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Observation of ^{186m}Ta

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Abstract Unreported tantalum isomer ^{186m}Ta has been produced through the reaction ^{186}W(n,p) by irradiation of ^{nat}W with 14 MeV neutrons. The activity of ^{186m}Ta and ^{186}Ta was measured using HPGe detectors and several X-γ as well as γ-γ coincidence arrangements. The ^{186m}Ta has been identified by means of measuring known γ rays from ^{186}Ta β-decay. The half-life of ^{186m}Ta has been determined to be (1.5±0.1) min.

Key words ^{186m}Ta, Neutron reaction, γ(X)-γ coincidence, β-decay

CLC numbers O571.22, O571.31^{+}5

1 Introduction

Growing attention has been paid to the heavy neutron-rich nuclides owing to the intriguing phenomena of nuclear structure and decay properties of nuclei in this region[1,2]. Especially, the synthesis and study of heavy neutron-rich nuclides are important to astrophysical investigations[3].

The study of excited states of neutron-rich nuclei helps to test nuclear models for nuclei far from stability. In some favorable cases, excited states can be observed in their isomeric states. Isomers give valuable information on nuclear structure because of their unique character among many other excited states. These isomers are present in the whole chart of nuclei, including the spherical and deformed regions and they have generally higher angular momenta than those at the ground states. This is particularly interesting in odd-odd nuclei, where only low spin level can be fed by β-decay of the even-even mother nuclei.[4] Here, higher spin states are made accessible from the decay of isomeric levels.

There are only two main reports concerning the half-life of ^{186}Ta. As early as in 1955, Poe[5] studied the (n,p) products of tungsten isotopes gained by irradiating ^{nat}W in the form of tungstic acid with fast neutrons. Radiochemical procedure was used for the separation of Ta fractions in the experiment. The half-life of ^{186}Ta is 10.5 min, which was obtained by the measurement of β particles. Latterly in 1970, another result on the half-life measurement of ^{186}Ta was reported by Pathak et al[6]. The sources of ^{186}Ta were produced via the (n,p) reaction by irradiating ^{186}W-enriched and spectroscopically pure natural tungsten powder with 14.8 MeV neutrons. The assigned half-life of ^{186}Ta was also 10.5 min through observation of β-ray activities.

But ^{186m}Ta was not reported yet. In this work, we attempt to investigate the short-lived ^{186m}Ta with γ (X) spectroscopic method. Since the (n,p) reaction is one of the very useful techniques for producing heavy neutron-rich nuclei in the region not accessible from fission[5–9], the sources were produced through the (n,p) reaction by irradiation of tungsten with 14 MeV neu-

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trons.

2 Experimental procedure

The experiment was performed at the 600-kV Cockcroft-Walton accelerator in the Institute of Modern Physics, Chinese Academy of Sciences. The accelerator provided 14 MeV neutrons by the reaction of TiT targets with deuterons. Tantalum activities were produced by irradiating the natural metallic tungsten powder of ~100 mg/cm^2 with 14 MeV neutrons. Each tungsten target was used only one time in order to effectively reduce the accumulation of long-lived activities. To observe this possibly short-lived component, the irradiating time of 4 min was adopted, which can reduce the ^{186}Ta activity. After irradiation, the tungsten targets were transferred into a shielded lead room by an improved rabbit system. The measurement started 20 s after the end of irradiation with the following two detectors: 1) a planar HPGe X-ray and low energy γ-ray detector with an energy resolution of 580 eV for the 122 keV line of ^{57}Co, an active diameter of 32 mm, and a sensitive depth of 10 mm; 2) a clover detector consisting of four coaxial N-type germanium detectors in which each has a 25% efficiency and an energy resolution of 2.1 keV for 1332 keV line of ^{60}Co. The two detectors were placed face-to-face on both sides of the source. The measurement lasted for 27 min to fit the 10.5 min half-life of ^{186}Ta[10]. The procedure mentioned above was repeated to improve the counting statistics. γ (X) ray singles events and three parameter coincidences γ(X)-γ-*t* were recorded with a multi-parameter data acquisition system, where *t* is the time of each event after the beginning of a counting period. The γ spectra were measured with the clover detector, which has an energy range of 10 keV—1.5 MeV.

3 Results and discussion

During the irradiation, several radioactive isotopes of W, Ta, and Hf were produced by (n,2n), (n,γ), (n,p), and (n,α) reactions, respectively. The γ singles spectrum measured in the experiment is shown in Fig. 1. Inspection of the sample by γ-ray spectroscopy shows that the γ rays following β$^-$ decay of ^{186}Ta are clearly visible except for those from some impurities such as ^{179}W, ^{179m}W, ^{185m}W, ^{187}W, ^{182m}Ta, ^{184}Ta, ^{185}Ta, and ^{183}Hf. The assignment of ^{186m}Ta was primarily based on the time variation of the ^{186}Ta decay γ rays. The six ^{186}Ta γ rays with energies 197.9, 307.5, 417.7, 615.3, 737.5, and 739.2 keV, which are clean and intense as shown in Fig.1, were followed carefully as presented in Fig.2. It can be seen that a shorter-lived component appears in the decay curves. A computer code for analyzing the two component radioactive decays was used and the weighted average values for the half-lives of two components were extracted to be (1.5±0.1) min and (10.4±0.4) min from the data of Fig. 2, respectively. The latter is consistent with the previous result of ^{186}Ta half-life[10]. The six γ rays mentioned above cannot originate from any of known activity impurities produced in the "(14 MeV) n + ^{nat}W" reactions due to their energies and half-lives. None of them (see Fig. 1) has similar energy with the half-life around 1.5 min. So the shorter-lived component with a 1.5 min half-life could only come from two possible sources. It would be either ^{186m}Ta β$^-$ decay or ^{186m}W IT. The latter one can be excluded based on the following arguments.

1. In the decay curves mentioned above, the intensity ratio of the short half-life component to the long half-life one from ^{186}Ta was extracted to be larger than 3 at the initial time of measurement. If it came from the ^{186m}W IT, strong γ-rays from ^{186m}W should be observed clearly. But after careful analysis, no new γ ray can be found in the measured γ singles spectra (Fig. 1).

2. Of course it was impossible to observe the γ rays from ^{186m}W IT through γ singles spectra if these γ rays were dominated by some other strong γ rays. So X-γ coincidence was made to observe possible γ rays from ^{186m}W. As a result only γ rays from ^{185m}W and ^{186}Ta can be observed in the γ ray spectra gated by W K_α and W K_{β_2} X-rays (see Fig.3), whereas no new γ ray was found. (No attention was paid to W K_{β_1} X-rays in the data analysis because they were disturbed by Ta K_{β_2} X rays.)

All the evidence mentioned above indicate that the shorter-lived component should come from ^{186m}Ta β$^-$ decay, and the half-life of ^{186m}Ta was found to be (1.5 ± 0.1) min. A sketch of the ^{186}Ta and ^{186m}Ta decay scheme is shown in Fig. 4.

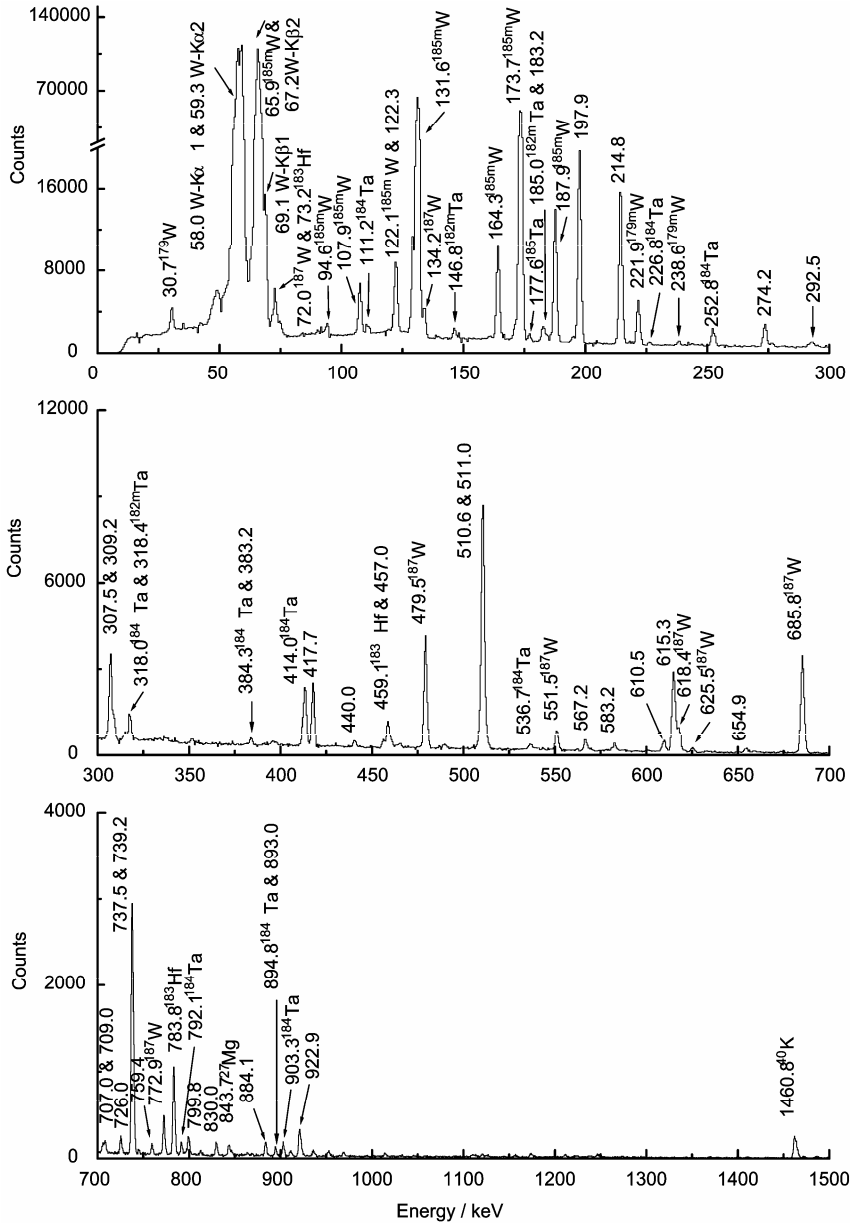

Fig. 1 The measured γ-ray spectrum.

We supposed that in the experiments of Refs. [5] and [6], ^{186m}Ta had already been produced, whereas it was not discovered. In the experiment reported by Ref. [5], the relative proportion of the produced short-lived ^{186m}Ta activity was low compared to ^{186}Ta in the irradiated target material because of the longer irradiation time (10 min). The remaining ^{186m}Ta activity in the Ta fraction could not be found after the long chemical separation process. In Ref. [6], the activities were directly measured without chemical separation besides the way similar to that described in Ref. [5]. They measured the irradiated sample of enriched ^{186}W using GM counter. The measured decay curve of the electron intensity is shown in Fig. 5. After analysis, they extracted two components with the half-life of 1.6 min and 10.5 min from the decay curve, respectively. Actually this 1.6 min component should belong to ^{186m}Ta. But unfortunately it was mistakenly assigned to ^{185m}W in Ref. [5]. Since ^{185m}W could not emanate β rays for its 100/100 IT property,[11] it could not appear in the measured β spectrum (Fig. 5). It is likely that no IT component exists or it is very weak during the decay

of ^{186m}Ta based on the following arguments:

1. No any new γ ray was obtained in the measured γ singles spectrum (Fig. 1).

2. Of course it was impossible to observe the γ rays from ^{186m}Ta IT transition through γ singles spectra if these γ rays were weak. X-γ coincidence was made so as to observe possible γ rays of ^{186m}Ta IT transition. The measured X-γ coincidence spectra were carefully analyzed. As a result there was no new γ ray in the γ ray spectra gated by Ta $K_{\alpha 2}$ and Ta $K_{\beta 1}$ X rays, whereas no attention was paid to Ta $K_{\alpha 1}$ and Ta $K_{\beta 2}$ X-rays in the data analysis because they were disturbed by W $K_{\alpha 2}$ and W $K_{\beta 1}$ X-rays, respectively.

3. The time variation of the ^{186}Ta decay γ rays was followed carefully. The fact that there is neither build-up nor consequent decay indicates that the ^{186m}Ta IT transition appears to not exist.

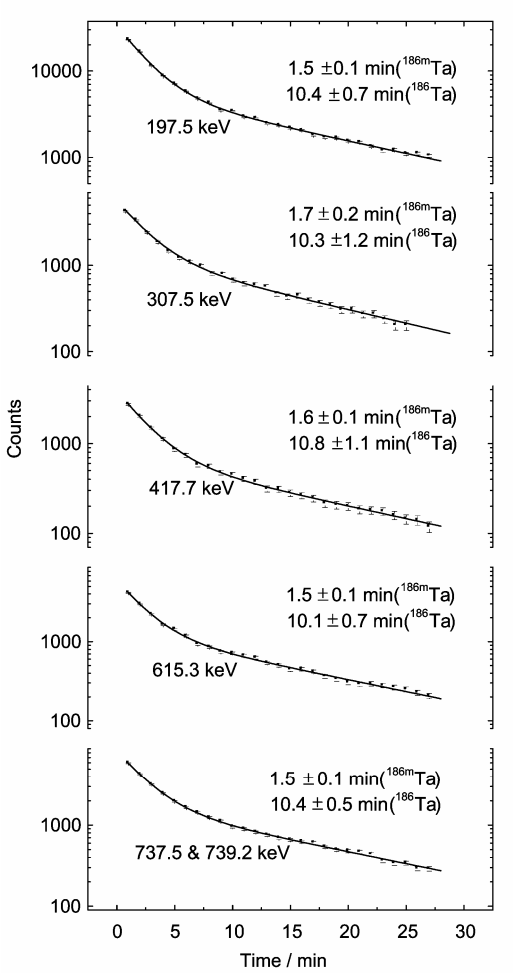

Fig. 2 The measured decay curves for 197.9, 307.5, 417.7, 615.3, 737.5, and 739.2 keV γ rays.

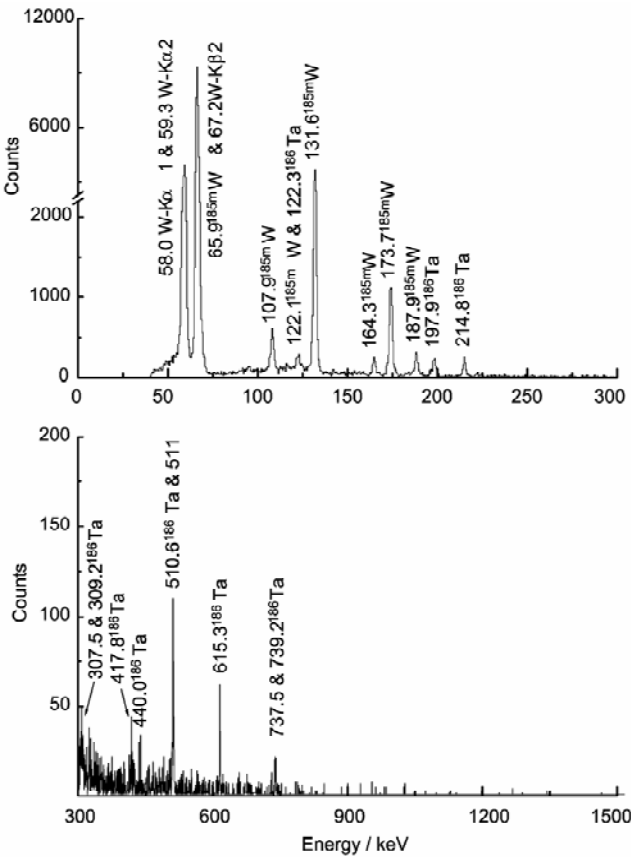

Fig. 3 The γ ray spectrum gated by W K_{α} and $K_{\beta 2}$ X rays.

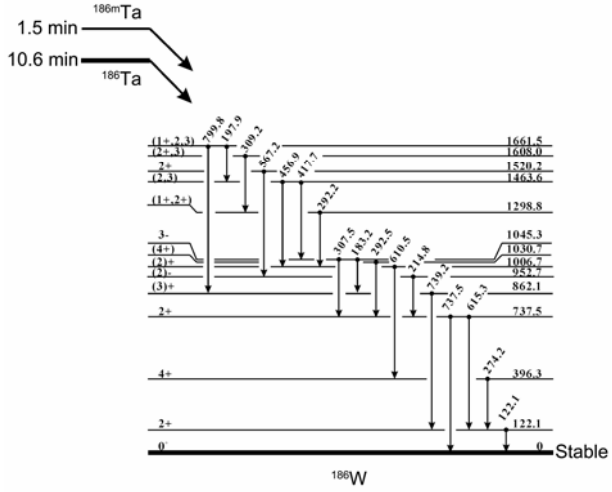

Fig. 4 A sketch of the ^{186}Ta and ^{186m}Ta decay scheme.

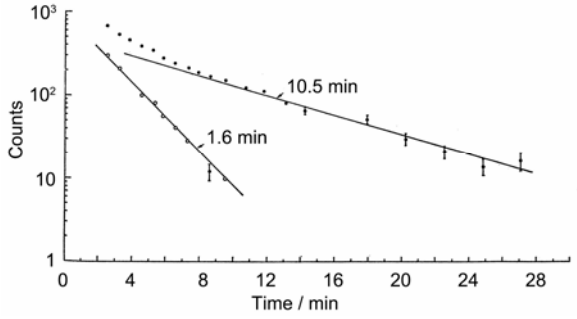

Fig. 5 The measured decay curve in Ref. [2].

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