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Preliminary study of the ^{10}Li nucleus via one-neutron transfer

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Abstract

The structure of the ^{10}Li unbound nucleus is a subject of large interest and its description is nowadays a matter of debate. We have investigated this system using the d(^{9}Li,p)^{10}Li one-neutron transfer reaction at 100 MeV in inverse kinematics. The experiment was performed at the ISACII facility at TRIUMF laboratory. The excitation energy spectrum has been reconstructed by measuring the emitted protons at backward angles and the ^{9}Li at forward angles.

1 Introduction

The exploration of the ^{10}Li nucleus is an interesting topic since it is an exotic system, unbound in the ground state. New phenomena are expected and/or observed in the continuum, showing an evolution of nuclear structure from closed to open systems beyond a mean-field description [1], [2]. In addition the knowledge of the ^{10}Li structure is a key ingredient in the description of the two-neutron halo nucleus ^{11}Li [3], [4]. Structure calculations for the weakly bound system ^{11}Li = ^{9}Li + 2n require in fact the interaction between one neutron and the ^{9}Li core as an important input quantity. This can be deduced directly from the binding energy and excitation energies of the states of ^{10}Li.

The properties of the ^{10}Li continuum remain still unclear and even the energy and the spin-parity assignment of the ground state are still controversial. The systematics of the N = 7 isotones suggest that the energy difference between the 2s1/2 and 1p1/2 energy levels is small and that the order of the two levels could be inverted, with the 2s1/2 level lower than the 1p1/2 level. The energy and ordering of the 2s1/2, 1p1/2 and 1d5/2 orbitals can be represented as in Fig. 1, according to the excitation energy of the known single particle states. In the case of ^{15}O, ^{14}N, ^{13}C and ^{12}B ground states, it is well known that the main component of the 1d5/2 shell lies above the 2s1/2, which is in turn above the 1p1/2. In the ^{11}Be (Z = 4) ground state a shell inversion between 2s1/2 and 1p1/2 is known to appear [5], [6]. If this anomaly is maintained also in the ^{10}Li (Z = 3) case, the lowest energy state in ^{10}Li is expected to have a dominant configuration with one neutron in the 2s1/2. On the other hand, if one supposes that the presence of shell inversion in ^{11}Be is related to the 2-alpha cluster structure of Be isotopes, such a structure is not possible for ^{10}Li and the configuration of the ^{10}Li ground state is expected to be a ^{9}Li core + one neutron in the 1p1/2.

Transfer reactions are essential tools to probe selected components of the nuclear wave functions [7], [8]. Thanks to that they have been used in the past and are still crucial for nuclear spectroscopy purposes. With the advent of radioactive beam facilities, the new opportunity to explore nuclear phenomena far from the stability valley has driven a renewed interest to transfer reactions, to be studied in inverse kinematics. On one hand there is a specific attention to understand how the transfer mechanism is influenced by the reduction of the binding energy of the projectile. On the other hand, the measured spectra could reveal unexpected features due to nucleon correlations which are beyond the mean field description of nuclear structure.

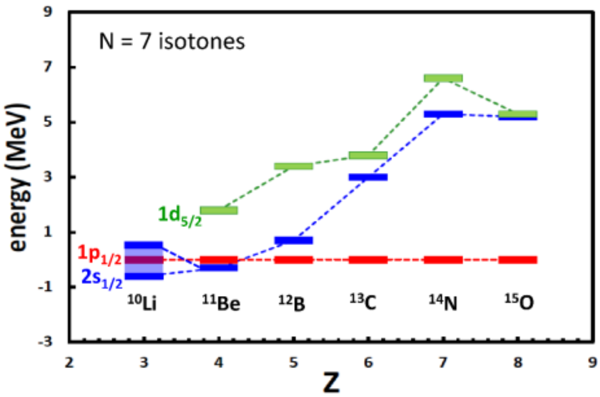

Figure 1: Relative energy of the 1d5/2, 2s1/2 and 1p1/2 shells for the N = 7 isotones in the region of ^{10}Li.

Recently ^{10}Li has been the subject of different theoretical works and challenging experimental studies [9], [10], [11], [12] including two attempts to explore the resonant energy spectrum by the d(^{9}Li,p)^{10}Li transfer reaction at 2.35 AMeV incident energy at REX-ISOLDE [10] and at 20 AMeV at NSCL-MSU, respectively [9]. However, due to the poor statistics, not much was added to our understanding of ^{10}Li states.

In a recent theoretical study of the ^{10}Li low energy resonances [13], a state dependent treatment of the pairing interaction, beyond the usual BCS approximation, has proven to be necessary to reproduce the energy spectra measured in the REX-ISOLDE experiment. In addition it was shown that, despite the complications due to the resonant structure of the final states, the cross sections can be accurately described within the DWBA. Nevertheless, due to the limitations of the existing data, many of the details predicted by the theory were not tested. For example only a measurement of the angular distribution at forward angles in the centre of mass would disentangle contributions from s, p and d orbitals in different portions of the energy spectrum. Also the behaviour of the observed s1/2 and p1/2 orbitals should be better addressed, since in both cases the coupling with the p3/2 proton generates a doublet of ^{10}Li states, namely 1^-, 2^- for the s1/2 and 1^+, 2^+ for the p1/2, while experimentally there is no indication of such doublets. In addition, according to the theory, p3/2 and d5/2 orbitals should generate resonances above 1 MeV, but these have not been observed experimentally.

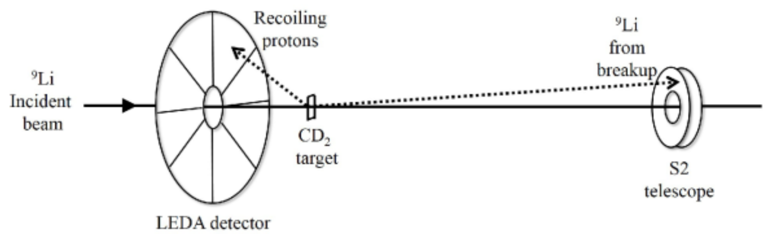

Figure 2: Schematic layout of the experiment.

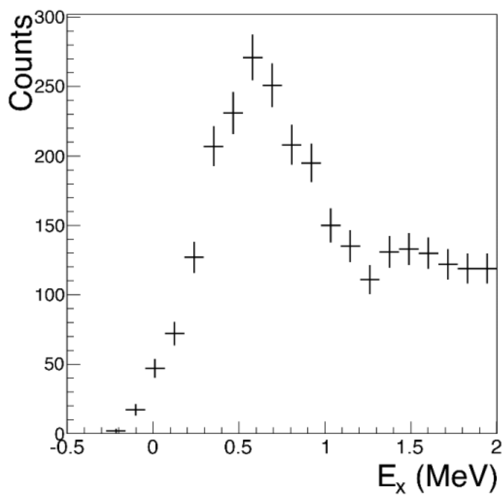

Figure 3: ^{10}Li excitation energy spectrum reconstructed from the d(^{9}Li,p)^{10}Li reaction at 100 MeV incident energy in the angular region $\theta_{c.m.}$ = 8.3° - 16.2°.

2 Experiment and results

We studied the d(^{9}Li,p)^{10}Li reaction at 11 AMeV incident energy at the TRIUMF laboratory (Canada). At this energy the recoiling protons can be detected at backward laboratory angles, thus allowing the exploration of the crucial region at forward angles in the centre of mass.

A ^{9}Li beam, produced by the ISAC-II facility with an average current of 10^6 pps. The beam charge was collected by a Faraday cup located downstream of the target. In order to check the reliability of the Faraday cup measurement, the absolute cross-section of elastic scattering data was compared to Rutherford scattering at forward angles. The beam impinged on a

CD2 target, 126 g/cm^2 thick. The target thickness was chosen to improve the energy resolution maintaining an acceptable count rate. The recoiling protons were detected at backward angles $\theta_{lab} = 127°$ - $161°$ by the LEDA array of silicon strip detectors [14], thus allowing the study of the ^{10}Li emitted at forward angles. Protons were detected in coincidence with the ^{9}Li fragments produced from the break-up of the corresponding ^{10}Li. ^{9}Li fragments were detected and identified by a $\Delta E - E$ telescope of annular Double Sided Silicon Detectors located downstream the target. A schematic layout of the experimental setup is shown in Fig. 2.

The ^{10}Li excitation energy was reconstructed with significant statistics allowing to explore its level structure at low excitation energy. Fig. 3 shows the excitation energy spectrum obtained up to 2 MeV in the angular region $\theta_{c.m.} = 8.3°$ - $16.2°$. The centroid (E = 0.6 MeV) and full width at half maximum (FWHM = 0.6 MeV) of the unbound ground state were extracted by a best fir procedure. A second peak, weaker than the first, appears at around 1.4 MeV. The sharp fall down of the tail of the first peak toward zero excitation energy shows that there is no evidence in the present data of the existence of a s1/2 low lying virtual state as supposed by [10]. The data analysis of the region at higher excitation energy is in progress and will be published elsewhere.

The highly segmented detection system also allowed to measure the angular distributions of the observed resonances at forward angles. The analysis of the angular distribution, which is still in progress, would give more indication about the controversial question of the spin-parity of the ^{10}Li unbound ground state.

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