Reaction Studies and Continuum Spectroscopy with Exotic Neutron-Rich Nuclei ^{B,G}

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Break-up reactions of neutron-rich ^{6,8}He isotopes have been studied at energies of 240 and 226 MeV/u respectively. The one neutron knockout channel provides essential information about the nuclear structure of the projectile and intermediate unbound resonance states, populated in the reactions.

For the ^{6}He reactions, the ^{5}He invariant mass, $\alpha - n$ angular correlation spectra, the ^{5}He-fragment momentum distributions and one-neutron knockout cross sections have been compared for hydrogen, carbon and lead targets detecting one neutron in coincidence with the α in the exit channel. While the ^{5}He invariant mass spectra do not reveal target dependence, the ^{5}He momentum distribution becomes wider for lighter targets. The neutron knockout model in the sudden approximation reproduces satisfactorily the experimental observables. The difference in momentum distributions is explained by a smooth dependence of the cut-off parameter R_{cut} on the target size. It is introduced to assure fragment survival in the reaction and thus reflects the effective size of the ^{5}He subsystem inside ^{6}He. The R_{cut} parameter is therefore as well directly connected with the neutron knock-out cross section:

$$\sigma_{-1n} = \sigma_T < n > P(R_{cut}) \qquad (1)$$

where the cross section σ_T for free neutron-target interaction was taken from published experimental data, R_{cut} is obtained from the fit to the measured momentum distribution of the ^{5}He fragments, $P(R_{cut})$ is the probability to find a $p_{3/2}$ neutron in the projectile outside a cylindrical cut through the ^{6}He nuclear matter density distribution, and $< n >$ is the mean number of neutrons in the $p_{3/2}$ shell. $P(R_{cut})$ was obtained by integration of the squared single-neutron wave function $|\psi(r)|^2$. The $\psi(r)$ functions were calculated by solving Schrödinger equations with Gaussian-shaped potentials. The radial parameter of the potential was fixed by the known r.m.s. radii of ^{6}He ($< r^2 >^{1/2} = 2.48 \pm 0.03$) while the potential depths were chosen to reproduce the known one-neutron binding energy (1.87 MeV for $^{6}\text{He} \rightarrow {}^{5}\text{He+n}$). The good agreement between calculated and measured values shown in Table 1 gives evidence that the neutron knockout mechanism remains important even for heavy targets.

Table 1: Calculated and experimental one-neutron knockout cross sections, including the parameters used in the calculations.

^{6}He 240 MeV/u				
Target	R_{cut}	$P_n(R_{cut})$	σ_{-1n}^{calc} (mb)	σ_{-1n}^{exp} (mb)
^{1}H	2.6	0.298	22.6	30 ± 13
^{12}C	3.1	0.202	111	127 ± 14
^{208}Pb	3.95	0.105	358	320 ± 90

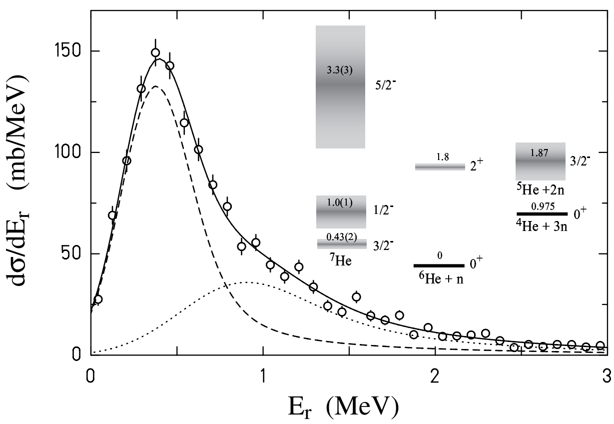

Figure 1: Coincidence cross section of the ^{6}He-n system after breakup of 227 MeV/u ^{8}He on a carbon target as function of the relative energy E_r. The lines show the decomposition of a fit to the data (solid) into the groundstate (dashed) and the proposed first excited state (dotted), using a R-Matrix expression folded with the experimental acceptance and response. The inset shows the proposed level scheme with the new $1/2^-$ state in ^{7}He.

While the measured invariant mass spectrum for the unbound ^{5}He shows dominantly a contribution from the known ground state, for ^{7}He a similarly simple description fails [1]. The invariant mass spectrum of ^{7}He displayed in Figure 1 shows a structure near the threshold, which can only be interpreted in a consistent way, if an overlap of the known ^{7}He $J^\pi = 3/2^-$ ground state resonance with an excited state at 1.0(1) MeV and of a width $\Gamma = 0.75(8)$ MeV is assumed. We assign this new resonance to the $J^\pi = 1/2^-$ spin orbit partner. A profound statistical analysis has been applied to prove that (i) the observed structure cannot be described as a single resonance and (ii) the known ground state properties are consistently reproduced in a free parameter fit. The spin assignment is supported by an independent measurement of an angular correlation function for which the anisotropy was found to be reduced by a factor of two compared with the ^{5}He case where only a small admixture of the first $1/2^-$ excited state was observed. Theoretical models result in a wide spread for the spin-orbit splitting for ^{7}He to be between about 0.9 and 3.0 MeV. The current observation is good agreement with the lowest value obtained in recent many-body quantum Monte-Carlo calculations [2].

References

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