Isomers with exceptionally long half-lives in ^{205,206}Bi

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Introduction

Nuclear isomers are metastable states which are realized due to the hindrance in the deexcitation of that nuclear level. This hindrance can result from either large spin, shape or angular momentum projection change between neighbouring levels. Quantum mechanically, a substantial difference in the associated wavefunctions of nearby levels can lead to isomerism. This usually brings in up to orders of magnitude of difference between the transition rates associated with the decay of such levels when compared with non-isomeric transitions. The study of such isomeric nuclear levels provides crucial insights towards the understanding of nuclear phenomena and the interactions leading to the specific structure of that nucleus and the region in general. Thus, isomeric properties also play an important role in improving effective interactions for shell-model calculations of near-spherical nuclei [1]. The present work was motivated by the fact that isotopes near the ^{208}Pb region exhibit the presence of isomeric levels with halflives ranging from nanoseconds up to the hundreds of microseconds time range at different excitation energies [2–4]. The 23.6(21) μs isomer in ^{212}Fr at 8.5 MeV was thus far the longest-lived state above 7 MeV across the nuclear chart [5]. The presence of high-j proton and neutron orbitals makes this region promising in terms of the search for long-lived states at very high excitation energy.

Experiment

In previous work on ^{205}Bi, alpha beams on ^{205}Tl were used resulting in the identification of levels up to 39/2 $\hbar$ and excitation energy about 6 MeV [6]. In the present work, excited levels in the ^{205,206}Bi isotopes were populated up to high spin using two highly-energetic, heavy beam and target combinations. Multinucleon transfer reactions between a 1450-MeV ^{209}Bi and a 1430-MeV ^{207}Pb beam from the ATLAS accelerator at the Argonne National Laboratory, and a thick target of ^{197}Au, were employed. Two-, three- and higher-fold γ-ray coincidence data were recorded using the Gammasphere detector array which comprised of 100 HPGe detectors. The availability of pulsed beams with different beam sweeping intervals from the ATLAS accelerator enabled the exploration of metastable states and their decay paths [1]. The data were sorted into a number of different histograms and analyzed using the Radware suite of programs [7, 8].

Results and Discussion

The high-spin structure of ^{206}Bi had already been established up to 10.17 MeV [9] and is confirmed from the present data [Fig. 1(a)]. The half-life of the 10.17 MeV level was reported to be ≥ 2 μs [9]. The time distribution of the most intense transitions in the 800-μs beam-off data implies a half-life of 27(2) μs, as indicated in Fig. 2(a). The level structure of ^{205}Bi has been expanded upto ≈ 8 MeV with the inclusion of twenty new transitions as displayed in Fig. 1(b). The newly identified transitions and the ones in the previous level scheme of ^{205}Bi exhibited evidence of delayed feeding. The time distribution of the 641-600-516 keV cascade in the 800 μs and 3 ms beam-off data indicated that the isomer is longer lived than 3 ms. Therefore, data in the 3-s beam-off period were inspected and the halflife of the new $E_x = 7.913 + x$ MeV state was determined to be $T_{1/2} = 8(2)$ ms [1], as shown in Fig. 2(b). The isomer in ^{205}Bi is thus the

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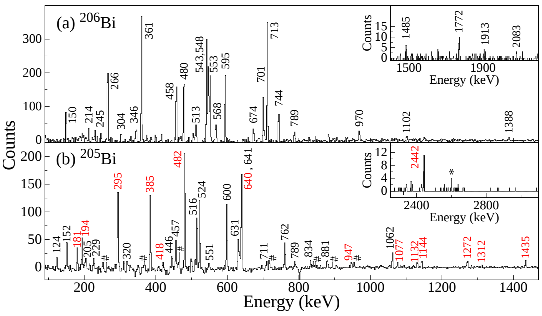

FIG. 1: Coincidence spectra with observed γ rays in (a) ^{206}Bi and (b) ^{205}Bi, respectively. Hash marks designate contaminant γ rays. New transitions in ^{205}Bi are marked in red.

longest-lived nuclear level, by up to two orders of magnitude, above $E_x \geq 7$ MeV, ever identified in the nuclear chart. The newly identified transitions also consist of several high-energy γ rays, some of which can be associated with the excitation of the ^{208}Pb core. The 2442-keV transition deexciting the 7136-keV level is observed to feed the previously established $37/2^-$ level at 4694 keV. An empirical calculation of the energy of the $E3$ excitation by accounting for the perturbations caused by the configuration of the $37/2^-$ level yields a value of 2447 keV, in agreement with the observed 2442-keV value. Therefore, the 7136-keV level can be assigned a tentative $43/2^{(+)}$ spin-parity. The application of intensity balance considerations for the 2442-482-295-keV cascade allows a spin assignment of $47/2\ \hbar$ for the 7913-keV level. A comparison of the population of the transitions in the prompt and delayed data implies that the decay of the isomer likely proceeds through an unobserved low-energy γ ray. Shell model calculations were performed using the KHH7B effective interaction for ^{205}Bi which suggest a probable $51/2^-$ assignment for the 8-ms isomer in ^{205}Bi. These observations of isomers at $I = \geq 25\hbar$ and $E_x \geq 7$ MeV indicate the existence of an island of extreme nuclear isomerism arising from core-excited configurations at high excitation in the vicinity of the doubly closed-shell nucleus ^{208}Pb, which is a remarkable result.

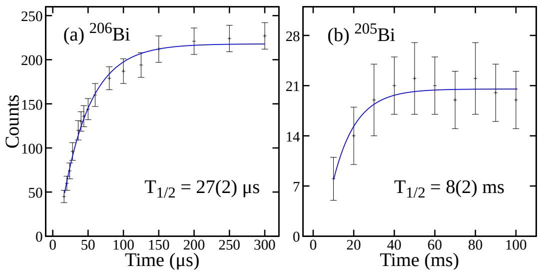

FIG. 2: Time distributions from the decay of isomers in (a) ^{206}Bi and (b) ^{205}Bi, and fits thereof.

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