Contribution ID: **112** Type: **Contributed Oral/Poster**

# Spins and decays in neutron-rich sodium isotopes via (d,p$_{\gamma}$)

*Monday, 11 July 2016 11:10 (15 minutes)*

Using neutron transfer reactions, the evolution in energy of single-particle levels can be studied whether they are occupied or not, in the ground state of the final nucleus. Therefore, the levels of interest in the development of the island of inversion at N=20 and the emergence of the magic numbers N=16, 32 and 34 can be studied via excited states in less neutron-rich isotopes. The excited states of interest need to be not too high in energy and, ideally, bound to gamma-ray decay. We have completed a detailed study of $^{26}$Na using an intense beam of $3 \times 10^7$ pps $^{25}$Na at 5 MeV/nucleon obtained from ISAC2 at TRIUMF. The experiment used the SHARC array of DSSDs with the TIGRESS gamma-ray array. States in $^{26}$Na that were closely spaced in excitation energy were separated experimentally using the Doppler-corrected gamma-ray energy. Differential cross sections were extracted with gating on the gamma-ray energy. A detailed study was performed of the possible biasing effects of the gamma-ray gating and methods for dealing with this were devised. As an essential part of the analysis, gamma-ray branching ratios for all of the observed states were measured. In a further study using a beam of $^{24}$Na ions at 8 MeV/nucleon our knowledge of the structure of $^{25}$Na has been greatly extended, thanks to the highly selective population of states in neutron transfer.

The angular momentum transfer and gamma-ray branching ratios have been measured for many bound states in $^{26}$Na, extending our earlier analysis that concentrated on just the states gamma-deacying directly to the ground state. It has been possible to identify the experimental counterparts to almost all of the bound states predicted by shell model calculations, including negative parity states, and to extract spectroscopic factors in most cases. For $^{25}$Na the analysis is more preliminary, but the population of final states shows good agreement with shell model expectations. Overall, there is excellent agreement with (0+1)$\hbar\omega$ shell model predictions obtained using the WBC interaction which includes the USD-A interaction in the $sd$-shell. In each of these Na isotopes, almost nothing was known about the excited states apart from some excitation energies, prior to the present work. This work demonstrates explicitly the enormous potential of (d,p) studies with HPGe arrays, provided that radioactive beam facilities are able to provide beams of $10^5$ to $10^7$ pps at the appropriate energies.

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**Track Classification:** Shell evolution through direct reactions - Spectroscopy of nuclear levels and nuclear shapes through direct reactions