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Search for halo nucleus in Mg isotopes through the measurements of reaction cross sections towards the vicinity of neutron drip line

M. Takechi[1,2,a], S. Suzuki[3], D. Nishimura[4], M. Fukuda[5], T. Ohtsubo[3], M. Nagashima[3], T. Suzuki[6], T. Yamaguchi[6], A. Ozawa[7], T. Moriguchi[7], H. Ohishi[7], T. Sumikama[8], H. Geissel[1], M. Ishihara[1], N. Aoi[9], Rui-Jiu Chen[2], De-Qing Fang[10], N. Fukuda[2], S. Fukuoka[7], H. Furuki[6], N. Inabe[2], Y. Ishibashi[7], T. Itoh[3], T. Izumikawa[3], D. Kameda[2], T. Kubo[2], C. S. Lee[3], M. Lantz[11], Yu-Gang Ma[10], K. Matsuta[5], M. Mihara[5], S. Momota[12], D. Nagae[7], R. Nishikiori[7], T. Niwa[7], T. Ohnishi[2], K. Okumura[7], T. Ogura[3], H. Sakurai[2,13], K. Sato[3], Y. Shimbara[3], H. Suzuki[2], H. Takeda[2], S. Takeuchi[2], K. Tanaka[2], H. Uenishi[5], M. Winkler[1], Y. Yanagisawa[2], S.Watanabe[14], K. Minomo[14], S. Tagami[14], M. Shimada[15], M. Kimura[15], T. Matsumoto[14], Y. R. Shimizu[14], and M. Yahiro[14]

[1] *Gesellschaft für Schwerionenforschung GSI, 64291 Darmstadt, Germany*
[2] *RIKEN, Nishina Center, Wako, Saitama 351-0106, Japan*
[3] *Department of Physics, Niigata University, Niigata 950-2102, Japan*
[4] *Department of Physics, Tokyo University of Science, Chiba, 278-8510, Japan*
[5] *Department of Physics, Osaka University, Osaka 560-0043, Japan*
[6] *Department of Physics, Saitama University, Saitama 338-8570, Japan*
[7] *Institute of Physics, University of Tsukuba, Ibaragi, 305-8571, Japan*
[8] *Cyclotron and Radioisotope Center, Tohoku University, Aoba-ku, Sendai 980-8578, Japan*
[9] *Research Center of Nuclear Physics (RCNP), Osaka University, Ibaraki 567-0047, Japan*
[10] *Shanghai Institute of Applied Physics, Chinese Academy of Sciences, P. O. Box 800-204, Shanghai 201800, China*
[11] *Department of Physics and Astronomy, Uppsala University, 751-20, Uppsala, Sweden*
[12] *Faculty of Engineering, Kochi University of Technology Kochi, 782-8502, Japan*
[13] *Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[14] *Department of Physics, Kyushu University, Fukuoka 812-8581, Japan*
[15] *Creative Research Institution (CRIS), Hokkaido University, Sapporo 001-0021, Japan*

Abstract. Reaction cross sections (σ_{R}) for $^{24-38}$Mg on C targets at the energies of around 240 MeV/nucleon have been measured precisely at RIBF, RIKEN for the purpose of obtaining the crucial information on the changes of nuclear structure in unstable nuclei, especially around the so-called "island of inversion" region. In the island of inversion region, which includes neutron-rich Ne, Na, and Mg isotopes, the vanishing of the N = 20 magic number for neutrons have been discussed along with nuclear deformation. The present result suggest deformation features of Mg isotopes and shows a large cross section of weakly-bound nucleus ^{37}Mg, which could be caused by a neutron halo formation.

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[a] e-mail: m.takechi@gsi.de

1 Introduction

During the past few decades, our knowledge of the features of exotic nuclei have been much enhanced. In 1980s, neutron halo structure of neutron drip-line nucleus, which is one of the most notable abnormal features of exotic nuclei, have been found [1]. Since 1990s, the number of studies about the vanishing of the $N = 20$ magic number for neutrons in neutron-rich region have been quite increased. In so-called island of inversion region which includes neutron-rich Ne, Na, and Mg isotopes, strongly-deformed nuclei have been found despite of their neutron magic number 20 [2]. For the further understanding of the mechanism of those changes in nuclear structure of unstable nuclei, it is important to investigate these changes from the stable nuclei to the neutron drip line systematically. Our experimental approach to achieve this systematic study is that to probe nuclear radius of each nucleus in Mg isotopic chain from stable to the vicinity of neutron drip line on the basis of same experimental and analysis technique. Nuclear size is the informative physical quantity to investigate the deformation and halo features of unstable nuclei. The method to relate the σ_{R} to nuclear size have been established since 1980s[3]. We measured the σ_{R} for Mg isotopes from ^{24}Mg to ^{38}Mg in order to study the changes of nuclear sizes and nuclear structure as the neutron number increases.

2 Experiment

The experiment was performed at the RIBF operated by the RIKEN Nishina Center and the Center for Nuclear Study, University of Tokyo. A primary beam of ^{48}Ca accelerated to 345 MeV/nucleon with a maximum beam intensity of $\sim$ 100 pnA, and Be production targets were used to produce $^{24-38}$Mg secondary beams. The beam energy of $^{24-38}$Mg were around 260 MeV/nucleon. The BigRIPS fragment separator [4, 5] was used as a spectrometer to identify incoming and outgoing particles [7] and σ_{R} were measured by the transmission method. The σ_{R} is derived from $\sigma_{\mathrm{R}} = -\frac{1}{t}\ln(\frac{\Gamma}{\Gamma_0})$, where Γ is the ratio of the number of noninteracting outgoing particles to the number of incoming particles, Γ_0 is the same ratio for an empty-target measurement to correct for nuclear reactions in the detectors, and t denotes the thickness of the reaction target. The schematic view of the BigRIPS beam line and the experimental setup is shown in Fig. 1. The carbon reaction targets of 1.80 or 3.59 g/cm^2 thickness were located at the F5 dispersive focal plane of BigRIPS. Incoming particles were separated and identified using the beam line between the F3 and F5 focal plane, and outgoing particles were identified between the F5 and F7 focal plane. For particle identification before and after the reaction target, magnetic rigidity, energy-loss, and time-of-flight (TOF) information were used. Atomic numbers of particles are identified from the energy-loss measured by ion chambers at F3 and F7. At F3, we set a

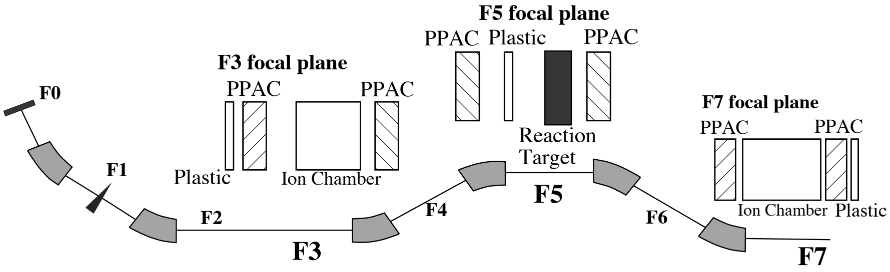

Figure 1. The schematic view of the experimental setup.

multi-sampling ionization chamber (MUSIC) [8], of which diameter of sensitive area is 116mm and the thickness is 410 mm. The ion chamber at F7 is the standard detector of BigRIPS. TOF and the magnetic rigidity of the particles are determined from the time and position information from plastic scintillation counters at F3, F5, and F7. The plastic scintillation counter at F3 is also the standard detector of BigRIPS and the ones at F5 and F7 have the area of 240 mm x 100 mm, and 0.5 mm and 2 mm thicknesses, respectively. The position information from the PPACs at F3 was used to apply an appropriate emittance-cut for the incident beam so as to accurately count all of the noninteracting particles without missing them after the reaction target. In this experiment, the position information of plastics are used for the particle identification after the reaction target rather than PPACs at F5 and F7 to avoid the miscounting of outgoing noninteracting particles due to the incomplete efficiency of the PPACs [6]. With this setup, incoming particles can be completely separated from the other fragments and noninteracting outgoing particles can be also separated from other nuclides except for the case of inelastic scattering, in which particles have same atomic and mass numbers but slightly different energies. In the $\sigma_{\rm R}$ analysis, the inelastic scattering cross sections are often estimated from the energy distribution of the particles [9]. In this work, TOF and magnetic rigidity distribution of the particles are used to estimate the inelastic scattering cross section. The inelastic scattering cross sections contribute to the $\sigma_{\rm R}$ by less than ~ 3% (especially at most 1.4% for very neutron-rich nuclei $^{36-38}$Mg) and the uncertainty of the estimation caused a systematic error in $\sigma_{\rm R}$ of less than 2 % (for $^{36-38}$Mg, less than 0.8%) .

3 Result

In Fig. 2, preliminary results of $\sigma_{\rm R}$ for Mg isotopes are plotted as a function of mass number. The precision of the data are from 1 to 2 %. The errors of the data are determined by the statistics for ^{37}Mg and ^{38}Mg. On the contrary, the systematic errors caused by the estimation of inelastic scattering cross sections are dominant for nuclei near the line of stability. In Fig. 2 the results of Glauber-type calculations are shown for comparison. Solid curve is obtained assuming spherical Fermi-type nucleon density distributions of which radii are proportional to $A^{1/3}$ and dashed lines with triangles are obtained assuming deformed Fermi distributions of which deformation parameters are determined to reproduce experimental quadrupole moment values for ^{25}Mg [12], ^{29}Mg [13], and ^{33}Mg [14] (For the details of the calculation, also refer to [7].). The $\sigma_{\rm R}$ for ^{27}Mg and ^{30}Mg seem to follow the spherical calculation and $\sigma_{\rm R}$ for ^{25}Mg, ^{29}Mg and ^{33}Mg seem to follow the calculation which takes into account their quadrupole deformation. This result of comparison up to ^{33}Mg may indicate that the size of $\sigma_{\rm R}$ for each nucleus reflects the deformation characteristics. At the vicinity of neutron drip line, the sudden increase of $\sigma_{\rm R}$ for ^{37}Mg has been observed. This sudden increase is similar to the gap observed between ^{27}Mg and ^{28}Mg, and also between ^{30}Mg and ^{31}Mg which can be interpreted as the difference of nuclear sizes between spherical and deformed nuclei. In the case of ^{37}Mg, two possibilities can be considered to explain this sudden increase. Either a strong deformation that is even larger than one of ^{36}Mg which is considered to be well deformed[15] or a halo formation caused by the weakly-bound system of ^{37}Mg of which estimated neutron separation energy is 0.16 ± 0.68 MeV[16]. In order to conclude the deformation features of Mg isotopes and possible halo structure in ^{37}Mg, the further careful analysis of the experimental data and also analysis based on theoretical model [10, 11] are in progress.

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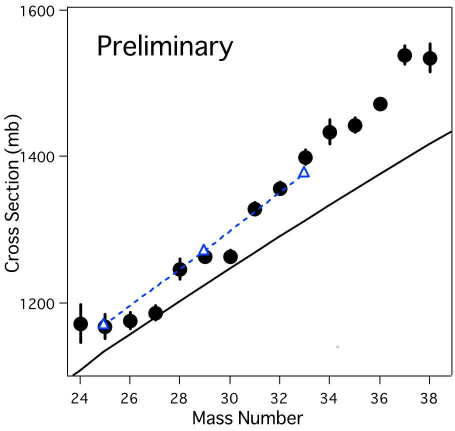

Figure 2. The present σ_R for Mg isotope as a function of the mass number.

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