Different mechanism of two-proton emission from excited states of proton-rich nuclei ^{23}Al and ^{22}Mg†

Y. G. Ma,*1 D. Q. Fang,*1 X. Sun,*1 P. Zhou,*1 Y. Togano,*2 N. Aoi,*2 H. Baba,*2 X. Z. Cai,*1 X. G. Cao,*1 J. G. Chen,*1 Y. Fu,*1 W. Guo,*1 Y. Hara,*3 T. Honda,*3 Z. Hu,*4 K. Ieki,*3 Y. Ishibashi,*5 Y. Ito,*5 N. Iwasa,*6 S. Kanno,*2 T. Kawabata,*7 H. Kimura,*8 Y. Kondo,*2 K. Kurita,*3 M. Kurokawa,*2 T. Moriguchi,*5 H. Murakami,*2 H. Ooishi,*5 K. Okada,*3 S. Ota,*7 A. Ozawa,*5 H. Sakurai,*2 S. Shimoura,*7 R. Shioda,*3 E. Takeshita,*2 S. Takeuchi,*2 W. Tian,*1 H. Wang,*1 J. Wang,*4 M. Wang,*4 K. Yamada,*2 Y. Yamada,*3 Y. Yasuda,*5 K. Yoneda,*2 G. Q. Zhang,*1 and T. Motobayashi*2

For proton-rich nuclei, the proton decay mechanism is complicated, especially for two-proton (2p) radioactivity[1]. The proton-rich nucleus ^{23}Al has attracted a lot of attention in recent years since it may play a crucial role in understanding the depletion of the NeNa cycle in ONe novae[2]. The measurement of its reaction cross section and fragment momentum distribution has shown that the valence proton in ^{23}Al is dominated by the d wave but with an enlarged core[3]. The spin and parity of the ^{23}Al ground state was found to be $J^{\pi}= 5/2^{+}$[4]. Also of great interest is ^{22}Mg because of its importance in determining the astrophysical reaction rates for ^{21}Na(p,γ)^{22}Mg and ^{18}Ne(α,p)^{21}Na reactions in the explosive stellar scenarios.

An experiment was performed to study the two-proton decay channels of ^{23}Al and ^{22}Mg using the RIPS beamline at the RI Beam Factory (RIBF) operated by RIKEN Nishina Center and Center for Nuclear Study, University of Tokyo.

In this study, we examined the relative momentum spectrum (q_{pp}) and opening angle (θ_{pp}) of the two protons in the three-body decay system for ^{23}Al and ^{22}Mg. Without any cut in the excitation energy, a broad q_{pp} spectrum and structure-less θ_{pp} distribution are observed. These results indicate that the main mechanism of two proton emission from ^{23}Al and ^{22}Mg are sequential or three-body emission with very weak correlation between the two protons. However, since the decay mode for different excited states or excitation energies is different, it is interesting to check q_{pp} and θ_{pp} spectrum at different excitation energies. For the diproton or ^{2}He emission, a clear peak should appear at small relative momentum as well as opening angle. Fig. 1 show the experimental results of the above two distributions for ^{23}Al in the excitation energy window $10.5 < E^{*} < 15$ MeV. Evident peaks at $q_{pp} \sim 20$ MeV/c (a) and small opening angle (b) are absent. Instead, the q_{pp} spectrum is broad and the θ_{pp} distribution is structure-less. Similar analysis has been done in different E* windows other than $10.5 < E^{*} < 15$ MeV and similar behaviors for q_{pp} and θ_{pp} are observed.

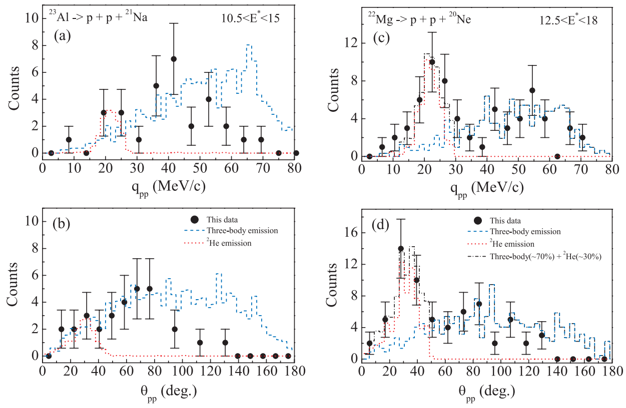

Fig. 1. Relative momentum (a) and opening angle (b) distributions between two protons by the decay of ^{23}Al into two protons plus ^{21}Na for $10.5 < E^{*} < 15$ MeV; (c) and (d) are the results by the decay of ^{22}Mg into two protons plus ^{20}Ne for $12.5 < E^{*} < 18$ MeV.

For ^{22}Mg, Fig. 1 shows the q_{pp} (c) and θ_{pp} (d) data in the excitation energy window $12.5 < E^{*} < 18$ MeV. The peaks of the q_{pp} distribution at 20 MeV/c and of the corresponding small θ_{pp} are clearly observed. These features are consistent with the diproton emission mechanism. However, no significant enhancements for $q_{pp} \sim 20$ MeV/c and small θ_{pp} are observed for other E^{*} windows.

In order to quantitatively understand the q_{pp} and θ_{pp} spectra, a Monte Carlo simulation has been performed. A mixture of diproton and simultaneous three-body decay or sequential decay was used to fit the q_{pp} and θ_{pp} data. As shown in the figure, the sequential decay is overwhelmingly dominant for ^{23}Al. For ^{22}Mg, on the other hand, the diproton or ^{2}He emission peaks are well reproduced by the simulation. The fraction of the diproton emission is determined to be around 30%.

† Condensed from the article in Phys. Lett. B **743**, 306 (2015)

*1 Shanghai Institute of Applied Physics, CAS
*2 RIKEN Nishina Center
*3 Department of Physics, Rikkyo University
*4 Institute of Modern Physics, CAS
*5 Institute of Physics, University of Tsukuba
*6 Department of Physics, Tohoku University
*7 Center for Nuclear Study (CNS), University of Tokyo
*8 Department of Physics, University of Tokyo

References

1) V. I. Goldansky, *Nucl. Phys.* **19** (1960) 482.
2) V. E. Iacob et al., *Phys. Rev. C* **74** (2006) 045810.
3) D. Q. Fang et al., *Phys. Rev. C* **76** (2007) 031601(R).
4) A. Ozawa et al., *Phys. Rev. C* **74** (2006) 021301(R).