Strong $E0$ Transition in ^{206}Pb Following the Decay of ^{206}Tl

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Pb K x rays and ~1.08-MeV K-conversion electrons have been found among radiations emitted in the decay of 4.2-min ^{206}Tl. These radiations imply the existence of weak β transitions (0.08%) to the 1.17-MeV 0^+ state in ^{206}Pb, which decays primarily by an $E0$ transition to the ground state.

The β spectrum of ^{206}Tl has been investigated by Alburger and Friedlander,[1] who used a magnetic-lens spectrometer and samples prepared by reactor irradiation of thallium. Their results are consistent with a statistical shape for the 1.52-MeV β transition to the ground state of ^{206}Pb. Later Howe and Langer,[2] using a $4\pi\beta$ scintillation spectrometer and samples of ^{206}Tl in equilibrium with long-lived ^{210m}Bi, obtained results which were interpreted in terms of a nonstatistical shape for this transition. This interpretation was based on the assumption that ^{206}Tl decays by a single β transition. Bühring[3] has pointed out the theoretical difficulty in reconciling an energy-dependent shape factor (which would require substantial destructive interference) with the low log*ft* value of 5.3 for this transition. Zoller and Walters[4] have detected the 803.3-keV γ ray ($2^+ \to$ g.s. in ^{206}Pb) in the decay of ^{206}Tl. However, this branch has neither the intensity nor the energy to influence the apparent shape of the ground-state transition.

We have prepared ^{206}Tl by irradiating $TlNO_3$ (100–300 mg, natural isotopic composition) in the pneumatic transfer facility of the University of Michigan Ford Nuclear Reactor. The irradiated samples were dissolved in 150 milliliters of water (to reduce external bremsstrahlung and Tl x-ray fluorescence), and photon spectra were obtained with Ge(Li) detectors. The disintegration rate of a given source was determined by $4\pi\beta$ counting of an aliquot of the aqueous solution. The results for high energies are consistent with those obtained by Zoller and Walters,[4] namely, a 803-keV γ ray with an intensity of $(4\pm1)\times10^{-5}$ and an upper limit of 10^{-5} for γ rays of about 365 keV (corresponding to $E2$ transitions from the 0^+ state at 1.17 MeV[5]). The presence of Pb K x rays is evident in the low-energy spectrum (see Fig. 1). These x rays were found to have an intensity of $(10\pm2)\times10^{-4}$ and to follow a half-period of 4.2 ± 0.2 min.

The most likely source of the x rays is K internal conversion in ^{206}Pb. The yield of K x rays from the "shakeoff" process is expected[6] to be about 2×10^{-4}. Even if substantial amounts of Pb and Bi were present in the irradiated material, these impurities would not be expected to yield products which emit Pb x rays with the requisite half-period. (The only impurities identified in the target material were insignificant amounts of Mn, Br, and In.) In order to determine the origin of the x rays, we obtained spectra in a plastic scintillator in coincidence with K x rays detected in a Be-shielded NaI(Tl) scintillator. An example of these spectra is given in Fig. 2. Analysis of successive spectra yielded a half-period of 5 ± 1 min, an energy of 1075 ± 30 keV (K conversion of a transition of 1165 ± 30 keV), and an e_K intensity of $(6\pm2)\times10^{-4}$.

We conclude that, in addition to the previously identified β transitions to the ground state and to the 803-keV 2^+ first-excited state, the decay of ^{206}Tl involves a β transition to the 1.17-MeV 0^+ state with an intensity of $(8\pm2)\times10^{-4}$. This state decays primarily to the ground state by an $E0$ transition with very little competition from an $E2$ transition to the 2^+ state. The ratio $E0/E2 \geq 60$

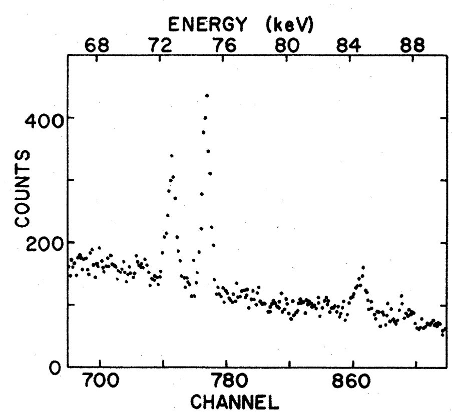

FIG. 1. Spectrum of K x rays emitted in the decay of ^{206}Tl. The major peaks are indistinguishable from the spectrum of Pb K x rays emitted by ^{207}Bi, which was used for the energy calibration. The near absence of Tl K x rays is indicated by the low intensity of the peak at 70.8 keV (Tl $K\alpha_2$).

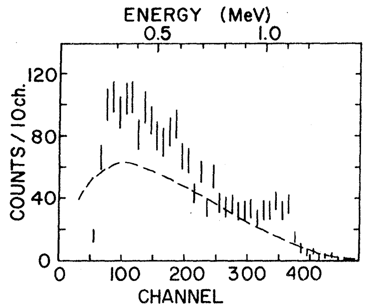

FIG. 2. Spectrum of electrons coincident with photons of ~75 keV. The data bars correspond to $N \pm \sqrt{N}$. The dashed curve shows the shape of the "singles" spectrum observed with the same source, which consisted of a few milligrams of $TlNO_3$ powder spread over an area of 3 cm^2.

is in distinct contrast to the results of Goldman *et al.*[7] for other nuclides in this region. In the high-geometry measurements of Howe and Langer,[2] coincidence summing between conversion electrons and β rays would provide a contribution consistent with the nonstatistical shape reported for the ground-state transition.

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Radiative Pion Capture by ^{12}C†

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The neutron-photon angular-correlation and energy spectrum of neutrons from radiative pion capture by carbon are presented and provide new evidence for excitation of a $J^\pi = 1^-$ axial-vector collective mode. Asymmetry in the angular correlation increases with neutron energy and is accounted for by direct neutron emission.

The spin-isospin structure of the nuclear giant dipole resonance can be studied by radiative pion capture.[1] The capture rate is dominated by the same axial-vector operator that appears in muon capture[2] and in transverse electromagnetic interactions.[3] Thus these processes complement each other with pion and muon capture exciting the $\Delta T_z = -1$ analog states.

A recent measurement[4] of the high-energy photon spectrum from radiative pion capture at rest by ^{12}C has disclosed resonances in ^{12}B at 4.8 and 8.2 MeV with widths of 0.45 and 1.1 MeV, respectively. The 4.8-MeV peak can be associated with the 19.4-MeV complex observed by electroexcitation of ^{12}C.[5,6] For a momentum transfer appropriate to pion capture (~120 MeV/c), this complex is dominated by the $J^\pi = 2^-$ giant magnetic quadrupole excitation. The resonance at 8.2 MeV corresponds to an excitation energy of 23.3 MeV in ^{12}C and may be due to excitation of a $J^\pi = 1^-$ axial-vector collective mode. This interpretation is supported by a high-resolution electroexcitation experiment on carbon,[6] where evidence was found that this spin-isospin mode is at 22.7 MeV, rather than at 25 MeV as suggested by particle-hole calculations.[3]

The energy spectrum of neutrons from radiative pion capture will also reflect the nature of the capture process.[7] Furthermore, the n-γ angular correlation can be observed. This correlation will be isotropic when a large number of highly excited states participate leading to exaporation neutrons, strongly peaked near 180° when the neutrons are emitted directly, and symmetric about 90° when isolated nuclear states predominate. In the latter case information on the spin of the excited states can be obtained.

To explore these possibilities experimentally we have measured the n-γ angular correlation following radiative capture of stopped pions by ^{12}C, together with the energy spectrum of neutrons. Neutrons between 1.7 and 28 MeV were