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Measurements of the (n,γ) and (n,n') reaction cross sections on ^{186,187,189}Os and ^{187}Re-^{187}Os cosmochronology

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We measured the neutron capture cross sections of the ^{186,187,189}Os isotopes reaction by taking their pulse height spectra for neutrons between 10 and 90 keV by means of an anti-Compton NaI(Tl) spectrometer, and also the neutron inelastic scattering cross section for ^{187}Os as well as the neutron elastic scattering cross sections for ^{186,187}Os using ^{6}Li-glass scintillation detectors with a small systematic uncertainty.

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1. Introduction

The ^{187}Re nucleus is known to be produced only by the r-process, its half-life of 42.3±1.3 Gyr is quite long, and the geochemical property of Re is similar to that of Os [1]. Hence, in taking the ratio of ^{187}Re abundance to that of the isobaric daughter ^{187}Os, one could derive the stellar duration of the r-process nucleosyntheis and deduce the age of universe. These features of ^{187}Re mentioned provides the Re-Os pair to be one of the good cosmochronometers [2]. However, there are several problems inherent to this chronometer. First, ^{186}Os is the s-only isotope, and therefore ^{187}Os is also produced by the s-process by ^{186}Os. Second, the first excited state is so low at 10 keV in ^{187}Os that the state could be significantly populated at a stellar temperature. Hence, ^{187}Os is depleted by the neutron capture process not only via the ground state of ^{187}Os but also its excited state. In order to extract the abundance of ^{187}Os, which can be attributed to ^{187}Re decay, one must know both the production and depletion rates (via the excited state as well as the ground state) of ^{187}Os. The production rate of ^{187}Os and the depletion rate of ^{187}Os via its ground state could be obtained by measuring the neutron capture cross section of ^{186}Os and ^{187}Os, respectively. On the other hand, the depletion rate via the excited state should be calculated theoretically, since it is not possible to measure the neutron capture cross section for the first excited state of ^{187}Os. In order to construct reliable theoretical models to calculate the excited state neutron capture cross section, the measurements of the inelastic scattering cross section off the ground state (J^{π}= 1/2$^-$) of ^{187}Os to its excited 10keV state (J^{π}= 3/2$^-$), and of the neutron capture cross section of the ground state (J^{π}= 3/2$^-$) for ^{189}Os were suggested.

So far, the neutron capture cross sections for ^{186,187,189}Os, and the neutron inelastic scattering cross section for ^{187}Os were extensively measured by several groups. However, previous data are not consistent and/or have a large uncertainty, and therefore they are hardly used to discriminate theoretical models [3,4,5,6,7].

Hence, in the prsent study we aimed to accurately measure the neutron capture cross sections of ^{186}Os, ^{187}Os, and ^{189}Os, and the inelastic scattering cross section for ^{187}Os for neutrons between 10 and 90 keV by developing a new experimental method.

2. Experimental procedures and results

The experiments were carried out using pulsed keV neutrons, which were produced by the ^{7}Li(*p,n*)^{7}Be reaction. A pulsed proton beam was provided from the 3.2 MV Pelletron accelerator at Tokyo Institute of Technology.

2.1 Neutron capture reaction cross sections for ^{186,187,189}Os

The measurements of the neutron capture cross sections for ^{186,187,189}Os were carried out by employing a prompt discrete γ-ray detection method. Prompt γ-rays emitted from the neutron capture reaction of Os isotopes were detected by means of an anti-Compton NaI(Tl) spectrometer [7]. The cross sections were obtained by comparing the γ-ray yield of the ^{186,187,189}Os(n,γ) reactions to that of the ^{197}Au(n,γ) reaction, whose cross section is well known within an error of 3 %. The obtained capture cross sections of ^{186,187,189}Os are shown in Figs.1

together with previous ones. The obtained cross sections decrease quite smoothly with increasing neutron energy, and therefore the present keV neutron capture reaction is considered to dominantly proceed via an s-wave neutron capture process. The present result for ^{187}Os is ~20 % larger than previous data, while the result for ^{186}Os (^{189}Os) is in good agreement with the previous result taken by Browne et al.[4] (Winters et al.[3]).

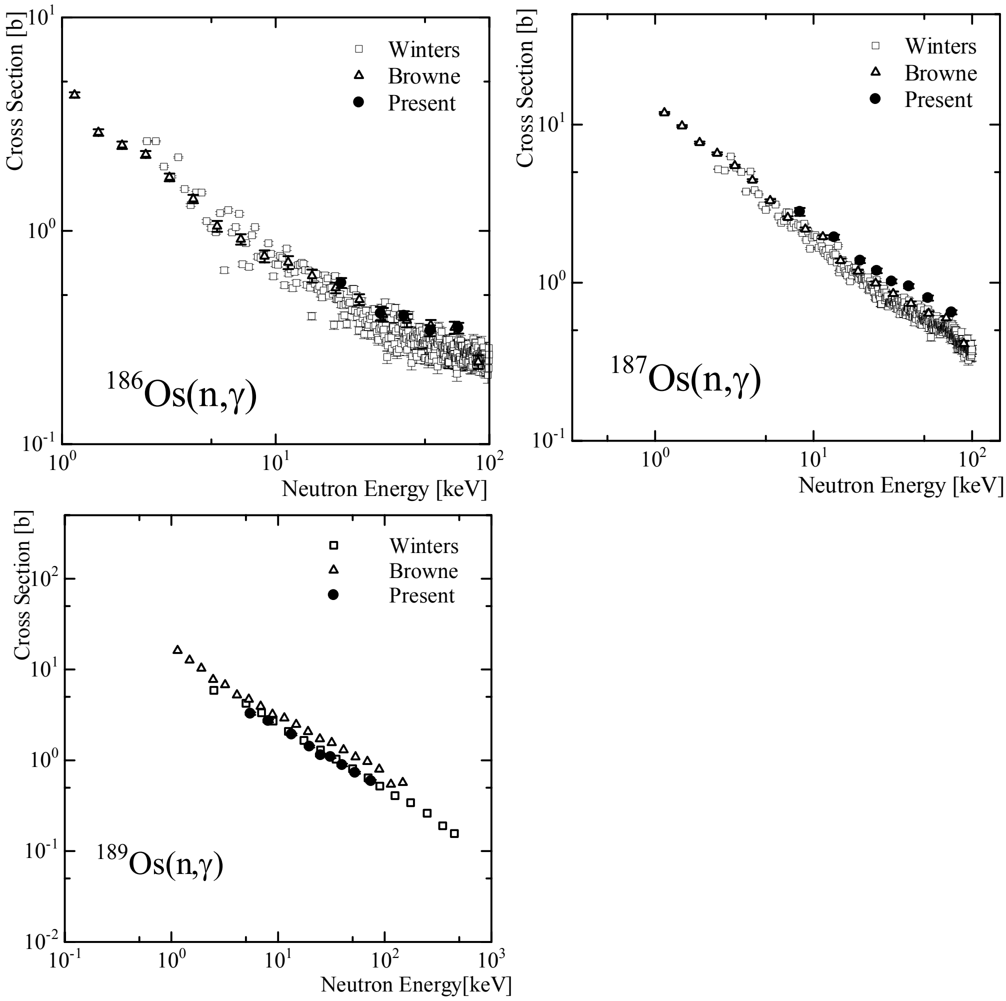

Fig.1 The obtained neutron capture cross sections for ^{186,187,189}Os together with previous data .

2.2 Neutron elastic and inelastic scattering cross sections for ^{187}Os

The measurement of the neutron elastic scattering cross sections of ^{186}Os and ^{187}Os, and of the inelastic scattering cross section of ^{187}Os was performed by detecting neutrons scattered by the samples with four ^{6}Li-glass detectors with a TOF method (see also Ref. [8], in which one can find a detailed description of the present experimental method). A schematic view of the experimental setup is shown in Fig. 2.

In this study we used neutrons of E_n=10-70 keV, but not mono-energetic neutrons. Note that both neutrons scattered inelastically and elastically by ^{187}Os were measured simultaneously by ^{6}Li-glass detectors. Hence, we could not separate neutrons scattered inelastically by ^{187}Os from those scattered elastically by ^{187}Os. In order to subtract the yield of the elastically scattered neutrons from total neutrons scattered by ^{187}Os to obtain the yield due to the inelastic scattering by ^{187}Os, we measured the neutron yield $Y_n(^{186}Os)$ due to the elastic scattering by ^{186}Os. Note that $Y_n(^{186}Os)$ only contained the neutrons due to the elastic scattering by ^{186}Os, since the first excited state of ^{186}Os is as high as 137 keV. Here, energy dependence of the elastic scattering cross section by ^{186}Os is calculated to be the same as that for ^{187}Os (private communication by Goriely et al.).

Using the thus obtained neutron yield due to the inelastic scattering by ^{187}Os, we could determine the neutron inelastic scattering cross section by referring the neutron elastic scattering cross section for ^{12}C, which is known accurately within an uncertainty of 4%. The detailed analysis for the elastic as well as inelastic scattering cross sections for Os isotopes mentioned is in progress.

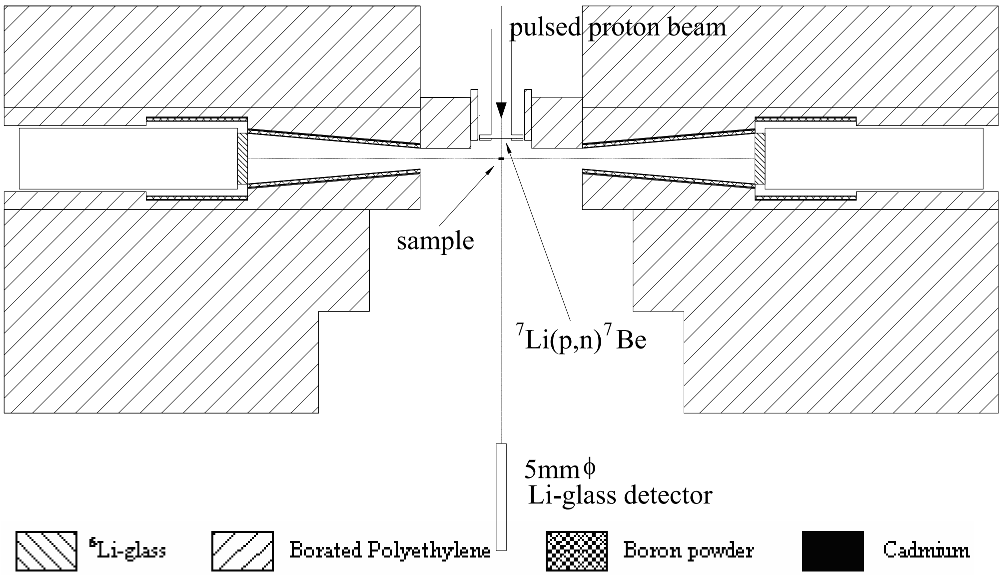

Fig.2 Experimental set up for neutron inelastic scattering cross section measurement for Os isotopes.

3. Summary

We measured successfully prompt γ-rays from the neutron capture reactions for ^{186,187,189}Os using an anti-Compton NaI(Tl) spectrometer. We also succeeded to measure the inelastically scattered neutrons spectrum for ^{187}Os accurately.We expect that the inelastic scattering cross section for ^{187}Os could be determined with an uncertainty of less than 10% with use of this newly constructed system. Detailed data analysis is in progress.

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