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SEARCH FOR NEW NEUTRON-RICH NUCLEI WITH A 70*A* MeV ^{48}Ca BEAM

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The results of a RIKEN-JINR collaboration experiment on search for new Ne, Na, Mg, Al isotopes close to the neutron drip line are presented. We found for the first time three new neutron-rich nuclei ^{38}Mg and ^{40,41}Al. Some clue for particle unstability of ^{33}Ne was also obtained. These nuclei were produced by the projectile fragmentation of a 70*A* MeV ^{48}Ca beam on a ^{181}Ta target. The reaction fragments were analysed by the fragment separator RIPS at RIKEN, and were unambiguously identified by measuring the magnetic rigidity, time-of-flight, energy loss and total kinetic energy.

Исследование стабильности нейтронно-избыточных ядер с использованием пучка ^{48}Ca (70*A* МэВ)

Х.Сакураи и др.

Приводятся результаты совместного РИКЕН–ОИЯИ эксперимента по исследованию стабильности нейтронно-избыточных ядер. Впервые обнаружена стабильность ядер ^{38}Mg и ^{40,41}Al. Получены также некоторые свидетельства о ядерной нестабильности ^{33}Ne. Эксперимент проводился на ускорительном комплексе РИКЕН с использованием пучка ионов ^{48}Ca (70*A* МэВ) на фрагмент-сепараторе RIPS. Продукты взаимодействия ионов ^{48}Ca с танталовой мишенью после сепарации идентифицировались на основе измерений магнитной жесткости, времени пролета, потерь и полной кинетической энергии.

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1. Introduction

The location of the neutron drip line and the particle stability of nuclei can be used for testing the various mass predictions, and may give clues concerning characteristic structures of exotic nuclei. At present, no experimental evidence on the neutron drip line for $Z \geq 10$ has been shown. In the region of $10 \leq Z \leq 13$, the most neutron-rich nuclei observed so far are ^{32}Ne [1], ^{35}Na [2], ^{37}Mg [3] and ^{39}Al [4].

This paper describes the results of an experiment to synthesize and observe extremely new neutron-rich nuclei in the region $10 \leq Z \leq 13$. Such productions and observations have been made possible by the combination of a high-energy, rare-isotope beam of ^{48}Ca and the Riken Projectile Fragment Separator (RIPS) [5] at RIKEN. The RIPS has a large momentum acceptance (6%) and solid angle (5 msr), as well as a maximum rigidity of 5.76 Tm. Those performances afford a high productivity of neutron-rich nuclei produced in the projectile fragmentation reaction. The first attempt at the RIPS was made by using an 80*A* MeV ^{50}Ti beam reacting a ^{181}Ta target, and two new neutron-rich nuclei ^{31}Ne and ^{37}Mg were produced and observed [3]. Compared with the ^{50}Ti beam, a ^{48}Ca beam is expected to provide 1–2 orders of magnitude higher production cross sections for the extremely neutron-rich nuclei. Thus, we performed the experiment by using a 70*A* MeV ^{48}Ca beam. Here we report on the first production and identification of three new neutron-rich nuclei ^{38}Mg and ^{40,41}Al as a result of this experiment.

2. Experimental Set-Up

The 65% enriched ^{48}Ca oxide powder was used to produce the ^{48}Ca ions at the ECR source of the AVF cyclotron. The ^{48}Ca beam accelerated at the AVF and ring cyclotron reacted with a ^{181}Ta target, 400 mg/cm^2 thick. The thickness was chosen according to a theoretical estimation in which the INTENSITY code of Ref.[6] was used to predict the secondary beam intensities. The production rates for $A/Z \sim 3.4$ nuclei for the given acceptance of the RIPS spectrometer were optimized.

The reaction fragments were collected and analysed with the RIPS spectrometer operated in the achromatic mode [5]. Figure 1 shows a schematic layout of RIPS. Taking into account the energy loss in the target for both the beam and fragments with $A/Z \sim 3.2$, the magnet rigidity of the RIPS spectrometer was set to be 3.438 Tm. The experimental method used to identify very neutron-rich nuclei is similar to that used at GANIL and MSU [1,3,7]. Particle identification was performed event-by-event by measuring the magnetic rigidity (B_ρ), time-of-flight (TOF), energy loss (ΔE) and total kinetic energy (TKE).

The positions of the fragments at the momentum dispersive focal plane (F1) were measured using a parallel plate avalanche chamber (PPAC) in order to determine the B_ρ value (see Figure 1). The sensitive area of the PPAC was 15 cm(W) × 10 cm(H), which covered a full rigidity acceptance of RIPS (6%). Position measurements by two independent x-projective cathodes of the PPAC helped to reject spurious position information caused by the δ-rays.

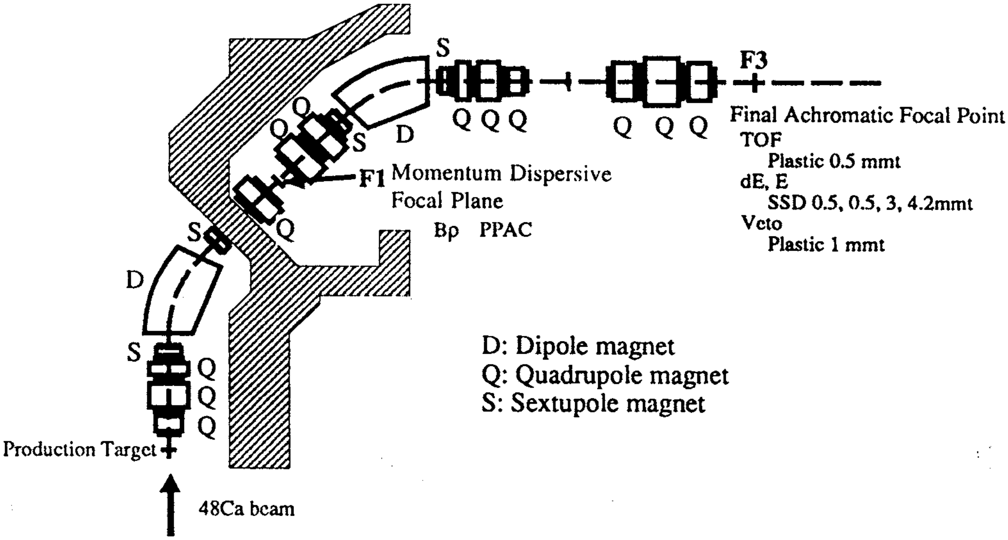

Fig.1. Experimental set-up for the production and identification of new neutron rich isotopes at the RIKEN-RIPS spectrometer

All of the other detectors were located at the final focal point (F3), involving a 0.5 mm thick plastic scintillation counter (PL), a four-element silicon-detector telescope and an 1 mm thick plastic scintillation veto counter. The TOF of a fragment over the 27.5 m flight path between the target and F3 was determined from the PL timing and RF signal of the cyclotron. The silicon telescope consisted of two 0.5 mm thick surface-barrier-type silicon detectors, and 3 mm and 4.2 mm thick lithium-drift silicon detectors. This configuration provided two or three independent ΔE measurements and all the silicon detectors combined provided a TKE measurement. The veto counter was used for rejecting events piled up due to light fragments.

The measured values of B_ρ, TOF, ΔE and TKE were combined to give redundant particle identifications for obtaining the proton number (Z), charge (Q) and mass number (A) of the fragment, as described in Ref.[3,7,8]. It is probable that those fragments which were not fully ionized were subject to being mis-identified as more neutron-rich nuclei. Hence, we employed selectively fully stripped fragments.

3. Results and Discussion

Figure 2 shows a two-dimensional plot, A/Z versus Z. The result was obtained from the data accumulated for one day with an average beam intensity of ~ 2 pnA. Significant numbers of events were observed for new isotopes, ^{38}Mg (18 events), ^{40}Al (34 events), and ^{41}Al (4 events).

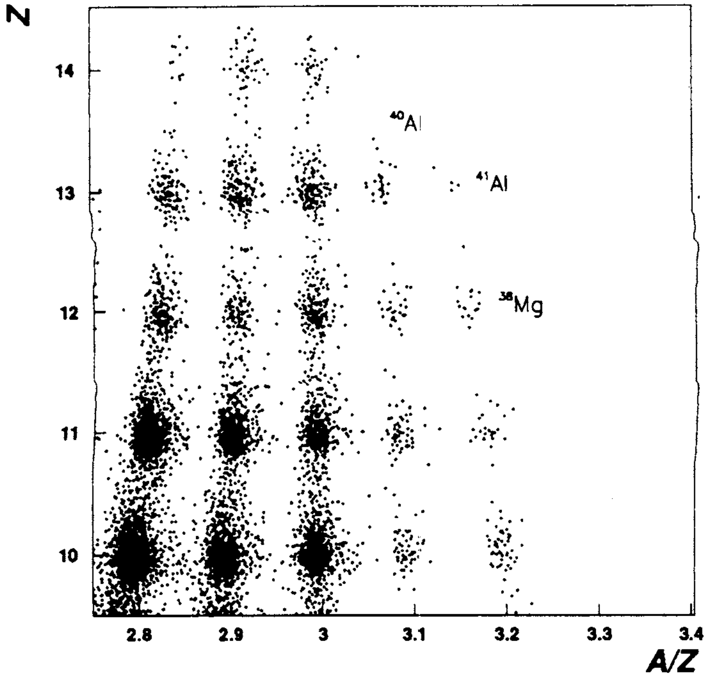

Fig.2. Two-dimensional A/Z versus Z plot, which was obtained in the reaction of the ^{48}Ca beam at 70A MeV on a 400 mg/cm^2 tantalum target during a 1-day run with a magnetic rigidity of 3.438 Tm of the RIPS spectrometer. The ^{38}Mg, ^{40}Al, and ^{41}Al isotopes are clearly visible

Table 1. One- and two-neutron separation energy in MeV of the new neutron-rich nuclei predicted by different mass formulae; MMST, Möller et al. [9]; CKZ, Comay-Kelson–Zidon [10]; TUYY, Tachibana et al. [11]; JM, Jänecke–Masson [12]; and MNMS, Möller et al. [13]

	MMST		CKZ		TUYY		JM		MNMS	
	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}
^{38}Mg	1.90	3.06	2.91	2.87	3.34	3.95	2.76	2.53	2.89	2.56
^{40}Al	1.12	3.44	1.30	4.48	1.50	5.11	1.43	4.50	– 0.02	3.17
^{41}Al	2.99	4.11	3.11	4.41	3.12	4.62	3.09	4.52	5.79	5.77

The particle stability found for ^{38}Mg and ^{40,41}Al implies that their one- and two-neutron separation energies (S_{1n} and S_{2n}) are positive. Tabulated in Table 1 are the predictions by different mass formulae; MMST, Möller et al. [9]; CKZ, Comay–Kelson–Zidon [10]; TUYY, Tachibana et al. [11]; JM, Jänecke–Masson [12]; and MNMS, Möller et al. [13]. All the above formulae except MNMS predict well the stability of three nuclei we found. Concerning only the particle stability, no exotic aspects are shown for the newly found nuclei.

We observed about 2800 events of ^{30}Ne, 90 events of ^{31}Ne, and 70 events of ^{32}Ne, but no events associated with ^{33}Ne. We took also the data with different B_{ρ} settings, e.g., for $A/Z \sim 3.3, 3.4$, and with a higher beam intensity up to 4 pnA, where no ^{33}Ne events were observed, either. Further evaluations of these data sets may afford to deduce an expected yield of ^{33}Ne, and to conclude that ^{33}Ne is particle-unbound.

It should be noted that a ^{64}Ni target was also used, concerning target dependences of production cross sections for very neutron-rich nuclei [1,3,14]. The ^{64}Ni target thickness was energy-loss equivalent to the ^{181}Ta target. It was found that the ^{181}Ta target is more preferable than ^{64}Ni one to produce nuclei close to the neutron drip line in the range Ne–Mg. In addition, γ-rays from the known isomeric states of ^{26}Na and ^{32}Al were measured by means of two Ge detectors located near the silicon detectors, in order to deduce the isomer ratios. These information may give us clues for the production mechanism of very neutron-rich nuclei.

Here we compare the production yields of very neutron-rich fragments between the ^{50}Ti and ^{48}Ca beams. The ^{50}Ti beam with intensity of ~ 2 pnA provided, for example, 4 events of ^{32}Ne and 3 events of ^{37}Mg during four days [3], while in the case of the ^{48}Ca beam with the similar intensity, we obtained during only one day about 70 and 30 events for ^{32}Ne and ^{37}Mg, respectively. Thus, the production cross sections of such very neutron-rich nuclei with the ^{48}Ca beam are 1–2 orders of magnitude higher than with the ^{50}Ti beam. This high productivity of ^{48}Ca would allow us to perform measurements of beta-decay properties unknown for very neutron-rich nuclei. In near future, an oven-system [15] will be installed at the ECR source and proved to produce a more intense and stable ^{48}Ca beam. With such a development, we could extend the attempt to determine the neutron drip-line for $Z \geq 10$ nuclei.

4. Summary

We produced and observed the new neutron-rich nuclei ^{38}Mg and ^{40,41}Al from the reaction 70*A* MeV ^{48}Ca + ^{181}Ta at the RIKEN–RIPS, by means of measuring the magnetic rigidity, time-of-flight, energy loss and total kinetic energy. We obtained also a clue for particle instability of ^{33}Ne.

Acknowledgements

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