Title

MEASUREMENTS OF INTERNAL CONVERSION COEFFICIENTS

Authors

Hultberg, Solve
Horen, Daniel J.
Hollander, Jack M.

Publication Date

1961-06-01

UCRL - 9608 Rev.

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation Laboratory

BERKELEY, CALIFORNIA

DISCLAIMER

UCRL-9608 Rev

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

MEASUREMENTS OF INTERNAL CONVERSION COEFFICIENTS

Sölve Hultberg, Daniel J. Horen and Jack M. Hollander

June 1961

MEASUREMENTS OF INTERNAL CONVERSION COEFFICIENTS

Sölve Hultberg, Daniel J. Horen and Jack M. Hollander

Lawrence Radiation Laboratory
University of California
Berkeley, California

June 1961

ABSTRACT

Internal conversion coefficients of M1, M4 and E2 transitions from the Y^{87}, Cs^{137}, Au^{198} and Ir^{192} decays have been studied by using the internal-external conversion (IEC) method. For unhindered transitions of the 2+ -> 0+ type we have found $\alpha_{2(317)} = 0.054 \pm 0.003$ for the 317 kev transition from Ir^{192} and $\alpha_{2(412)} = 0.029 \pm 0.0015$ for the 412 kev transition from Au^{198}, showing good agreement with theory.

MEASUREMENTS OF INTERNAL CONVERSION COEFFICIENTS

Sölve Hultberg †, Daniel J. Horen and Jack M. Hollander

Lawrence Radiation Laboratory
University of California
Berkeley, California

June 1961

I. INTRODUCTION

Recently a considerable effort has been devoted to the experimental study of internal conversion coefficients of E2 transitions, particularly those proceeding from 2+ to 0+ states in even-even nuclei. Because these transitions are pure it is possible to make a detailed comparison of the experimental results with the calculations of Rose and Sliv [1)]. The theoretical calculations take into account the influence of finite nuclear size by the application of certain corrections which are much smaller for E2 than for M1 conversion coefficients [1)]. However, some evidence has been found for significant deviations between theoretical and experimental E2 conversion coefficients, deviations amounting to some 10% or more [2)]. Most of the experimental values have been obtained by the peak-to-beta-spectrum (or PBS) method or by the internal-external conversion (or IEC) technique. However, the experimental situation is not satisfactory because in some cases the measured values spread fairly much. This is particularly evident in the well-known case of the 412 keV E2 transition which follows the decay of Au^{198}. Here the experimental results range from agreement with theory to figures that are about 20% low.[2,6)]

It is important to clarify the situation in general and in the 412 keV (Au^{198}) case in particular. Therefore we have re-measured the $\alpha_{2(412)}$ and

† On leave from the Nobel Institute of Physics, Stockholm 50, Sweden

other conversion coefficients, using the IEC method.

2. EXPERIMENTAL TECHNIQUE

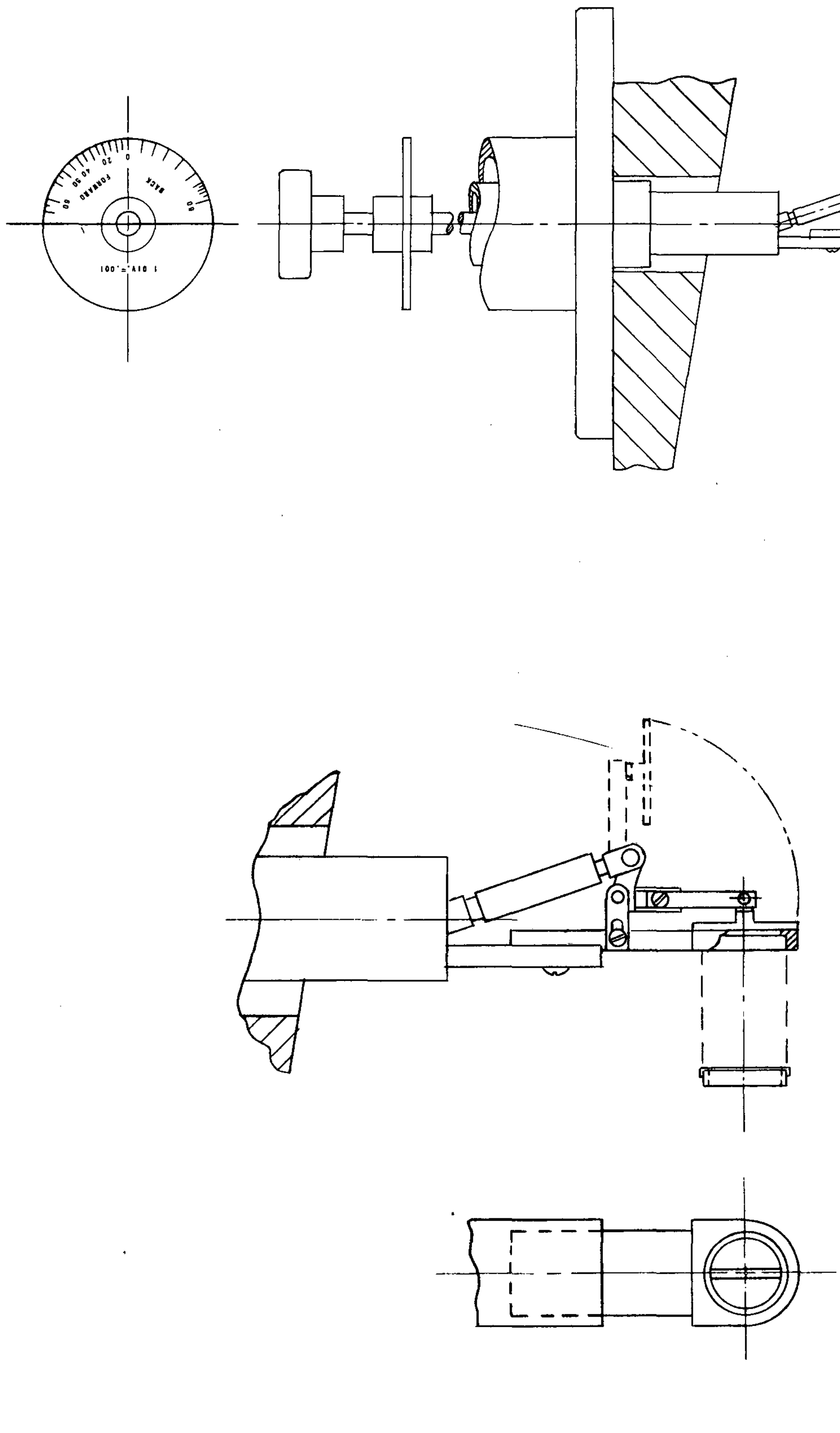
The technique for measuring internal conversion coefficients absolutely with the IEC method has been described elsewhere [3,4] and need not be repeated here.

The instrument used is a flat, double-focusing beta-ray spectrometer of 25 cm mean radius which employs as a detector a flow-type methane proportional counter. To accommodate the activity and the photoelectric converter a special holder has been constructed which permits the location of the converter to be shifted from outside the spectrometer. Thus, by operating a shaft the converter could be placed either in front of the source or in a position where it did not obstruct the beam of internal conversion electrons emitted from the source. The arrangement is shown in Fig. 1.

We used two rectangular uranium converters of dimensions 5.0 x 9.8 mm^2 (both) and of surface thicknesses 2.19 ± 0.02 and 0.75 ± 0.02 mg/cm^2. The following activities were studied:

Y^{87} (388,483); Cs^{137}(662); Au^{198}(412); Ir^{192}(296,308,317)

Figures inside parentheses give energies in keV of the gamma rays investigated. The yttrium source was liquid deposited, the cesium was vaporized and the gold source was chemically plated. The iridium was painted as inactive material onto an aluminum backing and a rectangular piece, 3 x 8 mm^2, was then cut out and sent for activation. This method has the advantage of very easy handling after activation and it worked satisfactorily for the iridium experiments.



MUB-639

Fig. 1.

3. RESULTS

The results obtained for the measured K internal conversion coefficients ϵ_K are summarized in Table 1.

TABLE 1

Isotope	Energy of transition in keV	Source size mm^2	Multi-polarity	Experimental ϵ_K	Theoretical ϵ_K
$_{38}Sr^{87}$	388	4 x 10	M4	0.18±0.015	0.17
	483	- " -	M1	0.0026±0.00015	0.0026
$_{56}Ba^{137}$	662	1 x 9	M4	0.095±0.004[x]	0.093
$_{80}Hg^{198}$	412	2 x 4	E2[xx]	0.029±0.0015[xxx]	0.030
$_{78}Pt^{192}$	296	3 x 8	E2	0.063±0.009	0.062
	308	- " -	E2	0.058±0.005	0.057
	317	- " -	E2[xx]	0.054±0.003	0.054

[x] Using the BESK value τ_K = 20.2

[xx] 2+ → 0+ transition

[xxx] Using the BESK value τ_K = 59.5

The experimental results given in Table 1 represent in each case an average over four to five measurements. In the external conversion measurements on the 483 keV transition in Sr^{87} the 483 K line was not resolved from the 388 (L+M+N+...) peaks. However, by using measured values for photoelectric absorption ratios of the uranium K-, L- and M+N+...-shells[4)] together with appropriate f factors the contributions from the 388 (L+M+N+...) lines to the external conversion peak could be subtracted off.

For the calculation of the internal conversion coefficients we used the expression[3,4)]

$$\epsilon_K = \frac{A_\beta}{A_\gamma} \tau_K f \; d \; k \; b, \qquad (1)$$

where A_β and A_γ are the intensities per unit momentum interval of the internal and external conversion lines, respectively. τ_K is the absolute photoelectric cross-section (in barns/atom) for the K-shell of the converter. f is a correction factor which depends upon the photoelectric angular distribution and the particular values of the parameters which describe the sizes of the source and the converter and their relative distance. The appropriate f values were obtained by use of the BESK service. k is the ratio of intensities of sources used to measure the external and internal conversion lines. In these experiments we have k = 1 because the same source was employed for both measurements. b is a dimension factor which is a constant for a given converter material.

In the case of a rectangular converter and a radioactive source of no extension (point source) the factor f is given by

$$f = \frac{\frac{2}{\pi}\int_0^{\theta_2} J(\theta + \Delta)\cdot \mathrm{tg}\,\theta \left[\arcsin\left(\mathrm{tg}\theta_0/\mathrm{tg}\theta\right) - \arccos\left(\mathrm{tg}\theta_1/\mathrm{tg}\theta\right)\right] e^{\frac{-ug}{\cos\theta}}\, d\theta}{\int_0^{\pi} J(\theta)\sin\theta\, d\theta} \qquad (2)$$

where $J(\theta)$ denotes the photoelectric angular function for unpolarized incident photons. Definition of the various symbols is given in ref. 4. The attenuation of the gamma rays in the absorbing material between source and converter is taken into account by the exponential factor exp $(-ug/\cos\theta)$. u is the absorption coefficient in cm^{-1} and g is the absorber thickness in cm. Self-absorption in the source material can also be taken into account by putting in appropriate values for u and g.

According to a method given in ref. 4 the source dimensions can be taken into account in the calculation of the f factor. The source and converter are assumed to have rectangular shape. Such an assumption simplifies the analysis and introduces no practical limitation since for flat spectrometers the rectangular shape is nearly always desired. Moreover, the source and converter are assumed to be symmetrically positioned with respect to each other (cf Fig. 12, ref. 4). The source is "decomposed" into a number of parts, each of which is small compared with the converter, so that Eq. (2) can be applied to every such part. The resulting f value will then simply be the arithmetic average of all f values computed. This method has been tested experimentally [4] and is used in the BESK calculations.

DISCUSSION

As a check on the experimental set-up we measured the internal conversion coefficient of the 662 keV M4 transition following the decay of Cs^{137} and the result was found to be in good agreement with theory and earlier measurements of both the PBS and IEC type [2d,3,5]. It should be observed that in calculating the result we have used the theoretical BESK value τ_K = 20.2 barns/atom while in the references 2d and 3 a somewhat lower experimental value has been used.

The main reason for remeasuring the 412 keV E2 internal conversion coefficient, in the following denoted $\alpha_{2(412)}$, was the peculiar disagreement from various experimental methods of the "true" value of the $\alpha_{2(412)}$ (cf Introduction). Although the IEC method had already been used twice [2d,e] with consistent results it was felt that an additional effort might possibly be of some value since the experimental conditions could still be somewhat modified and it must be satisfactorily proved that such conditions do not influence the result. Thus it may be observed that the IEC results for the $\alpha_{2(412)}$ have been obtained by using

1) A GM counter and two different sources for internal and external conversion, the latter process taking place in gold (ref. 2d),

2) A GM counter with one source, taking advantage of the short half-life of Au^{198} (a uranium converter was used, ref. 2e),

3) A proportional counter with one source, performing all measurements in rapid succession and using a uranium converter (present paper).

These efforts prove for the $\alpha_{2(412)}$ that the IEC method is independent of changes in the experimental conditions to within estimated errors, as expected. How then do we explain the difference between the low values of refs: 2d, 2e and the result in Table 1 of the present paper, which is in essential agreement with theory?

Let us turn our attention to Eq. (1). The quantities A_β, A_γ, d and k require no particular comment as their evaluation is quite straightforward; we shall only observe here that the d values were determined by two independent methods of analysis, the results agreeing to within 1 - 3%, and that any error in the k factor may be avoided by using the same source for both internal and external conversion, as was done in the measurements reported here.

It remains to consider the factors τ and f, the determination of which is more complicated. The "integrated" or "total" photoelectric cross-section τ (for a particular shell) forms the basis for the determination of ϵ from Eq. (1). Most often τ_K (K denoting the K-shell) is used and can conveniently be derived from the τ_a values (a denoting the whole atom) of the NBS Circular No. 583. Because of the importance of τ_K for determining ϵ it is necessary to know τ_K accurately. However, it is not possible to estimate the error in τ_K from the NBS tables since the underlying theoretical and experimental information is scanty and very approximate, except for the six numerical values of Hulme et al. Only very recently has it been possible, through calculations by Hultberg, Nagel and Olsson[8] on the electronic computer BESK, to compare the NBS values for τ_K with accurate theoretical computations. The numerical work is based on the formalism of Nagel [7] whose formulae are, theoretically, valid at all energies. In practice, however, the calculations cannot at present be carried much above 800-1000 keV for Z = 92 because of limitations in computer capacity and speed. The results from the BESK calculations so far show that, below 500 keV, the NBS tables give τ_K values that are generally good to within 1 - 3%. For computing the $\alpha_{2(412)}$ of Table 1 we used the BESK value τ_K = 59.5 barns/atom which agrees to within 1% with the NBS table.

For Z = 92 BESK has also computed differential photoelectric cross-sections at hν = 412 and 662 keV and also at some other energies. These numerical results are correct to any order in αZ and should thus be directly compared with the experimental angular functions $J(\theta)$ of ref. 4 and 10. Such a comparison shows that theory and experiment agree satisfactorily at 279 and at 662 keV. This is not surprising since in these cases careful "extrapolation" experiments were carried out [4, 10]. However, at 412 keV no such "extrapolation" experiments were done and the "true" shape of the angular function was obtained only approximately by using observable trends at the two higher energies 662 and 1332 keV. Thus theory and experiment can be expected to compare less favourably at 412 than at 279 and 662 keV. Significant differences occur at large angles (larger than 40 - 50°) and are such that the experimental angular function is higher.

Though mathematically involved the process of photoelectric conversion of photons is a straightforward physical problem where effects from nuclear finite size and radiative corrections are expected to be unimportant. Moreover, for the K-shell screening effects should be negligible and thus the BESK calculations should be accurate and one should not expect experiment to show deviations of any significance. The differences that are observed between the tabulated 412 keV angular function of ref. 4 and the BESK calculations are probably connected with scattering phenomena and have the consequence of correcting the f_{412} factor so that the latter will become larger than before. By introducing such a correction we have arrived at a value of $\alpha_{2(412)}$ that agrees rather well with theory (cf Table 1). The IEC results reported in refs. 2d and 2e should then be subjected to corresponding upward adjustments which are of the order of 10% and will thus be brought into agreement with the results from other investigations. Moreover, it has been suggested [2d)] that the PBS value of de Vries should be adjusted upwards on account of certain scattering effects, bringing his PBS value into better agreement with the results from other PBS investigations. A very recent PBS measurement seems to give a value in the range 0.027 - 0.029[9)] and thus there now seems to be little doubt that the $\alpha_{2(412)}$ agrees with theory to within some 10%. Whether the rather persistent tendency (except for ref. 6) towards values that are somewhat lower than theory is a real effect remains, however, to be seen.

Correction of the f_{412} factor also leads to good agreement of $\alpha_{2(317)}$ with theory (cf Table 1). This is important since the 317 keV transition in Pt^{192} is of pure E2 character. To within the experimental accuracy it must therefore be concluded that our experiments do not give evidence for a deviation from theory of unhindered E2 transitions.

One of us (S. H.) would like to express his sincere gratitude to Professor I. Perlman for the opportunity of spending the summer (1960) with the Chemistry Division of the Radiation Laboratory. We wish also to thank Mr. A. D. Carneiro for his careful design of the source-holder and converter assembly.

REFERENCES

1) L. A. Sliv and I. Band, Tables of internal conversion coefficients, published by the Academy of Sciences of the USSR, Moscow-Leningrad 1956.
M. E. Rose, Internal conversion Coefficients, North-Holland Publ. Co., Amsterdam, 1958.
L. S. Kisslinger, Phys. Rev. 114, 292 (1959).

2) a. A. H. Wapstra, G. Nijgh, N. Salomons-Grobben and L. Ornstein, Nuclear Physics 9, 538 (1958/59).
b. G. Nijgh and A. H. Wapstra, Nuclear Physics 9, 545 (1958/59).
c. F. K. McGowan and P. H. Stelson, Phys. Rev. 107, 1674 (1957).
d. C. de Vries, E. J. Bleeker and N. Salomons-Grobben, Nuclear Physics 18, 454 (1960).
e. J. H. Hamilton, W. F. Frey and S. Hultberg, Bull. Am. Phys. Soc. 5, 449 (1960).

3) S. Hultberg and R. Stockendal, Arkiv för fysik 14, 565 (1959).

4) S. Hultberg, Arkiv för fysik 15, 307 (1959).

5) A. H. Wapstra, Arkiv för fysik 7, 275 (1954).

6) B. G. Pettersson, J. Thun and T. R. Gerholm, Nuclear Physics 24, 243(1961).

7) B. Nagel, Arkiv för fysik 18, 1 (1960).
B. Nagel and P. O. Olsson, Arkiv för fysik 18, 29 (1960).

8) S. Hultberg, B. Nagel and P.O. Olsson, in print (Phys. Rev. Letters).

9) R. Stockendal and J. H. Hamilton, private communication.

10) Z. Sujkowski, in print (Arkiv för fysik).