EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/79-124
18 October 1979

THE (K^-,π^-) STRANGENESS-EXCHANGE REACTION ON ^{6}Li, ^{7}Li, AND ^{9}Be

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ABSTRACT

The $^6_\Lambda$Li, $^7_\Lambda$Li, and $^9_\Lambda$Be hypernuclear spectra have been obtained by means of the (K^-,π^-) strangeness-exchange reaction on ^{6}Li, ^{7}Li, and ^{9}Be. The kaon momentum was either 720 MeV/c or 790 MeV/c. The pions were detected at 0° by the SPES II spectrometer, and the over-all resolution was 2 MeV. An independent particle model gives good account of the hypernuclear spectra, where the strongly populated states are due to recoilless transitions.

Paper presented at the
8th International Conference on High-Energy Physics
and Nuclear Structure
Vancouver, 13-17 August, 1979

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*) Work supported in part by the BMFT.

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1. INTRODUCTION

In this paper we report a study of the light hypernuclei ${}^{6}_{\Lambda}\mathrm{Li}$, ${}^{7}_{\Lambda}\mathrm{Li}$, and ${}^{9}_{\Lambda}\mathrm{Be}$ produced by means of the strangeness-exchange reaction (K^-,π^-) on ${}^{6}\mathrm{Li}$, ${}^{7}\mathrm{Li}$, and ${}^{9}\mathrm{Be}$. The experiment was performed on a low-momentum (720 MeV/c or 790 MeV/c) separated K^- beam at the CERN Proton Synchrotron. The experimental set-up has been described previously$^{1)}$. The pions were detected at 0° in a 20 msr solid angle; an over-all resolution of about 2 MeV in the hypernuclear mass spectra was achieved.

In the (K^-,π^-) reaction the transferred momentum is much smaller than the Fermi momentum, provided the kaon momentum is less than about 1 GeV/c and the pions are detected near 0°. In these conditions one produces preferentially the so-called recoilless transitions in which the Λ particle takes the same spin-space state as that of the neutron it replaces. A smaller part of the cross-section goes to hypernuclear states corresponding to the strangeness-exchange reaction on one of the outer neutrons accompanied by a jump of the Λ particle to one of the neighbouring orbitals (quasi-free production)$^{1-3)}$.

With the same interpretation of the experimental spectrum in terms of recoilless and quasi-free contributions, the data on p and s-d shell nuclei (from ${}^{12}\mathrm{C}$ to ${}^{40}\mathrm{Ca}$) were analysed with a distorted-wave impulse approximation shell-model calculation$^{4)}$.

The single-particle energies for the Λ particle have been calculated using an energy-independent shell-model potential with a Woods-Saxon form for the central term and a Thomas form for the spin-orbit terms.

From a phenomenological analysis of the data (see Ref. 4 for detailed discussion), the depths of the two potentials were determined as follows:

$$\begin{aligned} V_{\Lambda}^{\mathrm{cent.}} &= (32 \pm 2)\ \mathrm{MeV}\ , \\ V_{\Lambda}^{LS} &= (\ 4 \pm 2)\ \mathrm{MeV}\ . \end{aligned} \tag{1}$$

Using the same model calculation, our purpose now is to see whether or not such values are able to give a reasonable fit to light nuclei. The difference in the two calculations is the replacement of the j-j coupling model by the intermediate coupling model, which is more appropriate for light nuclei with the coefficients of fractional parentage as determined by Cohen and Kurath$^{5)}$.

In Fig. 1 the hypernuclear mass spectra are given as a function of B_{Λ}, the binding energy of the Λ particle. Also instructive is the transformation energy scale $M_{HY} - M_A$ (the Q value of the reaction), where M_{HY} and M_A are the masses of the hyperfragment and the target, respectively:

$$M_{HY} - M_A = M_{\Lambda} - M_N + B_N^{\mathrm{last}} - B_{\Lambda} = E_K - E_{\pi} - E_R\ .$$

Here, E_K and E_π denote the energies of the mesons, E_R is the recoil energy of the hypernucleus, and B_N^{last} the separation energy of the last-shell neutron.

2. THE REACTION $^6Li(K^-,\pi^-)^6_\Lambda Li$

From (p,d) experiments[6] the separation energy difference between the $1p_{3/2}$ and $1s_{1/2}$ neutron-hole states in ^6Li is 15.7 MeV. One expects the two observed peaks at B_Λ = -14 MeV and B_Λ = -4 MeV to correspond to the two recoilless transitions built on the $1s_{1/2}$ and $1p_{3/2}$ orbitals, respectively. Therefore the 10 MeV difference between these peaks gives 5.7 MeV for the separation energy difference between the Λ single-particle energies in the $1s_{1/2}$ and $1p_{3/2}$ orbitals.

This value is rather in agreement with the value of 8 MeV estimated with the shell-model potential for the Λ particle [with the set of parameters (1)]. Moreover, the intensity ratio in the two observed peaks is in rough agreement with the ratio 2:1 of the number of neutrons in the s and p shells of ^6Li.

The shape of the calculated intensity spectrum agrees quite well with that of the observed one. The weak intensity at B_Λ = 4.5 MeV corresponds to a quasi-free transition $(1s_{1/2}, 1p_{3/2}^{-1})^{1^-}_{\Lambda n}$ and may probably be assigned to the ground state of $^6_\Lambda Li$. This state, however, would be unstable against proton emission, since the $(^5_\Lambda He + p)$ mass is smaller by 600 keV. For this reason it has not been observed in emulsion experiments.

3. THE REACTION $^7Li(K^-,\pi^-)^7_\Lambda Li$

The situation is somewhat more complex for ^7Li since in (p,d) experiments the $1p_{3/2}$ transition strength is distributed over several states in ^6Li (actually the five low-lying states), the strongest being the ground state $J = 1^+$, $T = 0$, and the state $J = 3^+$, $T = 0$ at 2.2 MeV excitation energy. The separation energy difference between the $1s_{1/2}$ and $1p_{3/2}$ neutron holes amounts to about 20 MeV.

One expects the two peaks at B_Λ = -15.5 MeV and B_Λ = -3.5 MeV to correspond to the two recoilless transitions built on the $1s_{1/2}$ and $1p_{3/2}$ orbitals. The Λ separation energy difference between these states in therefore estimated to be 8 MeV, a value in agreement with that given by the Λ shell-model potential.

A comparison between the observed and theoretical intensity spectra shows that the weak intensity at B_Λ = 5 MeV results from a quasi-free transition $(1s_{1/2}, 1p_{3/2}^{-1})^{1^-}_{\Lambda n}$ from a $3/2^-$ state to a $1/2^-$ state.

4. THE REACTION $^9Be(K^-,\pi^-)^9_\Lambda Be$

The interpretation of $^9_\Lambda Be$ is much more involved. It is well known from (p,d) experiments that the $1p_{3/2}$ strength is distributed over many states in ^8Be, the strongest ones being $J = 2^+$, $T = 0$ at 3 MeV excitation energy, and $J = 2^+$, $T = 0.1$ at 17 MeV excitation energy. Therefore the two dominant peaks at $B_\Lambda = -17$ MeV and $B_\Lambda = -6$ MeV are believed to belong to the $1p_{3/2}$ Λ-particle configurations built on these states. In addition, the separation energy difference between the $1p_{3/2}$ and $1s_{1/2}$ neutron-hole states is about 23 MeV. Therefore the peak at $B_\Lambda = -17$ MeV is expected to be a mixture of the two recoilless transitions $(1s_{1/2}, 1s_{1/2}^{-1})^{0^+}_{\Lambda n}$ and $(1p_{3/2}, 1p_{3/2}^{-1})^{0^+}_{\Lambda n}$. The shell-model calculation reproduces those features quite well.

The weak intensity at $B_\Lambda = 7.5$ MeV is a quasi-free transition $(1s_{1/2}, 1p_{3/2}^{-1})^{1^-}_{\Lambda n}$ from a $3/2^-$ state to a $1/2^+$ state. This is consistent with the position and the spin determination of the ground state of ${}^9_\Lambda$Be obtained in nuclear emulsion.

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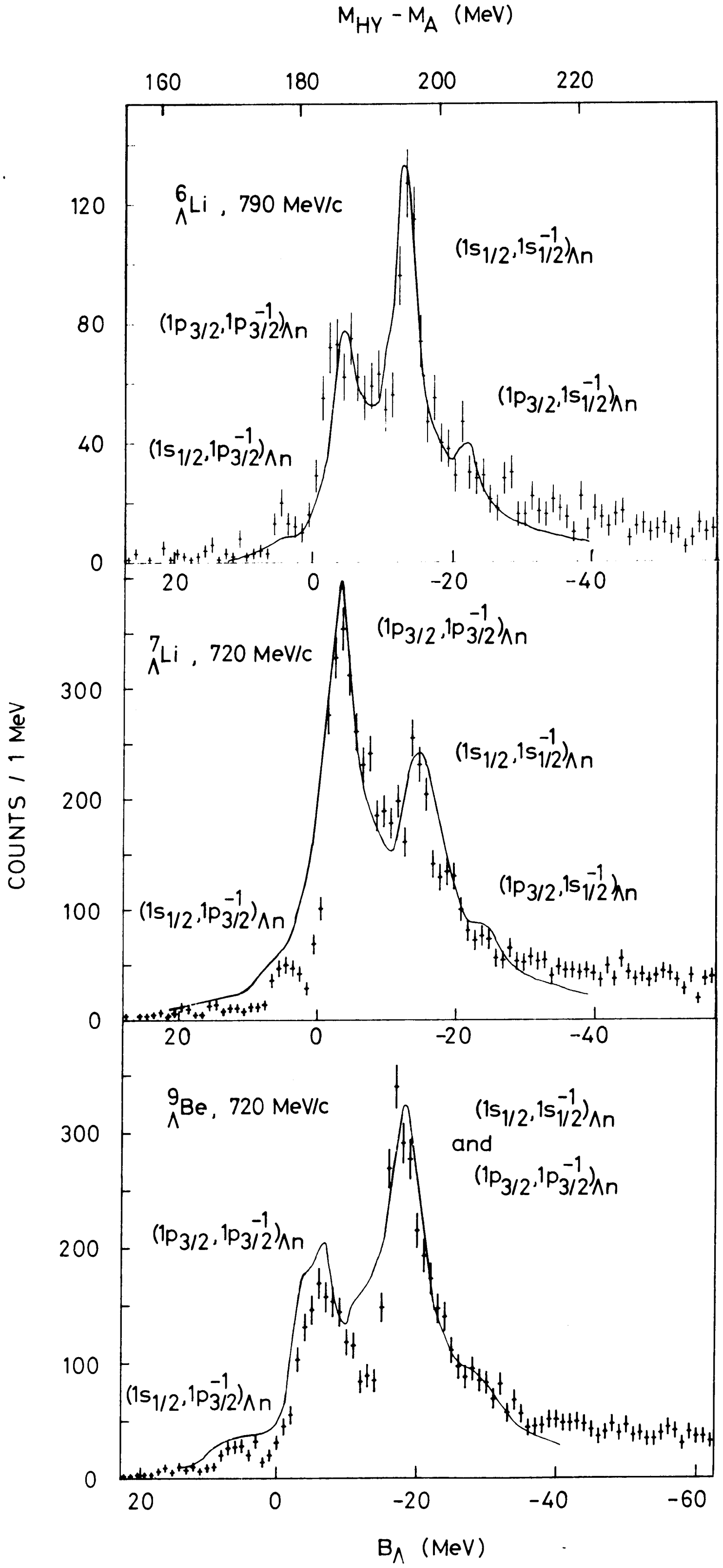
Figure caption

Fig. 1 : Hypernuclear mass spectra of ${}^6_\Lambda$Li, ${}^7_\Lambda$Li, and ${}^9_\Lambda$Be. The solid line represents the described fit to the data.



$M_{HY} - M_A$ (MeV)
160
180
200
220
$^6_\Lambda$Li , 790 MeV/c
$(1s_{1/2},1s^{-1}_{1/2})_{\Lambda n}$
$(1p_{3/2},1p^{-1}_{3/2})_{\Lambda n}$
$(1p_{3/2},1s^{-1}_{1/2})_{\Lambda n}$
$(1s_{1/2},1p^{-1}_{3/2})_{\Lambda n}$
120
80
40
0
$^7_\Lambda$Li , 720 MeV/c
$(1p_{3/2},1p^{-1}_{3/2})_{\Lambda n}$
$(1s_{1/2},1s^{-1}_{1/2})_{\Lambda n}$
$(1p_{3/2},1s^{-1}_{1/2})_{\Lambda n}$
$(1s_{1/2},1p^{-1}_{3/2})_{\Lambda n}$
300
200
100
0
COUNTS / 1 MeV
$^9_\Lambda$Be, 720 MeV/c
$(1s_{1/2},1s^{-1}_{1/2})_{\Lambda n}$
and
$(1p_{3/2},1p^{-1}_{3/2})_{\Lambda n}$
$(1p_{3/2},1p^{-1}_{3/2})_{\Lambda n}$
$(1s_{1/2},1p^{-1}_{3/2})_{\Lambda n}$
300
200
100
0
20
0
-20
-40
-60
B_Λ (MeV)

Fig. 1