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Direct Determination of Internal Conversion Coefficients

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Using the same source and instrument geometry, both the external as well as internal conversion lines of the 1.17- and 1.33-Mev gamma rays of Co^{60} are scanned in a Siegbahn-Slätis spectrometer. From the known internal conversion coefficients of these gamma rays, the instrument is calibrated for the direct determination of internal conversion coefficient of any other gamma rays having energy near 1.3 Mev. As an example, the internal conversion coefficient of the 1.408-Mev gamma ray, in the decay of Eu^{152}, is measured. The value obtained is 4.99×10^{-4}.

I. INTRODUCTION

VERY recently a series of work has been reported by Hultberg and Stockendal[1] in which they have made an absolute determination of the internal conversion coefficient (I.C.C.) of the 662-kev gamma ray in Cs^{137}, and also the various gamma rays in the decay of Bi^{205} and Bi^{206}.[2] Using a common source and spectrometer geometry the peak areas of both the external and internal conversion lines are measured in a double-focussing spectrometer. The principle is briefly as follows: If A be the area under the external K photopeak of a gamma ray of energy E, then

$$A=KN_\gamma\tau_K(E)\omega f(E), \qquad (1)$$

where K is the instrument transmission factor, which depends mainly upon source and baffle positions. N_γ is the total number of gamma rays emitted from the source, $\tau_K(E)$ is the K-shell photoelectric cross section, ω is the solid angle subtended by the source at the radiator, and $f(E)$ is a complicated function which accounts for the angular distribution of the photoelectrons, and contains the converter thickness. In Eq. (1), disturbing effects like the multiple scattering of electrons in the converter is neglected. The term $\omega f(E)$ (called *fdb* in reference 1) can be easily calculated assuming a point source from a knowledge of the angular dependence of photoelectrons. The effect of the finite extension of the source has been qualitatively discussed by Hultberg.[3]

Similarly, if B be the area under the internal K-conversion line, then

$$B=KN_{eK}, \qquad (2)$$

where N_{eK} is the total number of internally converted K-shell electrons emitted from the same source corresponding to N_γ, the number of gamma rays of energy E. In this we have assumed that K, the spectrometer transmission, is practically independent of the electron energy.

From Eqs. (1) and (2), the internal conversion coefficient is

$$\alpha_K(E)=N_{eK}/N_\gamma=(B/A)\tau_K(E)\omega f(E). \qquad (3)$$

The photoelectric cross section $\tau_K(E)$ has been tabulated extensively by White[4] for different Z, and from this $\tau_K(E)$ may be obtained graphically for any E. Thus it would be possible to estimate $\alpha_K(E)$ if one could calibrate the spectrometer for $\omega f(E)$.

This method of the determination of the I.C.C. is straightforward, since here a previous assumption about the decay scheme is not necessary to evaluate α_K. Thus, the conversion coefficient of any of the gamma rays in a complicated decay can be easily and accurately determined.

It is relatively simple to get a theoretical estimate of $\omega f(E)$ for a flat type spectrometer. This is because the angular spread of the electron trajectories is small, and so the integrations involved due to the angular distribution of photoelectrons become sufficiently simple for numerical evaluation. As is well known, because of the low transmission of such an instrument ($K=1\%$ in reference 1) rather strong sources are necessary to get statistically significant counting rates. However, for the measurement of internal conversion lines very thin sources are absolutely essential. These two contradictory requirements limit the choice of radioisotopes. Although a helical spectrometer has very high transmission, the theoretical estimation of $\omega f(E)$ becomes much more tedious, since the angular spread of the electron trajectories is larger. For a point source, the determination of N_γ from A, the area under the photopeak, is reported by Thomas[5] for a lens type spectrometer. For a finite source it is almost impossible to find $\omega f(E)$ numerically. The situation is more complicated in a Siegbahn-Slätis type helical spectrometer (which has a high transmission, $K=8\%$) since there it is very difficult to get a correct knowledge of the actual electron trajectories, because of the complicated field shape near the source.

Nevertheless, we have used a Siegbahn-Slätis spectrometer for the direct determination of I.C.C., and in what follows, a simple experimental method is described which overcomes this formidable mathematical difficulty in evaluating $\omega f(E)$. Since the internal conversion

[1] S. Hultberg and R. Stockendal, Arkiv Fysik **14**, 565 (1959).
[2] R. Stockendal and S. Hultberg, Arkiv Fysik **15**, 33 (1959).
[3] S. Hultberg, Arkiv Fysik **15**, 307 (1959).
[4] G. White, National Bureau of Standards Circular No. 583, April 30, 1957 (U. S. Government Printing Office, Washington, D. C., 1957).
[5] R. G. Thomas and T. Lauritsen, Phys. Rev. **88**, 969 (1952).

coefficients of the gamma rays in the decay of Co^{60} are unambiguously determined, their α_{KL} can be used to calibrate the spectrometer [see Eq. (3)] in the energy range 1.17 to 1.33 Mev, and thus, knowing $\omega f(E)$, α_{KL} for any other gamma ray can be determined.

II. EXPERIMENTS AND RESULTS

The Siegbahn-Slätis spectrometer, purchased from the L.K.B. Sweden,[6] is set at a transmission of about 5%. The detector is a G.M. counter with 0.5 mg/cm² Mylar film as window. The sources are prepared on a similar Mylar film, mounted on an aluminum ring, and grounded by a strip of aluminum foil, 1 mg/cm² thick. Sources are prepared by the evaporation of a drop of the active solution under an infrared lamp. Since the geometry is very important, particular care has been taken to place the drop exactly at the center of the mounted foil. It is also important to keep the diameter of the source fixed. In our case the source diameter is 2 mm.

The entrance and the central baffle of the spectrometer can be accurately adjusted from outside, and once they are set, they are not disturbed during the experiments. The source can be placed in the chamber through an air lock, and a calibrated rod helps to fix the position of the source to within 0.25 mm. Scanning the 1.17-Mev internal conversion line of Co^{60}, the best source position is found, for which the counting rate is highest. Unfortunately, it is found that the transmission, K, depends rather sensitively on the source position.

Both the continuous beta and the internal conversion lines of Co^{60} are then scanned. For external conversion measurements a Pb foil ($\sim$11 mg/cm²) of diameter 3.5 mm is attached at the center of an aluminum plate 0.5 mm thick. A Cu stop ($\sim\frac{1}{64}$ in. thick) is also placed in front of the source to cut off the beta particles. The distance between the source and the converter is 1.5 mm. A resolution of 3% is obtained for external conversion lines. The resolution is slightly better ($\sim$2.8%) for the internal conversion lines, since the diameter of the source is smaller than that of the converter.

In order to get the Compton continuum, a similar experiment is made with an Al plate 0.5 mm thick. Figure 1(a) gives the external conversion lines of the gamma rays from Co^{60}, along with their Compton edges. Figure 1(b) presents the corresponding internal conversion lines, taken with the same source and with the same instrument geometry. The relative intensities of the conversion lines are carefully measured, and the term $\omega f(E)$ is calculated for the two energies from Eq. (3). We have used the values of α_{KL} as reported by Kamada et al.[7] and used White's table to evaluate $\tau_K(E)$. Table I presents the results.

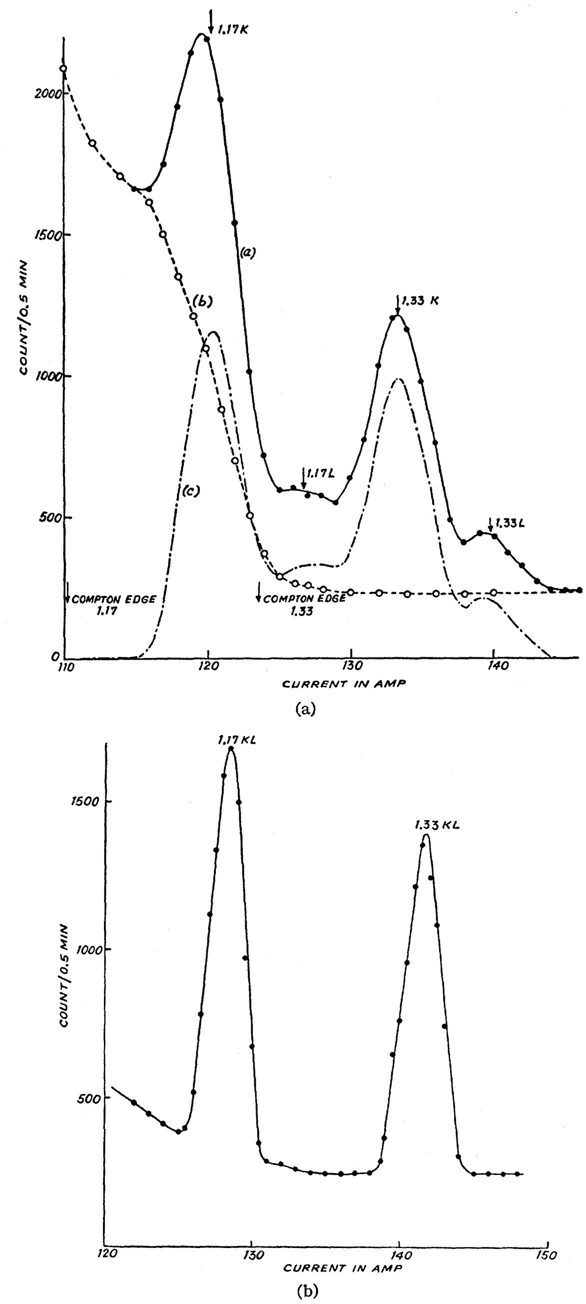
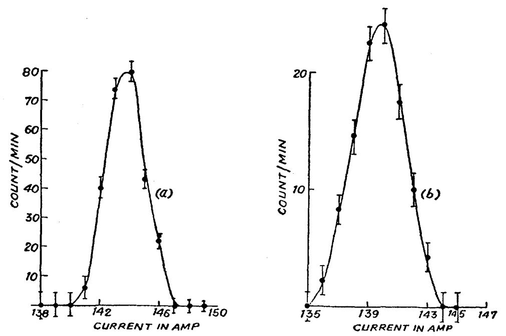


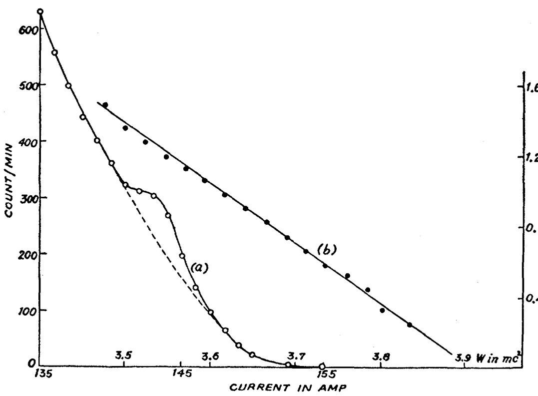
FIG. 1. (a) External conversion spectrum of Co^{60}. Curve (a) is the Compton plus photoelectric spectrum using a Pb radiator; Curve (b) is the Compton spectrum produced by an Al radiator. [Curves (a) and (b) are normalized at 110 and 114 amp, respectively.] Curve (c), which is the difference between curves (a) and (b), is the actual photoelectric spectrum in Pb. (b) Internal conversion spectrum of Co^{60}.

From the table it is found that (ωfE), in our case, is not very sensitive to E in the energy region 1.17 to 1.33 Mev. This fact is utilized to measure the α_{KL} of the 1408-kev gamma ray in the decay of Eu^{152}. The decay of Eu^{152} is rather complicated,[8] and unless several

[6] LKB-Produkter, Fabriksaktiebolag. Stockholm 12.
[7] K. Kamada, T. Teranishi, and Y. Yoshizawa, J. Phys. Soc. Japan 13, 763 (1958).
[8] O. Nathan and M. A. Waggoner, Nuclear Phys. 2, 548 (1956).



(a)



(b)

FIG. 2. (a) Internal [Curve (a)] and external [Curve (b)] conversion spectra of the 1408-kev gamma ray in Eu^{152} decay. (b) Curve (a) is the total beta spectrum of Eu^{152} showing the weak 1408-kev conversion line riding on the tail of the continuous spectrum. Curve (b) is the Kurie plot to determine the dotted background in Curve (a).

assumptions are made about the decay mode, α_{KL} cannot be found for the gamma rays. The most reliable work seems to be that of Nathan and Hultberg,[9] where they have measured the relative gamma-ray intensities by studying the external conversion lines. But they have assumed the theoretical value of α_K for the 344-kev gamma ray (which is definitely $E2$) to get the α_K of the 1408-kev gamma ray. Mukherjee and co-workers[10] have measured the α_K of the 344-kev gamma ray from beta group analysis, and their value agrees well with the theoretical value of Rose.[11] But the presence of the low-energy beta group, as reported by them, is rather embarrassing, and a direct determination of the I.C.C. of any of the gamma rays in the decay of Eu^{152} seems to be instructive.

The internal and external conversion lines of the 1408-kev gamma rays, measured by following the same procedure as outlined for Co^{60}, are shown in Fig. 2(a). Since the internal conversion line is riding on the tail

[9] O. Nathan and S. Hultberg, Nuclear Phys. **10**, 118 (1959).
[10] P. N. Mukherjee, I. Dutt, A. K. Sen Gupta, and R. L. Bhattacharyya, Physica (to be published).
[11] M. E. Rose, *Internal Conversion Coefficient* (North Holland Publishing Company, Amsterdam, 1958), p. 80.

TABLE I. The function $\omega f(E)$.

Energy Mev	$\alpha_{KL}\times 10^{+4}$ Exp.	Theo.	Intensity in (arbitrary scale) External conversion	Internal conversion	$\omega f(E)$ $\times 10^{-20}$
1.172	1.65	1.67	46.2	29.0	0.61 ±0.03
1.332	1.29	1.27	42.1	23.6	0.67 ±0.03

TABLE II. α_{KL} of 1408-kev gamma ray.

Authors	$\alpha_{KL}\times 10^{+4}$
Nathan and Hultberg[a] (α_K)	4.9 ±0.4
Mukherjee, Dutt, et al.[b]	4.9 ±0.4
Direct determination (present work)	4.99±0.25

[a] See reference 8.
[b] See reference 9.

of the 1512-kev beta group [Fig. 2(b)] a careful Kurie plot analysis is made to determine the background. Altogether four runs are made. The intensities of the conversion lines are measured, and using the $\omega f(E)$ for the 1.33-Mev gamma ray (Table I), α_{KL} is found from Eq. (3). This is presented in Table II.

III. DISCUSSIONS

Thus the present determination checks the previous assumptions about the decay mode of Eu^{152}. This method is relatively simple for measuring the I.C.C. of any gamma ray, provided the function $\omega f(E)$ is carefully measured, as indicated above, for a number of energies. Calibrating sources like Hg^{203}, Cs^{137}, etc., can be used for this purpose. Such work has already been undertaken here. Apart from the usual statistical error in A and B (which can be easily brought down to 1%), the main source of error comes from the deviation of the source from the spectrometer axis, which means that the transmission K is no longer fixed. Particular care should be given to place the source exactly on the spectrometer axis. This can be easily tested by rotating the source holder and noting the peak counting rate. The source and baffle geometry can be checked from the energy-calibration constant, $H\rho/I$, of the instrument, and during the present experiment it is found to be constant to within 1%. The error in the α_{KL} of the 1.33-Mev gamma ray is claimed to be 5%.[6] It also agrees well with the theoretical value of Rose ($\alpha_{KL}=1.27\times 10^{-4}$). Finally the error in the tabulated value of $\tau_K(E)$ is not well known, but an estimate of it is discussed in reference 1.

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