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Experimental evidence of a $\nu(1d_{5/2})^2$ component to the ^{12}Be ground state

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Abstract. Data have been obtained on exclusive single neutron knockout cross sections from ^{12}Be to study its ground state structure. Preliminary cross sections for the first (0.32 MeV, $1/2^-$) and second (1.78 MeV, $5/2^+$, *unbound*) excited states in ^{11}Be have been obtained, giving evidence of significant admixtures of both $\nu(1p_{1/2})^2$ and $\nu(1d_{5/2})^2$ configurations in the ground state of ^{12}Be.

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1 Introduction

In stable nuclei, the $N = 8$ magic number corresponds to the shell gap between the $\nu(1p_{1/2})$ and $\nu(1d_{5/2})$ orbitals; for example, the stable nuclei ^{16}O and ^{14}C exhibit closed shell behaviour, corresponding to a predominantly $\nu(1p_{1/2})^2$ configuration. However, the ground state of ^{11}Be is a $J^\pi = 1/2^+$ intruder state (with a predominantly $^{10}\text{Be} \otimes \nu(2s_{1/2})$ structure); the $1/2^-$ state lies 320 keV above, corresponding to a predominantly $\nu(1p_{1/2})$ valence neutron. Consequently, the structure of ^{12}Be is not unambiguously inferred from the systematics of neighbouring nuclei. An experiment at MSU [1] to measure the 1 n knockout cross sections from ^{12}Be gave approximately equal spectroscopic factors for the $1/2^-$ and $1/2^+$ states in ^{11}Be, indicating breaking of the $N = 8$ magic number in ^{12}Be. A significant yield to the *unbound* $5/2^+$ state at 1.78 MeV was suggested, indicating a $\nu(1d_{5/2})^2$ component to the ^{12}Be ground state. This was unobservable experimentally, as it results in breakup to ^{10}Be + n. The present experiment was focussed on measuring the cross section to this $5/2^+$ state in ^{11}Be, along with the bound $1/2^-$ state to give an overlap with the MSU measurement. The yield to the ground state of ^{11}Be was not measurable without the reduction in background from a coincidence requirement.

2 Experimental configuration

A fragmentation beam of ^{12}Be, (~ 5000 pps) produced using the LISE3 spectrometer [2] at the GANIL laboratory, was incident on a 180 μg/cm^2 carbon target at a mid-target energy of 39.3 MeV/A. Beam particle energies were determined from time-of-flight, which also allowed unique identification of ^{12}Be ions from the 5% contaminants in

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the beam. Two drift chambers were employed to track beam particles onto the target. Beam-like residues were detected in a 3-stage telescope mounted at 0°, covering ±9° in both x and y directions, consisting of two 500 μm thick resistive-strip silicon detectors, mounted to allow resistive measurement in both x and y, and a close-packed array of 16 CsI detectors, in a 4×4 arrangement. Neutrons were measured in the DéMoN array [3] of 91 liquid scintillation detectors, between 2.4 m and 6.3 m downstream of the target, spanning angles to 32°, with an efficiency of $\sim$ 10%. Neutron energies were derived from time-of-flight, and neutrons were distinguished from γ rays via pulse shape discrimination. The target was surrounded by four NaI detectors, to detect the 320 keV γ rays from the $1/2^-$ state in ^{11}Be with an efficiency of 3.5%.

A result of using a 0° charged particle telescope is that the entire beam flux is incident on these detectors. Consequently, the number of beam particles that undergo nuclear reactions in the telescope is significant relative to the target-induced reactions. An effect of these reactions was to produce a CsI signal which overlaps with the ^{10,11}Be particles of interest. Additionally, these reactions were a source of neutrons with velocities close to that of the beam. Coupling these effects can give a neutron of approximately the expected energy, in coincidence with a false identification of a charged particle of interest. This background was measured separately by acquiring data with no target present, with the beam energy lowered to account for the average energy loss in the target, and was scaled and subtracted from the target-in data.

3 Analysis and results

A cross section of 33.5(5.6)mb was extracted for the production of the $1/2^-$ state in ^{11}Be, from the Doppler-corrected γ ray spectrum measured in coincidence with a detected ^{11}Be. Corrections were made for detector efficiencies, attenuation in the target, and the geometric effects of relativistic focussing of γ rays.

For reactions leading to neutron unbound states in ^{11}Be*, the decay energy to ^{10}Be + n, along with a spread of momenta introduced via the neutron removal process, determines angular spread of the neutrons in the laboratory frame and hence their detection efficiency. To interpret the experimental data, detailed simulations were performed using a Monte Carlo simulation code [4]. The simulations included the effects of the geometrical acceptance of the DéMoN array, energy and angular straggling of charged particles, beam divergence and energy spread, and detector acceptances, resolutions and efficiencies, along with the absorption of neutrons by the telescope. The momentum distribution induced by the neutron removal process was determined from the angular distribution of neutrons from a very low energy decay, where the neutron momentum distribution is dominated by the momentum distribution of the ^{11}Be* before decay. The measurement of a neutron diffracted from ^{12}Be, in coincidence with ^{10}Be from the subsequent decay of the remaining ^{11}Be* was included, using a momentum distribution determined from diffracted neutrons only (those in coincidence with a bound ^{11}Be).

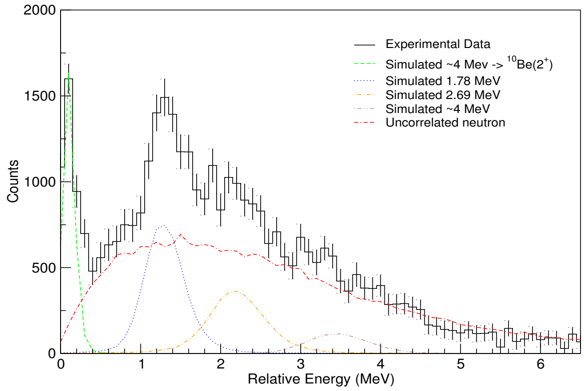

Fig. 1. Relative energy spectrum of ^{10}Be + n, where the stepped line represents the experimental data. The dotted and dashed lines depict the individual line-shapes of the simulation, which are dominated by the excitation energy resolution.

Full kinematic reconstruction of unbound states in ^{11}Be was performed from the momentum vectors of coincident ^{10}Be ions and neutrons. Simulations were performed for the breakup of states in ^{11}Be below 4 MeV, including the decay from a state at $\sim$ 4 MeV to the first 2^+ state in ^{10}Be (the efficiency for the detection of γ rays from this state was prohibitively small to separate this channel), and for the detection of neutrons diffracted from ^{12}Be in coincidence with ^{10}Be core. The simulated data were analyzed in the same manner as the experimental data. The simulated relative energy ($E_{\rm rel}$) line-shapes were fitted to the experimentally measured distribution, shown in fig. 1. These weightings well reproduced the $E_{\rm rel}$ spectrum, the reconstructed ^{11}Be* transverse momentum distribution, and the neutron angular distributions in coincidence with ^{10}Be (diffracted neutrons plus sequential decay neutrons) and ^{11}Be (diffracted neutrons only). The weighting for the diffraction component, whilst necessary to fit to the $E_{\rm rel}$ spectrum, neutron angular distribution and the transverse momentum distribution of reconstructed ^{11}Be*, is too large to be assigned entirely to the diffraction process. Some of the events described by this curve could be due to other sources of uncorrelated neutrons, such as the direct three-body breakup of ^{12}Be into ^{10}Be + n + n, the $E_{\rm rel}$ line-shape for which would be of a similar form to that of the diffracted neutrons. Furthermore, the measured form of such a broad distribution is partially determined by the form of the array efficiency, which decreases with increasing $E_{\rm rel}$. Using the geometric detection efficiency determined from the simulations, a (preliminary) cross section for production of the $5/2^+$ state was determined as 30.3(2.5) mb (statistical error). A further 30% is assigned to account for the uncertainty in precise form of the "uncorrelated" neutron distribution. That the cross section for the production of the $5/2^+$ and $1/2^-$ states in

^{11}Be are comparable suggests a strong $\nu(1d_{5/2})^2$ component to the ground state of ^{12}Be. Further simulations and analysis are being performed to improve the quantitative interpretation of the data.

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