K-shell fluorescence yield of Cs

K. Singh, Gurmel Singh, R. K. Sharma, and H. S. Sahota
Department of Physics, Punjabi University, Patiala-147002, India
(Received 13 July 1983)

A new technique has been developed in the measurement of the K-shell fluorescence yield of cesium from the analysis of the sum peaks observed with a high resolution intrinsic Ge detector. The value found is $\omega_k(\text{Cs})=0.896(16)$, which is in good agreement with the fitted value of Bambynek *et al.*

[RADIOACTIVITY ^{133}Ba: measured I_γ, I_{Kx}, sum peak area, deduced ω_K.]

I. INTRODUCTION

The filling of an initial atomic vacancy may result in the radiative emission of an x ray in direct competition with allowed nonradiative transitions. The experimental determination of the K-shell fluorescence yield ω_K is of greater interest to workers in the field of x-ray physics. Methods for determining ω_K vary according to the ionization process, target material, or decay scheme of the radionuclide; the detectors; and the requirements for necessary corrections. Boyles *et al.*[1] pointed out that the K-fluorescence yield defined by the expression

$$(\omega_K/1-\omega_K)^{1/4}=BZ$$

did not fit experimental data well, and that screening and relativistic effects should be taken into consideration. This was done by Burhop,[2] who obtained the semiempirical expression

$$(\omega_K/1-\omega_K)^{1/4}=A+BZ+CZ^3 .$$

Values of the constants A, B, and C have been determined by a number of authors by adjusting to available experimental determinations of the K-shell fluorescence yield. Bambynek *et al.*[3] have reviewed all published measured values and chosen from these a total of 33 values on the basis of accuracies and reliabilities of the experimental procedures employed. We find that very few methods have been employed for the measurement of ω_K for $Z=55$. Most of these works are based on the fluorescence excitation of solid targets and Auger and conversion electron spectroscopy.

With nuclides that decay by electron capture, feeding a gamma transition in the daughter nucleus, sum peaks are observed between K x rays and gamma rays in a single detector. In the present work, a new method has been employed in measuring the K-shell fluorescence yield from the analysis of a sum spectrum taken with an intrinsic Ge detector.

II. EXPERIMENT AND RESULTS

A source of ^{133}Ba was obtained from Bhabha Atomic Research Centre Bombay in the form of $BaCl_2$. A weak point source was prepared by drop deposition on a single thin layer of cellutape, and the same layer was used to cover the source. The spectra were taken with the source at a distance of 3 mm from the window of the detector (active area 200 mm^2, sensitive depth 7 mm) having an energy resolution of 535 eV at 122 keV of ^{57}Co. The spectra were recorded in a 4096 channel analyzer (ND 600).

The nuclide ^{133}Ba decays by electron capture to the excited states of ^{133}Cs. The decay scheme is shown in Fig. 1. The pulse height spectrum (Fig. 2) contains a K x-ray peak, a gamma ray peak, and a sum peak arising from K x-ray—gamma-ray coincidences in the detector. The vacancies leading to K x-ray emission are created by K capture and K conversion of the transitions following electron capture.

It is apparent from Fig. 1 that the 356 keV gamma ray is in coincidence with the K x ray arising after the K capture to the 437 keV level and the K conversion of the 81 keV gamma ray. The areas under the $356+K\alpha$ and $356+K\beta$ sum peaks can be written as

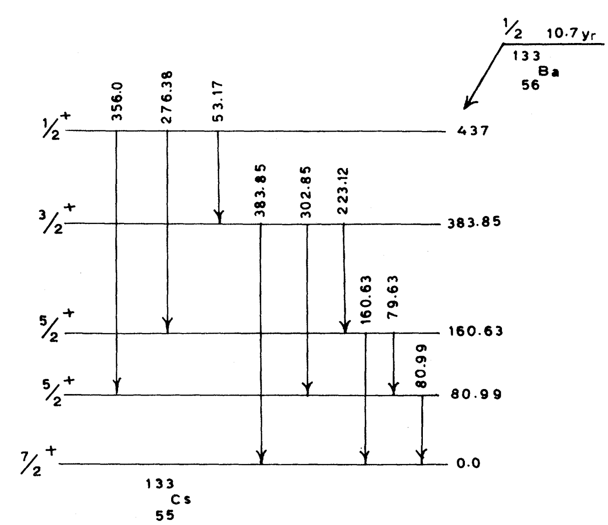

FIG. 1. The decay scheme of ^{133}Ba.

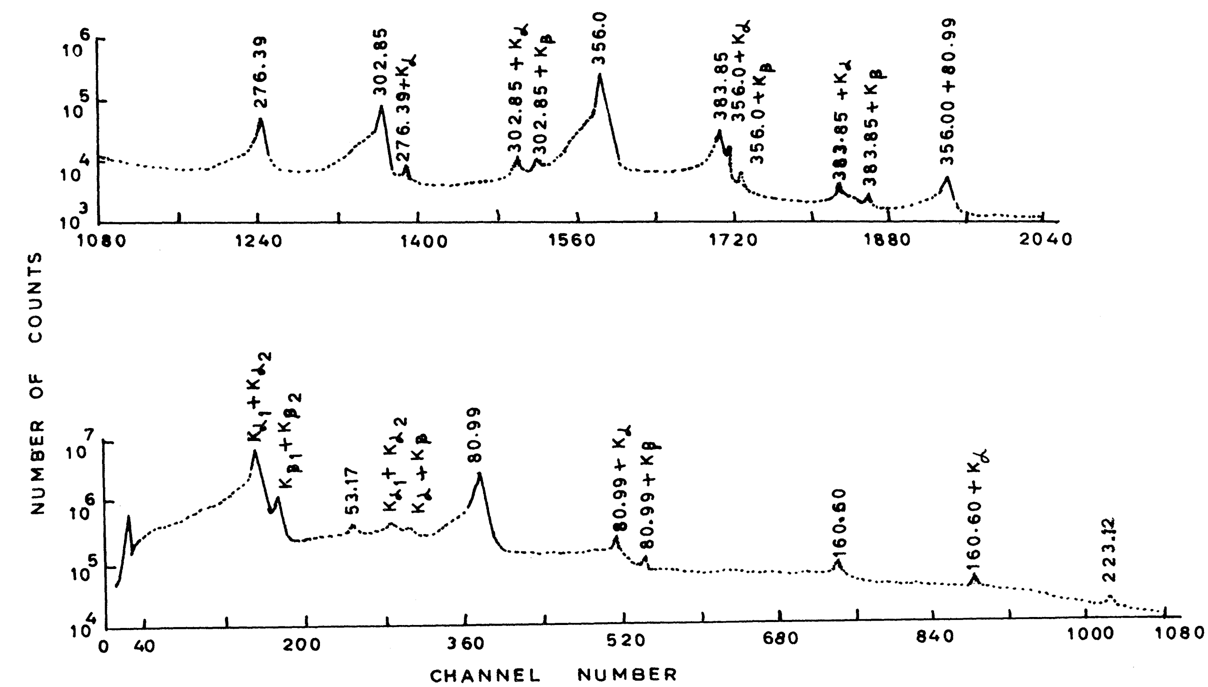

FIG. 2. The sum spectrum of ^{133}Ba taken with an intrinsic Ge detector at a distance of 3 mm from the window of the detector.

$$N^{\rm sum}_{356+K\alpha}=\omega_K\frac{I_{K\alpha}}{I_{K\alpha}+I_{K\beta}}\epsilon_{K\alpha}\left[P_{K1}(437)+\frac{\alpha_K^{81}}{1+\alpha_T^{81}}\right]N_{356} \tag{1a}$$

and

$$N^{\rm sum}_{356+K\beta}=\omega_K\frac{I_{K\beta}}{I_{K\alpha}+I_{K\beta}}\epsilon_{K\beta}\left[P_{K1}(437)+\frac{\alpha_K^{81}}{1+\alpha_T^{81}}\right]N_{356}\ . \tag{1b}$$

Values of the K-conversion coefficient α_K and the total conversion coefficient α_T have been taken from Ref. 4 and from Bosch *et al.*[5] $\epsilon_{K\alpha}$ and $\epsilon_{K\beta}$ are the absolute photopeak efficiencies for the $K\alpha$ x ray and $K\beta$ x rays and have been determined from the relative efficiency curve for the detector by the method of Das Mahapatra and Mukherjee[6] using the expression for the sum peak (356 + 81) as

$$\begin{aligned}N^{\rm sum}_{356+81}&=N\frac{1}{1+\alpha_T^{356}}\epsilon_{356}\frac{1}{1+\alpha_T^{81}}\epsilon_{81}\\&=N_{356}\frac{1}{1+\alpha_T^{81}}\epsilon_{81}\ ,\end{aligned} \tag{2}$$

where N is the total number of 356 keV events and N_{356} denotes the area under the photopeak corrected for summing. From the measurement of the ratios $\epsilon_{K\alpha}/\epsilon_{81}$ and $\epsilon_{K\beta}/\epsilon_{81}$ from the relative efficiency curve together with the absolute efficiency ϵ_{81} [Eq. (2)], the absolute photopeak efficiencies for the $K\alpha$ and $K\beta$ x rays are 0.039(2) and 0.042(2), respectively.

The values of ω_K have been calculated from equations similar to (1a) and (1b) corresponding to sum peaks $N^{\rm sum}_{356+K\alpha}$, $N^{\rm sum}_{356+K\beta}$, and $N^{\rm sum}_{276+K\alpha}$. To calculate ω_K the values of the relative intensities of gamma rays and x rays were measured keeping the source at a distance of 10 cm from the detector, and the value of P_{k1}, the K-capture probability to the 437 keV level, was calculated using the expression given by Martin and Blichert-Toft[7] as

TABLE I. The K-shell fluoresence yield of Cs.

		ω_K values		
Sum peak	Present work	Bambynek *et al.* (Ref. 3)	Graham *et al.*	Erman
356+$K\alpha$	0.882(50)			
356+$K\beta$	0.882(51)			
276+$K\alpha$	0.886(51)			
384+$K\alpha$	0.896(47)			
384+$K\beta$	0.886(51)			
302+$K\alpha$	0.906(49)			
302+$K\beta$	0.898(53)			
161+$K\alpha$	0.910(52)			
81+$K\alpha$	0.911(54)			
81+$K\beta$	0.905(55)			
Weighted average result	0.896(16)	0.889(20)	0.898[a]	0.873[a]

[a]Value taken from the compilation of Bambynek *et al.* (Ref. 3).

$$\frac{Q_{\mathrm{EC}}-E_{L1}}{Q_{\mathrm{EC}}-E_K}=\left[\frac{\left[\dfrac{1}{P_K}-1\right]}{\dfrac{B_{L1}}{B_K}\dfrac{g_{L1}^2}{g_K^2}\left[1+\dfrac{B_{L2}}{B_{L1}}\dfrac{f_{L2}^2}{g_{L1}^2}+\dfrac{P_{MN}}{P_{L1}}\cdots\right]}\right]^{1/2}, \quad (3)$$

where E_K and E_{L1}, the K and L_1 shell binding energies of Cs, and g and f, the electron radial wave functions of the respective shells evaluated at the origin, have been taken from Ref. 4 and from the compilation of Bambynek *et al.*,[8] respectively. B_K, B_{L1}, and B_{L2} are the exchange correction factors for the respective shells introduced by Bahcall[9] and P_{MN}/P_{L1} is the correction for capture from higher shells.

Again using the values of P_{K1} and P_{K2}, the K-capture probability to the 384 keV level calculated from Eq. (3), ω_K, has been measured from all four equations similar to (1a) and (1b), corresponding to the sum peaks $N_{302+K\alpha}^{\mathrm{sum}}$, $N_{302+K\beta}^{\mathrm{sum}}$, $N_{384+K\alpha}^{\mathrm{sum}}$, and $N_{384+K\beta}^{\mathrm{sum}}$. As an illustration let us consider the sum-peak (302 + Kα) keV:

$$N_{302+K\alpha}^{\mathrm{sum}}=\omega_K\frac{I_{K\alpha}}{I_{K\alpha}+I_{K\beta}}\epsilon_{K\alpha}\left[\frac{I_{53}}{I_{223}+I_{302}+I_{384}}\left[P_{K1}+\frac{\alpha_K^{53}}{1+\alpha_T^{53}}\right]+P_{K\alpha}\left[1-\frac{I_{53}}{I_{223}+I_{302}+I_{384}}\right]+\frac{\alpha_K^{81}}{1+\alpha_T^{81}}\right]N_{302}\ . \quad (4)$$

Similar expressions can be written corresponding to sum peaks $161+K\alpha$, $81+K\alpha$, and $81+K\beta$ keV. The values of ω_K calculated from different sum peaks are listed in Table I. It is clear from the table that the weighted average result is in good agreement with the values of Bambynek *et al.*[3]

III. CONCLUSION

The high resolution precisely calibrated semiconductor detector has been used to measure the K-shell fluorescence yield. Besides using $K\alpha$ x ray plus gamma ray sum peaks, $K\beta$ x ray plus gamma-ray sum peaks have been used to find the value of ω_K. Moreover, the value of ω_K has been deduced from ten different sets.

The authors are thankful to Prof. M. L. Narchal, Head, Department of Physics, Punjabi University, Patiala, for providing facilities necessary for this work.

[1]C. D. Boyles, D. A. Thomas, and S. K. Haynes, Phys. Rev. 89, 715 (1953).

[2]E. H. S. Burhop, J. Phys. Radium 16, 625 (1955).

[3]W. Bambynek, B. Crasemann, R. W. Fink, H. U. Freund, H. Mark, C. D. Swift, R. E. Price, and P. Venugopala Rao, Rev. Mod. Phys. 44, 717 (1972).

[4]*Table of Isotopes,* 7th ed., edited by C. M. Lederer and V. S. Shirley (Wiley, New York, 1978).

[5]H. E. Bosch, A. J. Haverfield, E. Szichman, and S. M. Abecasis, Nucl. Phys. A108, 209 (1968).

[6]B. K. Das Mahapatra and P. Mukherjee, J. Phys. A 7, 388 (1974).

[7]M. J. Martin and P. H. Blichert-Toft, Nucl. Data A8, Nos. 1 and 2 (1970).

[8]W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledinghaus, H. Genz, M. Mutterer, and R. L. Intemann, Rev. Mod. Phys. 49, 78 (1977).

[9]J. N. Bahcall, Phys. Rev. 132, 362 (1963).