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Short note

Level sructure in ^{206}At

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Abstract. The high-spin states of ^{206}At have been studied in the reaction ^{197}Au (^{12}C, 3n) ^{206}At at ^{12}C energies from 60 to 80 MeV. In-beam measurements of γ-ray excitation functions, γ-γ-t coincidences, and γ-ray angular distributions were carried out with seven BGO(AC)HPGe detectors and one intrinsic Ge planar detector. A level scheme for ^{206}At with 25 γ rays was established for the first time, including a 10^- isomer with a measured half-life of 410± 80 ns. The level scheme of ^{206}At consists of two disconnected cascades, probably corresponding to the proton excitations and the neutron-hole excitations, respectively.

PACS. 23.20.Lv Gamma transition and level energies – 27.80.+w $190 \leq A \leq 219$

For the nuclei near ^{208}Pb with a few protons outside the Z=82 shell closure and a number of neutron holes in the N=126 closed shell, their level schemes exhibit a competition between proton excitations and neutron-hole excitations. [1-4] The level structure in ^{208}At [1] is composed of two disconnected parts, which was formed by proton excitations corresponding to the proton excited states in ^{210}At [5], and neutron-hole excitations analogous to the neutron-hole states in ^{206}Bi [6], respectively [1]. Furthermore, the experiment results show that there is no direct preference for either type of excitation in ^{208}At, but states with about the same spins occur at about the same energies. The two types of excitations without mixing have been also observed experimentally in the odd-even ^{201,203,205,207}At nuclei [2,3,4]. Therefore, it is interesting to extend the study to ^{206}At nucleus, for which no excited states were previously known.

The excited states in ^{206}At were populated via the reaction ^{197}Au(^{12}C, 3n)^{206}At. The ^{12}C beams were delivered from the 13-MV tandem accelerator at the China Institute of Atomic Energy in Beijing. In order to determine the optimum beam energy and identify transitions in ^{206}At, first the excitation functions for producing γ rays were measured in the energy range 60-80 MeV using a 1 mg/cm^2 ^{197}Au target. Then the beam energy of 63 MeV, at which the yield of ^{206}At was a maximum, was chosen to populate the high-spin states in ^{206}At. In our later measurements, the thin ^{197}Au target was replaced by a thick natural Au target to increase the production of ^{206}At. γ-γ-t coincidence measurements were performed at this optimum beam energy with seven BGO(AC)HPGE detectors and one intrinsic-Ge planar detector which was used to detect the low energy photons. Here, t refers to the relative time difference between any two coincident γ rays detected within ±300 ns. A total of 78 × 10^6 coincidence events were recorded event by event for off-line analysis. After accurate gain matching, the γ-γ coincidence data were sorted off-line according to the energies of the two γ rays into three 4K × 4K matrixes with a prompt (-51ns < t < 51ns), a prior-prompt (-300ns < t< -51ns), and a post-prompt (51ns < t < 300ns) time condition, respectively. In order to obtain information on the transition multipolarities, the γ-ray angular distributions were measured at six laboratory angles between 29° and 145° relative to the beam direction. The angular distribution coefficients, as well as the relative γ-ray intensities, were extracted from least-squares fits to the normalized photopeak areas.

Assignment of the observed γ rays to ^{206}At was based on the γ-ray excitation functions and on the observation of γ-X and γ-γ coincidences. The excitation functions for some of the observed γ rays are shown in Fig. 1. The excitation functions for the 616 and 686 keV γ rays are centered at about 63 MeV ^{12}C beam energy, shifting significantly from the peaks for the γ rays from ^{205}At [7]. This along with the fact that the 616 and 686 keV γ rays were in coincidence with astatine K X rays measured with the planar detector, allows unambiguous assignments of these transitions to ^{206}At. Based on coincidences with these intensive γ rays of ^{206}At, some weak γ rays could also be assigned to ^{206}At.

Three gated spectra were obtained for each of the γ rays studied, under prompt, prior-prompt, and post-

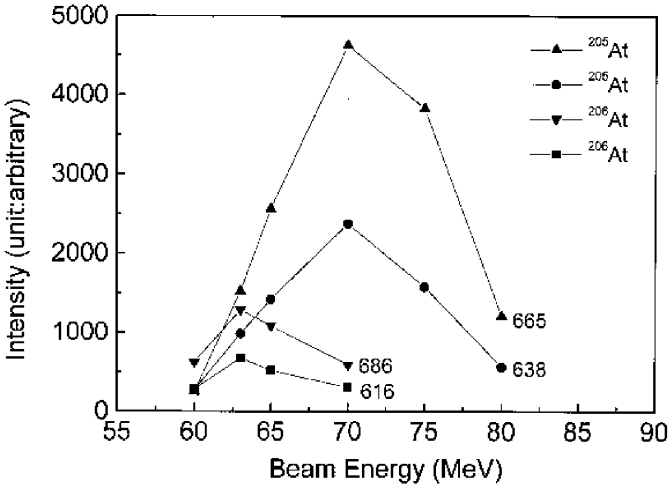

Fig. 1. Excitation functions for γ rays from products of the reaction $^{12}C+^{197}Au$

prompt coincidence time conditions. These spectra greatly helped to identify and locate the isomer of ^{206}At, and to place transitions into a level scheme for ^{206}At. In Fig. 2, coincidence spectra are shown as typical examples useful in the construction of the ^{206}At level scheme. Fig. 2(a) shows the spectrum for γ rays within ± 300 ns of the gating 686 keV γ ray, while Fig. 2(b) shows the spectrum for γ rays precede the 686 keV transition by at least 51 ns. The time before between the γ rays in Fig. 2(b) and the 121 keV transition indicated the presence of an isomeric level. A level scheme for ^{206}At, including a 10^- isomer, is proposed as shown in Fig. 3. The half-life of 410 ± 80 ns for this isomer was determined from fits to the coincidence time spectra between the two γ-ray groups lying above and below the isomer, respectively.

The nucleus ^{206}At has three protons and five neutron holes outside a ^{208}Pb core. The excited states of ^{206}At should be determined by excitations of the nine valence nucleons. Two-quasiparticle excitations are expected at low-lying states in this doubly odd nucleus, namely those arising from the configurations of $\pi h_{9/2}\nu f_{5/2}^{-1}$, $\pi h_{9/2}\nu i_{13/2}^{-1}$ and so on. The $[\pi h_{9/2}\nu i_{13/2}^{-1}]10^-$ isomeric states were observed systematically in the odd-odd bismuth and astatine nuclei [1,8]. From the systematic of the 10^- isomers in doubly-odd astatine nuclei, the isomer at 807 keV in ^{206}At is most probably of the $\pi h_{9/2}\nu i_{13/2}^{-1}$ configuration. Assuming an electric dipole character for the 121 keV transition depopulating the 807 keV isomer, a reduced transition probability B(E1) of 1.92×10^{-6} Weisskopf units (W.u.) could be obtained for the 121 keV transition from the measured half-life of 410 ns, indicating a hindrance of 5.20×10^{6} over the Weisskopf estimate for the 121 keV transition. This hindrance is very close to that for the corresponding E1 transition in ^{208}At, and is typical for E1 transitions in the lead region. The above argument strongly supports the assignment of the $\pi h_{9/2}\nu i_{13/2}^{-1}$ configuration to the 807 keV isomer, and suggests the spin and parity values of 9^+ to the state at 686 keV. In [1], it

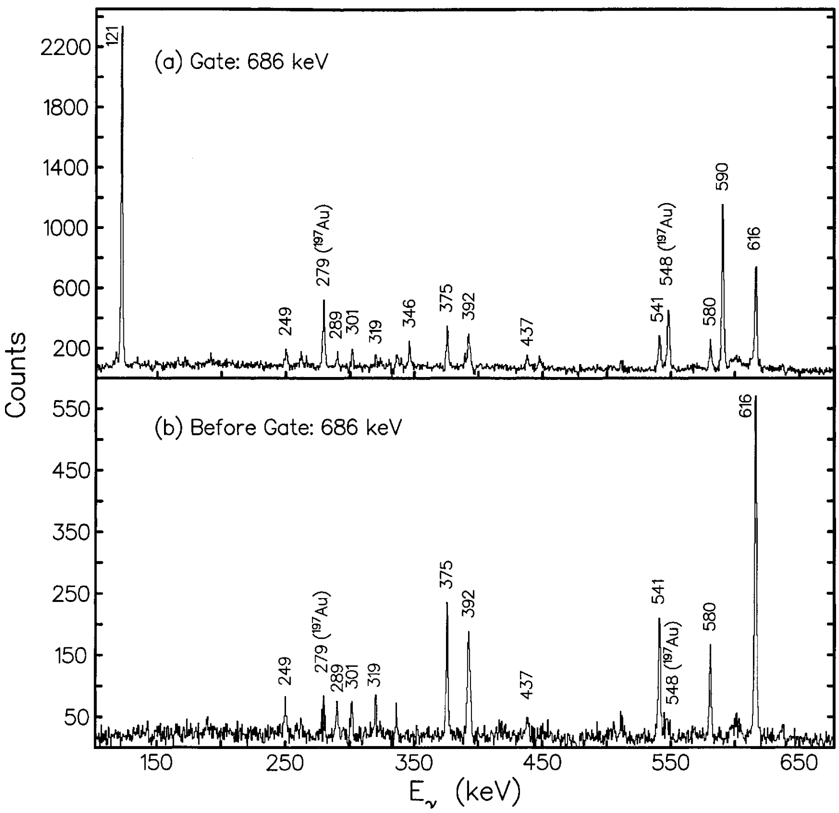

Fig. 2. γ-ray coincidence spectra gated on the 686 keV transition, (a) shows all the γ rays coincidence with the 686 keV transition, (b) shows the γ rays preceded by the 686 keV transition by at least 51 ns

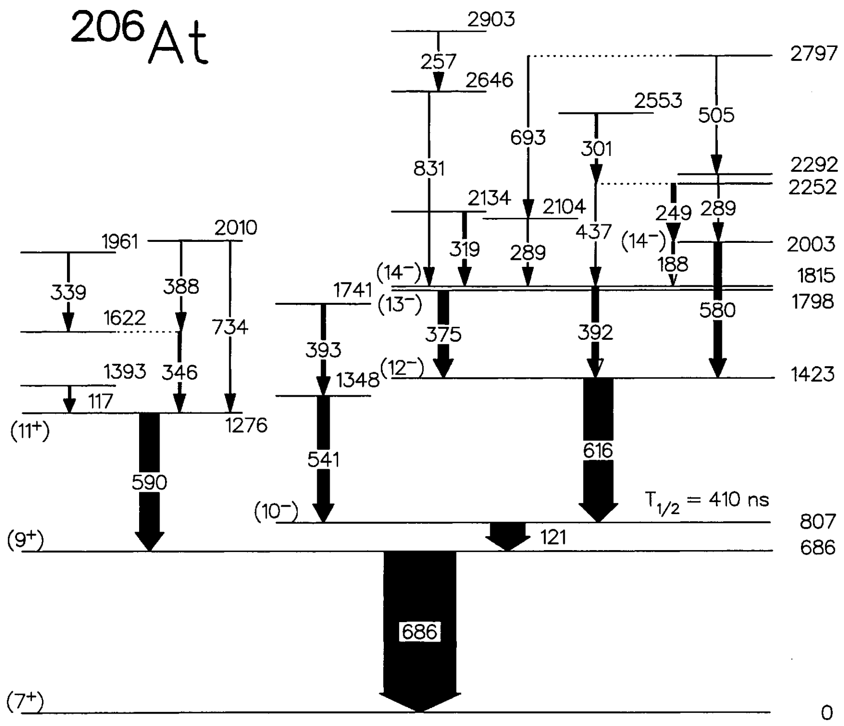

Fig. 3. The proposed level scheme for ^{206}At. All energies are in keV

was suggested that the 9^+ state in ^{208}At arises from the configurations of $\pi h_{9/2}\nu f^{-1}_{5/2}\otimes 2^+$ or $\pi h^3_{9/2}\nu p^{-1}_{1/2}$, so the 9^+ state in ^{206}At might originate from the same configurations. From the result of the γ-ray angular distribution measurement, a quadrupole character is obtained for the 686 keV transition which feeds the lowest energy level in the level scheme. Considering the low-lying level structures in ^{204}Bi [9] and ^{208}At, the $\pi h_{9/2}\nu f^{-1}_{5/2}$ configuration may be assigned to the lowest level, to which a zero energy was set as a reference in the present work. The spin and parity value of 5^+ was assigned to the ground state in ^{206}At [10]. Maybe, the transition energy linking the 7^+ state and ground state is too low to be observed in the present work.

At the 9^+ state the feeding cascade is divided into two disconnected branches, which is very similar to the case in ^{208}At. By comparing the level structures in ^{206}At and ^{208}At, we may get some qualitative conclusions. The levels shown on the left-hand side of the level scheme, are formed by proton excitations, and might have positive parities. The level complex feeding into the 10^- isomer might comprise mainly neutron-hole excitations, and these states might have negative parities. The possible negative-parity states with spins less than 14 may arise from configuration$\pi h_{9/2}\nu i^{-1}_{13/2}\otimes J^\pi$, where J^π stand for the 2^+, 3^+, 4^+, $\cdots$ excitations in the even Pb core. Six-quasiparticle excitations should be involved to interpret the higher-lying states shown on the right-hand side of the level scheme.

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