356\cdot0}$ denotes the area under the 356·0 keV photopeak corrected for summing. From the measurement of the ratio $\epsilon_{K_\alpha}/\epsilon_{81\cdot0}$ from the relative efficiency curve together with the absolute photopeak efficiency $\epsilon_{81\cdot0}$, measured as above, the absolute photopeak efficiency for the K_α x ray is determined. Since the relative photopeak efficiency of the detector remains constant over an energy range 35 keV to 55 keV (figure 3), we can check the accuracy of our absolute photopeak efficiency determination in the following way. The absolute photopeak efficiency, 0·040, of the 53·2 keV gamma ray as determined from the sum-peak (53·2 + 81·0) keV compares well with the absolute photopeak efficiency, 0·042, for the K_β x ray utilizing the above method. This close agreement between these two values ensures that the procedure we have adopted for the determination of the absolute photopeak efficiency is correct. As will be evident from figure 1 the lineshape of the photopeaks contains a pronounced tailing. This tailing introduces some difficulty in the estimation of the sum-peak and photopeak area. Fortunately for the x ray detector the gamma-ray background level is low and flat, so the peak area can be measured graphically for most of the sum-peaks. One can also incorporate the standard peak-fitting procedure to get better accuracy, but this has not been used in the present investigation.

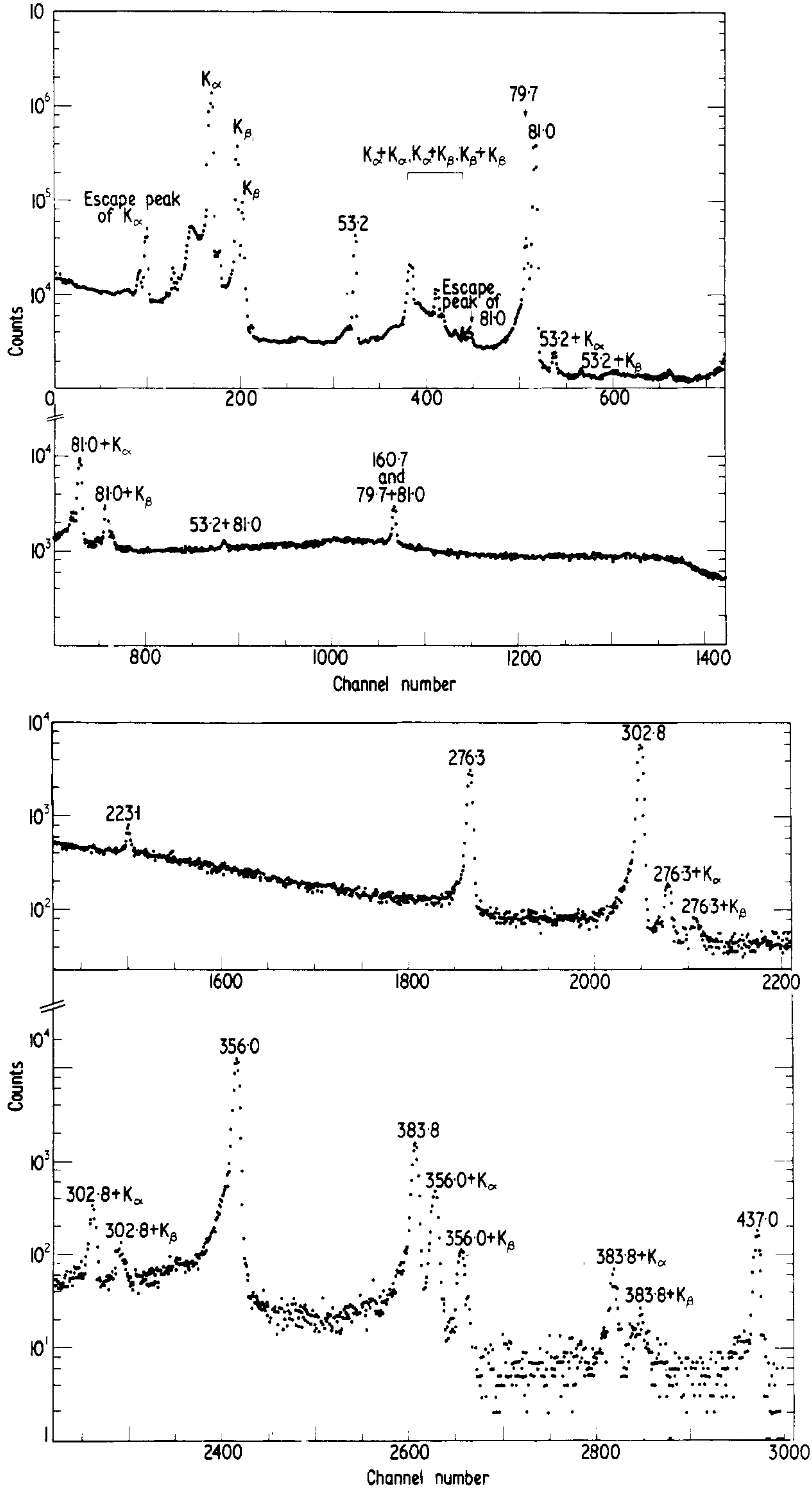

Figure 1. A typical gamma-ray spectrum in the decay of ^{133}Ba with the source at 2 mm from the detector window. The 437·0 keV is a sum-peak with dominant contribution from the 356·0 keV–81·0 keV cascade.

Table 1. Electron conversion coefficients of the transitions in the decay of ^{133}Ba used in the present investigation

E_γ (keV)	α_K (Schmidt-Ott and Fink 1972)		α_T (Bosch *et al* 1968)	
53·2	5·0 ± 0·9	(4·85 ± 0·05)†	5·84 ± 1·05‡	(5·66 ± 0·06)†
79·7	1·52 ± 0·16	(1·50 ± 0·01)†	1·73 ± 0·18§	(1·75 ± 0·02)†
81·0	1·36 ± 0·09		1·72 ± 0·06	
160·7	0·202 ± 0·013		0·25 ± 0·06	
223·1	0·071 ± 0·005		0·081 ± 0·006§	
276·3	0·0465 ± 0·0032		0·058 ± 0·004§	
302·8	0·037 ± 0·003		0·043 ± 0·004	
356·0	0·0211		0·0255	
383·8	0·0171 ± 0·0012		0·0205 ± 0·0015	

† For the analysis of P_K the conversion coefficients given in parenthesis are used. These are calculated assuming the transitions to be pure M1 (Schmidt-Ott and Fink 1972, Winn and Sarantites 1970) and using the theoretical conversion coefficients (Hager and Seltzer 1968) provided by Dr W B Ewbank of ORNL, USA.
‡ Calculated from $\alpha_K^{53.2}/(1+\alpha_T^{53.2})$ and $\alpha_K^{53.2}$ of Schmidt-Ott and Fink (1972).
§ Calculated using K/LM of Notea and Gurfinkel (1968).

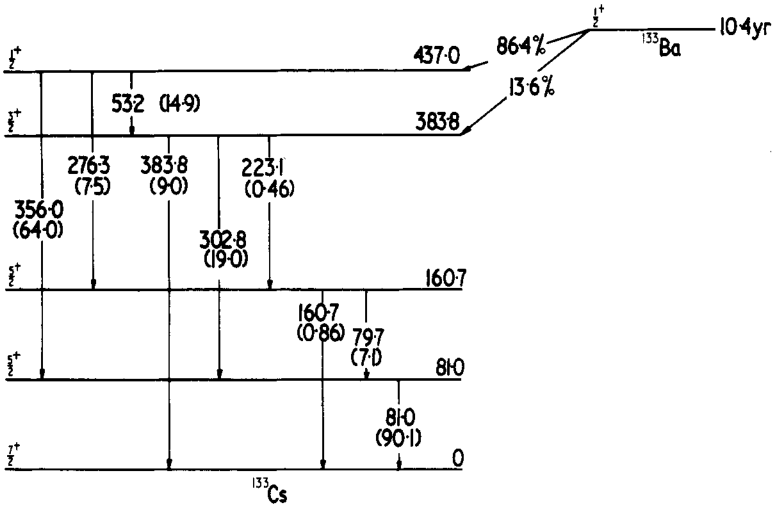

Figure 2. Decay scheme of ^{133}Ba. Intensities per 100 disintegrations are from the present work with uncertainty 2% to 5% depending on the strength of the transitions.

2.4. P_{K1} and P_{K2} from the analysis of the sum-peaks

The (Kx + γ) sum-peaks will contain, in general, contributions from K x rays arising from K-electron capture to the two excited states of ^{133}Cs and K conversion of the gamma ray in cascade (figure 2). Considering the decay scheme and the branching ratios for transitions from the different levels with their absolute intensities (figure 2), one can set up the equations for all possible (Kx + γ) sum-peaks. As an illustration let us consider the sum-peak (356·0 + K_α) keV.

It is seen that the 356·0 keV gamma ray is in coincidence with K x rays originating after the K capture to the 437·0 keV level and the K conversion of the 81·0 keV gamma rays.

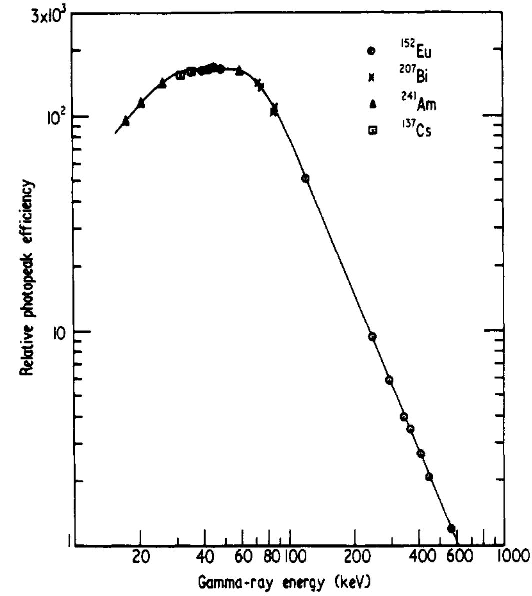

Figure 3. Efficiency curve for the 4·88 mm deep × 10 mm diameter Ge(Li) x-ray detector.

The sum-peak area can be expressed as

$$N^{\text{sum}}_{356\cdot 0+K_\alpha} = f\left(P_{K1} + \frac{\alpha_K^{81\cdot 0}}{1+\alpha_T^{81\cdot 0}}\right) N_{356\cdot 0} \tag{2}$$

where

$$f = \omega_K \frac{I_{K_\alpha}}{I_{K_\alpha} + I_{K_\beta}} \epsilon_{K_\alpha};$$

ω_K is the K-fluorescence yield in Cs. The values of ω_K and $I_{K_\alpha}/(I_{K_\alpha}+I_{K_\beta})$ used in the present work are taken from *Nuclear Data Tables* (1970) and Hansen *et al* (1970), respectively. Similarly, the equations for other $(K_\alpha + \gamma)$ sum-peaks observed in the spectrum can be written down.

In table 1 we give the values of α_K, α_T for the transitions used to calculate P_K in the present work. P_{K1} can be measured from three independent equations similar to (2) corresponding to the sum-peaks $N^{\text{sum}}_{356\cdot 0+K_\alpha}$, $N^{\text{sum}}_{53\cdot 2+K_\alpha}$ and $N^{\text{sum}}_{276\cdot 3+K_\alpha}$. The corresponding values of P_{K1} are: $0{\cdot}74 \pm 0{\cdot}09$, $0{\cdot}75 \pm 0{\cdot}09$ and $0{\cdot}84 \pm 0{\cdot}14$. The mean value for P_{K1} is $0{\cdot}76 \pm 0{\cdot}06$. This value is found to be in excellent agreement with $P_{K1} = 0{\cdot}72 \pm 0{\cdot}04$ measured by Schmidt-Ott and Fink (1972) and $P_{K1} = 0{\cdot}680 \pm 0{\cdot}045$ measured by Narang and Houtermans (1968) from the K x–γ coincidence. Using the above value of P_{K1}, P_{K2} is measured from either of the two equations similar to (1) corresponding to the sum-peaks $N^{\text{sum}}_{302\cdot 8+K_\alpha}$ and $N^{\text{sum}}_{383\cdot 8+K_\alpha}$. The value of P_{K2} found by us, $0{\cdot}87 \pm 0{\cdot}14$, is in agreement with $P_{K2} = 0{\cdot}80 \pm 0{\cdot}07$ measured by Schmidt-Ott and Fink (1972).

2.5. P_K from the measurement of the gamma-ray and the K x-ray intensities

From the decay scheme (figure 2) It is seen that most of the electron captures (86·4%) follow through the 437·0 keV level. Therefore, a measurement of total P_K in the decay can be compared with P_{K1} or more rightly with the weighted average of P_{K1} and P_{K2}. The total P_K is found from the measured K x-ray and gamma-ray intensities as follows.

Let I_K and $I_{L+M+\ldots}$ be the intensities of the total K and (L+M+ ...) electron capture, respectively. From the intensity balance we get

$$I_K + I_{L+M+\ldots} = \sum I_\gamma(1+\alpha_T) \tag{3}$$

where the I_γ are the intensities of the gamma rays and Σ denotes the sum over all the gamma rays feeding the ground state of ^{133}Cs. Let I_{Kx} be the total intensity of the K x rays measured, then

$$I_{Kx} = \omega_K\left(I_K + \sum \alpha_K I_\gamma\right) \tag{4}$$

where Σ denotes the sum over all the gamma-ray quanta observed in the decay. From equations (3) and (4) one gets

$$P_K = \frac{I_K}{I_K + I_{L+M+\ldots}} = \frac{(I_{Kx}/\omega_K) - \Sigma\alpha_K I_\gamma}{\Sigma I_\gamma(1+\alpha_T)} \tag{5}$$

From the analysis of our data we find

$$P_K = 0{\cdot}79 \pm 0{\cdot}07.$$

This value agrees well with $P_{K1} = 0{\cdot}76 \pm 0{\cdot}06$ or the weighted average of P_{K1} and P_{K2} ($0{\cdot}78 \pm 0{\cdot}09$) determined from the analysis of the sum-peaks.

3. Conclusions

The present investigation clearly supports the results of the recent work (Schmidt-Ott and Fink 1972, Narang and Houtermans 1968, Schulz 1967). The method used by us is relatively simple compared to the earlier methods. From a single sum spectrum we could determine the K-capture probability for the two states. A clear advantage of this method is the measurement of P_{K1} from three sum-peaks independently. It is possible to get a slightly better accuracy than quoted by us in the determination of P_K by improving the statistical error in the sum-peak areas. In the present work the typical run was for five to six hours, which can be made longer. However, the other source of error contained in the conversion coefficients cannot be minimized so easily.

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