a photon with energy more than 1 Mev is 3×10^{-4} per ordinary decay. The average photon energy per decay is 12 kev. It would be of interest to have an experimental determination of these quantities.

In the interaction (1) we have assumed that a π-meson interacts directly with a μ-meson. Of the alternative assumptions concerning the mechanism of the decay, that in which the mesons interact only through nucleons[12] might be of special interest and is under consideration.

The author wishes to express his hearty thanks to the Departments of Physics of both Iowa State College and Kyushu University for making it possible for him to study in the former institution. He is also indebted to Professor J. K. Knipp for his valuable advice and constant encouragement and to Dr. W. F. Fry for making available his latest data on this problem.[13]

* On leave from Kyushu University, Fukuoka, Japan.

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Internal Conversion in the *L*-Shell*

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In a previous paper,[1] the authors have given the results of calculations for the internal conversion of γ-radiation in the L_{I}-shell. The present communication contains a summary of these results together with the corresponding results for the L_{II}- and L_{III}-shells. The calculations reported here complete a program undertaken with the object of providing a table of internal conversion coefficients for the L-shell covering the range of γ-ray energies and atomic numbers employed by Reitz.[2]

All values given for the internal conversion coefficient are based on formulas derived from those obtained by Goertzel and Rose.[3] The method of derivation of those formulas has been reported earlier, together with a summary of the actual formulas for: the L_{I}-shell—electric dipole, electric quadrupole, and magnetic dipole; the L_{II}-shell—electric dipole; and the L_{III}-shell—electric dipole.

The additional modified formulas required for the present calculations are quite similar and we hope to publish them at a later date. It should be noted that these formulas take account of relativistic terms but not the effects of screening. It is expected that numerical values for internal conversion coefficients for the L-shell will be computed by a method which, like that of Reitz, allows for screening effects; at that time the present results should furnish a good estimate of the importance of screening effects for internal conversion in the L-shell.

TABLE I. Internal conversion coefficients for electric dipole radiation (observed L_N-electrons/observed photons of energy k).

Atomic number Z	Gamma-ray energy k (mc^2 units)	L_{I} shell	L_{II} shell	L_{III} shell	L shell
92	0.09273	0.2372	0.2567	0.2856	0.7795
	0.2927	0.02097	0.009763	0.007779	0.03851
	0.6427	0.003916	0.001076	0.0006813	0.005673
84	0.0833	0.2910	0.2606	0.3544	0.9060
	0.2333	0.03011	0.01241	0.01185	0.05437
	0.5333	0.004569	0.001080	0.0008520	0.006501
49	0.0283	2.202	1.347	2.531	6.080
	0.2083	0.01520	0.001819	0.002605	0.01962
	0.4083	0.002440	0.0001763	0.0002468	0.002863

TABLE II. Internal conversion coefficients for electric quadrupole radiation (observed L_N-electrons/observed photons of energy k).

Atomic number Z	Gamma-ray energy k (mc^2 units)	L_{I} shell	L_{II} shell	L_{III} shell	L shell
92	0.09273	9.199	235.2	202.9	447.3
	0.2927	0.1548	1.239	0.7025	2.096
	0.6427	0.01694	0.04557	0.01660	0.07911
84	0.0833	5.300	195.4	195.9	396.6
	0.2333	0.1103	1.617	1.184	2.911
	0.5333	0.01546	0.04494	0.02219	0.08259
49	0.0283	5.787	1792.	3260.	5058.
	0.2083	0.1026	0.1059	0.1188	0.3273
	0.4083	0.01176	0.004734	0.005271	0.02176

TABLE III. Internal conversion coefficients for magnetic dipole radiation (observed L_N-electrons/observed photons of energy k).

Atomic number Z	Gamma-ray energy k (mc^2 units)	L_{I} shell	L_{II} shell	L_{III} shell	L shell
92	0.09273	43.98	4.244	0.06309	48.29
	0.2927	1.896	0.1758	0.002150	2.074
	0.6427	0.2079	0.02046	0.0003458	0.2287
84	0.0833	27.85	2.397	0.02979	30.28
	0.2333	1.381	0.1123	0.002503	1.496
	0.5333	0.1313	0.01071	0.0003588	0.1424
49	0.0283	19.22	1.299	0.05643	20.58
	0.2083	0.05396	0.001244	0.0004160	0.05562
	0.4083	0.007751	0.0001476	0.00007558	0.007974

Tables I, II, and III give values for the internal conversion coefficient in the electric dipole, the electric quadrupole, and the magnetic dipole cases, respectively. Values are shown for each of three atomic numbers and for three γ-ray energies. Except for the use of IBM machines in the calculation of the hypergeometric functions, all numerical work was done on Marchant and Friden desk calculating machines.

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Fine Structure and Angular Correlation in Po^{210}*

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Polonium^{210} is usually considered as a pure α-emitter, although the presence of a weak γ-radiation (energy 803 kev, intensity about 10^{-5} per α) is definitely established.[1,2] The low energy α-particles preceding these γ-rays have escaped observation despite repeated attempts to study the fine structure of Po.

By using a coincidence method we were able to detect the low energy α-group and to study its angular correlation relative to the γ-rays following it.

For the first part of our experiments a source of Po was immersed in a scintillating solution (terphenyl phenylcyclohexane) and the height of the scintillation pulses was studied with a differential pulse-height selector (Fig. 1, curve I). Then, a thick piece of stilbene was located near the α-source and used to detect the γ-rays in coincidence with the α-particles. A fast coincidence circuit[3] (3×10^{-9} sec resolving time) was used in order to minimize the random counting rate. The pulse-height distribution produced by α-particles in coincidence with γ-rays is shown in Fig. 1, curve II. The shift between the two curves of Fig. 1 is, within experimental error, in agreement with an energy difference of 0.8 Mev.

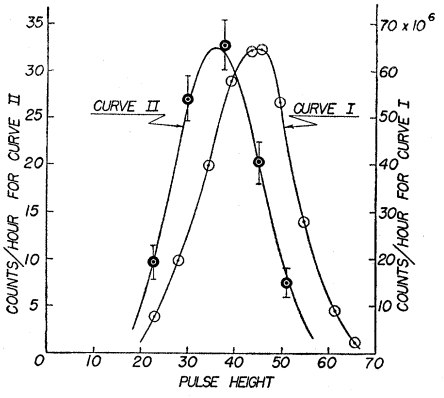

FIG. 1. Scintillation pulse-height distributions for Po-α-particles. Curve II is the distribution produced by α-particles in coincidence with γ-rays.

The number of coincidences was also studied as a function of artificial delays introduced in the coincidences selector. The result indicated that the half-life of the γ-emitting state of Pb^{206} is less than 10^{-9} sec.

In the second part of the experiment a stronger Po source was used. The α-particles were collimated by means of an aperture defining the direction of their emission within $\pm 10°$, and detected by a stilbene crystal after having traveled 1 cm in air. The γ-detector defined the angle of emission of the γ-rays within $\approx \pm 15°$, and the coincidences were counted as a function of the angle between α- and γ-rays. From the raw data was subtracted the background due to random coincidences (measured by interposing a sufficiently long delay) and that caused by spurious immediate coincidences (measured as a function of angle, with the α-detector covered by a thin absorber).

The results are plotted in Fig. 2 together with the curve $\sin^2 2\vartheta$. The total background amounted to about 30 percent of the net counting rate on the maxima.

If one assumes that both Po^{210} and Pb^{206} have 0 spins in their ground states, they must have the same parity (probably even) since they are connected by α-decay. Thus the γ-rays cannot be of magnetic polarity, having to carry the same angular momentum and parity as the short range α-particle. The agreement of the experimental curve with the $\sin^2 2\vartheta$ distribution indicates that the γ-rays are electric quadrupole ($E2$) and that the short-range α-particles have angular momentum 2. The fact that the 0.8-Mev excited state of Pb^{206} has spin 2 and the same parity as the ground state is in agreement with the behavior of most other even-even nuclei.[4] The $E2$ assignment is also consistent with the short half-life of the γ-emitting state.

However, this assignment seems difficult to reconcile with measurements of conversion coefficients of the γ-rays from Pb^{206}.[1,2] One might look for an explanation of this disagreement in the incompleteness in the theory of K/L ratios for high Z, and in the experimental difficulties of an absolute measurement of K conversion coefficients.

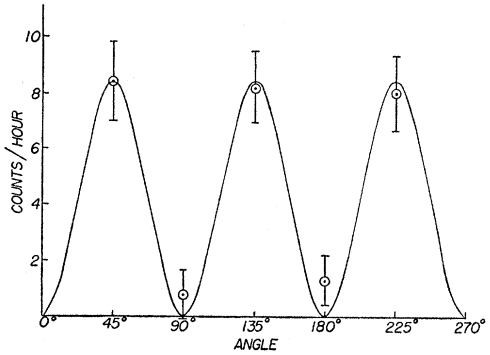

FIG. 2. Angular distribution of γ-rays from Po. The background has been subtracted. The curve is a plot of $\sin^2 2\vartheta$.

* Supported in part by the AEC.

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Zinc as an Acceptor in Germanium

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IT has long been known that some third and fifth column elements can act as donor (electron) or acceptor (hole) impurities for germanium and silicon. In particular, arsenic, antimony, and phosphorus are donors; indium, aluminum, gallium, and boron are acceptors. Numerous other elements (notably tin) have been taken to be effective as impurities.[1] In most, if not all, such cases, it has not been established that traces of impurity in the added element were not responsible for the observed effects.

In the present note, I wish to report what seems to be convincing evidence that zinc can act as an acceptor element in germanium. The evidence is based upon two sorts of experiments.

In the first experiments, several samples of single crystal germanium were prepared by adding small amounts of highest purity zinc (Johnson-Mathey 99.99 percent material) to the melt. In all such melts, the germanium crystals were p-type. The resistivity of the single crystals was measured in the temperature range of liquid hydrogen to room temperature. A curve of log conductivity *versus* $1/T$ for a single crystal of zinc-doped germanium is shown in Fig. 1. The activation energy for excitation of carriers from the impurity state can be obtained from the slope of the $\log\sigma$ *versus* $1/T$ curve. This value for the zinc single crystals is 0.031 ev. The significant point for this discussion is that this value is greater by a factor of five or ten than values obtained for such acceptors as indium. A high activation energy might be expected for zinc in a substitutional site because of its position in the second column of the periodic table.

A striking fact is that the activation energy for zinc-doped samples is the same, within experimental error, as the activation energy previously found for heat-treated germanium.[2] This may

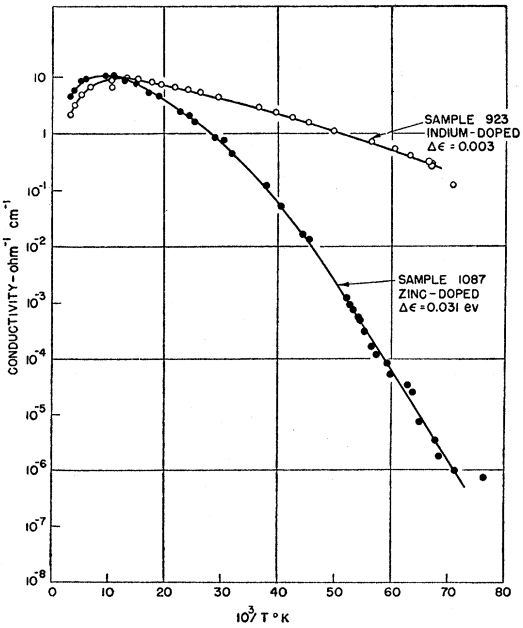

FIG. 1. Conductivity *vs* $1/T$ plots for indium-doped and zinc-doped single crystals of germanium in the temperature range 12–300°K.