High Resolution Spectroscopy of $^9_A\text{Li}$ by Electroproduction


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An experiment measuring electroproduction of hypernuclei has been performed in Hall A at Jefferson Lab on a $^9_A\text{Li}$ target for the first time with sub-MeV energy resolution. In order to increase counting rates and provide unambiguous kaon identification two superconducting septum magnets and a Ring Imaging CHERenkov detector (RICH) were added to the Hall A standard equipment. The $^9_A\text{Li}$ spectrum shows disagreement with respect to the theory due to the poor knowledge of the underlying $^7_A\text{Li}$ nucleus structure.
Hyperm- nucl- e provide a unique playground for the inves- tigation of hadronic many-body system with strangeness -1 and new aspects of the strong and weak interaction in nuclei. Moreover there is a growing evidence of the hyperon (and hyperon–nucleon interaction) in cosmology [1]. A Λ–hyperon can be placed deep inside the nucleus as an impurity providing a sensitive probe of the nuclear interior, allowing us to extract information on the behavior of the hyperon–nucleon interaction. Because of missing direct measurements on hyperon–proton scattering at low energies, this is the only way to study such an interaction. Therefore there is a unique opportunity to obtain this information by observing the fine structures of hypernuclei caused by the specific spin-dependent hyperon–nucleon interaction [13, 14]. Such characteristics are realized only in Λ–hypernuclei and are hardly seen in other hypernuclei, and thus the spectroscopy of Λ–hypernuclei has a unique value in the strangeness nuclear physics.

In the past, hypernuclear spectroscopy has been carried out with limited resolution by means of hadronic reactions, such as the strangeness exchange and associated production reactions. More recently, γ-ray spectroscopy has been used to measure hypernuclear transition energies. Here, the few-keV energy resolution has allowed precise level assignments and the measurement of doublet spacings [1] but the method is limited to the bound region below particle emission thresholds and to bound levels reached following particle emission.

The experimental knowledge can be enhanced using the (e, e′K+) electroproduction reaction characterized by a large momentum transfer to the hypernucleus (q > 250 MeV/c) and strong spin-flip terms, even at zero K+ production angles, resulting in the excitation of both natural- and unnatural-parity states [13, 14]. Such characteristics are realized only in Λ–hypernuclei and are hardly seen in other hypernuclei, and thus the spectroscopy of Λ–hypernuclei has a unique value in the strangeness nuclear physics.

The left-hand side of Fig. 1 shows the missing energy spectrum of 9Λ Li for the full range of energy acceptance. The right-hand side of Fig. 1 shows the excitation energy of the 9Λ Li production. The background is rather flat. Fig. 2 shows the experimental data of excitation energy (red curve) and the corresponding Monte Carlo simulations where radiative effects were turned off (blue curve). The experimental data errors are statistical. The red curve fits the experimental data well and the corresponding χ²/ndf value is equal to 40.23/36. Several peak configurations, with different number, heights, positions and widths of the peaks, reproduce the red curve. All of them, however, should be expected to generate the same spectrum (the blue curve of Fig. 2) when radiative corrections are applied. This can be understood noting that radiative corrections are independent on the assumption on the number and kind of the peaks that build the experimental spectrum up, providing that the Monte Carlo is able to fit it reasonably well. In practice, because the Monte Carlo simulated data do not overlap perfectly with the experimental data, the Monte Carlo spectrum obtained when radiative corrections are applied, slightly depends on the peak configuration used to fit experimental data. This produces small systematic errors on the radiative corrected spectrum. The unfolding for radiative corrections has been done using the bin-by-bin method. The content of each bin of the radiative corrected spectrum
FIG. 1: Left panel shows the missing energy spectrum obtained after kaon selection with aerogel detectors and RICH; right panel shows excitation energy of the data shown in the left panel, restricted to the region of interest.

FIG. 2: The $^9\Lambda$Li binding-energy spectrum. Experimental excitation energy vs. Monte Carlo data (red curve) and vs. Monte Carlo data turning off radiative effects (blue curve). The result is hence obtained multiplying the corresponding bin of the experimental spectrum by the correction factor given by the ratio of the blue and red curves of Fig. 2 for that bin. The result is shown in Fig. 3 that reports the radiative corrected experimental data (points with statistical errors) vs. theoretical data (thin curve). The band at the bottom of the histogram shows the systematic errors, due to the fact that the blue curve of Fig. 2 depends slightly on the peak configuration used to fit the experimental data. The theoretical histogram was obtained supposing an energy resolution of 580 keV (FWHM). Once radiative corrections are applied, the excitation energy spectrum resolution is small enough to clearly show a three peak structure of the spectrum.

The theoretical cross sections were obtained in the framework of the distorted-wave impulse approximation (DWIA) [25] using the Saclay-Lyon (SLA) model [26] for the elementary $p(e,e'K^+)$A reaction.

Here Slavek should write few rows to explain how the cross sections were calculated.

FIG. 3: Radiative corrected experimental excitation energy vs theoretical data (thin curve). The thick curve shows the result of fitting the radiative-corrected data with three gaussians.

The resulting energy spectrum, dominant components of the wave functions, and calculated cross sections are reported in Table I.

The plot in Fig. 3 and the Table I show disagreement between the standard model of p-shell hypernuclei and the measurements both for the position of the peaks and for the cross section.

This can be due to the poor knowledge of the underlying core of $^8$Li nucleus structure. In fact this is an unstable nucleus with rather large excess of neutral particles. The choice of the radii of the distribution of protons and neutrons and of the spectroscopic factors is important in the calculation of the cross section of the reaction.

In summary, a high-quality $^9\Lambda$Li hypernuclear spectrum has been obtained for the first time with sub-MeV energy resolution. The measured cross sections are in good agreement for the first peak with the values predicted using the SLA model and simple shell-model wave functions. The disagreement in strength and position for the second and third peak is probably due to the poor knowledge of the underlying core $^8$Li nucleus structure.

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TABLE I: Excitation energies, widths, and cross sections obtained by fitting the $^9$Be($e,e'K^+)^{\Lambda}\text{Li}$ spectrum (first three columns) compared with theoretical predictions (last three columns).

<table>
<thead>
<tr>
<th>Experimental data</th>
<th>Theoretical predictions</th>
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<tbody>
<tr>
<td>$E_x$ (MeV)</td>
<td>$J^p$</td>
</tr>
<tr>
<td>Width (FWHM, MeV)</td>
<td>Cross section (nb/sr²/GeV)</td>
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<td></td>
<td></td>
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<tr>
<td>0.00 ± 0.05</td>
<td>0.98 ± 0.10</td>
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<tr>
<td>1.14 ± 0.06</td>
<td>0.81 ± 0.20</td>
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<tr>
<td>2.05 ± 0.08</td>
<td>0.61 ± 0.14</td>
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</tbody>
</table>

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[28] D.H. Davis and D.N. Tovee, fit to data from Ref. [9], private communication.
[29] H. Tamura, erratum to Ref. [10], private communication.