In-beam γ-ray spectroscopy of ^{34,36,38}Mg: Merging the $N = 20$ and $N = 28$ shell quenching†

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The neutron-rich $_{10}$Ne, $_{11}$Na, and $_{12}$Mg isotopes are located within a region known as the "Island of Inversion" and form one of the most notable regions of sudden shell structure change. Abnormally high masses were discovered for ^{31,32}Na, leading to the presumption that the $\nu f_{7/2}$ orbitals intrude into the sd shell orbitals, thereby quenching the $N = 20$ shell gap. Later theoretical works predicted, however, that not the entire orbitals are inverted but $\nu(sd)^{-2}(fp)^2$ $(2\hbar\omega)$ configurations are lowered so much in energy that they form the ground states for $10 \leq Z \leq 12$, $20 \leq N \leq 22$ nuclei instead.

The $N = 28$ magic number is originally formed by the large $\nu f_{5/2}$–$\nu f_{7/2}$ spin-orbit splitting but is also known to vanish, as seen in the large deformation arising for $^{42}_{14}$Si[1,2]. Initially believed to be two isolated regions, we show in this letter that the $N = 20, 28$ shell quenching is interlinked via the neutron-rich magnesium isotopes, thereby forming a new connected large area of deformation in the Segré chart.

Key information on the shape of a nucleus can be obtained for even-even nuclei from the energy of the first excited 2^+ state $E(2_1^+)$, the first 4^+ state $E(4_1^+)$, and their $E(4_1^+)/E(2_1^+)$ ratio, $R_{4/2}$. Previous studies revealed a low excitation energy of 660(6) keV for the 2_1^+ state in ^{36}Mg and suggest that the "Island of Inversion" stretches at least to neutron number $N = 24$ for the magnesium isotopes and thus beyond its originally proposed boundaries[3]. In the present study, the experimental knowledge of the $E(2_1^+)$ and $E(4_1^+)$ is extended to the $N = 26$ nucleus ^{38}Mg via one- and two-proton removal reactions..

A primary beam of ^{48}Ca with an average intensity of 70 particle nA and an energy of 345 MeV/nucleon was impinging on a 15 mm thick rotating Be target located at the BigRIPS fragment separator's entrance. Secondary beams were selected and purified via the $B\rho - \Delta E - B\rho$ method, and identified with the $\Delta E - B\rho - $ TOF method. The rate for ^{39}Al and ^{40}Si isotopes transported through BigRIPS was 75 and 3000 pps, respectively. The secondary beams were incident on a 2.54 g/cm^2 thick carbon secondary target, which was surrounded by the DALI2 spectrometer[4]. Reaction residues from the secondary target were identified by the ZeroDegree Spectrometer, applying again the $\Delta E - B\rho - $ TOF method.

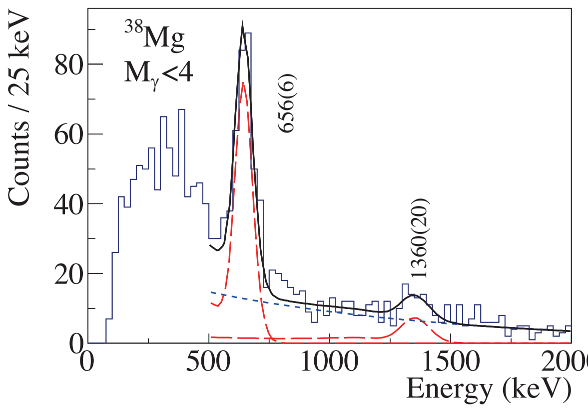

Fig. 1. Doppler corrected γ-ray energy spectrum in coincidence with ^{38}Mg detected in BigRIPS and ZeroDegree.

Two γ-ray transitions were observed in ^{38}Mg from the $1p$ and $2p$ knockout channels after correcting for the Doppler shift, as shown in Fig. 1, which were attributed to the $2_1^+ \to 0_{gs}^+$ and the $4_1^+ \to 2_1^+$ decays. In ^{36}Mg, following a different reaction channel, a second transition was observed and attributed to the $4_1^+ \to 2_1^+$ decays, while for ^{34}Mg known values were determined with higher accuracy[5]. Almost constant $R_{4/2}$ ratios of 3.14(5), 3.07(5), and 3.07(5) were obtained for ^{34,36,38}Mg at $N = 22, 24, 26$, close to the ideal value of 3.33 for a rigid rotor. The values were in agreement with state-of-the art shell model calculations and suggested that the $N = 20$ and $N = 28$ shell quenching merge for the neutron-rich magnesium isotopes.

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