# First spectroscopy of the near drip-line nucleus $^{40}$Mg[†]

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Magnesium isotopes offer an opportunity to experimentally study the transition from well-bound to weakly-bound nuclei and its influence on the excited states, which may reflect the correlations at the limits of stability. While knowledge on the heaviest Mg isotopes is limited, an overall consistent picture of the structure along $Z = 12$ has emerged between $N = 20$ and $N = 28$, of persistent prolate deformation from $^{32}$Mg to $^{38}$Mg,[1)] which likely extends to $^{40}$Mg.[2)]

$^{40}$Mg represents a particularly intriguing case for study. Theoretical expectations and experimental systematics suggest $^{40}$Mg to be a well-deformed prolate rotor as well, structurally very similar to $^{36,38}$Mg. However, the occupation of the relatively weakly-bound $2p_{3/2}$ neutron orbital near the Fermi surface may add a new degree of freedom. In this report, the first $\gamma$-ray spectroscopic information of $^{40}$Mg is presented and discussed in the context of the systematics along the magnesium isotopes.

Experimentally, a drastically different prompt $\gamma$-ray spectrum is observed for $^{40}$Mg (see Fig. 1 (c)) as compared to $^{36,38}$Mg (see Fig. 1 (a), (b)), contrary to expectations. The tentatively assigned $2^+_1 \to 0^+_1$ transition at 500(14) keV is 20% below that in $^{38}$Mg, a trend that is outside the shell-model and other state-of-the-art theoretical predictions. The second $\gamma$-ray transition is even more puzzling. Given that $^{40}$Mg is very near the neutron dripline, and the low-$\ell$ $\nu 2p_{3/2}$ orbital sits at the Fermi surface, the observed spectrum may be an indication of the manifestation of weak-binding effects, as discussed fully in the published Letter.

The experiment was carried out at the Radioactive Isotope Beam Factory (RIBF) at RIKEN Nishina Center. An intense (450 pnA) primary beam of $^{48}$Ca was fragmented on a rotating production target, producing a secondary cocktail beam centered on $^{41}$Al. This beam was transported through BigRIPS[3)] and was incident upon a thick polyethylene secondary target at the focal plane in front of ZeroDegree, which was tuned to center $^{40}$Mg reaction residues. Prompt $\gamma$ rays depopulating the excited states in $^{40}$Mg and other reaction residues were detected in the DALI2 spectrometer,[5)] which consistisof 186 large-volume NaI(Tl) detectors surrounding the secondary target.

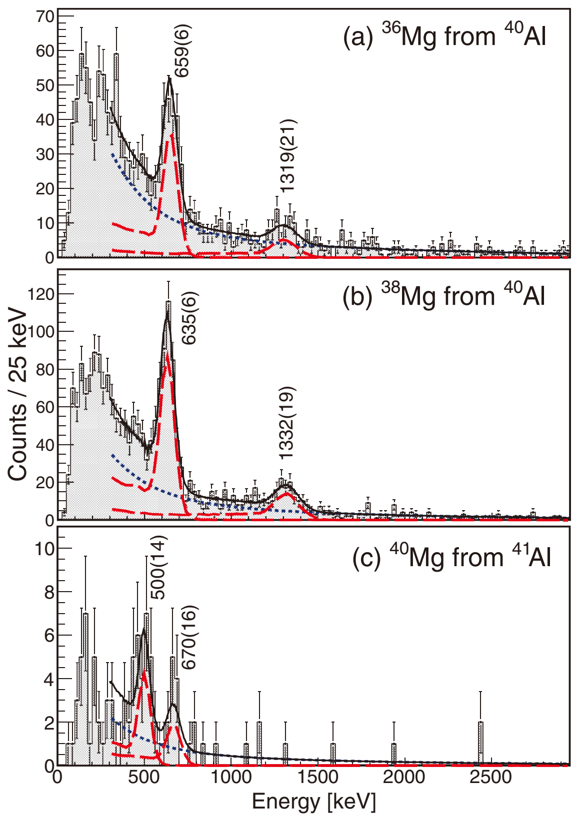


Fig. 1. (color online) Prompt $\gamma$-ray spectrum associated with (a) $^{36}$Mg, (b) $^{38}$Mg and (c) $^{40}$Mg (populated in $-1$p removal from $^{41}$Al). Spectra were fit using the simulated DALI2 response (red dashed curves) and a smooth background (dotted blue line); the solid black line represents the total fit.

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