Evidence for Reduction of $M1$ K-Shell Internal Conversion Coefficient

F. K. McGowan and P. H. Stelson
Oak Ridge National Laboratory, Oak Ridge, Tennessee
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THE internal conversion coefficients calculated by Rose *et al.*[1] assume a point charge for the nucleus. Calculations of Sliv[2] indicate that the finite nuclear size should appreciably reduce the $M1$ K-shell internal conversion coefficient for high Z. The very limited experimental evidence which has been reported[3,4] seems to confirm this reduction. We wish to report information on K-shell internal conversion coefficients and values for $E2/M1$ derived from Coulomb excitation experiments which give evidence in support of this reduction.

The ratio of K x-rays to gamma rays for α-particle Coulomb excitation of nuclei with $Z=73$ to 83 has been determined. From these measurements, one can deduce the K-shell internal conversion coefficients for several gamma-ray transitions. The absolute yields of K x-rays and gamma-rays were measured with a 3-inch×3-inch NaI(Tl) scintillation spectrometer for 3.0-Mev α particles incident on thick targets. The yield of K x-rays resulting from the stopping of the α particles is as much as two times smaller than the yield of K x-rays resulting from internal conversion of nuclear γ rays following Coulomb excitation. The number of K-shell vacancies produced by the stopping of the α particles in targets of different Z was determined for a few elements for which either there is no appreciable nuclear excitation (Bi, Pb, Tl, and Ce) or the yield of K x-rays from internal conversion could be determined from the intensity of the nuclear γ ray of known $E2$ multipole. The results are given in Fig. 1. No correction is assumed for $E2$ K-shell internal conversion coefficients, $\alpha_2{}^K$. (A reduction in $\alpha_2{}^K$ would produce an even larger reduction in $\beta_1{}^K$.) In the cases of W^{184}, W^{186}, and Os, the yield of K x-rays from internal conversion was 67%, 58%, and 10% of the total yield, respectively. The K-shell internal conversion coefficients deduced for several γ-ray transitions in odd-mass nuclei are listed in Table I. The $E2$ and $M1$ internal conversion coefficients $\alpha_2{}^K$ and $\beta_1{}^K$ are taken from Rose *et al.*[1]

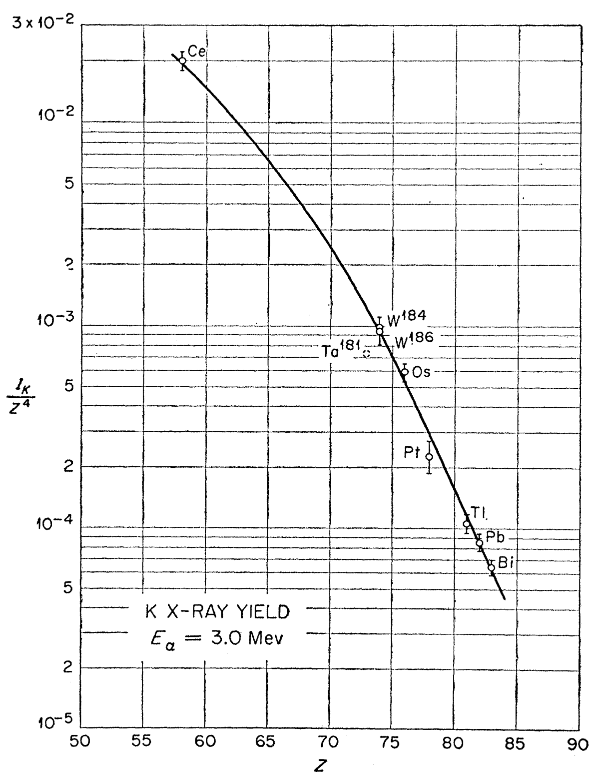

Fig. 1. Yield of K-shell vacancies resulting from the stopping of 3-Mev α particles incident on thick targets as a function of Z. I_K, the number of K-shell vacancies per microcoulomb of singly charged helium ions, is the yield of K x-rays corrected for the fluorescent yield.

Tantalum-181.—$E2/M1$ ratio is taken from directional angular correlation measurements[5] which have been reinterpreted in light of the new spin assignments[6–8] for the 482- and 615-kev states in Ta^{181}. With this $E2/M1$ ratio and using $\alpha_2{}^K$ and $\beta_1{}^K$ as given by Rose, the expected α^K is 1.57 ± 0.10 and the yield of K x-rays from stopping 3-Mev α particles on a Ta target would fall well below the curve of I_K/Z^4 *vs* Z as shown in Fig. 1. We list in Table I the reduction factor G to be applied to $\beta_1{}^K$, assuming no correction for $\alpha_2{}^K$, to fit the experimental $\alpha_{\mathrm{exp}}{}^K$. If we were to assume a 10% reduction of $\alpha_2{}^K$ for the measurements on W^{184}, W^{186}, and Ta^{181}, the factor G becomes 0.49 for the 137-kev transition in Ta^{181}.

Gold-197.—From the angular distribution of the 277-kev γ rays following Coulomb excitation we know $(E2/M1)^{\frac{1}{2}}=-(0.75\pm0.20)$.[9] The large uncertainty in $E2/M1$ results from the fact that A_2, the angular distribution coefficient, has a broad maximum at this value of $E2/M1$. This uncertainty has been reduced by a polarization-direction measurement which is rather sensitive with regard to $E2/M1$ (a brief account of this type of measurement has already been reported.[10]) This result for $E2/M1$ in Table I is not compatible with the $E2/M1=0.12\pm0.03$ deduced from a $\gamma-\gamma$ directional correlation measurement by Kane and Frankel.[11] Using their result, the factor G is 0.70.

Table I. Evidence for reduction of $M1$ K-shell internal conversion coefficients. The reduction factor G is given by $\alpha_{\mathrm{exp}}{}^K=I_{E2}\,\alpha_2{}^K+I_{M1}\beta_1{}^K G$.

Nucleus	E_γ (kev)	$E2/M1$	$\alpha_{\mathrm{exp}}{}^K$	$\alpha_2{}^K$	$\beta_1{}^K$	G
$_{73}Ta^{181}$	137	0.25 ± 0.10	$1.05\ \pm0.15$	0.47	1.84	0.65 ± 0.15
$_{75}Re^{187}$	134	(1/9)	$1.50\ \pm0.29$	0.48	2.34	0.69 ± 0.15
$_{75}Re^{185}$	128	...	$2.10\ \pm0.43$	0.54	2.65	...
$_{79}Au^{197}$	277	0.30 ± 0.07	$0.29\ \pm0.03$[a,b]	0.077	0.45	0.79 ± 0.12
$_{81}Tl^{203}$	279	2.25 ± 0.25	0.159 ± 0.004[c]	0.0763	0.53	0.65 ± 0.07

a Huber, Halter, Joly, Maeder, and Brunner, Helv. Phys. Acta **26**, 591 (1953).
b J. W. Mihelich and A. de-Shalit, Phys. Rev. **91**, 78 (1953).
c See reference 4.

Thallium-203.—Extensive measurements of the internal conversion coefficients of the 279-kev transition in Tl^{203} have recently been made by several groups of workers.[3,4] Starting with experimental values for α^K, $\alpha^{L_{\rm I}}$, and $\alpha^{L_{\rm II}}$ and with the assumption $G_K=G_{L_{\rm I}}=G_{L_{\rm II}}$ they found $E2/M1=1.38\pm0.25$ and $G_K=0.53\pm0.08$. Since this reduction factor depends rather decisively on the value of $E2/M1$, we felt that a measurement of $E2/M1$ independent of internal conversion coefficients would be desirable. The measured angular distribution of the 279-kev γ rays following Coulomb excitation could be fitted equally well by $(E2/M1)^{\frac{1}{2}}=1$ to 2. However, a polarization-direction measurement is very sensitive to this range of $(E2/M1)^{\frac{1}{2}}$ for a transition of the type $3/2(E2+M1)\tfrac{1}{2}$ and the value observed for $E2/M1$ is listed in Table I.

Rhenium-187, -185.—These transitions are of limited value as evidence for a reduction in β_1^K because of the uncertainty in $E2/M1$. The determination of the $E2/M1$ value from the angular distribution is unfavorable for these transitions because the transition of the type $7/2(E2+M1)5/2$ is nearly isotropic for a wide range of $E2/M1$. The angular distributions have been measured and they are found to be isotropic. A K/L measurement has been made for the transition in Re^{187}, [12] and the $E2/M1$ value of 1/9 is based on this measurement.

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[10] P. H. Stelson and F. K. McGowan, Bull. Am. Phys. Soc. Ser. II, **1**, 164 (1956).
[11] J. V. Kane and S. Frankel, Bull. Am. Phys. Soc. Ser. II, **1**, 171 (1956).
[12] Cork, Brice, Nester, LeBlanc, and Martin, Phys. Rev. **89**, 1291 (1953).

Beta Decay of a C^9 Nucleus*

M. S. Swami, J. Schneps, and W. F. Fry
Department of Physics, University of Wisconsin, Madison, Wisconsin
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In a systematic survey of photographic emulsions, exposed to 3-Bev protons, for excited nuclear fragments, a connected double star was found which is interpreted to be the disintegration of a C^9 nucleus. It was thought worthwhile to describe the event in detail since there has been no evidence for a long-lived C^9 nucleus.

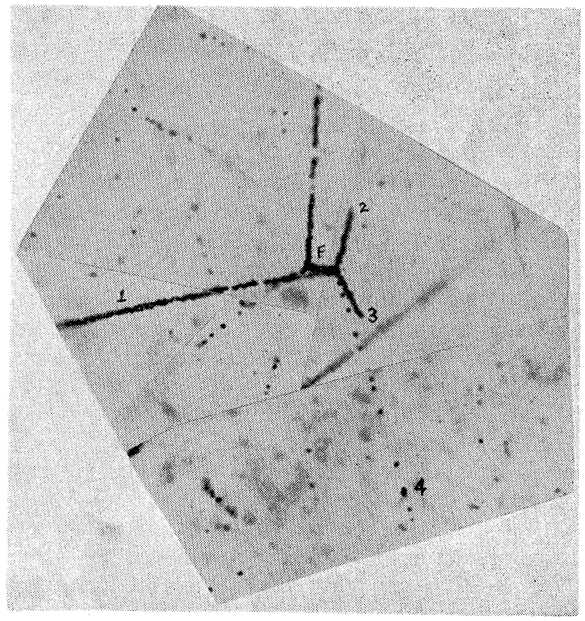

Fig. 1. A photograph of an event interpreted as the beta decay of C^9. The C^9 nucleus (track *F*) was produced in star (*A*) and disintegrated into a proton, two alpha particles, and a positron (tracks 1, 2, 3, and 4, respectively).

A photograph of the connected stars is shown in Fig. 1. The primary star (*A*), which was probably produced by a neutron, has three outgoing tracks. Track *F* is saturated, 6.2 microns long and was caused by a slow multiply-charged particle. The absence of δ rays and the presence of some visible scattering along *F* suggest that the particle came to rest before it gave rise to the secondary star (*B*). The secondary star which appears at the end of track *F* consists of four charged particles. The main characteristics of the secondary star and the fragment are given in Table I. Measurements of multiple Coulomb scattering and grain density along track 4 indicate that it was caused by a 3.1-Mev electron. Tracks 1, 2, and 3 are coplanar to within one degree. The coplanarity strongly suggests that the fragment that caused track *F* came to rest before it decayed and that no neutrons were involved in the decay. Since track 1 was produced by a singly-charged particle, the coplanarity and the momentum balance uniquely determine that the particles which produced

Table I. Characteristics of C^9 decay.

Track	Range in microns	Identification	Energy in Mev	Angles
F	6.2	C^9	9.4	65°
1	341.0	P	7.6	115°
2	9.9	He^4	2.7	
3	7.8	He^4	2.1	136.5°
4	...		3.1	11°