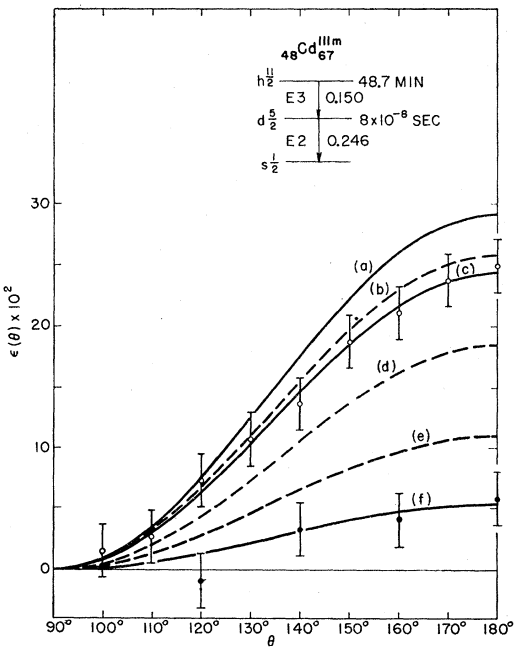

FIG. 1. Directional correlation of Cd^{111m}. (a) Theoretical curve based on pure $E3$-$E2$ scheme; (b) $CdCl_2$ solution fitted by least squares and corrected for angular resolution; (c) $CdCl_2$ solution, least-squares fit; (d) CdO solid, fitted and corrected; (e) solid Cd metal, fitted and corrected; and (f), theoretical "hard-core" assuming axially symmetric fields. The experimental points are shown for $CdCl_2$ solution (open circles) and solid $CdCl_2$ (solid circles).

The correlations were measured in solid CdO, $CdCl_2$ in acidic aqueous solution, dry $CdCl_2$, and solid Cd metal. In addition, the anisotropy $\epsilon(150°)$ was observed with molten Cd metal. The enriched isotope was in the form of powdered CdO and this was first bombarded and used directly. The corrected least-squares fit to the CdO data, taken at 180°, 160°, 140°, and 120° is shown as curve (d) in Fig. 1.

Aqueous solutions were obtained by dissolving irradiated CdO in about 0.1 ml of dilute HCl. The experimental points using those sources are shown (open circles) in Fig. 1, to which curve (c) represents a least-squares fit and curve (b), that corrected for angular resolution.

Solid $CdCl_2$ was obtained by evaporation of solutions prepared as above to dryness. The four low-lying solid experimental points in the figure represent these data.

Metallic cadmium was prepared from the enriched CdO by electrodeposition from a cyanide solution onto a carbon cathode[10] of such purity that no activity could be detected from the carbon irradiated separately. Data collected from the resulting sources, consisting of small metal particles mixed with carbon, are represented by curve (e) which is corrected for angular resolution.

Molten metallic sources were prepared as above and, after irradiation, sealed into glass capsules containing a reducing atmosphere of hydrogen at NTP. The sources were held above the 376°C melting temperature of the metal by a heater below, and the upper part of the capsule was made hotter by a second heating coil above the source to prevent deposition of the metal on the walls. The procedure was found to produce bright droplets of liquid metal with larger pieces of ordinary cadmium.

Curve (a) represents the theoretical correlation based on the suggested decay scheme involving pure multipoles.[11] Empirically from the lifetimes, less than 0.01 percent mixture of $M4$ with the $E3$ upper transition would be expected, and in the second transition mixing of $M3$ with the $E2$ should be several orders less. The corrected measured anisotropy, $\epsilon(150°)=0.216\pm0.018$, for the molten metal is in good agreement with the value 0.2227 from the theoretical curve. The lower bound of the standard deviation allows less than 3 parts in 10^3 admixture of $M4$. Curve (a) can thus be taken as representing the undisturbed correlation.

The results for the various sources can be summarized by values of attenuation factors G_2 and G_4 such that the correlation is given as $W(\theta)=1+G_2A_2P_2(\cos\theta)+G_4A_4P_4(\cos\theta)$,[1] with $A_2=0.1786$ and $A_4=-0.0043$.[12] The smallness of $|A_4|$ makes impossible the determination of meaningful values of G_4 from the data, so the term in P_4 has been ignored. The values obtained for G_2 are listed in Table I.

Under $eQ(\partial^2V/\partial z^2)/h$ are listed approximate values for the electric quadrupole interaction necessary to explain the various attenuation factors.[1] For the aqueous solution, a correlation time

TABLE I. Attenuation coefficients and electric quadrupole interaction frequencies for the various sources of Cd^{111m}.

Source	G_2	$eQ(\partial^2V/\partial z^2)/h$ Mc/sec
Molten metal	0.97 ± 0.08	...
$CdCl_2$ solution	0.88 ± 0.05	~200
CdO solid	0.63 ± 0.08	4.1–6.6
Solid metal	0.40 ± 0.07	8.4–14.1
$CdCl_2$ solid	0.19 ± 0.06	>26

τ_c of 10^{-11} sec has been arbitrarily assumed, and the frequency given is the rms value. The molten metal would not be expected to have an rms interaction much larger than in the hexagonal solid metal and therefore, the disturbance in the molten metal should be negligible, as observed. Although CdO has a cubic crystal structure, the fine, irradiated powder may well possess average interactions of the scale suggested as the result of lattice defects.[13] The interaction in hexagonal $CdCl_2$ is sufficient to reduce the correlation to the "hard-core" for axially symmetric fields represented by curve (f) in the figure. The value of G_2 is in excellent agreement with $G_2(\text{lim})=\frac{1}{5}$. In contrast, results for the In^{111} scheme for $InCl_3$ fell well below the hard core.[4,6] The present results thus suggest that after-effects of the K capture are involved in such In^{111} correlations.

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Internal Conversion and Directional Angular Correlation of the Bi^{207} Gammas

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LONG-LIVED (approximately 50 yr) Bi^{207} is known to decay by ϵ-capture to stable Pb^{207} via the 0.82-sec Pb^{207m} isomer,[1–3] which decays by the emission of 1.055-Mev and 0.555-Mev γ rays in cascade. In addition, Neumann and Perlman report[4] five

additional γ rays following the decay of Bi^{207}, but we do not observe these in the decay of the long-lived Bi^{207} source prepared at this laboratory. From lifetime and nuclear shell theory considerations these transitions are probably to be identified with $M4$ and $E2$ transitions between the levels $i_{13/2} \rightarrow f_{5/2} \rightarrow p_{1/2}$.[5]

The source of Bi^{207} was produced by bombarding Pb with 25-Mev protons in the Oak Ridge National Laboratory cyclotron. After a careful chemical separation[1] the carrier-free Bi^{207} was used in three forms: a dilute $Bi(NO_3)_3$ solution, solid $Bi(NO_3)_3 \cdot 5H_2O$, and bismuth chloride fixed on an anion exchange resin in 0.5N HCl. The differential pulse height spectrum of the γ radiation from Bi^{207} obtained with a NaI scintillation spectrometer four months after the bombardment is shown in Fig. 1. In addition to the K x-rays of Pb and the 0.555-Mev and 1.055-Mev γ rays, there are two weaker γ rays with energies 0.700 Mev and 1.76 Mev

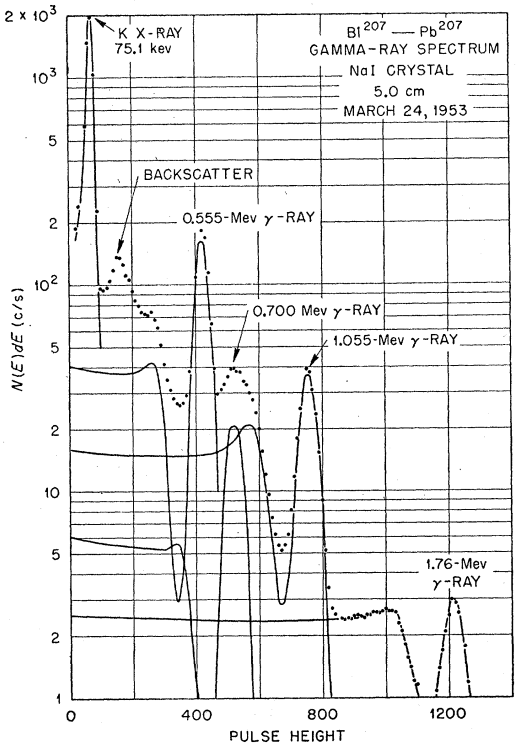

FIG. 1. Differential pulse-height spectrum of the Bi^{207} γ radiation incident on a NaI scintillation spectrometer. Each point in the spectrum contains 4096 counts.

which follow the decay of a much shorter period. The decay of the 1.76-Mev γ ray pulse spectrum with time does not appear to be a simple exponential decay. These two weaker γ rays are probably associated with the decay of bismuth but not necessarily Bi^{207}. The pulse spectrum above 1.76 Mev decreases to two decades below the peak height of the 1.76-Mev full energy peak. The K-shell internal conversion coefficients of the 0.555-Mev and 1.055-Mev γ rays were obtained from intensity measurements of the K-shell internal conversion electrons and the γ radiation with an anthracene and a NaI scintillation spectrometer, respectively. To check the method of measurement the K-shell internal conversion coefficient of the 0.661-Mev γ ray transition of Ba^{137m} was measured. The result agreed to within 6 percent of the accepted $M4$ assignment for the transition. In all experiments involving intensity measurements of the conversion electrons, the air between the source and detector was displaced with H_2 gas. The results together with the theoretical internal conversion coefficients[6] are tabulated in Table I.

TABLE I. Experimental and theoretical internal conversion coefficients.

E_γ (Mev)	$\alpha_{exp}{}^K$	Theoretical coefficients	Classification
1.055	0.096±0.010	$\alpha_5{}^K=0.0393$, $\beta_4{}^K=0.104$, $\beta_5{}^K=0.180$	$M4$
0.555	0.015±0.002	$\alpha_1{}^K=0.0064$, $\alpha_2{}^K=0.017$, $\beta_1{}^K=0.091$	$E2$

From intensity measurements of the gamma radiation it appears that Bi^{207} decays 81.5 percent to the 1.610-Mev excited state and 18.5 percent to the 0.555-Mev excited in Pb^{207}, which agrees with some recent measurements by Wapstra.[7] The half-life of the excited state at 0.555 Mev above the ground state is $T_{1/2}<10^{-9}$ sec as measured with a delayed-coincidence scintillation spectrometer using anthracene and NaI detectors.

The directional angular correlation of the 1.055- and 0.555-Mev cascade was measured with a coincidence scintillation spectrometer using NaI detectors. The windows of the differential pulse-height analyzers were set such that one accepted only the full energy pulse spectrum from the 0.555-Mev γ ray and the other accepted only the full energy pulse spectrum from the 1.055-Mev γ ray. The resolving time 2τ of the coincidence is 1.40×10^{-8} sec. Under these conditions the true coincidence rate is of the order of one count per sec while the random rate is one percent of this. The directional angular correlation coefficients obtained from 10^6 coincidence counts collected at 90°, 135°, 180°, 225°, and 270° are summarized in Table II, together with the coefficients corrected for the finite angular resolution of the detectors.[8] There appears to be no significant change of the angular correlation with the form of the source.

TABLE II. Directional angular correlation coefficients for the Pb^{207} γ-ray cascade.

Form of the source	Experimental values A_2	Experimental values A_4	Corrected values A_2	Corrected values A_4
Bi^{207} attached to resin in 0.5 N HCl	0.1993 0.1943	−0.0073 −0.0247	0.2168 0.2114	−0.0097 −0.0328
Dilute Bi^{207} $(NO_3)_3$ solution	0.2077	−0.0157	0.2260	−0.0209
		Mean values	0.218±0.0043	−(0.0211±0.0067)
		Theory	0.2208	−0.0180

These results are in good agreement with the angular distribution expected from a decay sequence $13/2(M4)5/2(E2)1/2$ for which the theoretical angular correlation function is

$$W_{\gamma\gamma}(\theta)=1+0.2208P_2(\cos\theta)-0.0180P_4(\cos\theta).$$

It appears that both the internal conversion and the directional angular correlation data are consistent with the interpretation that both transitions are predominantly pure multipoles.

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Internal Conversion Electron-Gamma Directional Angular Correlation of Bi^{207}

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SINCE the long-lived Bi^{207} provides an excellent source of monoenergetic electrons[1] from the internal conversion of the 0.555- and 1.055-Mev γ rays of Pb^{207}, the conversion electron-gamma directional angular correlation between the K-shell