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Electron-Capture-to-Positron Ratio in ^{207}Bi Decay*

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Positron emission in the second-forbidden nonunique transition from the ground state of ^{207}Bi to the first excited level of ^{207}Pb was found to occur in $(1.2 \pm 0.2) \times 10^{-4}$ of all decays. Taking into account newly assigned relative intensities of the ^{207}Bi electron-capture decay branches, the EC/β^+ ratio is found to be $(6 \pm 1) \times 10^2$. From the β^+ intensity and the measured ^{207}Bi half-life of 38 ± 4 yr, it follows that $\log ft = 12.6 \pm 0.1$ for this transition.

The decay scheme of ^{207}Bi has recently been revised[1] on the basis of new γ-ray intensity measurements.[2] In the second-forbidden $\frac{9}{2}^- \to \frac{5}{2}^-$ decay branch, β^+ emission had not been observed, although it is energetically possible; only an experimental upper limit of 5×10^{-3} positrons per decay had been established.[3] We have measured the β^+ intensity, not only to clarify the decay scheme of this widely used isotope, but also to provide a further test of the theoretical prediction[4,5] that K/β^+ ratios are enhanced in second- and higher-forbidden nonunique transitions, as compared with such ratios in corresponding allowed decays. This prediction had been borne out in ^{36}Cl, the only case previously tested.[6-9]

In coincidence with 0.570-keV γ rays, we observed annihilation radiation that indicated a β^+ intensity one order of magnitude below the previously set limit.[3] The actual intensity was established by comparing γ-ray and annihilation-radiation peaks in singles spectra measured with a 60-cm^3 Ge(Li) detector (Fig. 1). A contribution to the annihilation peak arises from internal and external pair production by the 1.06- and 1.77-MeV transitions (cf. Fig. 2). The rate of internal pair production in the 1.77-MeV transition can be derived from theory[10,11] and has been verified by experiment.[12] External pair production was minimized by removing massive objects from the vicinity of the apparatus and choosing Al as the material for detector housing and annihilator. The external pair-production rate was measured with a ^{60}Co source in identical geometry; theoretical cross sections[13] were used to correct the result for the relatively small energy difference between ^{60}Co and ^{207}Bi γ rays.

Measurements were made with a 40-μCi ^{207}Bi source at distances of 9, 13, and 18 cm from the detector. From 50 to 70% of the 511-keV photon counting rate was due to background, and from 12 to 25% was due to external pair production (more than 80% of this contribution came from the 1.77-MeV transition). Experiments with a thinner annihilator and ^{60}Co showed that ~40% of all external pair production took place in the annihilator. Internal pair production accounted for only 2–3% of the detected annihilation radiation. Approximately 25% of the total 511-keV photon counting rate could be ascribed to the annihilation of positrons from the 1.83-MeV transition. A check for systematic errors was performed by repeating the experiment in different locations and with variations in geometry.

Estimated errors in solid-angle reproduction were 1–5%. Decentralizing the source inside the annihilator by 0.5 cm did not affect the counter-subtended solid angle within experimental error. The γ-ray energy-dependent variation in pair-

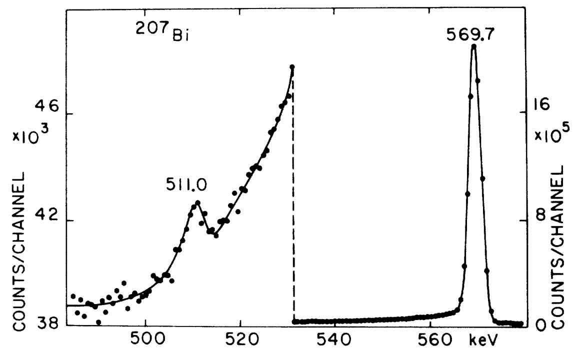

FIG. 1. A typical γ-ray singles spectrum. The left ordinate refers to the 511-keV peak, and the right ordinate to the 570-keV peak.

production loci could be neglected in the ^{60}Co-^{207}Bi comparison. Pair production by the 1.77-MeV γ rays in the annihilator required a ~+5% correction for escape of the most energetic positrons. Absorption of γ rays between sources and detector was negligible. Careful examination of the entire γ-ray and conversion-electron spectra from the 3-yr-old ^{207}Bi source excluded the presence of impurities that could have contributed to the annihilation peak.

From 31 ^{207}Bi and 14 ^{60}Co runs (>600-h total counting time), the average β^+ intensity in the $\frac{9}{2}^- \to \frac{5}{2}^-$ transition was found to be $(1.2 \pm 0.2) \times 10^{-4}$ per ^{207}Bi decay. The uncertainty is derived from one standard deviation of the mean. Statistical counting-rate fluctuations contribute approximately one half of the quoted uncertainty; the remainder is due to uncertainties in pair-production cross sections and γ-ray intensities.

The relative intensity of the 1.83-MeV branch in ^{207}Bi decay quoted by Lederer, Hollander, and Perlman[14] has been superseded by more recent measurements.[2] Further utilizing a new, precise value for the 1.06-MeV/0.57-MeV γ-ray intensity ratio[15] and a theoretical internal-conversion coefficient for the 1.06-MeV transition,[16] the relative electron-capture transition intensities indicated in Fig. 2 are calculated. Consequently, the EC/β^+ ratio in the 1.83-MeV transition is $(6 \pm 1) \times 10^2$. For an allowed transition of the same energy, the theoretical K/β^+ ratio[17] is 2×10^2. Hence, as in the previously known[6-9] case of ^{36}Cl, the EC/β^+ ratio of the second-forbidden nonunique transition is substantially enhanced. A definite theoretical prediction from first principles is precluded by the large number of contributing matrix elements.

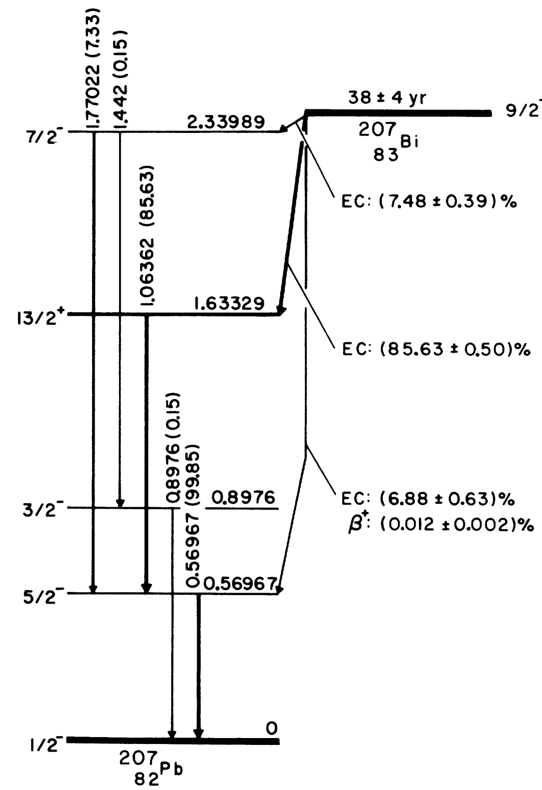

FIG. 2. Revised ^{207}Bi decay schemes.

The half-life of ^{207}Bi, for which results ranging from 8 to 50 yr have been reported,[1,18] was redetermined from some of the data gathered in an experiment[19] that required six months of counting the 570-keV γ rays with two NaI(Tl) scintillation spectrometers. We find $\tau_{1/2} = 38 \pm 4$ yr, in agreement with the determination[20] adopted in the latest survey[1] of the $A = 207$ isobars.

From the measured β^+ intensity and half-life, the reduced half-life of the 1.83-MeV β^+ transition is given[21] by $\log ft = 12.6 \pm 0.1$, confirming the second-forbidden nonunique assignment.

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Electromagnetic Transitions for ^{16}O, ^{40}Ca, ^{48}Ca, and ^{208}Pb in the Renormalized Random-Phase Approximation*

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Transition rates and mean lifetimes for odd-parity levels of ^{16}O, ^{40}Ca, ^{48}Ca, and ^{208}Pb are obtained by using the wave functions of a renormalized random-phase approximation (RPA) treatment. For ^{208}Pb the even-parity levels are also included.

I. INTRODUCTION

In a recent paper[1] the normalized random-phase approximation (RPA) approach was treated for density-dependent particle-hole forces deduced from the bare nucleon-nucleon force. Migdal's renormalization constants[2] were determined for different assumptions about the propagation of the quasiparticles and quasiholes. For the following cases the energy eigenvalues and eigenvectors have been calculated in Ref. 1:
(1) negative-parity levels of good isospin for ^{16}O, ^{40}Ca, assuming quasiparticle (hole) propagation in harmonic-oscillator (H.O.) states;
(2) negative-parity levels of good isospin for ^{16}O and ^{40}Ca assuming propagation in Woods-Saxon states;
(3) negative-parity states without good isospin for ^{16}O, ^{40}Ca, ^{48}Ca, and states of both parity for ^{208}Pb with propagation in harmonic-oscillator states.

It is the aim of this note to complete the investigation by giving the transition amplitudes. We use the same conventions as in Ref. 1 and refer to Ref. 1 as W, so that [W; (III.8)] means Eq. (III.8), etc.

II. ELECTROMAGNETIC TRANSITIONS

The transition amplitudes can be expressed by the matrix elements of the density operator. In the case of good isospin one obtains the following expressions for the partial widths of a 2^λ-pole transition from the initial state $|N_i\rangle$ to the final state $|N_f\rangle$[3]:

$$\Gamma(k,\lambda,\pi;|N\rangle\to|0\rangle)=N(k,\lambda)\frac{1}{(2J+1)(2T+1)}\delta_{\lambda,J_N}\delta_{T,T_N}\times\Big|\sum_{j,m}\langle m\|\Omega_T(\pi,\lambda)\|j\rangle[U^N_{jm}+(-)^{l_j-l_m}W^N_{jm}]\Big|^2:=N(k,\lambda)B(\lambda\pi,|N\rangle\to|0\rangle),\qquad(\text{II}.1)$$