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Inelastic scattering of ^{9}Li and excitation mechanism of its first excited state

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ABSTRACT

The first measurement of inelastic scattering of ^{9}Li from deuterons at the ISAC facility is reported. The measured angular distribution for the first excited state confirms the nature of excitation to be an E2 transition. The quadrupole deformation parameter is extracted from an analysis of the angular distribution.

The neutron-rich nuclei close to the drip-line are subject of great interest due to the variance in their properties from our conventional knowledge of nuclear structure. The neutron halo in ^{11}Li [1] continues to be an intriguing quantum system whose complete understanding, from a microscopic view, is still an outstanding problem. It is important to understand how the two fragile halo neutrons are correlated and bound to the ^{9}Li core. It has been discussed that the bare nucleon–nucleon pairing interaction is not sufficient to bind the halo neutrons. The ^{9}Li core is suggested to play a more dynamic role in providing the glue to bind the halo neutrons through quadrupole vibrational phonon exchange [2]. Knowledge on the properties of ^{9}Li is therefore important for a complete understanding of the structure of the neutron-rich lithium isotopes.

The two-neutron transfer reaction from ^{11}Li, interestingly, observed some fraction of the ^{9}Li core in its first excited state [3]. The angular distribution of this reaction channel could be interpreted in the framework of nuclear field theory [4] using a wavefunction of ^{11}Li that contains a component with the ^{9}Li core in its first excited state. However, no experimental information exists on the nature of excitation of ^{9}Li to its first excited state.

The neutron-rich *p*-shell nuclei also offer the scope of investigation using *ab initio* theories, which have significantly advanced in recent times. This makes it important to have experimental information on their structure and excitation mechanisms, that serve as testing grounds for the newly developed models.

In this Letter we report the first measurement of inelastic scattering of ^{9}Li from deuterons. The observation shows evidence of a quadrupole collective excitation component for the first excited state in ^{9}Li at 2.69 MeV.

The early measurements of two-neutron transfer in ^{7}Li(t, p)^{9}Li showed the first excited state of ^{9}Li [5,6] to be located at excitation energy (E_{ex}) of 2.691 ± 0.005 MeV. The next excited state was observed at 4.296 ± 0.015 MeV [7]. The ^{11}B(^{6}Li, ^{8}B)^{9}Li reaction [8] showed a strong population of the ^{9}Li ground state which was consistent with predicted two-proton transition strengths. A weaker population of excited states at 2.69, 4.31 and 6.41 MeV was also seen. The observed excitation energies are in good agreement with

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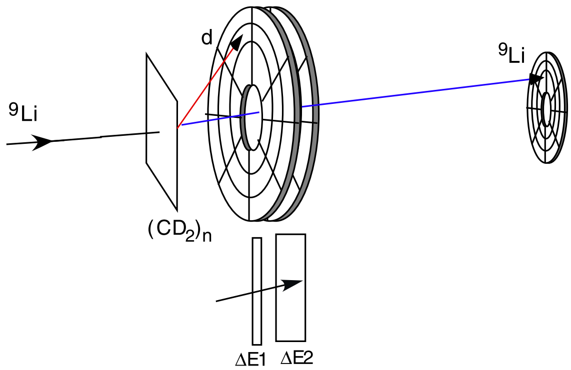

Fig. 1. Schematic view of the experimental setup.

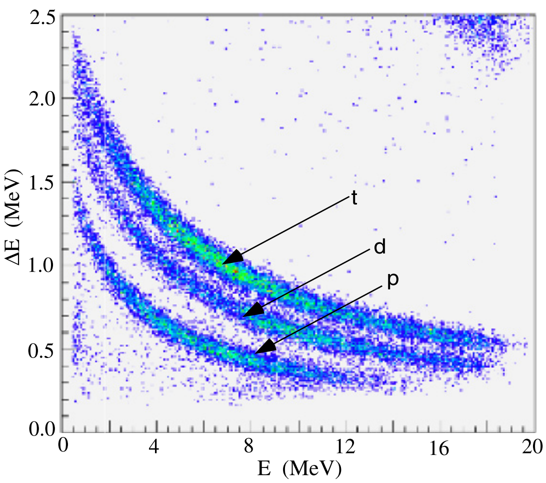

Fig. 2. Particle identification by ΔE–E correlation.

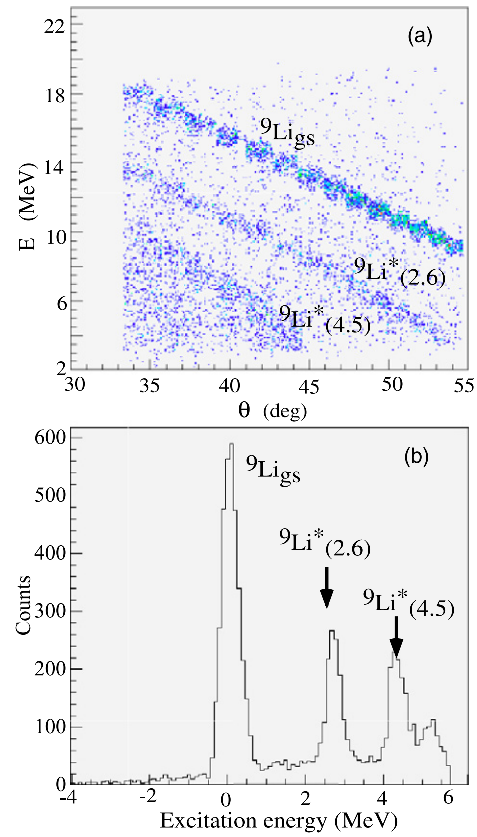

Fig. 3. (a) The kinematic loci from the deuterons detected in the YY1 detector array. (b) The Q-value spectrum of $d(^9Li, d)$ reactions.

shell model predictions of Poppelier et al. [9]. The spin of the first excited state predicted by the $(0+1)\hbar\omega$ model space in this shell model calculation [9] is $1/2^-$, while a $5/2^-$ spin is predicted with a $(0+2)\hbar\omega$ model space.

Ab initio calculations using either the Green's function Monte Carlo method [10] or the no-core shell model [11] predict a $1/2^-$ first excited state for ^{9}Li (see Table I of Ref. [12]). In both cases, the excitation energies are in better agreement with observations if a realistic three-nucleon potential is added to the underlying two-nucleon force.

The one-neutron transfer reaction on ^{8}Li [12] was found to populate the excited states at 2.69, 4.31, 5.38 and 6.43 MeV in ^{9}Li. A DWBA analysis of the angular distribution of the 2.69 MeV first excited state yielded a spectroscopic factor of 0.73(15). This value in general is higher than theoretical predictions and agrees only at the lower end of the uncertainty with the value of 0.52 predicted by the Variational Monte Carlo [10] and the no-core shell model [11] predictions.

To investigate the nature of the first excited state in ^{9}Li, an inelastic scattering experiment was performed at the ISAC-II facility at TRIUMF. The schematic view of the setup is shown in Fig. 1. The radioactive beam of ^{9}Li with an average intensity of 5×10^4/sec and energy of 5*A* MeV was inelastically scattered off a deuterated polyethylene foil $(CD_2)_n$ target of thickness 490 μg/cm^2. Annular arrays of segmented silicon strip detectors (YY1), arranged in two layers, detected the scattered deuterons and other light target-like charged particles from the reaction. The layers were arranged as energy loss (ΔE) followed by the stopping detector (E) configuration. This enabled an identification of the reaction channel from a ΔE–E correlation (Fig. 2). The ΔE layer covered laboratory angles from 35° to 60°. Another annular detector, S2, placed further downstream covering laboratory angles from 2.6° to 8.0° was used to detect the heavy projectile-like residue.

The kinematic loci of the scattered deuterons from elastic and inelastic scattering are shown in Fig. 3(a). The $^9Li_{gs}$, ^{9}Li*(2.69 MeV) first excited state and the ^{9}Li*(4.5 MeV) second excited states were populated. The discrete band-like structures seen in the loci are due to segmentation of the detectors. The corresponding Q-value spectrum is shown in Fig. 3(b).

The inclusive spectrum of the S2 detector is shown in Fig. 4(a). The elastic scattering from the carbon in the $(CD)_2$ foil target is observed as the intense nearly horizontal band. In the very small laboratory angles Rutherford scattering on carbon dominates, whose cross section allows a determination of the beam intensity and the absolute normalization of the data. The ^{9}Li elastically scattered from the deuterons appears as the curved bright band in Fig. 4(a). This corresponds to the forward center of mass scattering angles. The band observed at energies higher than the Rutherford scattering originates from the $d(^9Li, ^8Li)t$ reaction. The kinematic correlation of the S2 detector in a coincidence condition with the ΔE detector allowed the detection of forward center of mass angle events for the ^{9}Li first excited state (Fig. 4(b)).

The angular distribution for the elastic scattering of ^{9}Li from deuterons is shown in Fig. 5. The uncertainties include a 5% systematic error arising from the target thickness uncertainty. The inelastic scattering data have been interpreted in a zero-range one-step distorted wave Born approximation framework using the computer code DWUCK4 [13] as well as the coupled channels framework using FRESCO [14].

The optical potential parameters for the $^9Li + d$ interaction were determined from a best fit to these data by a χ^2 minimiza-