EPJ Web of Conferences **66**, 11017 (2014)
DOI: 10.1051/epjconf/20146611017

Present Status of KEK Isotope Separation System

Y. Hirayama[1,a], S.C. Jeong[1], Y.X. Watanabe[1], N. Imai[1], H. Ishiyama[1], H. Miyatake[1], M. Oyaizu[1], Y.H. Kim[2], M. Mukai[3], T. Sonoda[4], M. Wada[4], M. Huyse[5], Yu. Kudryavtsev[5], and P. Van Duppen[5]

[1] *Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[2] *Seoul National University, Seoul, 151-742, Korea*
[3] *Tsukuba University, Tsukuba, Ibaraki 305-0006, Japan*
[4] *Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan*
[5] *Instituut voor Kern-en Stralingsfysica, K.U. Leuven, B-3001 Leuven, Belgium*

Abstract. KISS (KEK Isotope Separation System) has been constructed at Nishina Research Center (NRC) of RIKEN to study the decay properties of heavy neutron-rich isotopes with mass number around A∼200 along the neutron magic number of $N = 126$ for the astrophysical interest. The isotopes of interest will be produced by multi-nucleon transfer reactions in neutron-rich heavy ion collisions (e.g. ^{136}Xe projectile on ^{198}Pt target). KISS consists of a gas-cell system for thermalizing (stopping and neutralizing) and fast-transporting reaction products to the gas cell exit hole, a laser system for the resonant ionization, and a mass-separator system followed by a detection system for the decay spectroscopy. KISS will allow us to study unknown isotopes produced in weak reaction channels under low background conditions. The off-line test of the KISS has been finished. As a next step, on-line test experiments have been performed to investigate the overall efficiency and selectivity of the system as a function of the injected ^{56}Fe beam intensity from the RIKEN Ring Cyclotron (RRC).

1 Introduction

The beta-decay properties of nuclei with $N = 126$, which are believed to act as progenitors in the rapid neutron capture (r-) process path forming the third peak ($A \approx 195$) in the observed elemental abundance pattern, are considered critical for clearly understanding astrophysical sites for the production of the heavy elements such as gold and platinum [1]. We are going to produce and study ^{200}W, ^{201}Re, ^{202}Os and ^{203}Ir ($Z = 74$–77, $N = 126$) by carrying out multi-nucleon transfer (MNT) reactions [2] between an energetic stable isotope beam ^{136}Xe at 10 MeV/nucleon and a ^{198}Pt target. In order to investigate the effectiveness of the reaction system of ^{136}Xe+^{198}Pt, we performed reaction studies using the large acceptance magnetic spectrometer VAMOS++ and the high efficiency gamma detector array EXOGAM at GANIL [3]. These experimental results are reported in the present proceedings [4].

From the reaction dynamics calculations using GRAZING code [5], the recoil energies of the nuclei with $N = 126$ produced as target-like fragments (TLFs) are found to be as low as 1 MeV/nucleon

[a] e-mail: yoshikazu.hirayama@kek.jp

and the reaction products have a wide energy distribution. A large spread in the calculated emission angle was observed, and an average value of the emission angles of 65° in the laboratory frame was obtained. These characteristics of the MNT reaction products make it difficult to collect the reaction products with $N = 126$ using an in-flight-type electromagnetic spectrometer. In the KISS project, we employ a gas catcher to efficiently collect all reaction products, and we adopt laser resonance ionization technique to selectively ionize the nuclei with specific atomic numbers Z coupled to an electromagnetic separator (ISOL) to obtain the nuclei with specific mass numbers A [6, 7].

2 KEK Isotope Separation System

KISS has been constructed at the RIBF facility in RIKEN in the beginning of 2011. It consists of a laser system, a mass-separator system, a decay measurement station and a gas-cell system [8]. The decay measurement stations will be installed later this year. KISS has been tested at the off-line [8] and on-line conditions using the stable ^{56}Fe beam.

The laser system consists of two frequency-tunable dye lasers (ScanMate and FL3002) pumped by two Excimer (LPX240i, XeCl, 308 nm) lasers and has been installed in the shielded separate room below the KISS experimental hall.

The mass-separator system has QQDQQ configuration, in which Q and D denote the quadrupole and dipole magnets, respectively. The deflection angle and the pole gap of the D magnet are 45 degrees and 70 mm, respectively. The measured mass resolving power equals to 900, which is in good agreement with the expected value [8].

The decay measurement station has a tape transport device for the decay measurements under the condition of pulsed beams from the separator. Plastic scintillator telescopes followed by the germanium gamma-ray detectors surrounding the implantation point in the tape transport device.

3 Gas cell system

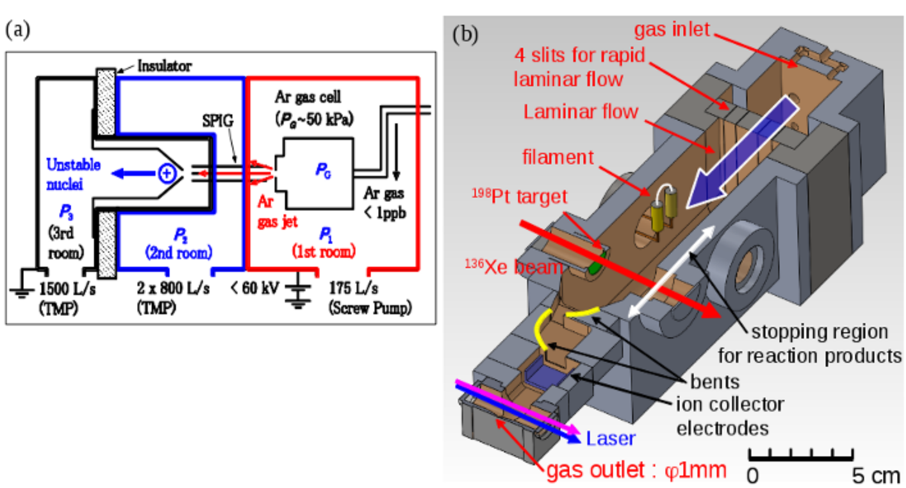

Figure 1. (a) Schematic view of the gas cell system. (b) Schematic cross sectional view of the gas cell.

The gas cell system includes an argon gas feeding line with a getter-based gas purifier (Monotorr Phase II 3000), a sextupole ion-guide (SPIG) and a gas-catcher cell [8] as shown in Fig. 1-(a). The vacuum chamber of the gas-cell system is separated into three rooms for the differential pumping. The boundaries of first, second, and third rooms are indicated by the red, blue and black thick lines, respectively. Typical pressure values in the three rooms are P_1 = 8.7 Pa, P_2 = 0.9 Pa and $P_3 = 3\times10^{-4}$ Pa for the gas cell pressure P_G = 50 kPa [8].

In order to obtain a high stopping efficiency (90%) for the MNT products around N =126, a large gas cell volume was considered as shown in Fig. 1-(b). A laminar flow of argon gas transports nuclei to the exit of the gas cell. The gas cell has four slits to generate a rapid laminar flow of argon gas. The nuclei of interest are selectively ionized by laser resonance ionization technique and are extracted as a beam with the energy of 28 kV. The evacuation time of the gas cell was measured to be about 200 ms, which was in good agreement with the simulated value. The transport efficiency of the gas cell is calculated to be 56% and the rest is lost at the wall due to the diffusion. The present gas cell has ion collector electrodes (ICE) that collect unwanted ions to increase the selectivity of the laser ion source. The bend structure for the gas flow is introduced in order to shadow the regions of ICE and laser ionization from an argon plasma induced by the primary ^{56}Fe beam. In this way, neutralization of laser-produced ions is essentially reduced, and ICE can collect non-neutralized ions [6, 7].

4 Efficiency and selectivity measurements

The absolute extraction efficiency and selectivity of KISS can be evaluated only in on-line experiments by measuring the beam intensities implanted in- and extracted from the gas cell. Those measurements were performed by stopping of the ^{56}Fe beam with the energy of 90 MeV/nucleon and the maximum intensity of 4 pnA in argon as buffer gas. The thermalizing and neutralizing ^{56}Fe beam was re-ionized in the gas cell, extracted and measured after mass-separation.

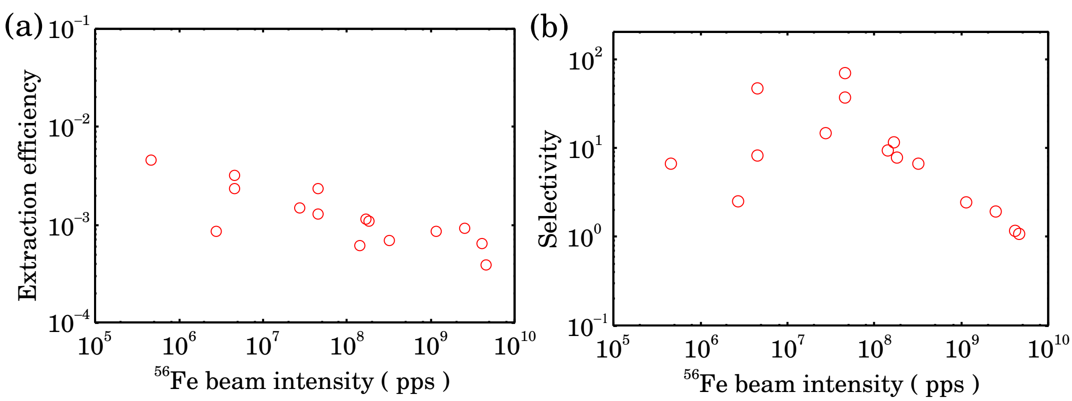

Figure 2. (a) extraction efficiency of ^{56}Fe ions and (b) selectivity measured as a function of ^{56}Fe beam intensity.

Figures 2-(a) and -(b) show the measured efficiency and selectivity as a function of the ^{56}Fe beam intensity, respectively. In Fig. 2-(a), ^{56}Fe ions were observed with 0.5% extraction efficiency at the injection rate of 5×10^5 pps. The efficiency decreased with increasing the ^{56}Fe beam intensity. The selectivity for ^{56}Fe ion production defined as the ratio of the laser ionized ions to non-laser ionized ions (which survived as a single ion.). The selectivity is also decreased with increasing the ^{56}Fe beam intensity as shown in Fig. 2-(b). These results indicate that the shadowing effect by the bend structure of the gas cell is insufficient. Therefore, the argon plasma induced the re-neutralization of laser ionized ions and prevented for the ICE to work properly. As another reason, we suspect that the gamma-ray radiation emitted from the energy degrader for ^{56}Fe beam, which located about 100 mm upstream of the gas cell and reduced the beam energy from 90 MeV/nucleon to 1.5 MeV/nucleon, produced argon plasma all over the gas cell. This plasma reduced the extraction efficiency and selectivity.

The obtained extraction efficiency 0.5% was much smaller than the expected value of 7%. The possible reason could be a lack of sufficient laser power for saturation of the transition to the auto-ionizing state (AIS). It is necessary to increase the laser power on this transition or search for another AISs to increase the laser ionization efficiency.

5 Conclusion

We constructed the KEK Isotope Separation System (KISS) at RIKEN to study the β-decay properties of the neutron-rich isotopes with neutron number around $N = 126$ for astrophysical interest. The effectiveness of the MNT reaction system of ^{136}Xe+^{198}Pt was investigated using VAMOS++ and EXOGAM at GANIL and turned out to be promising for the KISS project. The performance test of the gas cell system and the KISS have successfully been performed at off-line conditions. The extraction efficiency and the selectivity of KISS were investigated during the on-line test runs. The measured efficiency of 0.5% was more than an order of magnitude smaller than the expected value, but possibilities to improve it have been identified. In order to increase the efficiency and selectivity, we will improve the laser ionization efficiency and plan to test a new configuration of the gas cell at a next on-line experiment, and subsequently perform the first spectroscopy studies of the unstable nuclei.

Acknowledgment

The authors acknowledge the staff of the RIKEN accelerator for their support. This work has been supported by Grant-in-Aids for Scientific Research (A) (S.C. Jeong, grant no. 23244060) and for young scientists (B) (Y. Hirayama, grant no. 24740180) from the Japan Society for the Promotion of Science (JSPS), by FWO-Vlaanderen (Belgium), GOA/2010/010 (BOF KU Leuven) and a grant from the European Research Council (ERC-2011-AdG-291561-HELIOS).

References

[1] E.M. Burbidge *et al.*, Rev. Mod. Phys. 29, 547 (1957).
[2] C.H. Dasso *et al.*, Phys. Rev. Lett. 73, 1907 (1994).
[3] Y.X. Watanabe *et al.*, Nucl. Instr. and Meth. B (2013) (*in press*).
[4] Y.H. Kim *et al.*, these proceedings.
[5] A. Winther, Nucl. Phys. A572 (1994) 191; A. Winther, Nucl. Phys. A594, 203 (1995).
[6] M. Huyse *et al.*, Nucl. Instr. and Meth. B 187, 535 (2002).
[7] Yu. Kudryavstev *et al.*, Nucl. Instr. and Meth. B 267, 2908 (2009).
[8] Y. Hirayama *et al.*, Nucl. Instr. and Meth. B (2013) (*in press*).