HINDERED PROTON COLLECTIVITY IN THE PROTON-RICH NUCLEUS ^{28}S: POSSIBLE MAGIC NUMBER AT $Z = 16$*

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The reduced transition probability $B(E2; 0^+_{gs} \rightarrow 2^+_1)$ for the proton-rich nucleus ^{28}S was determined experimentally using Coulomb excitation at 53 MeV/nucleon. The resultant $B(E2)$ value is smaller than those of neighboring $N = 12$ isotones and $Z = 16$ isotopes. The ratio of neutron/proton transition matrix amplitudes for the $0^+_{\rm gs} \rightarrow 2^+_1$ transition were obtained to be $1.9(2) \times N/Z$ from the present result and known $B(E2)$ value in the mirror nucleus ^{28}Mg. These results indicate the emergence of the magic number $Z = 16$ in ^{28}S.

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1. Introduction

Nuclear magic numbers characterize the shell structure of nuclei. Recent studies report changes in magic numbers for nuclei in the very neutron-rich region [1–3]. These phenomena are associated with nuclear collectivity, for instance, the enhanced collectivity in ^{32}Mg is caused by the disappearance of magicity at $N = 20$ [4].

The new neutron magic number $N = 16$ has been verified experimentally at around the neutron drip-line nucleus ^{24}O [3]. In analogy to the magic number $N = 16$, the proton magic number $Z = 16$ must also exist in

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proton-rich nuclei. However, prior to this work it has not been identified experimentally in the proton-rich sulfur isotopes.

The relative contribution of the proton- and neutron-collectivities can be evaluated using the ratio of the neutron transition matrix element to the proton one (the M_n/M_p ratio) [5, 6]. M_p is related to $B(E2)$ by $e^2M_p^2 = B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$. M_n can be deduced from the M_p value in the mirror nucleus by assuming isospin symmetry. Deviation from $|M_n/M_p|/(N/Z) = 1$ corresponds to hindrance of proton/neutron collectivity. Such a difference appears typically for singly-magic nuclei [5]. For proton singly-magic nuclei, the proton collectivity is hindered by the magicity, leading to $|M_n/M_p|/(N/Z) > 1$.

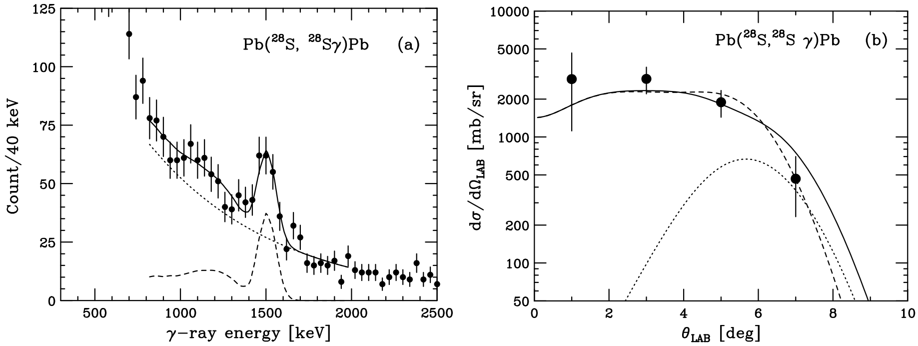
The present article reports on a study of the magic number $Z = 16$ at ^{28}S through a measurement of the reduced transition probability $B\left(E2; 0^+_{\mathrm{gs}} \to 2^+_1\right)$ by using Coulomb excitation at 53 MeV/nucleon.

2. Experiment

The experiment was performed using RIBF at RIKEN Nishina Center. A ^{28}S beam was produced via projectile fragmentation of a 115-MeV/nucleon ^{36}Ar beam incident on a Be target. The secondary beam was obtained by the RIKEN Projectile-fragment separator (RIPS) and a RF deflector system. Particle identification for the secondary beam was performed event-by-event by measuring time of flight, energy loss, and the magnetic rigidity of each nucleus. The secondary target was a 348 mg/cm^2-thick lead sheet which was set at the third focal plane. The average beam energy at the center of the lead target was 53 MeV/nucleon. Further details of the experimental setup can be found in Ref. [7].

3. Results and discussions

The Doppler-shift corrected γ-ray energy-spectrum measured in coincidence with inelastically scattered ^{28}S is shown in Fig. 1 (a). A peak is clearly seen at 1.5 MeV. The spectrum was fitted by a detector response obtained using a Monte-Carlo simulation (dashed curve) and an exponential background (dotted curve). The peak energy was deduced to be 1.497(11) MeV, which is consistent with the 2^+ state energy from a previous measurement [8]. The angular distribution of the scattered ^{28}S excited to its 1.5 MeV state is shown in Fig. 1 (b). The distribution was fitted by that for an angular momentum transfer of $\Delta L = 2$, calculated by the DWBA code ECIS97 [9], taking into account the detector resolutions. The optical potential parameters were taken from Ref. [10]. The dashed and dotted curves in Fig. 1 (b) show the Coulomb and nuclear contributions, respectively. The $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value was determined to be 181(31) e^2fm^4 from this analysis.



(a) (b)

Fig. 1. (a) Doppler-shift corrected γ-ray energy-spectrum in the Pb(^{28}S,^{28}S γ)Pb reaction. (b) Angular distribution for the scattered ^{28}S particles which were coincident with the 1.5 MeV γ-line.

The $B(E2)$ and $E_x(2_1^+)$ values for $N = 12$ isotones and $Z = 16$ isotopes are plotted in Fig. 2 (a) and (b), respectively. The filled circles show the present results. The open triangles for $B(E2)$ and $E_x(2_1^+)$ represent known values [11]. The $B(E2)$ value of ^{28}S is smaller than those of neighboring isotones and isotopes. An explanation of these smaller $B(E2)$ and $E_x(2_1^+)$ at ^{28}S is given by the hindered proton collectivity. A similar mechanism is proposed for ^{16}C [12], where small $B(E2)$ and $E_x(2_1^+)$ values in comparison with neighboring isotopes are observed. Figure 2 (c) shows the double ratios $|M_n/M_p|/(N/Z)$. The filled circle and open triangles show the present result and the known values, respectively. Data shown by the triangles are obtained using the $B(E2)$ values of the mirror pairs. The squares represent the double ratios which were extracted using the result from (p,p') experiments [13]. The ratio of 1.9(2) for ^{28}S, taking the present result and adopted $B(E2)$ of 350(50) e^2fm^4 for the mirror nucleus ^{28}Mg [11], shows the hindered proton collectivity in ^{28}S. This hindrance can be understood if ^{28}S is the proton singly-magic nucleus by the $Z = 16$ magicity. The double ratios of $N = 12$ isotones and $^{30-36}$S are close to unity, as seen in the figure, indicating that the hindrance of the proton collectivity does not appear in these nuclei. The large double ratios for ^{38,40}S can be explained by the neutron skin effect caused by the $Z = 16$ sub-shell closure [13, 14].

The dotted lines in Fig. 2 (a)–(c) show shell model predictions with the USDB effective interaction using the empirically optimized effective charges [15, 16]. The calculation shows relatively good agreement with the experimental results. It indicates that the shell model with the USDB interaction accounts for the phenomena observed in the present study.

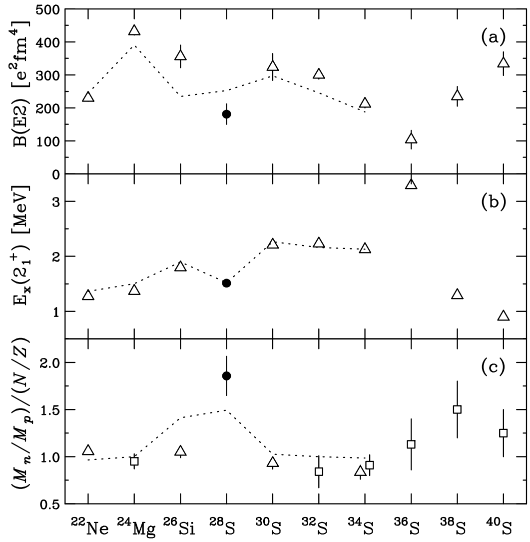


Fig. 2. Plot of the $B(E2; 0^+_{\rm gs} \to 2^+_1)$ values (a), the excitation energies of 2^+_1 states (b), and the double ratio $|M_n/M_p|/(N/Z)$ (c) for $N = 12$ isotones and sulfur ($Z = 16$) isotopes. The present result is represented by the filled circles.

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