stopover ratio is less than 1/100. This ratio is consistent with the predictions of the Scharff-Goldhaber and Weneser model of vibrational excitations of single phonon character. However, such a model predicts that the stopover transition must be pure electric quadrupole, in contradiction with the angular correlation measurements which require at least 10% $M1$ intensity. Moreover, this level is not explained by the recent theory of asymmetric rotors elucidated by Davidov and Filippov. This theory does not allow for a second excited state having less than twice the energy of the first excited state; the energy ratio in this case is 1.8. Even if we assume that this ratio will be lowered by interactions, we are still faced with the anomalous behavior of this level as compared to the similar states in Zn^{64} and Zn^{68}. These latter two levels at 1.79 and 1.60 Mev have crossover to stopover ratios which are close to 1. These nuclei, $Zn^{64,66,68}$, have been studied by (p,p') interactions by Beurtey et al.,[6] who examined both the elastic and inelastic distributions. They find similar behavior for the ground state as well as the first two excited states. Thus, the puzzle remains as to why the crossover transition in Zn^{66} should be so strongly suppressed. One can, of course, argue that only a small change in the wave function describing this state could cause such a suppression since even in Zn^{64} and Zn^{68} the crossover transition is much less than would be expected on a single-particle model.

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Accurate Method for Measuring Internal Conversion Coefficients*

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To reveal the effect on internal conversion due to the nuclear structure and extension, measurements are needed which have higher accuracy than is attainable from currently used methods. This article describes how, under certain conditions, the absolute value of the total internal conversion coefficient can be measured to ±0.5% by the use of a large NaI(Tl) detector with a thin well-type window. Complications encountered in the comparison between experimental and computed values are mentioned.

THE influence on internal conversion coefficients (hereafter denoted by I. C. C.) due to the finite extension of the nucleus and its internal structure has led to many recent theoretical discussions[1–6] and to extensive revisions[1,2] of the calculated I. C. C. tables which were heavily relied upon in the past. It has been mentioned[3] that although internal conversion is no longer the clean cut tool it was thought to be in determining many nuclear properties, its dependence on the nuclear wave function may reveal additional information about nuclear structure, provided that it can be measured experimentally with sufficient accuracy. At the present, only a few I. C. C. measurements are as accurate as ±5%. Even such measurements are not precise enough to reveal the nuclear effects which are generally small. It is the purpose of this paper to demonstrate a new method whereby the I. C. C. of many nuclear transitions can be measured with much improved accuracy. This method is a refinement based upon the same principle that the author described some years ago.[7] However, since it is not well known, the method and its capability will be described in more detail here.

As an illustration, let us consider Cd^{111m}, whose decay scheme consists of a simple cascade of two transitions as shown in Fig. 1. Each 150-kev $E3$ transition is in coincidence with a 247-kev $E2$ transition, and vice versa. To measure the I. C. C. of these transitions, the sample is placed at the center of a large NaI(Tl) scintillator which has a small diameter well, as shown in Fig. 2. The well is lined with a plastic test tube of 50 mg/cm² wall thickness which is thick enough to cut off all the

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
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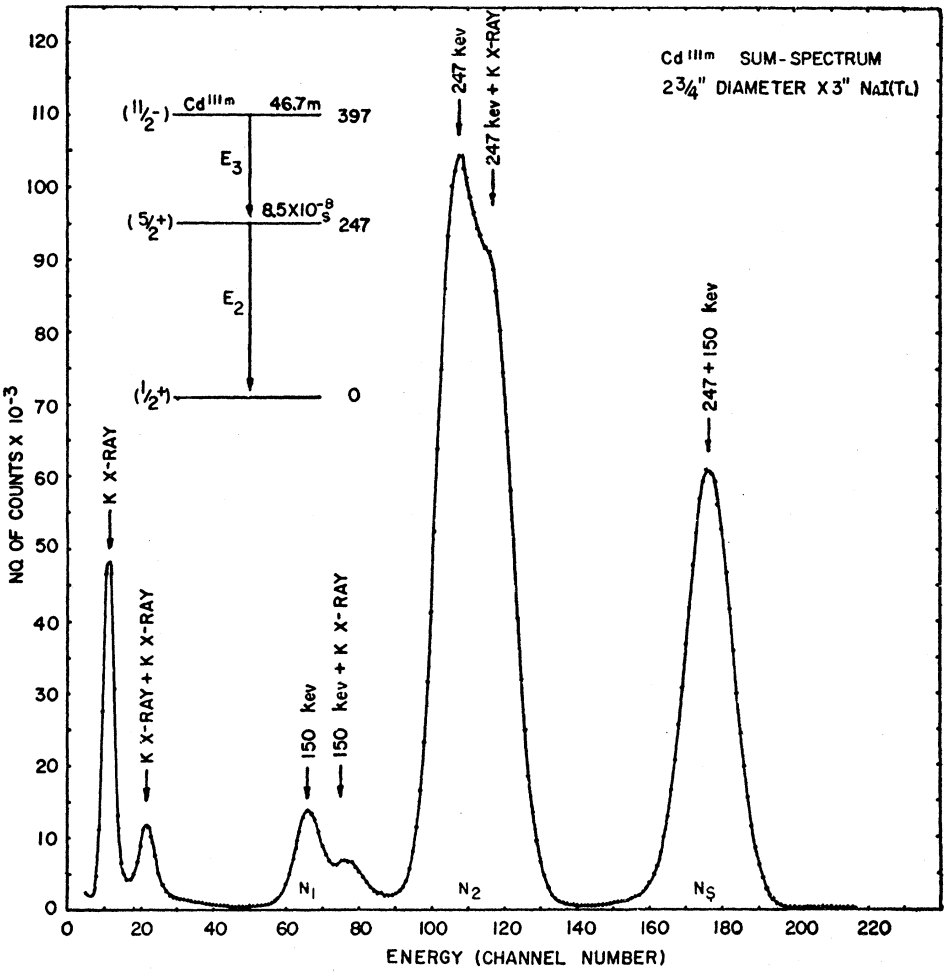

FIG. 1. Sum spectrum of Cd^{111m}.

conversion electrons, but thin enough to let through the gamma rays with very little attenuation. The scintillator is coupled to a DuMont 6363 photomultiplier, and the pulses are fed into a 256-channel pulse-height analyzer of the ANL design.

If the two gamma rays resulting from a disintegration are both detected by the scintillator, a pulse will result with a height corresponding to 247+150 kev, contributing one count under the sum peak in Fig. 1 marked as N_s. If for some reason, such as internal conversion, the gamma ray from the 150-kev transition is not detected by the scintillator, the 247-kev gamma ray if detected will produce one count under the peak at 247 kev, and vice versa. Quantitatively, the number of counts under each of the peaks, denoted by N_1, N_2, and N_s can be written as follows: let N be the total number of disintegrations; α_1, α_2 be the total I. C. C. of the 150- and 247-kev transitions, respectively; and ϵ_1, ϵ_2 be, respectively, the over-all detection efficiency for the 150- and 247-kev gamma rays (taking into account scintillator size, counting geometry, absorption due to well lining and sample thickness, gamma ray energies, etc.). Then the total number of 150-kev gamma rays detected, summed or not summed with the 247-kev gamma rays, will be;

$$N(150)=N\epsilon_1(1+\alpha_1)^{-1}.$$

Similarly,

$$N(247)=N\epsilon_2(1+\alpha_2)^{-1}.$$

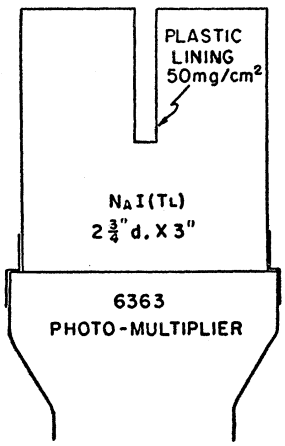

FIG. 2. The detector.

TABLE I. Internal conversion coefficient of the 150-kev $E3$ transition in Cd^{111m}.

Experimental	α (total)
Natural CdO	2.32 ±0.025
Enriched $Cd^{112}O$ (*a*-first run)	2.295±0.014
Enriched $Cd^{112}O$ (*b*-second run)	2.280±0.011
Computed[a]	$\alpha_K+\alpha_L$ $+\frac{1}{2}\alpha_M$(unscreened)
For 150 kev	2.30 ±
For 149.6±0.3 kev	2.32 ±0.015
For 149 kev	2.35 ±

[a] Values for α_K and α_L from L. A. Sliv and I. M. Band. Values for α_M (unscreened) from M. E. Rose.

The number of counts under the sum peak will be obviously,

$$N_s=N\epsilon_1(1+\alpha_1)^{-1}\epsilon_2(1+\alpha_2)^{-1}.$$

And the number of counts under the peak at 150 kev will be,

$$N_1=N(150)-N_s$$
$$=N\epsilon_1(1+\alpha_1)^{-1}(1+\alpha_2)^{-1}[\alpha_2+(1-\epsilon_2)].$$

Similarly,

$$N_2=N(247)-N_s$$
$$=N\epsilon_2(1+\alpha_1)^{-1}(1+\alpha_2)^{-1}[\alpha_1+(1-\epsilon_1)].$$

Taking the ratio N_1/N_s, we obtain,

$$N_1/N_s=(1/\epsilon_2)[\alpha_2+1-\epsilon_2].$$

Similarly,

$$N_2/N_s=(1/\epsilon_1)[\alpha_1+1-\epsilon_1].$$

Thus, to evaluate α_1, one needs only the value of ϵ_1 in addition to the measured numbers N_2 and N_s. And α_2 is evaluated from N_1, N_s, and ϵ_2. If the size of the scintillator is adequately large, and the sample is not unusually thick, the value of ϵ_1 can easily be made to be 0.99+. A rough estimate of the difference $(1-\epsilon_1)$ will suffice to make the measurement very accurate. However, it is obvious that the accuracy of this method depends upon the condition that $\alpha_1 \gg 1-\epsilon_1$. This condition is not fulfilled by higher energy transitions with small I. C. C.'s.

For the 150-kev transition in Cd^{111m}, the $2\frac{3}{4}$ in. diameter×3-in. long scintillator used in this experiment is quite adequate. The results obtained in three separate trials are listed in Table I. The sample used has a thickness of 10 mg/cm², and was produced by synchrotron activation of natural CdO or enriched $Cd^{112}O$ via the photonuclear reaction $Cd^{112}(\gamma,n)Cd^{111m}$, using the strong beam from the I. S. U. synchrotron.

Comparison with the computed value is complicated by the following factors. (a) The computed I. C. C. for M-shell electrons does not account for screening. The factor of $\frac{1}{2}$ used as a correction is somewhat arbitrary. (b) The energy of the transition has not been determined with sufficient accuracy. The best reported value of 149.6±0.3 kev[8] is adopted for the present purpose, although the present measurement by the scintillation spectrometer seems to indicate a slightly higher value. Considering all such factors, the agreement between the experimental value and the computed value is quite good.

No attempt was made to evaluate the I. C. C. of the 247-kev transition accurately from the present data since the scintillator used is obviously not large enough. In principle, however, a collateral experiment can always be made to measure ϵ_2 accurately, from which α_2 can be calculated.

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