Gamma and Alpha Decay from the 2.1-msec Isomer $^{213m}$Ra

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The isomer $^{213m}$Ra was produced by the reaction $^{209}$Bi($^{10}$B, 6$n$), as well as by bombardments of $^{12}$C on Pb isotopes, $^{14}$N on Bi, and $^{16}$O on natural Hg, with projectile energies in the range 60–100 MeV. The isomer decays with a half-life of 2.1 ms both via gamma internal transitions and via alpha branching to levels in $^{209}$Rn. A level scheme is proposed in which the isomeric state is assigned as either $17/2^-$ or $13/2^+$ with shell-model configurations either of the $h_9/2$ protons coupled to a $I_1/2$ neutron hole, or of an uncoupled $i_{13/2}$ neutron hole. On the basis of alpha decay rate predictions from the new Fliessbach theory, the $17/2^-$ isomeric assignment is to be preferred.

$E$ [Radioactivity $^{213m}$Ra [from $^{209}$Bi($^{10}$B, 6$n$), $^{204–6}$Pb($^{12}$C, 3$n$–5$n$)
 etc., $E=60–100$ MeV]; measured $E_x$, $E_y$, $I_x$, $I_y$, $I_z$, $\gamma$-coin,
 $x\gamma$-coin, $\gamma_T$, $T_{1/2}$. $^{213m}$Ra, $^{209}$Rn deduced levels, $J$, $\pi$,
 $\gamma$-multipolarity.]}

1. Introduction

With the advent of computer-based data collection systems, the 10-Hz 2 % duty cycle of Yale University’s Heavy Ion Accelerator (HILAC) was found to be particularly well suited to the investigation of activities with half-lives in the millisecond range. Such activities would be visible at the end of each 2-ms beam burst, but would decay completely during the 100 ms between bursts. Prior to the shutdown of Yale HILAC, the Nuclear Chemistry group there engaged in a series of investigations of such short-lived activities in the neutron-deficient nuclides characteristically produced by heavy-ion reactions. The work described here began with a survey for new millisecond activities near the “island of isomerism” that is found before the shell closure of the 126-neutron isotones. Gamma-ray spectroscopy of $^{213m}$Ra, a millisecond isomer thus discovered, was completed at Yale. After the shutdown of that facility, when it was realized that the isomer decayed via an alpha branch as well, the experiments continued with alpha-particle spectroscopy at the Berkeley SuperHILAC.

2. Experimental Configuration

2.1. Gamma Spectroscopy

In most of the experimental runs a heavy-metal target foil was placed at about a 45° angle in the Yale HILAC beam. Counting was carried out simultaneously with irradiation, using a detector positioned 90° from the beam line, obliquely facing the front of the target. Adequate statistics could be accumulated this way in a few hours of running.

The beams were of such nuclei as $^{10}$B, $^{12}$C, $^{14}$N, and $^{16}$O at laboratory energies between 5 and 10 MeV/ nucleon. The intensity was usually kept fairly low (on the order of nano-amperes) to avoid swamping the detector during beam bursts. In the earlier survey
and cross-bombardment runs, fairly thick (> 50 mg/cm²) targets of natural Au, Hg, Pb, and Bi were used; later we concentrated on thin (5–10 mg/cm²) self-supporting foils of bismuth produced by cold rolling or vacuum deposition. Bismuth was a convenient target material for the more detailed investigations of 213Ra since it is naturally monoisotopic, thus giving a cleaner reaction. We employed several high resolution Ge(Li) detectors with volumes around 10–40 cm³ placed about 5 cm from the target, outside the vacuum, and separated from the target by a plexiglas, mylar, or thin aluminum window. In some runs we used a 5 mm x 1 cm² intrinsic Ge detector for better resolution of x-rays and low-energy γ-rays. Spectra were accumulated by a PDP-8/I computer system. Several data collection programs were used, but in general the process involved starting the counting at the end of each beam burst and switching the counting from one storage block to another at preset intervals during the 100 ms between bursts. Thus, a series of spectra could be accumulated, each showing the activity during a particular several-millisecond interval following irradiation. The data were analyzed both by hand from computer-generated plots of the spectra and by various programs, including versions of the Lawrence Berkeley Laboratory’s SAMPO [1], on PDP-10, IBM 7094 DCS, and CDC 7600 computer systems.

For the coincidence experiments, a second Ge(Li) detector was placed 180° from the first, obliquely facing the back of the thin target. Three- and four-parameter coincidence events (E₁, E₂, nanosecond time between the two γ-rays, and sometimes millisecond time since beam burst) were recorded serially on magnetic tape by the PDP-8/I for later computer sorting and analysis. Also, to help in identifying the millisecond activities, a stacked-foil excitation-function run was made to trace the decay chains. For this we constructed a stack of six ≈ 3 mg/cm² Al foils on which ≈ 2 mg/cm² of Bi had been evaporated. The aluminum foils served both as supports and as beam degraders so that the bismuth layers were exposed to beam energies between 60 and 90 MeV. The stack was irradiated with a 105-MeV beam of 10B at ≈ 1 particle-μA for about 6 h, and the individual foils were then counted several times during the following week with a high-resolution Ge(Li) γ-spectrometer. The spectra were analyzed as described earlier. Since the activity induced in the aluminum support foils decayed in a matter of hours, no chemical separation was required. Thus, reaction product decay chains could easily be followed by observing the γ-activity due to EC-decay of their members.

2.2 Alpha Spectroscopy

The alpha spectroscopy experiments were performed at Berkeley SuperHILAC using the helium-jet technique to catch recoiling reaction products and transfer them...