NEUTRON EXPERIMENT FOR THE Re/Os COSMOCHRONOMETER

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We should clarify several problems for the Re-Os pair to be used as one of the good cosmochronometers. First, since ^{187}Os is formed and depleted by sequential neutron capture in stars, the effects should be corrected. Second, ^{187}Os is depleted by the neutron capture process through the excited state at 10keV. It is very important to find a proper way to correct for the s-process contribution in deducing the age of the Galaxy. In order to correct for the effect mentioned above and to determine the age of the universe, we are planning to measure the neutron capture cross section of the first excited state ($E_{excited}$ = 10 keV) of ^{187}Os, which is one of the key parameters in deducing the age of the Galaxy using the Re-Os cosmochronometer. In order to deduce the cross section we are preparing various detectors using a newly developed experimental method. In the present paper I briefly describe our experimental methods to accurately determine the neutron caprute cross section of the first excited state of ^{187}Os.

1. Introduction

It has been an interesting subject to determine the age of the universe. Among three different methods to determine the age using the Hubble constant, the age of stars in globular clusters and long-lived radioactive species, the last method based on a nuclear approach is unique in a sence that the method relys on a physics observable which can trace the history of galaxies. Since one can deduce the age of the Galaxy accurately if one can construct proper models for the slow(s) and rapid(r) process nucleosynthesis in stars. Hence, the age of the universe can be obtained by adding the time interval between the Big-Bang and the start of the Galatic first generation star formation. If one could find an old star, the age of the old star can be estimated by measuring a decay rate of the abundance of a long-lived nucleus in the star during a certain period. If the old star would be one of the oldest stars in the galaxy, the life would give the lower limit of the life of our galaxy [1]. It has been considered that ^{187}Re-^{187}Os pair can be one of the good cosmochronometers, since ^{187}Re is produced by only r-process, the half life of ^{187}Re is quite long 42.3$\pm$1.3Gyr [2] and ^{186}Os is the s-only isotope. Therefore one should keep in mind that ^{187}Os is produced not only by the decay of ^{187}Re but also by slow neutron capture process by

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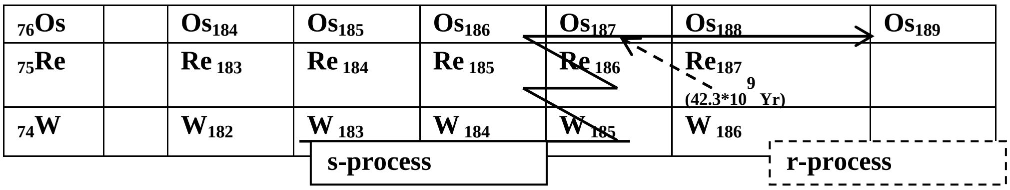
^{186}Os. Hence, principally if we know the production rate of ^{187}Os by the s-process neutron capture of ^{186}Os and the loss rate of ^{187}Os, we could obtain the amount of the decay product of ^{187}Re using the well known relation, $\sigma(^{186}\mathrm{Os})N(^{186}\mathrm{Os})=\sigma(^{187}\mathrm{Os})N(^{187}\mathrm{Os})$. Here, $\sigma(^{A}\mathrm{Os})$ and $N(^{A}\mathrm{Os})$ stand for the neutron capture cross section and the observed abundance of Os with mass number A, respectively. Consequently, we could deduce the age of the Galaxy. However, there is a problem originating from the excited state at 10 keV in ^{187}Os (Fig. 1). The 10 keV state could be significantly populated at the stellar temperature of kT≈ 30 keV, and therefore ^{187}Os is depleted by the neutron capture process through the excited state. Hence it is very important to find a proper way to correct for the the loss rate of ^{187}Os through the excited state in deducing the age of the Galaxy [3,4,5,6]. In order to correct for the effect mentioned above and to determine the age of the universe we are planning to measure both the neutron capture cross sections and neutron inelastic cross sections of ^{186}Os, ^{187}Os and ^{189}Os using a newly developed experimental method as described below.



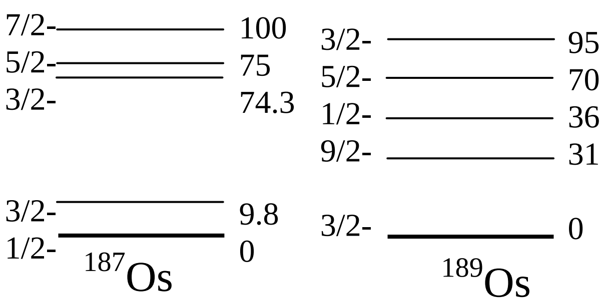


Fig.1 Partial level scheme of ^{187}Os and ^{189}Os

2. Experimental Procedure

The experiment has been carried out using keV neutrons produced by the $^{7}Li(p,n)$ reaction. The proton beam was provided from the Pelletron accelerator of the Research Laboratory for Nuclear Reactors at Tokyo Institute of Technology. Pulsed neutrons from 5.5 to 90 keV were bombarded on three enriched samples of ^{186}Os, ^{187}Os and ^{189}Os and ^{197}Au and a blank position to measure the neutron capture cross section of these Os isotopes. Here gold sample was used for normalization of the absolute capture cross section, since the neutron capture cross section of gold is well known with an uncertainty of less than 3%. For the measurement of the $^{189}Os(n,n')^{189}Os$ reaction cross section the incident neutron energy should be adjusted not to exceed the energy of the second state at 74.3keV, since ^{189}Os has the second excited state at 74.3 keV. The neutron capture cross section of Os isotopes was measured using an anti-Compton NaI(Tl) spectrometers by detecting prompt gamma rays feeding from a neutron capture state of Os to low lying states (Fig.2). Each spectrometer consists of a central NaI(Tl) detector with a diameter of 9 inches and a length of 8 inches and an annular NaI(Tl) detector with a diameter of 13 inches and a length of 11 inches. Each spectrometer was placed at 125 ° with respect to the proton beam direction, and therefore a gamma ray yield detected at this angle gives an angle integrated cross section. We are now developing a detection system to measure a neutron inelastic scattering cross section of ^{189}Os by means of four Li-glass detectors with a diameter of 50 mm and a thickness of 10 mm. Neutron energy scattered elastically and/or inelastically by ^{189}Os is determined by employing a TOF method. The discrimination between scattered neuron by ^{189}Os and gamma ray background can be made by their pulse heights. In order to obtain the inelastic scattering cross section of ^{189}Os accurately, it is crucial to prevent direct neutrons from the $^{7}Li(p,n)^{7}Be$ reaction entering into the Li-glass detector. Hence the detectors are enveloped carefully by borated paraffin blocks, Cd and Boron to attenuate neutrons. In order to find proper arrangement of these shield materials of borated polyethylene, cadmium and Boron, an extensive calculation has been made using a Monte Carlo Code, TIME-MULTI [7]. In addition, through many R&D works we have finally succeeded to construct a high sensitive measuring system of the inelastic scattering cross section of a nucleus. Using the new system we are aiming at measuring the $^{189}Os(n,n')^{189}Os$ cross section within an uncertainty less than 15%.

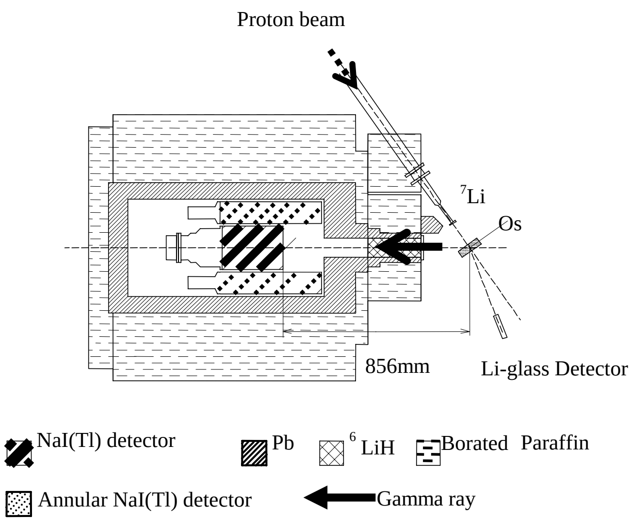


Fig.2 Schematic view of the experimental set up

3. Conclusion

We have for the firtst time succeeded to detect discrete gamma ray from the neutron capture reaction of ^{186}Os, ^{187}Os and ^{189}Os at a stellar energy by detection a prompt discrete gamma ray from these reactions (Fig. 3). Data anaylsis to determine the neutron capture cross section of these Os isotopes is in progress. It should be added that we have also observed for the first time a bump at around 5 MeV in the gamma ray spectrum, which could be discussed in terms of a Pigny Resonance. Concerning neutron inelastic cross sections we have installed successfully a high sesitive measuring system of neutron inelastic cross sections of ^{187}Os and ^{189}Os. Using a newly developed method, we hope that we could determine the age of the universe within an uncertainty of one billion year.

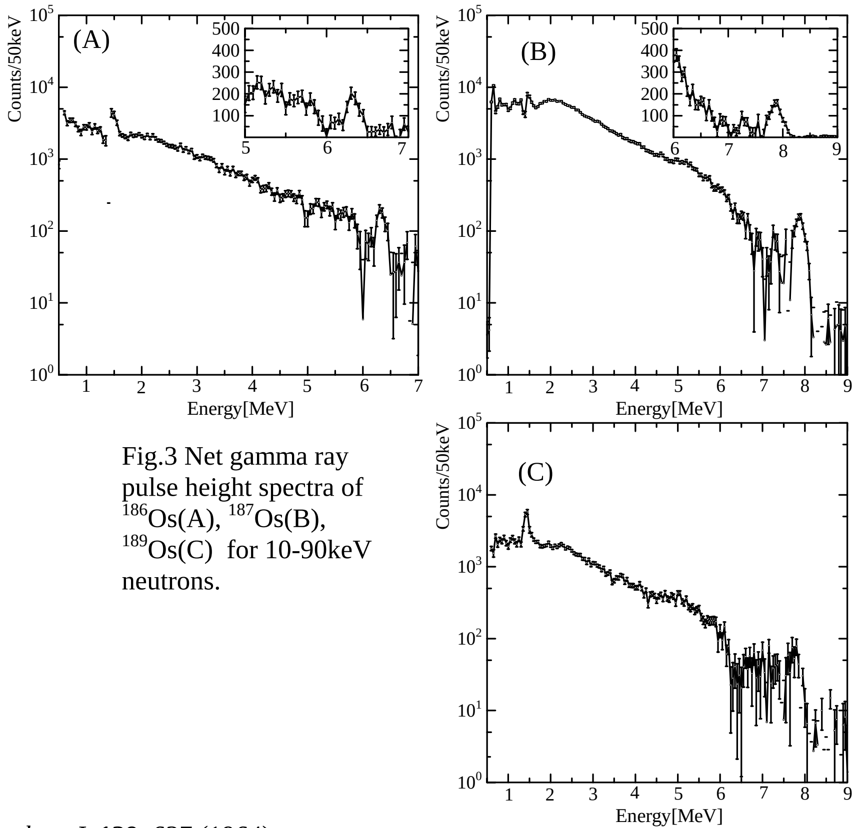


Fig.3 Net gamma ray pulse height spectra of ^{186}Os(A), ^{187}Os(B), ^{189}Os(C) for 10-90keV neutrons.

References

1. D. D. Clayton, *Astrophys. J.* **139**, 637 (1964).
2. M. Linder et al., *Geochim. Cosmochim. Acta*. **53**, 1597 (1989).
3. R. R. Winters, *Astron. Astrophys.* **171**, 9 (1987).
4. J. C. Brown, *Phys. Rev.* **C23**, 1434 (1981).
5. M. J. Harris, *Astrophy. Space. Sci.* **77**, 357 (1981).
6. S. E. Woosley, *Astrophys. J.* **233**, 411 (1979).
7. K. Senoo, Y. Nagai, T. Shima, T. Ohsaki, and M. Igashira, *Nucl. Instr. Meth.* **A339** (1994) 556.