ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

ДУБНА

E7 - 8060

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1974

ЛАБОРАТОРИЯ ЯДЕРНЫХ РЕАКЦИЙ

E7 - 8060

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Submitted *to Nuclear Physics*

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E7 - 8060

j-запрещенный изомерный переход в ядре ^{204}At

Изомерный переход с энергией 587,3 кэВ нами наблюдался в различных реакциях с тяжелыми ионами: $^{197}Au + ^{12}C$, $^{193}Ir + ^{16}O$ и $^{196}Pt + ^{15}N$. Измерение функции возбуждения для изомерного перехода в реакции $^{193}Ir(^{16}O, xn)^{209-x}At$ показало, что этот переход происходит в ядре ^{204}At. Изомерное состояние имеет характеристики $I^{\pi} = 10^{-}$ и конфигурацию $\pi(h_{9/2})^{3}_{9/2^{-}} \, \nu(i_{13/2})^{-1}$.

Препринт Объединенного института ядерных исследований. Дубна, 1974

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E7 - 8060

A j-Forbidden Isomeric Transition in ^{204}At

An isomeric 587.3 keV transition was investigated using several target-ion combinations: $^{197}Au + ^{12}C$, $^{193}Ir + ^{16}O$ and $^{196}Pt + ^{15}N$. From the measured excitation functions for the $^{193}Ir(^{16}O, xn)^{209-x}At$ reaction it follows that this transition belongs to ^{204}At. The isomeric level is ascribed to the 10^{-} state of the configuration $\pi(h_{9/2})^{3}_{9/2^{-}} \, \nu(i_{13/2})^{-1}$.

Preprint. Joint Institute for Nuclear Research. Dubna, 1974

1. Introduction

The Bi and At nuclei with one and three protons outside the closed Z=82 shell are of considerable interest from the framework of the shell model. By coupling a $h_{9/2}$ proton to the $13/2^{+}$ neutron hole states in odd lead nuclei a two-quasiparticle multiplet arises in the adjacent Bi isotones. The lowest lying level of this multiplet forms a 10^{-} isomeric state, which occurs with surprising regularity in the odd-odd Bi isotopes /1/ down to ^{198}Bi. Neutron hole states $13/2^{+}$ have also been found in the odd-A polonium isotopes /2,3/ but at somewhat higher excitation energies than in the corresponding lead isotones. Decay spectroscopic investigations /3/ showed that the ground state of the odd-A astatine nuclei is also characterized by $I^{\pi} = 9/2^{-}$. These similarities to the odd-A bismuth isotopes inspired the search for 10^{-} isomers in the odd-odd astatine nuclei, which are also expected to deexcite by highly retarded E3 transitions. An isomeric activity, first observed /4/ in 1969, was wrongly ascribed to ^{203}At due to an incompletely measured excitation function. We, therefore, reinvestigated this isomer by making use of different reactions leading to astatine compound nuclei.

2. Experimental Method and Results

2.1. Gamma-ray spectra

The experiments were carried out using the external beam from the U-300 heavy ion cyclotron, which was

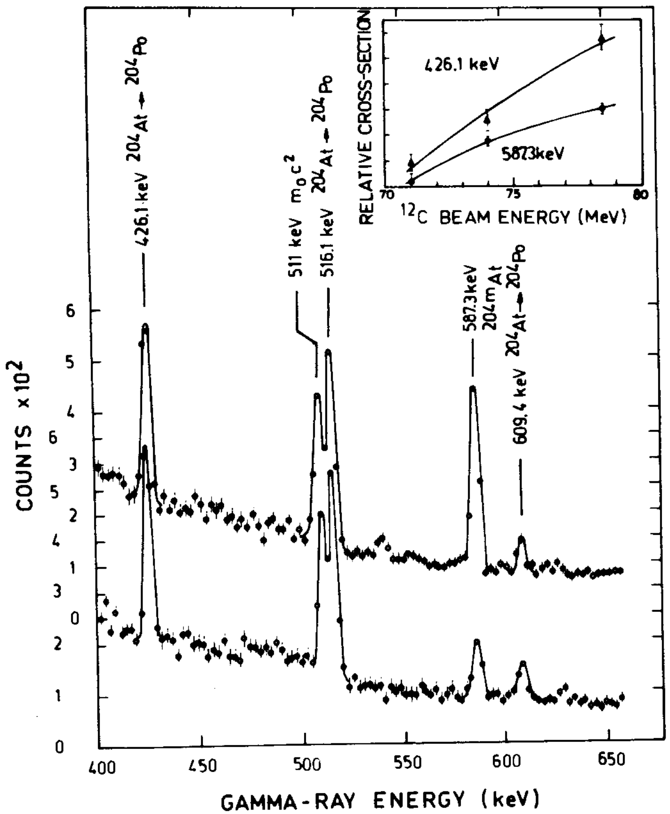

Fig. 1. A part of the γ -ray spectra obtained by bombardment of a gold target with 80 MeV ^{12}C ions. Both spectra were measured during 100 ms, the upper spectrum starting immediately and the lower spectrum 300 ms after the end of the 112 ms activation period. The insert shows the excitation functions of the 426.1 keV ($^{204}At \to ^{204}Po$) and the 587.3 keV transitions.

additionally pulsed by gating the dee voltage. In the energy range from 40 keV to 2.2 MeV the γ-rays were registered with a 25 cm^3 coaxial Ge(Li) -detector. The target materials ^{197}Au (2 $mgcm^{-2}$), enriched ^{196}Pt and enriched ^{193}Ir were bombarded with ^{12}C , ^{15}N and ^{16}O ions, respectively. In every case a delayed 587.3±0.2 keV

transition was observed, the half-life of which agreed with the earlier measured value /4/ of $T_{1/2}$ = 108±10 ms. Figure 1 shows a part of two subsequently detected γ -ray spectra of the Au+ ^{12}C bombardment. As is seen from the insert, the energy of the cyclotron did not permit the measurement of the complete excitation function. For this reason we bombarded ^{193}Ir with 137 MeV $^{16}O^{3+}$ ions. Figure 2 shows γ-ray spectra observed during the beam-off time for two different incident energies. The γ -ray energies were calculated by means of the computer code GAMMA /12/ using external and internal calibration lines. The accuracy of the transition energies given in fig. 2 amounts to about $\pm$ 0.3 keV. In the prompt spectra, measured during the 1 ms beam-on time, apart from Coulomb excited transitions of ^{193}Ir, no significant additional transitions of short-lived isomers could be observed.

2.2. Excitation functions

As is already shown in ref. /4/ , the energy difference of the K and L conversion electron lines of the isomeric transition is ΔE_{KL} = (79.2± 1.1) keV, which is in agreement with the value expected for Z = 85(At). In order to identify the mass number, the excitation functions of the reactions $^{193}Ir(^{16}O, xn)^{209-x}At$ were measured. The ^{193}Ir target (7.7 $mgcm^{-2}$ enriched to 98.1%) was made by sedimentation on a 1 $mgcm^{-2}$ Al backing. The beam energy was varied by calibrated Al foils. The energy loss in Al and Ir was taken from the energy-range tables /5/. Between subsequent runs at different bombarding energies the spectra of the long-lived activities were measured during 30 minutes. In measuring the excitation functions the remaining activity of the preceding runs was taken into account.

Figure 3 shows the excitation functions of γ -transitions of the $^{202-205}At$ decays. In the $^{193}Ir(^{16}O, 4n)^{205}At$ reaction the shift of the peak cross section towards higher energies is caused by the influence of the Coulomb barrier. For $^{202-204}At$ the positions of the peak cross

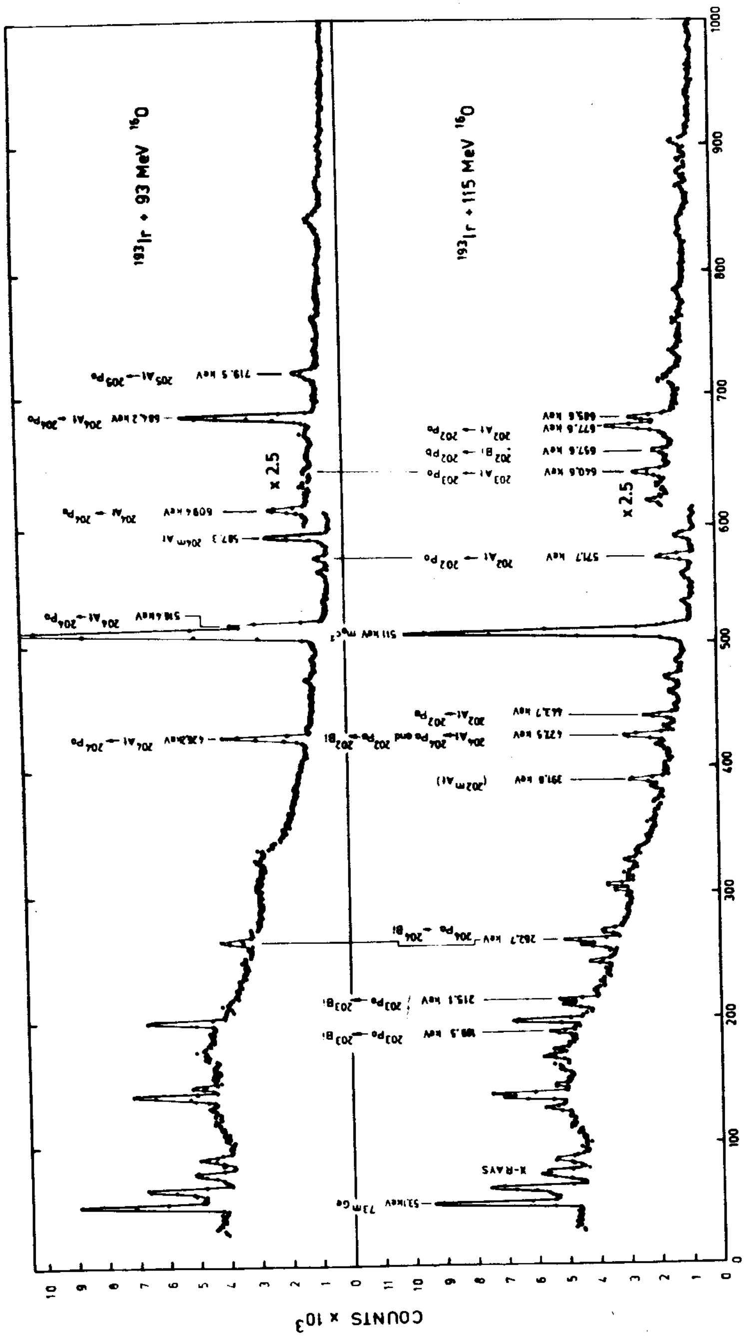

Fig. 2. Gamma-ray spectra from the bombardment of ^{193}Ir with ^{16}O, registered during a 2 ms interval between the beam pulses.

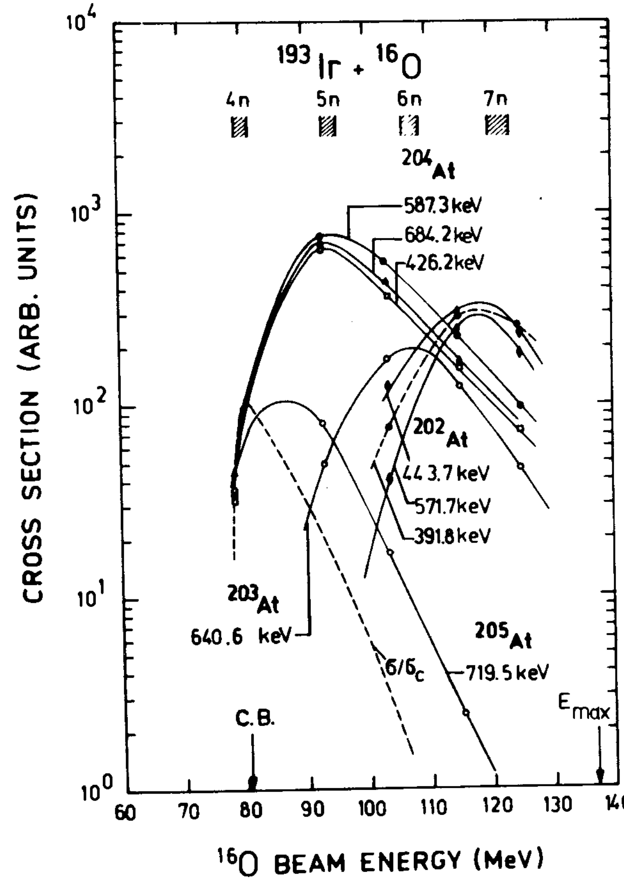

Fig. 3. Excitation functions of γ-ray-transitions of the $^{193}Ir(^{16}O,xn)\,^{209-x}At$ reactions. The hatched fields correspond to a $\pm 50\%$ deviation from the calculated positions of the peak cross sections. [6] C.B. denotes the Coulomb barrier ($r_0 = 1.5$ fm), E_{max} the initial energy of the $^{16}O^{3+}$ ions, σ_c the total cross section for compound nucleus formation.

sections are in fairly good agreement with calculations based on a semiempirical formula [6].

The 587.3 keV transition shows the same behaviour as the transitions of the $^{204}At \rightarrow {}^{204}Po$ decay, which agrees with the insert of fig. 1. Above 40 keV no further γ-ray-transitions of a similar excitation function were found.

As is shown in fig. 2, a γ-ray line of (391.8±0.3) keV was observed, with $T_{1/2} < 10$ s, the excitation function of which is quite similar to that of transitions belonging to the $^{202}At \to {}^{202}Po$ decay. To prove that this transition is a candidate for the expected isomeric transition in ^{202}At additional experiments should be carried out.

2.3. Decay scheme

Because no further γ-ray-transitions were found, we conclude that the 587.3 keV transition proceeds directly to the ground state of ^{204}At, for which an assignment of $I^{\pi} = 7^{+}$ is favoured. This is supported by the fact /7,8/ that the main branches of the ground state decay of ^{204}At proceed directly to the 8^{+} and 6^{+} two-quasiparticle states in ^{204}Po.

The earlier conversion electron measurements /4/ result in an experimental intensity ratio $K/(L+M) = 1.5 \pm 0.1$ which suggests an E3 assignment of the 587.3 keV transition.

From the present experiment it follows that the isomeric cross-section ratio shows a slight increase with increasing ion energy, i.e., the spin of the isomer should be higher than that of the ground state. As an independent check, the 3 min-decay $^{204}Rn \to {}^{204}At$ of the ^{204}Rn ground state /9/ with $I^{\pi} = 0^{+}$ was measured, where no 587.3 keV transition was found. Thus, the experimental data support an $I^{\pi} = 10^{-}$ assignment for the 108 ms isomeric state in ^{204}At. The proposed decay scheme is shown in fig. 4.

3. Discussion

The decay characteristics of the isomeric level in ^{204}At are quite similar to those of the corresponding neutron deficient bismuth isotopes. We assume, therefore, that the 10^{-} isomeric state in ^{204}At is formed by the $\nu(i_{13/2})^{-1}\,\pi(h_{9/2})^{3}$ configuration. The $I^{\pi} = 7^{+}$ ground state of ^{204}At is realized by the expected shell model

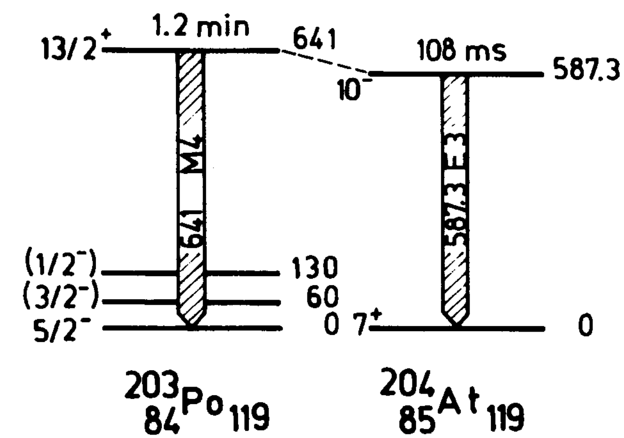

Fig. 4. Decay scheme of the ^{204}At and ^{203}Po isomers.

configuration $\pi(h_{9/2})^{3}_{9/2} - \nu(f_{5/2})^{1}$. The isomeric E3 transition is j-forbidden ($\Delta j = 4 > L = 3$), and the experimental half-life exceeds the Weisskopf estimate by a factor of $F = 6 \cdot 10^{3}$. This is the same order of magnitude as that observed for the corresponding E3 transitions in the odd-odd bismuth nuclei /1/.

For the isotonic pairs the energy differences between the M4 transitions depopulating the $13/2^{+}$ neutron hole states in Pb or Po and the E3 transitions from the adjacent 10^{-} isomeric two-quasiparticle states to the 7^{+} level in Bi or At are shown in fig. 5. Due to the very similar radial wave functions of the $i_{13/2}$ neutron and the $h_{9/2}$ proton the residual p–n interaction leads to a large splitting of the formed two-quasiparticle multiplet. The experimental data for nuclei with $N \geq 119$, showed that the isomeric 10^{-} state is shifted below the adjacent $13/2^{+}$ state. The 7^{+} levels of Bi contain $\nu(f_{5/2})$ and $\pi(h_{9/2})$ as the main components. Because both configurations have quite different wave functions, the p–n interaction is

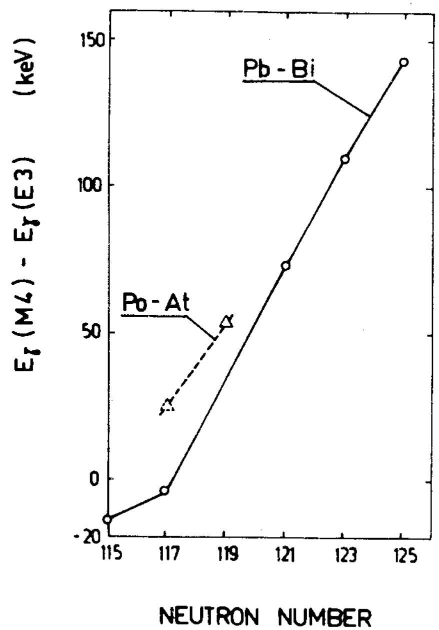

Fig. 5. Energy differences between the M4 and E3 transitions in isotonic pairs of Pb–Bi and Po–At as a function of neutron number.

diminished and results only in a slight shift of the 7^+ state above the $5/2^-$ state of the adjacent isotones.

The two-quasiparticle multiplet splitting depends also on the occupation of the orbit /11/, which results in the observed strong dependence of the energy difference of the M4 and M3 transitions on the neutron number. Beyond the half-filled orbit the level sequence of the $\nu(f_{5/2})^{I}\pi(h_{9/2})^{I}$ multiplet changes, which happens in our case for the $f_{5/2}$ orbit. As a consequence, we observe a negative value of the above-mentioned energy difference for the Pb–Bi isotones with $N < 119$ (see fig. 5).

The Po–At values exceed the Pb–Bi values. This may be explained by the fact that the presence of additional identical particles, i.e., two $h_{9/2}$ protons in the case of At magnifies the multiplet splitting /10/ of the $\pi(h_{9/2})^{n}\nu(i_{13/2})^{-1}$ multiplet. The systematics shown in fig. 5 may be a guide for the search of further j -forbidden E3 transitions in the At nuclei.

The authors wish to express their thanks to Academician G.N.Flerov, Profs. L.A.Sliv and L.K.Peker for their interest in this work and valuable discussions.

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Received by Publishing Department
on July 1, 1974.