The present results demonstrate the effect of crystal structure on the directional correlation of Pb^{204}. It is quite evident that more theoretical and experimental investigations are needed to clarify the major deviations from the expected behavior.

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Isomerism in Pb^{206}

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An investigation of the energy levels of Pb^{206}, formed in the electron capture decay of 6.4-day Bi^{206}, has been undertaken because of theoretical interest[1] in nuclei near closed-shell lead-208. Previous results[2] were inconclusive since the transition energies could not be determined with sufficient accuracy and a number of unresolved lines were known to be present.

The following measurements on Bi^{206} have been carried out at the Nobel Institute and at the Royal Institute of Technology, Stockholm; conversion line energies and intensities in a double-focusing spectrometer and in an intermediate-image spectrometer; coincidences between pairs of K conversion lines in a two-lens "spectrogoniometer"; and coincidences between conversion lines and gamma rays observed in the intermediate-image spectrometer modified with a NaI crystal detector near the source. The energy measurements, which establish a number of cascade crossovers, together with the coincidence data impose more than 50 restrictions on the level arrangement. Except for a few very weak unassigned gamma rays the tentative level scheme adopted contains 26 transitions and satisfies all of the conditions mentioned above.

Two sets of lines which are of special interest have their relative intensities listed in Table I. Both transitions are thought to

TABLE I. Relative conversion line intensities of $E3$ isomeric transitions in Pb^{206}.

$E\gamma$	K	L_{I+II}	L_{III}	M	N
202.5	0.084	0.57	0.25	0.22	···
516.1	18	10	~1.8	3.3	~0.6

originate from a 7− fifth excited state at 2200.3 kev going to the fourth and third levels at 1998.1 and 1683.8 kev, respectively. The latter are each assigned 4+ not only because the K to L ratios of the two transitions appear to be consistent with $E3$ but because of other features of the decay scheme. It is possible that the 7− level is analogous to that responsible for the 68-min isomer of Pb^{204}.

A measurement of the lifetime of the Pb^{206} isomeric state has been carried out by placing a Bi^{206} source very close to a NaI crystal and EMI photomultiplier detector and allowing the output pulses to trigger the sweep of a Tektronix type 511AD synchroscope. When a sweep is started by the pulse from a gamma ray which is "prompt" with respect to K capture and occurs in the upper part of the level scheme there is a chance of observing a delayed pulse from either the main isomeric transition or gammas in the lower part of the scheme. The efficiency for detecting delayed events is expected to be reasonably high since, on the basis of the assumed level scheme, 10 strong gamma-ray transitions precede the isomeric level and 5 strong ones follow it.

For optimum conditions the integral pulse-height selector was set as low as possible, i.e., to the point where the room background and noise counting rate from the shielded detector was about 150 per minute. A scope sweep of 500 microseconds (10 cm) was used and its calibration and linearity were checked by feeding in a 200-kc/sec sine wave from a G.R. type 805C signal generator and then counting the number of cycles per cm. To record the data a cardboard mask covered the base line and all other parts of the scope face except a 1.5-cm wide slot whose distance from the origin pulse could be adjusted as desired. A large diameter short focal length lens placed at a distance of 50 cm from the scope screen focused the light pulses appearing in the mask opening onto a 931 photomultiplier. The latter was provided with a long-time-constant circuit in order to smooth out the "hashy" pulse arising from the decay characteristics of the scope screen phosphor. Even with this precaution reliable operation was not attained until a one-kick multivibrator having a time constant of several milliseconds was inserted between the discriminator and scalar.

Figure 1 shows the delayed pulse distribution obtained with a source of approximately 5×10^{-4} microcurie which gave a triggering rate of 1500 counts per min. A calculated background of 2.8 counts per min has been subtracted and corrections have been made for nonlinearity of the oscilloscope trace. The slope of the curve corresponds to a half-life of 145 ± 15 microseconds. This value is just above the region 10^{-7} to 10^{-4} sec within which no lifetimes had been observed[2] by means of the more commonly used delayed-coincidence techniques.

The bismuth sources were prepared by cyclotron bombardment of lead with 16-Mev deuterons followed by chemical separation.[2] Measurements on the conversion electron spectrum showed that a small amount of 50-year Bi^{207} and a very minute amount of 14-day Bi^{205} were present. The decay rate of the isomer was therefore studied and its intensity was observed to decrease at approximately the 6-day rate of Bi^{206}.

The 145-microsecond lifetime, which is determined almost entirely by the 516.1-kev transition, appears to be shorter than expected[3] although no multipole order other than $E3$ gives as reasonable a fit. Using the K conversion coefficients[4] of Rose *et al.*, one can compute from the conversion line intensities in Table I that the ratio of the 516.1- to 202.5-kev transition probabilities is 300 (with an error of perhaps 25 percent) if it is assumed that both are $E3$. This leads to a partial half-life of about 0.04 sec for the 202.5-kev transition. The computed ratio of unconverted gamma rays is about 1600. The fact that the ratio would be 700 on the basis of a seventh-power energy dependence[3] seems to be in agreement with the observations.

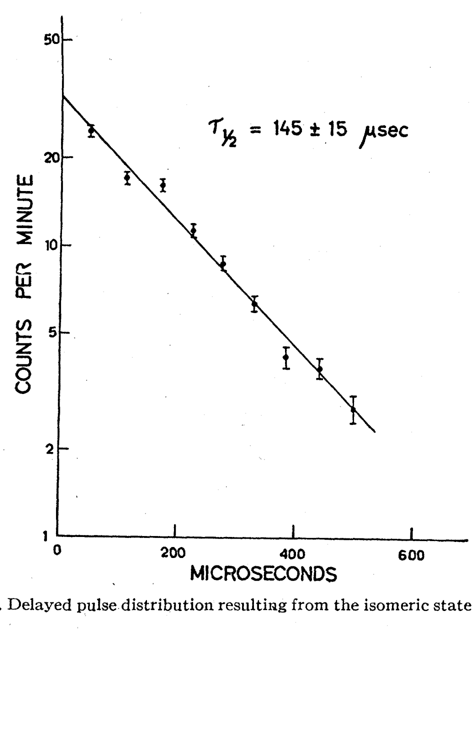

FIG. 1. Delayed pulse distribution resulting from the isomeric state of Pb^{206}.

A complete report on the Bi^{206} decay scheme will be published later. The authors are indebted to Dr. H. Atterling who arranged for the cyclotron irradiations and to Dr. W. Forsling and Mr. T. Karlsson who kindly performed the chemical separations. The first-named author would like to thank Professor Kai Siegbahn for the use of facilities at the Royal Institute of Technology and Professor Manne Siegbahn for extending the hospitality of the Nobel Institute during 1952–1953.

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Yields of Low-Energy Protons and Alphas Resulting from High-Energy Bombardment of Ag

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In this experiment, which has been previously described,[1,2] two experimental arrangements have been constructed to study the yield of charged secondary particles. For one arrangement, a thin foil of Ag (12.8 mg/cm²) has been bombarded by an internal beam of 332-Mev protons and 187-Mev deuterons. The secondary protons and alphas emitted at $0°\pm10°$ to the incident beam direction are detected in nuclear track plates located beneath the median plane of the cyclotron. There are five specific positions for these plates encompassing an energy region ranging from approximately 5 to 22 Mev for the secondary protons and alphas. Using a similar arrangement with the same thickness Ag foil, the angular distribution of secondary particles has been measured for 240-Mev alpha bombardment. Here, secondary protons and alphas emitted at $0°\pm10°$, $45°\pm10°$, and $135°\pm10°$ to the incident beam direction are detected in nuclear track plates at positions for which the mean energies are approximately 6 Mev.

Figure 1 shows the relative yield for the angular distribution of protons and alphas resulting from 240-Mev alpha bombardment. Figure 2 shows the relative yield of protons and alphas emitted at 0° to the incident beam direction for the two different bombardments as a function of their energy. In these plots, smooth curves have been arbitrarily drawn through the points.

Heretofore, there has been a considerable number of experiments performed in which nuclear emulsions have been directly bombarded either with cosmic-ray particles or with particles produced by artificial sources. The nuclear disintegrations which occur in the heavy nuclei (Ag and Br) in the emulsion have been studied extensively. The analysis of the black tracks (secondary particles having <30 Mev of energy) has generally been made using an evaporation model. Le Couteur[3] has probably made the most refinements using this model, and he has had considerable success predicting the low-energy spectrum of hydrogen and helium isotopes resulting from the cosmic ray bombardment of a heavy nucleus ($A=100$). However, recently Bernardini, Booth, and Lindenbaum,[4] in analyzing the results of their experiment, believe that at least 25 percent of the black tracks are knock-out protons.

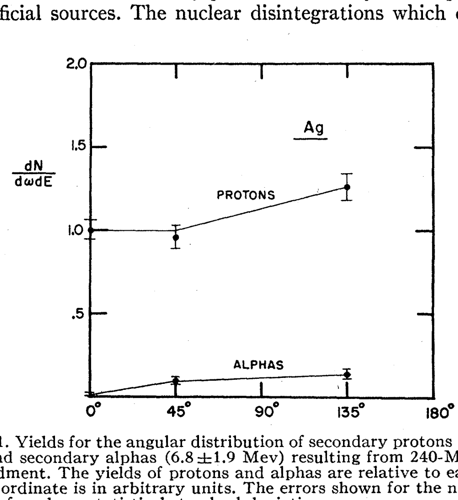

FIG. 1. Yields for the angular distribution of secondary protons (5.5 ± 0.6 Mev) and secondary alphas (6.8 ± 1.9 Mev) resulting from 240-Mev alpha bombardment. The yields of protons and alphas are relative to each other and the ordinate is in arbitrary units. The errors shown for the number of particles found are statistical standard deviations.

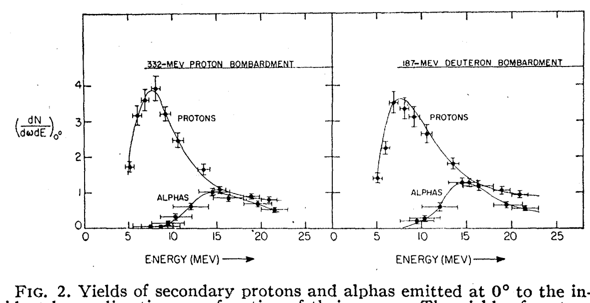

FIG. 2. Yields of secondary protons and alphas emitted at 0° to the incident beam direction as a function of their energy. The yields of protons and alphas are relative to each other and the ordinate is in arbitrary units. Smooth curves have been arbitrarily drawn through the points. The errors shown for the number of particles found are statistical standard deviations. The energy resolution for each point is the entire energy interval considered and is found by combining the energy spread determined by scanning a finite length of plate and the loss of energy by ionization in traversing the finite thickness of target.

The results of the angular distribution, Fig. 1, are consistent with isotropic emission. The rise in the backward direction for protons and alphas is attributed to the fact that the yields of these particles are strongly increasing functions of energy for the region around 6 Mev. If the residual nucleus retains a major portion of the incident momentum, then, for a constant laboratory energy, a proton emitted backwards in the center-of-mass system has ~1 Mev greater energy than a forward emitted proton. The increased yield for the higher energy would account for the backward rise. Similar considerations account for the alpha yield.

Figure 2 indicates that the shape of the spectra are quite similar for the two bombardments. This fact is significant since, according to an evaporation model, the only effect of the bombarding particle should be in the total excitation energy transferred to the nucleus. Le Couteur's analysis shows that the shape of the proton spectrum varies slowly with excitation, with a maximum at about 7 Mev independent of excitation energy. The predicted alpha spectra should have a maximum in the vicinity of 15 Mev for these excitation energies (presumed to be ~50–100 Mev). The results shown in Fig. 2 agree very well with these predictions. However, an evaporation model also implies an exponential fall off in the yield for energies higher than the most probable energy, and the yield is definitely not falling off exponentially for the proton spectra. It appears therefore that a considerable number of these higher-energy protons originate from another process, probably the knock-out process as postulated by Bernardini *et al.*

An analysis similar to reference 2 has been completed for 332-Mev proton bombardment and 187-Mev deuteron bombardment of Be, Al, Ni, Ag, Au, and U, as well as a similar analysis for the angular distribution of secondary particles resulting from 240-Mev alpha bombardment of Be, Al, Ni, and Ag. More detailed secondary proton and alpha energy spectra are also being found for these bombardments. The complete results will be published in the near future.

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