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

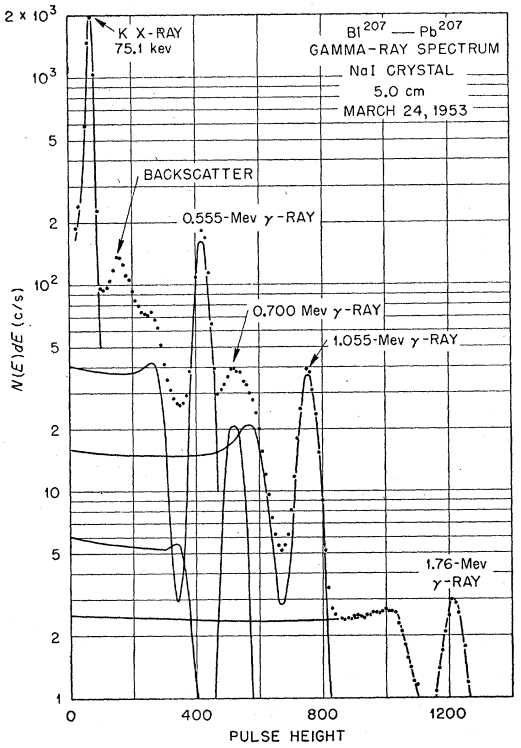

FIG. 1. Differential pulse-height spectrum of the Bi^{207} γ radiation incident on a NaI scintillation spectrometer. Each point in the spectrum contains 4096 counts.

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

internal conversion electrons of the 1.055-Mev transition and the 0.555-Mev γ ray has been measured.

A source of $Bi(NO_3)_3 \cdot 5H_2O$ 300 μg/cm^2 thick and 0.3 cm in a diameter was prepared by evaporating a drop of the liquid to dryness on a 100-μg/cm^2 Formvar film. To detect the K conversion electrons of 967 kev, one of the NaI detectors in the coincidence spectrometer was replaced with an anthracene detector 1.5 inches diameter and 0.5 cm thick. In order to diminish scattering of the conversion electrons, the air between the detector and source was displaced with H_2 gas at one atmosphere, which corresponds to 600 μg/cm^2 of scattering material for the conversion electrons to traverse. The differential pulse height spectrum of the Bi^{207} radiation incident on an anthracene scintillation spectrometer without and with a polystyrene absorber (345 mg/cm^2) to stop the conversion electrons is shown in Fig. 1. The difference between the gross pulse spectrum and the "gamma only" pulse spectrum

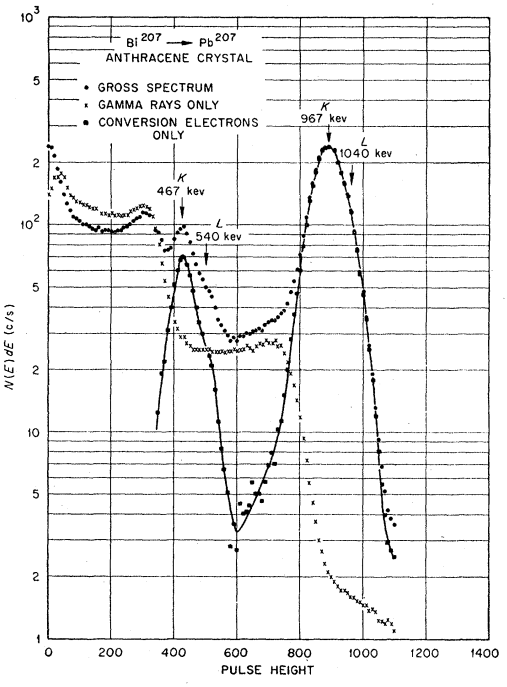

FIG. 1. Differential pulse-height spectrum of the Bi^{207} radiation incident on an anthracene scintillation spectrometer. Each point in the spectrum contains 4096 counts.

is the internal conversion electron pulse spectrum of the 0.555- and 1.055-Mev transitions. With the polystyrene in place, the Compton recoil electron spectrum is more intense than the gross spectrum at the lower energies. The additional recoil electrons being detected are some of the recoil electrons produced in the polystyrene by the γ rays.

TABLE I. Directional angular correlation coefficients for the Pb^{207} conversion electron-gamma cascade.

Experiment No.	Experimental values $\mathcal{A}_2'$	Experimental values $\mathcal{A}_4'$	Corrected values A_2'	Corrected values A_4'
1	0.2296	−0.0242	0.2526	−0.0335
2	0.2176	−0.0181	0.2394	−0.0250
3	0.2124	0.0000	0.2337	0.0000
4	0.2178	−0.0204	0.2396	−0.0282
		Mean values	0.2413 ± 0.0040	−(0.0216 ± 0.0075)
		Theory	0.2315	−0.0229

For the conversion electron-gamma angular correlation measurements, the window of the NaI scintillation spectrometer accepted only the full energy pulse spectrum from the 0.555-Mev γ ray and the window of the anthracene scintillation spectrometer accepted only the low energy edge of the conversion line due to 1.055-Mev transition. The true coincidence counting rate for the conversion electron-gamma correlation was of the order of two counts per sec while the random rate is one percent of this. The directional angular correlation coefficients obtained from 10^6 coincidence counts are summarized in Table I. Corrections for multiple scattering of the conversion electrons in the source, source backing, and the H_2 gas as described by Frankel[2] are very small for this high electron energy, i.e., amount to about 1 percent for the coefficient A_2' of $P_2(\cos\theta)$ and 2 percent for the coefficient A_4' of $P_4(\cos\theta)$. To check this point experimentally a 2-mg/cm^2 Al foil was inserted between the source and the detector, and no attenuation in the measured anisotropy was observed for an experimental run containing 4×10^4 coincidence counts. With the window of the analyzer set to include the L conversion electrons and part of the K conversion electrons, the measured anisotropy (uncorrected data) increased from 0.358 to 0.426.

The conversion electron-gamma angular correlation function[3] is given by

$$W_{e-\gamma}(\theta)=\sum_{\nu=0}^{\nu m} A_\nu b_\nu P_\nu(\cos\theta),$$

where the coefficients A_ν are the γ-γ correlation coefficients and the coefficients[4] b_ν for the sequence $13/2(M4)5/2(E2)1/2$ are $b_2=1.0487$ and $b_4=1.2760$. The results in Table I are in good agreement with the theoretical angular correlation function:

$$W_{e-\gamma}(\theta)=1+0.2315P_2(\cos\theta)-0.0229P_4(\cos\theta).$$

Additional measurements are in progress and more details of the present experiments will be published in a subsequent paper.

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