Narrowing of the neutron $sd$-$pf$ shell gap in $^{29}$Na$^*$

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The wave-function composition for the low-lying states in $^{29}$Na was explored by measuring their electromagnetic properties using the Coulomb-excitation technique. A beam of $^{29}$Na$^{5+}$ ions, postaccelerated to 70 MeV using ISAC-II at TRIUMF, bombarded a $^{110}$Pd target with a rate of up to 600 particles per second. Six segmented clover detectors of the TIGRESS γ-ray spectrometer were used to detect deexcitation γ rays in coincidence with scattered or recoiling charged particles in the segmented silicon detector, BAMBINO. A reduced transition matrix element $|\langle \frac{5}{2}^+ || E2 || \frac{3}{2}^+ \rangle| = 0.237(21)$ e$b$ was derived for $^{29}$Na from the measured γ-ray yields for both projectile and target, shown in Fig. 1. This first-time measured value is consistent with the most recent Monte Carlo shell-model calculation (MCSM) of Utsuno et al., predicted to be 0.232 e$b$ [1]. This is suggestive of a strongly-mixed first-excited state comprising a $30 \sim 40$% admixture of 2p-2h configurations in the wave function, and also provides evidence for the narrowing of the $sd$-$pf$ shell gap from $\sim 6$ MeV for stable nuclei to $\sim 3$ MeV for $^{29}$Na.

This result can also be interpreted at the phenomenological level. Within the framework of the rotational model and assuming a prolate deformation, the transition quadrupole moment, $Q_1 = 0.524(46)$ e$b$, is deduced from the measured transition matrix element for $^{29}$Na. This value also bears good agreement with the above MCSM calculation, $Q_1 = 0.513$ e$b$ [1]; a calculation utilising an effective interaction based on a shell-model space incorporating the full $sd$ space and the two lower orbits of the $pf$ space, with the inclusion of the cross-shell mixing terms in the effective Hamiltonian. Contrasting behaviour in the static and dynamic-nuclear properties of $^{29}$Na, arising from differences in the underlying single-particle configurations of the ground and excited states, may explain the difference between the present measurement and that of an earlier experimental result using β-NMR spectroscopy, $Q_0 = 0.430(15)$ e$b$ [2]. This intrinsic quadrupole moment, derived from the ground-state spectroscopic quadrupole moment, 0.086(3) e$b$, also compares well with the MCSM calculation, $Q_0 = 0.455$ e$b$.

FIG. 1: γ-ray spectrum for $^{110}$Pd($^{29}$Na,$^{29}$Na$^*$) at $E_{lab}(^{29}$Na) = 70 MeV with a beam intensity of up to $\sim 600$ pps; the particle angular coverage was between $20.1^\circ$ – $49.4^\circ$.


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