Temperature dependence of the total muonium emission yield from silica aerogel using μSR method

K. Ishida,[*1] K. Suzuki,[*2] T. Mibe,[*2] M. Iwasaki,[1,*3] S. Kamal,[*4] and J. Brewer[*4]

We are developing thermal-energy muonium (Mu $= \mu^+e^-$) production as a source of the cold muon beam for the muon g-2/EDM experiment planned at J-PARC.[1)] We observed at TRIUMF that the Mu emission rate from silica aerogel to vacuum is enhanced by surface ablation.[2,3)] However, the present Mu yield measurement performed by tracking the muon decay positron is limited to a region away (∼5 mm) from the surface owing to the large background from the muoniums decaying in aerogel. To enable measurement of the Mu emitted in vacuum including the region near the surface, where we are planning to shoot a Mu ionizing laser, we performed a new measurement using the Mu spin rotation (MuSR) method in the ARGUS spectrometer at the RIKEN-RAL Muon Facility. In MuSR, the precession of the muon spin can be detected by asymmetric emission of the muon decay positrons. Since the precession frequency of Mu is different from that of diamagnetic muon under an applied field, we can measure the fraction of muons forming the Mu state.

In the measurement, we added a gold foil to the downstream of the silica aerogel target. First, we set the muon-beam momentum so that the muons fully stop in the middle of the aerogel and measured the Mu spin relaxation intrinsic to the aerogel material. Then, we chose another momentum so that the muon stopping distribution peaked at the downstream surface of the aerogel. In this half-stopping condition, we observed an increase in the Mu spin relaxation rate.[4)] This was interpreted as a result of Mu transfer to the gold foil after emission to vacuum. Once in gold, Mu changes its state to diamagnetic muon and cannot contribute to the Mu precession signal anymore.

Here, we report the first measurement of the temperature dependence of the Mu emission rate. In a naive model, where Mu is emitted after diffusion in spaces in the aerogel nano-structure, we expect that the Mu emission rate is proportional to the thermal Mu velocity, $v \propto T^{1/2}$, where T is the aerogel temperature.

Keys for the experiment are the cooling of the aerogel and the aerogel temperature measurement. Since the thermal conductivity of the silica aerogel is very low, we relied on cooling by thermal radiation emission. We designed a sample holder that covers all the faces of the aerogel and mounted it on the cryostat. In a cooling test conducted prior to the MuSR measurement, we used a K-type thermocouple directly inserted into the aerogel in addition to the semiconductor thermometers on the cryostat and the sample holder. The thermocouple was chosen because of its small size and low heat mass. While cooling down from room temperature, the aerogel temperature initially followed that of the sample holder, though with some delay. Subsequently, the aerogel temperature was saturated at approximately 180 K and stabilized, however cold the sample holder was. This was understood as the effect of leakage of thermal radiation from the room-temperature surface through an opening used to insert the thermocouple. The saturation temperature was consistent with that expected with area fraction of the opening, which was about 10%. In the MuSR measurement, the thermocouple was removed, and the aerogel sample was completely surrounded by the cold surface. This ensured that the aerogel temperature reached equilibrium with that of the holder.

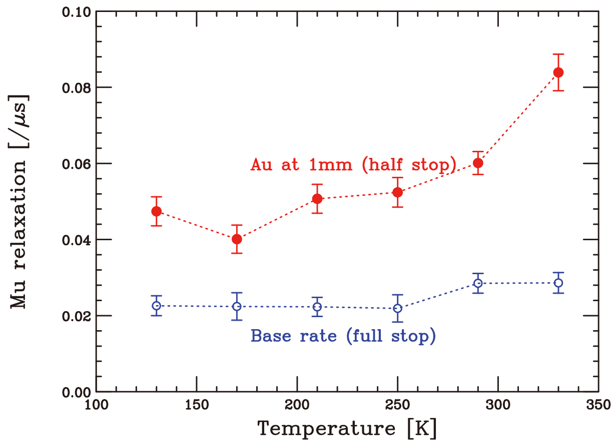

Fig. 1. Temperature dependence of the Mu relaxation rate with the muons stopped in the middle (full stop) and at the downstream edge of the silica aerogel (half stop).

A preliminary result of the Mu relaxation rate measurement is shown in Fig. 1. The relaxation rate in the aerogel (full stop) did not change much with the temperature, while the rate in the half-stop condition was larger and showed some temperature dependence. We plan a detailed analysis to study whether it agrees with the diffusion model assuming the Mu velocity distribution equilibrated with the temperature.

*1 RIKEN Nishina Center
*2 IPNS, KEK
*3 Meson Science Laboratory, RIKEN
*4 University of British Columbia

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