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K capture in the decay of ^{131}Ba

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A single high resolution intrinsic Ge detector was used to measure the gamma–K-x-ray sum coincidences in the electron capture decay of ^{131}Ba. The sum spectrum was then analyzed in order to determine the relative K-capture probabilities to different levels in ^{131}Cs. The measured P_K ratios compare well with the theoretical results.

I. INTRODUCTION

The analysis of gamma–K-x-ray sum peaks has been used by many workers[1–6] to determine the relative K-capture probabilities. Except for ^{153}Gd, the technique has so far been applied to measure the relative K-capture probabilities to different levels of the daughter nuclei in the case of isotopes having simple decay schemes.[1–5] The K-capture probabilities measured[6] for ^{153}Gd, having a somewhat complex decay scheme, were in disagreement with the theoretically calculated ones with $Q_{EC}=484$ keV reported by Lee.[7] P_K ratios to levels of ^{131}Cs in another complex decay scheme of ^{131}Ba are measured and compared with those computed from Eq. (3) due to Behrens and Janecke.[8]

The electron capture (EC) decay of ^{131}Ba is well established and an extensive amount of work has been done on the relative gamma intensities, internal conversion coefficients, multipolarities of gamma rays, spins of the excited states and their half-lives, etc. The amount of work done on the electron capture decay rates to different excited states of ^{131}Cs is comparatively very small. EC branching ratios to different levels of ^{131}Cs have been reported in the literature.[9] Van Pelt *et al.*[10] investigated the decay of ^{131}Ba by means of a 4π internal source scintillation spectrometer and a Ge(Li) detector and measured the L/K and M/L EC ratios of allowed transitions to 373 and 1048 keV levels in ^{131}Cs. Further, the ratio of β^+ emission to EC to the 216 keV level was measured by Gehrke *et al.*[11] using a Ge(Li) detector who recorded the 216 keV gated coincidences in the spectrum.

As far as the authors know, the relative K-capture probabilities to different levels of ^{131}Cs have not been measured so far. As the decay scheme of ^{131}Ba is very complex, the analysis of coincidence and sum-coincidence measurements is a tedious and complicated job. The lack of experimental data on the K-capture probabilities of ^{131}Ba inspired the authors to undertake the present work.

II. EXPERIMENTAL DETAILS

A high resolution intrinsic Ge detector (diameter 25.0 mm and sensitive depth 15.0 mm) was used in the present work. The resolution of the detector was 288 eV at the 5.9 keV x ray of ^{55}Fe and 537 eV at the 122 keV of ^{57}Co gamma ray. The spectra were recorded with 4 K channel Canberra-40 and ND-600 multichannel analyzers. A ^{131}Ba (11.8 d) radioactive source used in the present work was in the form of $BaCl_2$ dissolved in HCl. A drop of the liquid source was placed in a 2 mm$^2\times$2 mm cavity drilled in a strip of Perspex and dried under an infrared lamp. The experimental and calibration point sources prepared in this way were covered with a single layer of cellutape; as such, no correction for x-ray absorption in source cover was considered.

The source was placed at a distance of 10 cm in front of the detector so as to measure gamma and K-x-ray relative intensities. The main aim for the singles measurements was to check the purity of the source. A weak source was used for the purpose and the spectrum was obtained for nearly 100 h. The shapes and the resolutions of the peaks show that the electronics remained stable during the run. For the measurement of sum coincidences a very weak point source was placed at 3 mm from the detector housing on its axial line in front of the detector. In singles as well as in coincidence summing measurements, care was taken that the count rate did not exceed 1500 per second. Four spectra were recorded for singles and sum spectra, respectively, and one for each is shown in Figs. 1 and 2, respectively.

III. RELATIVE *K*-CAPTURE PROBABILITIES

Relative *K*-capture probabilities, i.e., the ratio of *K* to total capture rates (P_K ratios), were determined using the method of sum coincidences between *K* x rays and gamma rays in a single solid-state detector.

^{131}Ba nuclei capture electrons from their own atomic orbitals and decay to different excited states of ^{131}Cs (Fig. 3). The *K* capture of parent nuclei and *K* conversion of the gamma rays are followed by *K* x rays. When the gamma ray and the *K* x ray in cascade with it enter the sensitive volume of the detector simultaneously, within certain resolving time of the detector, both radiations are counted as a single one. A peak at an energy corresponding to the sum of energies of two radiations is observed in the spectrum. Thus in the spectrum (Fig. 2), in addition

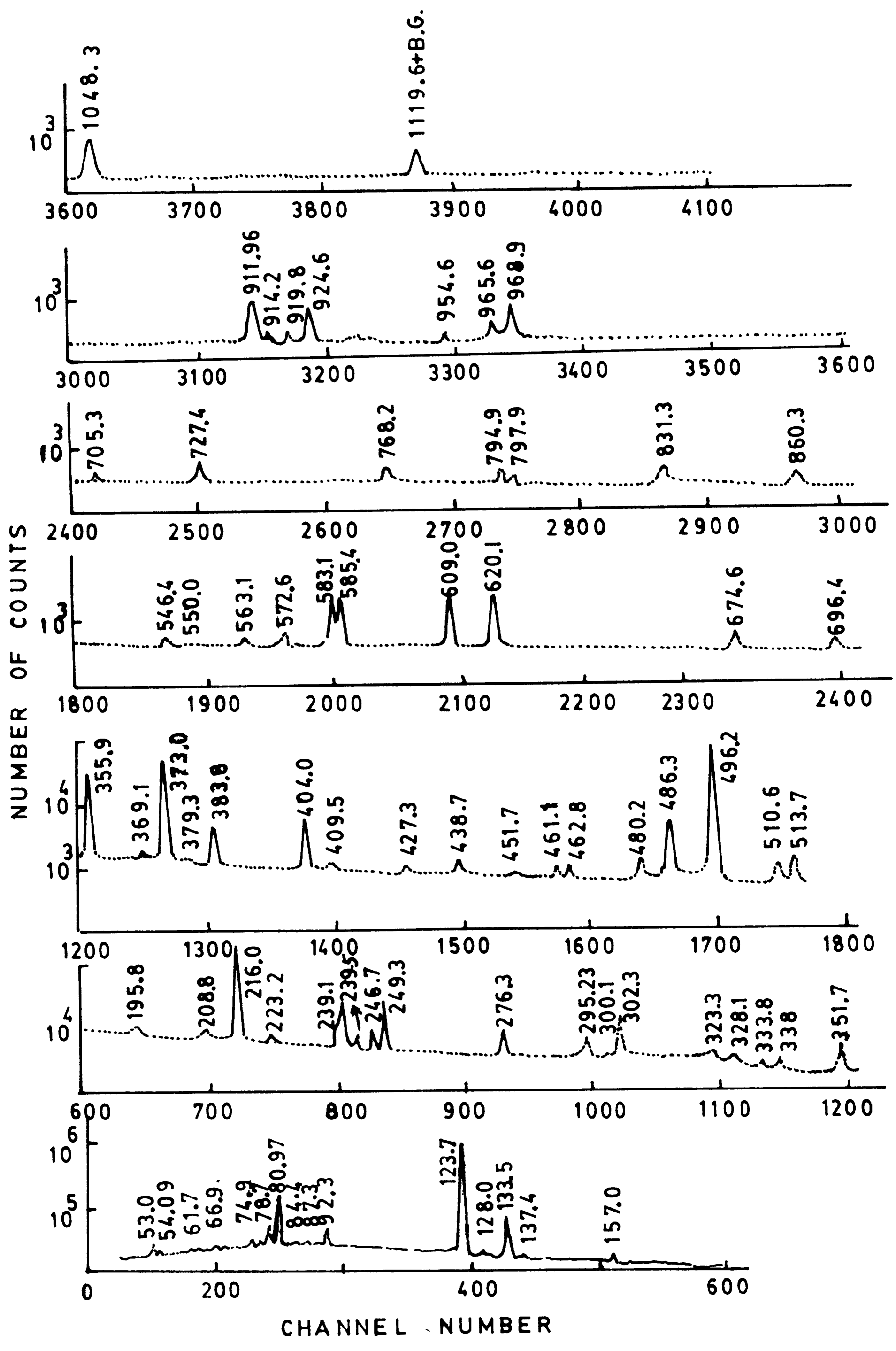

FIG. 1. Single spectrum of ^{131}Ba with a 25 mm$\times$15 mm HPGe detector with source at 10 cm from the detector.

to single gamma and single K x-ray peaks, the gamma–K-x-ray sum peaks are also observed. These gamma–K-x-ray sum peaks were analyzed in order to obtain the P_K ratios.

As an example, the relative K-capture probability to the 620 keV level [i.e., $P_K(620)$] is determined from the analysis of $(620+K\alpha)$ and $(620+K\beta)$ sum peaks in the following way. The K x rays in cascade with 620 keV gamma rays which give rise to $(620+K\alpha)$ and $(620+K\beta)$ sum peaks arise from the following events: (i) K capture to the 620 keV level; (ii) K conversion of the 428 keV gamma ray; and (iii) K capture to the 1048 keV level

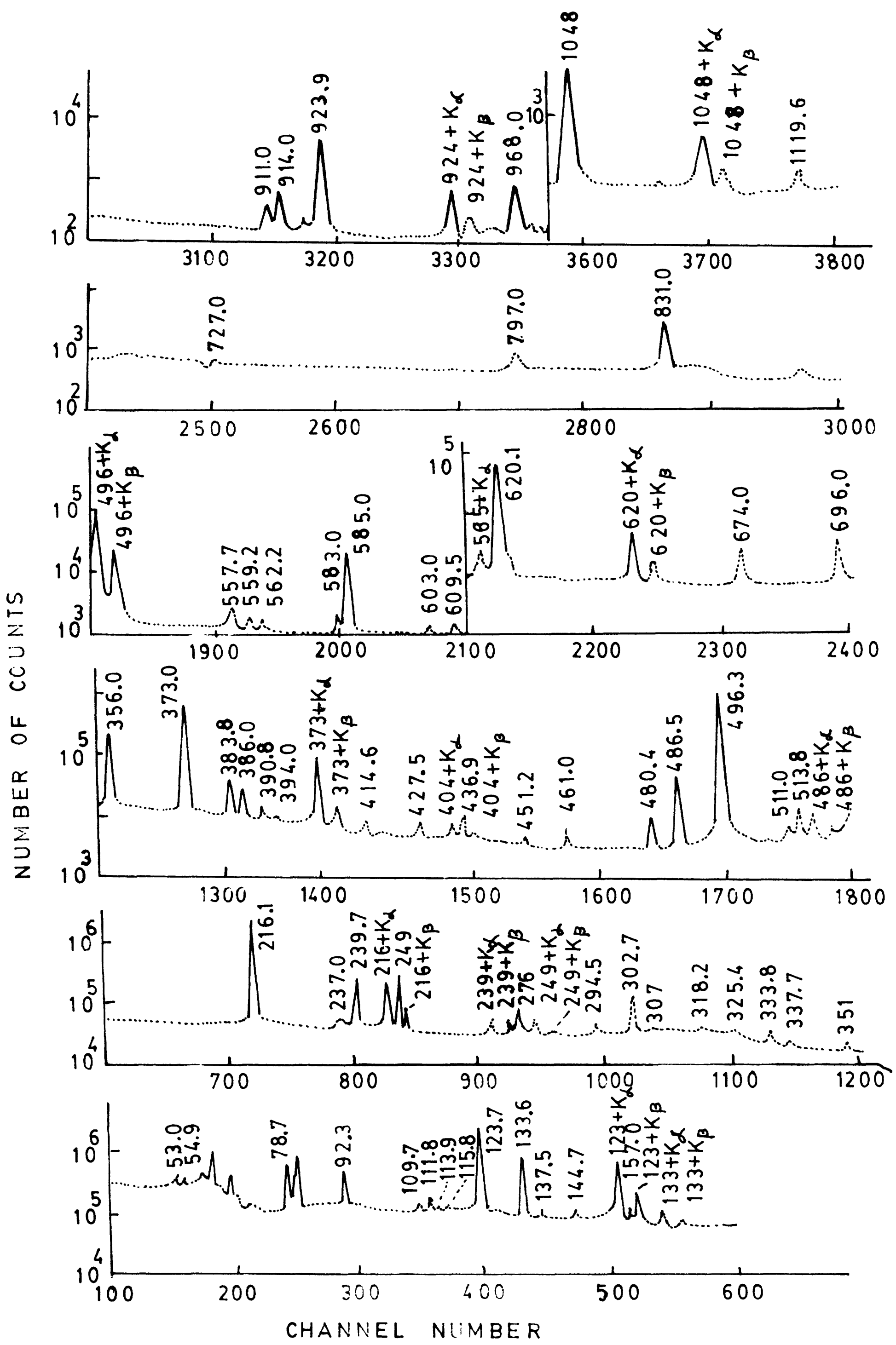

FIG. 2. Sum spectrum of ^{131}Ba with the 25 mm$\times$15 mm HPGe detector with source at 3 mm from the detector.

linked through the 428 keV line.

The area under the sum peak $(620+K\alpha)$ can be expressed as

$$N^{\mathrm{sum}}_{620+K\alpha}=\omega_K \frac{I_{K\alpha}}{I_{K\alpha}+I_{K\beta}}\varepsilon_{K\alpha} \times \left[\left[1-\frac{I_{428}}{T_{620}}\right] P_K(620) + \frac{I_{428}}{T_{620}}\left[P_K(1048)+\frac{\alpha_K^{428}}{1+\alpha_T^{428}}\right]\right] N_{620} \,. \tag{1}$$

Where $T_{620}=I_{620}+I_{496}+I_{486}+I_{404}+I_{246}$, α_K and α_T are the K and total conversion coefficients of respective gamma rays; ω_K is the K-shell fluorescence yield in daughter atoms; I_{620}, etc., are the transition intensities; and hence T_{620} is the sum of transition intensities depopulating the 620 keV level and $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$ are absolute photopeak detection efficiencies of the detector for $K\alpha$ and $K\beta$ x rays. Equation (1) is a representative equation showing the contributions of populating and depopulating transitions to the area of sum peak. However, the contribution of the second term in (1), i.e.,

$$\frac{I_{428}}{T_{620}}\left[P_K(1048)+\frac{\alpha_K^{428}}{1+\alpha_T^{428}}\right]$$

is only 0.18% compared with that of the first term. The $KX-K$-x-ray summing neglected here will further reduce it and the resulting $P_K(620)$ is not affected. The equations of this type were also written for the other sum peaks observed in the spectrum and then solved for the unknowns $P_K(1048)$, $P_K(620)$, $P_K(585)$, $P_K(373)$, and $P_K(216)$. Relative gamma and K-x-ray intensities were measured in the present work. The values of conversion coefficients and K-shell fluorescence yield ω_K were taken from the literature.[9] The method used to determine the absolute photopeak detection efficiencies for K x rays, i.e., $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$, is presented in the Sec. IV.

Seventeen sum peaks were analyzed in the present work to measure the K-capture ratios to different levels. Weak sum peaks, peaks mixed with background lines, and sum peaks disturbed in any other way were excluded from the analysis. Table I shows the values of P_K ratios along with the list of the sum peaks analyzed for the purpose.

IV. ABSOLUTE PHOTOPEAK DETECTION EFFICIENCIES FOR K X RAYS

The absolute photopeak detection efficiencies for K x rays of cesium were determined from the analysis of gamma-K-x-ray sum peaks. For this purpose the radioisotope ^{133}Ba with a simple decay scheme was used. A very weak point source of ^{133}Ba was prepared from the liquid source ($BaCl_2$ in HCl) in the way described in Sec. II and its sum spectrum was obtained with the same detector.

^{133}Ba decays to ^{133}Cs through the electron capture process. In it there are present, among others, two gamma

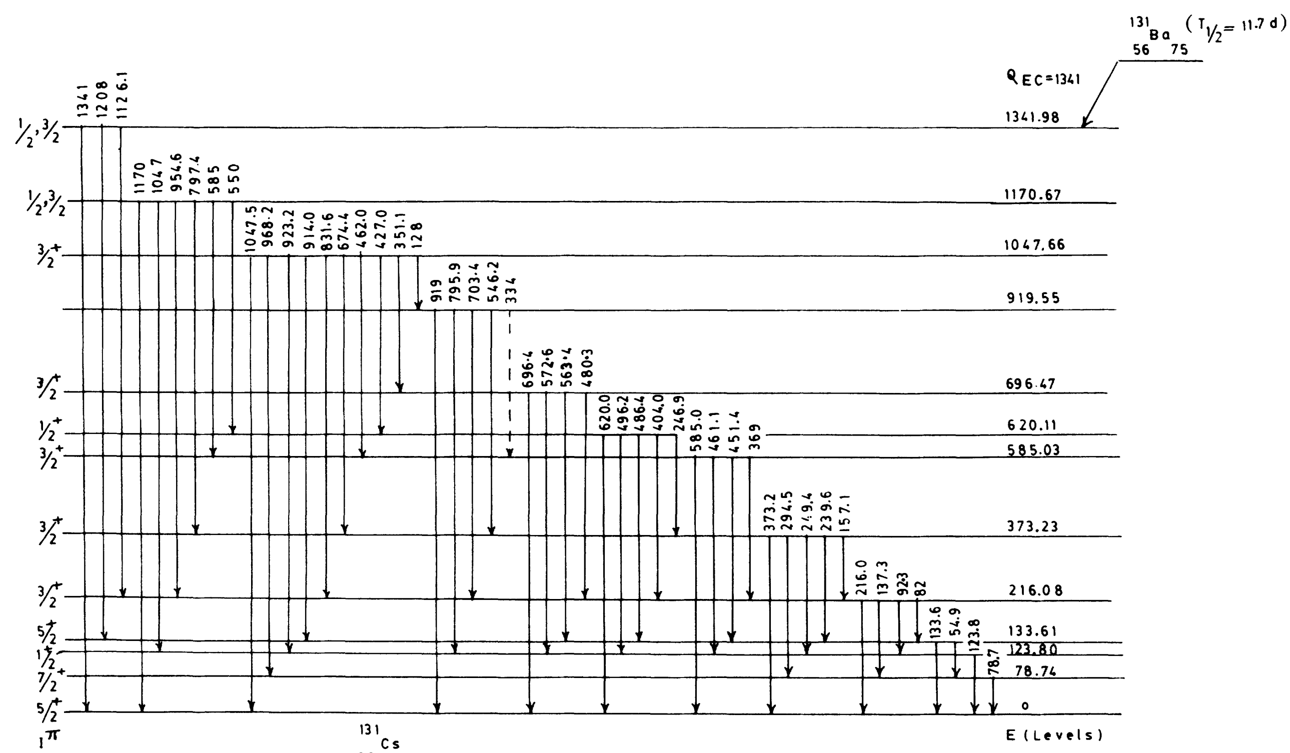

FIG. 3. Decay scheme of ^{131}Ba to ^{131}Cs (Ref. 11).

TABLE I. Relative K-capture probabilities to different levels of ^{131}Cs in the decay of ^{131}Ba.

Level (keV)	Sum peak	P_K Measured	P_K Theoretical
1048	$1048+K\alpha$	0.856(41)	
	$1048+K\beta$	0.885(75)	
	$924+K\alpha$	0.870(57)	
	$924+K\beta$	0.861(89)	
	Wt. Av. $P_K(1048)=0.865(29)$		0.868
620	$620+K\alpha$	0.869(37)	
	$620+K\beta$	0.872(50)	
	$496+K\alpha$	0.871(51)	
	$496+K\beta$	0.887(60)	
	$486+K\alpha$	0.883(67)	
	$486+K\beta$	0.886(74)	
	Wt. Av. $P_K(620)=0.875(21)$		0.882
585	$585+K\alpha$	0.88(5)	0.883
373	$373+K\beta$	0.878(47)	
	$249+K\alpha$	0.886(56)	
	$249+K\beta$	0.885(85)	
	$239+K\alpha$	0.890(55)	
	$239+K\beta$	0.879(72)	
	Wt. Av. $P_K(373)=0.883(26)$		0.885
216	$216+K\beta$	0.89(5)	0.886

rays of 356 and 81 keV in cascade. A gamma-gamma sum peak at (356+81) keV and a triple sum peak $(356+81+KX)$ are observed in the sum spectrum. The area under the triple sum peak $(356+81+K\alpha)$ can be expressed as

$$N^{\rm sum}_{356+81+K\alpha}=N^{\rm sum}_{437+K\alpha}=N_{437}P_K(437)\omega_K\frac{I_{K\alpha}}{I_{K\alpha}+I_{K\beta}}\varepsilon_{K\alpha}\ . \tag{2}$$

$P_K(437)$ is the relative K-capture probability to the 437 keV level of ^{133}Cs in the EC decay of ^{133}Ba. The value of $P_K(437)$ has been determined by many workers and is a well established one. ω_K is the K-shell fluorescence yield in Cs atoms and was taken from the literature.[9] N_{437} is the area under the (356+81) keV sum peak.

Putting the values of $I_{K\alpha}$, $I_{K\beta}$, $P_K(437)$, N_{437}, and ω_K in Eq. (2), the absolute photopeak detection efficiency $\varepsilon_{K\alpha}$ is determined. A similar equation was written for the $(356+81+K\beta)$ sum peak to obtain the value $\varepsilon_{K\beta}$. The energies of $K\alpha$ and $K\beta$ x rays following the decay of ^{133}Ba are the same as those of K x rays following ^{131}Ba decay as in both cases the K x rays of cesium atoms are ejected. Hence the values of $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$ are the same for both cases. The values determined from ^{133}Ba and used in the present case of ^{131}Ba decay are

$$\varepsilon_{K\alpha}=0.0495(18)\ ,$$

$$\varepsilon_{K\beta}=0.0557(27)\ .$$

The magnitudes of various contributions to the uncertainties in $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$ are as follows:

$N_{437}+K\alpha$	1.5%
N_{437}	0.17%
$P_K(437)$	2.7%
ω_K	1.5%
$N_{437}+K\beta$	3.8%

The errors when added in quadrature give the uncertainties given in parenthesis.

V. THEORETICAL P_K RATIOS

Behrens and Janecke[8] have derived a simple relation for P_K coefficients. Their method takes into account the effect of finite size of the nucleus, the screening of nuclear electrostatic field by orbital electrons, and electron exchange:

$$\frac{1}{P_K}=1+\left[\frac{Q-B_{L_1}}{Q-B_K}\right]^2\left[\frac{\beta_{L_1}}{\beta_K}\right]^2\times\left[1+\left[\frac{Q-B_{M_1}}{Q-B_{L_1}}\right]^2\left[\frac{\beta_{M_1}}{\beta_{L_1}}\right]^2\right]\ , \tag{3}$$

where β_K, β_{L_1}, β_{L_2}, and β_{M_1} are the Coulomb amplitudes in daughter atoms tabulated by Bambynek *et al.*[12]

B_K, B_{L_1}, B_{L_2}, and B_{M_1} are the electron binding energies in daughter atoms and are tabulated by Lederer and Shirley.[9] Q is the energy available for the decay and is given as

$$Q=Q_{\rm EC}-E\ ({\rm level})\ .$$

The total decay energy Q_{EC} is taken from the literature[9] and its value $Q_{EC} = 1342$ keV. The theoretically computed P_K ratios are listed in Table I.

VI. CONCLUSIONS

It is evident from Table I that good agreement is found between the theoretical and experimental values of P_K ratios. Further, the general trend of increase in the values of P_K coefficients with an increase in the amount of energy available for the decay is also observed. As no other experimental values are found in the literature, hence only theoretical ones are used for comparison. The good agreement justifies the suitability of the sum peak method for measurement of P_K values in nuclides with complex decay schemes also.

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