NEW EVIDENCE FOR PARITY INVERSION IN ^{10}Li FROM ^{9}Li-γ COINCIDENCES

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The structure of neutron-unbound ^{10}Li remains an open question and thus also the complete understanding of the two-neutron halo nucleus ^{11}Li. The knowledge of the (n+^{9}Li) interaction is of essential importance to theoretical calculations of the three-body Borromean system ^{11}Li (n+n+^{9}Li) for which the two sub-systems ^{2}n and ^{10}Li are unbound.

Simple shell-models predict a $\frac{1}{2}^-$ state as the ground state of ^{10}Li, however the appearance of the $\frac{1}{2}^+$ state from the sd-shell as the ground state of ^{11}Be instead of the $\frac{1}{2}^-$ was the first case of an intruder state in the shell structure of nuclei. This parity inversion has long ago been clearly observed experimentally where the non-normal parity state ($\frac{1}{2}^+$) is 320 keV below the normal parity state which is the first excited state. Theoretical predictions [1] presented on Figure 1 show that the energy of the lowest non-normal parity state with respect to the lowest normal parity state increases systematically with Z for

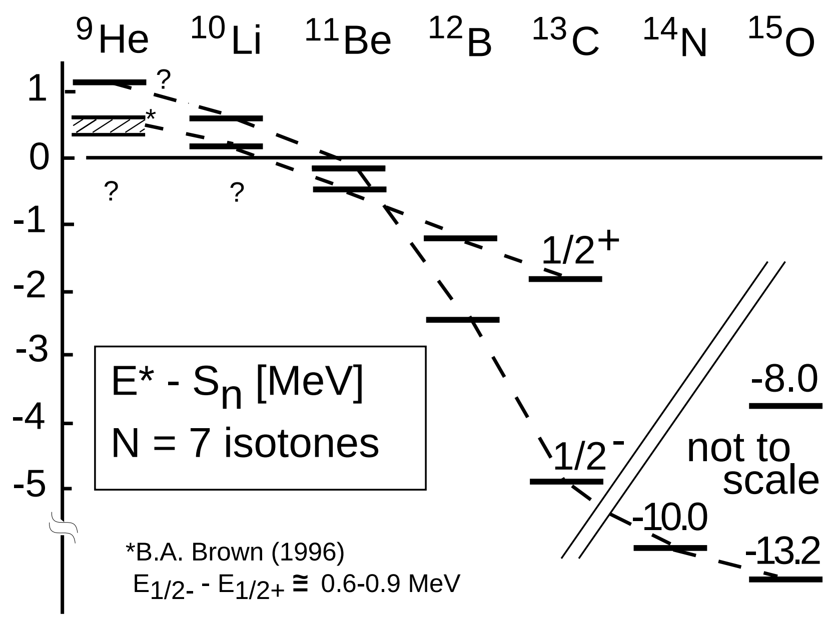

Figure 1: N = 7 isotone shell-model predictions for the lowest normal and non-normal parity states. Parity inversion is expected in neutron-unbound ^{10}Li and ^{9}He.

isotones with N = 7 and Z > 4. It is expected that this trend should continue in the other direction towards the lighter p-shell N = 7 isotones, and therefore the ground state of ^{10}Li is predicted to be a neutron s-state, i.e. a non-normal parity state (several calculations [2-4] agree that this $\frac{1}{2}^+$ neutron couples with the $\frac{3}{2}^-$ proton to a 2^- state).

Experimentally, the situation so far has been much more unclear. Several experiments using transfer reactions have shown evidence for a p-state around 240-540 keV, see Bohlen [5], Young [6], Caggiano [7] *et al.* The first experimental evidence for a neutron s-state at very low energy has been provided by the work of Kryger *et al* [8] using the method of sequential neutron decay spectroscopy at 0°.

A virtual s-state at ~ 50 keV was extracted corresponding to a scattering length of ~ -20 fm. However the s-state could represent a decay to the first excited state in ^{9}Li and would then not be the ground state. The observation by Zinser *et al* [9] of a narrow momentum distribution of the neutrons in coincidence with ^{9}Li nuclei from the single neutron stripping of ^{11}Li has been interpreted as final state interactions [10] and strongly suggested that the s-state couples to the ground state of ^{9}Li (the removal of a halo neutron is not expected to excite the ^{9}Li core).

An experiment was recently performed at the National Superconducting Cyclotron Laboratory of Michigan State University to investigate the possibility that the low decay energy s-state is not the ground state of ^{10}Li and feeds into the first excited state of ^{9}Li with the subsequent emission of a 2.7 MeV γ-ray.

A secondary beam of ^{11}Be (46 MeV/nucleon) produced and separated in the A1200 spectrometer bombarded a 300 mg/cm^{2} ^{9}Be target located in the N4 vault. A double-sided silicon strip detector located just after the target measured the energy loss (ΔE) and position of the charged fragments. Their residual energy (E) was measured in 8 vertical plastic scintillator bars located at the exit of a deflecting magnet. Particle identification was achieved from the ΔE-E matrix, showing a clear Z separation. The mass number identification required a Monte Carlo simulation to determine the shape of the contours to apply onto the ΔE-E matrix. Neutron and γ-ray coincidences from the breakup of ^{11}Be into the channels of ^{10}Li and ^{10}Be were measured using the MSU neutron walls at 0^o and the BaF_2 array of ORNL-NSCL-TAMU at 90^o. The two liquid scintillator filled neutron walls covered an area of 2×2 m^2 with a total efficiency of about 20 %. The 144 BaF_2 crystals covered a solid angle of approximately 1.5 sr with a total efficiency of about 5 % for γ-rays of 2.615 MeV (^{228}Th).

The γ-ray and charged fragment coincidence analysis required an event-by-event reconstruction of the γ showers to add back the pair production escape peaks located in the nearest neighbouring crystals. Moreover, since the γ-rays are emitted by a fast moving source ($\beta \approx 0.3$) Doppler shift correction was necessary.

The analysis of these coincidences was optimized for the ^{10}Be-γ data which could be easily interpreted using the known level scheme of ^{10}Be. Clear evidence was obtained (see Figure 2-a). for a 3.37 MeV γ-ray from the 2^+ state and for a 2.90 MeV γ-ray from the decay of the 2^- state at 6.26 MeV onto the first excited state (2^+). A weaker indication of a ~ 6 MeV γ-ray which had not been previously observed has been attributed to the decay of the 1^- state at 5.96 MeV onto the ground state (0^+). The study of the ^{10}Be-γ coincidences from the single-neutron stripping from ^{11}Be should shed light on the wave function of the ground state of ^{11}Be, the dominant part of which is known to be a $1s_{\frac{1}{2}}$. Sagawa *et al* [1] have suggested that the parity inversion in ^{11}Be can only be explained if more complex contributions, such as the coupling of $d_{\frac{5}{2}}$ to the 2^+ of ^{10}Be, are considered. Our data, as well as those from M. Fauerbach *et al* [11], show that not only the core excitation to its first excited state should contribute, but also higher states such as the 2^- and the 1^-. Relative intensities for these γ-rays have been preliminary determined and their final interpretation for the structure of ^{11}Be is on the way.

The number of ^{9}Li-γ coincidences (see Figure 2-b) correspond to a feeding of ^{9}Li* (2.7 MeV) in the single-proton stripping reaction from ^{11}Be of 4 $\pm$ 1 %, the dominant uncertainty coming from the poor fragment mass identification (a contamination of about 25 % from ^{8}Li was determined with the Monte Carlo simulation mentioned above). This branching ratio compares very well with a recent shell-model calculation [12] which leads to the formation of ^{9}Li* in the single-proton stripping from ^{10}Be of 5.2 %. As expected the number of 2.7 MeV γ-rays is small, therefore the triple γ-neutron-fragment coincidences did not provide sufficient statistics to be analyzed. Although, the angular neutron distributions showed,

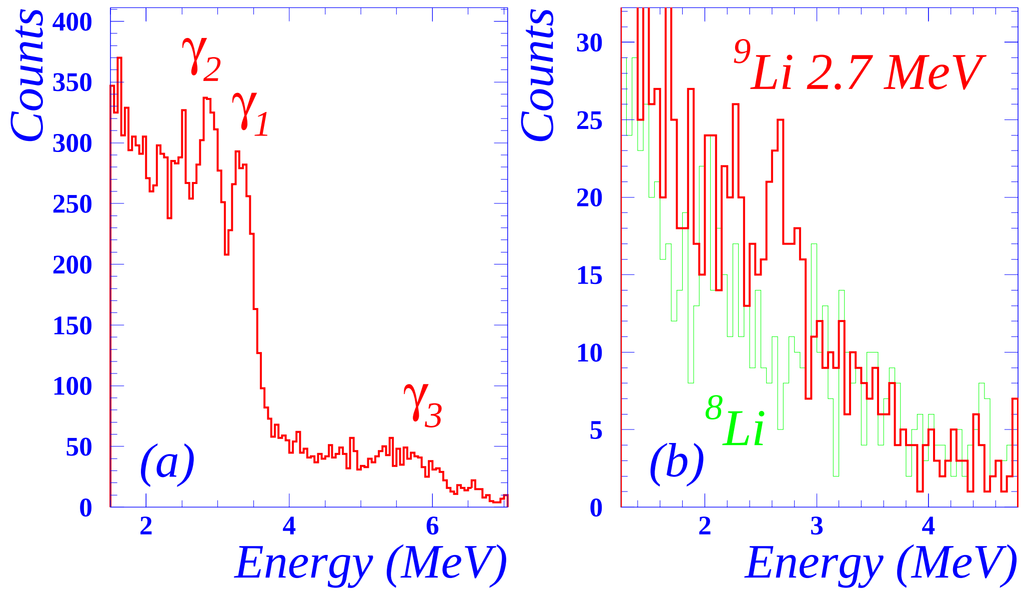

Figure 2: (a) ^{10}Be-γ coincidence spectrum showing evidence for 3.37 (γ_1), 2.90 (γ_2) and $\sim$ 6 MeV (γ_3) γ-rays. (b) ^{9}Li-γ coincidence spectrum (thick line) showing an excess of 80 ± 10 γ's at 2.7 MeV in comparison to the ^{8}Li-γ coincidence spectrum (thin line).

similarly to the GSI and GANIL data, a dependence of the width with respect to the selected fragment: a narrower distribution in the case of ^{9}Li resulting from final state interactions when a resonant intermediate state is formed in ^{10}Li than in the case of ^{10}Be corresponding to the diffraction dissociation of the neutron (this observation also supports the mass identification of the fragments).

Both, the weak population of the first excited state in ^{9}Li and the narrow momentum distribution of the neutrons in coincidence with ^{9}Li fragments indicating the formation of ^{10}Li lead to the conclusion that the ground state of ^{10}Li is an s-state which decays on the ground state of ^{9}Li. Thus we observe, like in the case of ^{11}Be, a parity inversion in neutron-unbound ^{10}Li.

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