Continuum effects and the interpretation of Σ hypernuclei

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The production of hypernuclei in the continuum above hyperon binding is calculated by a pole graph method. The continuum can exhibit a structure which complicates the interpretation of hypernuclear spectra, especially in the case of Σ hypernuclei.

A great deal has been learned from studies of Λ hypernuclei, primarily through the use of strangeness exchanging reactions. A rather rich spectroscopy has emerged, and a shell model adapted to the symmetry appropriate to the Λ hyperon has proved successful in describing the known energy positions and quantum members of the Λ hypernuclear states in the p shell.[1]

It would be extremely helpful to have similar spectroscopic information about Σ hypernuclei, so that the states comprising these two varieties of hyperons embedded in nuclei might be directly compared. Recently, claims for the observation of narrow structure in the $(K^-,\pi^\pm)$ reaction missing mass and the identification of that structure as Σ states have appeared in the literature.[2,3,4] If correct, those claims provide us with the expectation of achieving a detailed comparison of Λ and Σ-nuclear forces.

The purpose of this communication is to point out that the interpretation of hypernuclear spectra requires a more realistic calculation of the continuum than has been the practice heretofore in the interpretation of hypernuclear excitations. Calculations of the hypernuclear continuum have been previously based on the Dalitz and Gal[5] analysis, which assumes a Fermi-gas model to describe the nucleon momentum distribution, and consequently ignores nuclear structure effects. Since the proposed peaks lie well above Σ binding, it is essential that a more realistic calculation of the continuum (here to be called the quasifree process) be made, and removed before interpretation of any narrow structure can be properly performed. Such a calculation, based on the pole graphical method successfully employed for radiative pion capture,[6] has been adapted to $(K^-,\pi^\pm)$ reactions by one of us (T.K.).[7] (The results of Ref. 7 are preliminary and revised calculations will be published shortly.)

Figure 1 is a diagram of what we will define as the quasifree process. In this diagram two vertices, A and B, appear, and are connected by the propagator $(P^2-2mE-i\eta)^{-1}$. The scattering amplitude is written in the form

$$T_{fi} \propto \int dP_N^3 dE_N \left[\frac{M_A M_B}{P_N^2 - 2M_N E_N - i\eta} \right] \times \delta^3(P_A - P_{A-1} - P_N)\delta^3(P_K + P_N - P_\pi - P_Y) \times \delta(\omega_A - \omega_{A-1} - \omega_N)\delta(\omega_K + \omega_N - \omega_\pi - \omega_Y) ,$$

where M_A and M_B are form factors and the δ functions represent momentum and energy conservation at the vertices A and B.

The form factor of vertex A corresponds to the dissociation of the target nucleus into a nucleon and the residual nucleus, and has been discussed in detail by Shapiro.[8] The form factor M_A reproduces the experimental momentum distribution observed[9] in (e,e′p) on ^{12}C and ^{16}O. At vertex B the elementary Y production amplitude must be used.

Several features of the calculation are emphasized here.

(1) We assume that the Σ appears as a plane wave in the final state. Therefore, final state interactions between the Σ and the residual nucleus are not included.

(2) Nowhere in this calculation does the single particle potential U_N, appropriate to the struck nucleon, appear. Instead, one explicitly includes the particle binding energies. This can be important in light nuclei since the distribution of hole strengths in the recoiling nucleus is clearly not statistical. It is known, for example, in the case of ^{12}C, that almost 80% of the hole strength appears in the ground state of ^{11}B, while in the case of ^{16}O the strength is largely divided between the ^{15}N ground state and the 6 MeV state. Thus for these cases we might expect to see continuum structures associated with these states, with their respective binding energies.

(3) At vertex B the KN-Yπ amplitude as tabulated by Gopal[10] has been used. The inclusion of the proper momentum dependence of the amplitude is especially important near 400 MeV/c, where a resonance in $KN \rightarrow Y\pi$

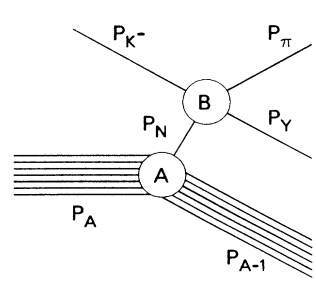

FIG. 1. The diagram for the quasifree production of hypernuclei. The hyperon final state is presumed to be a plane wave state. The form factors at vertices A and B are described in the text.

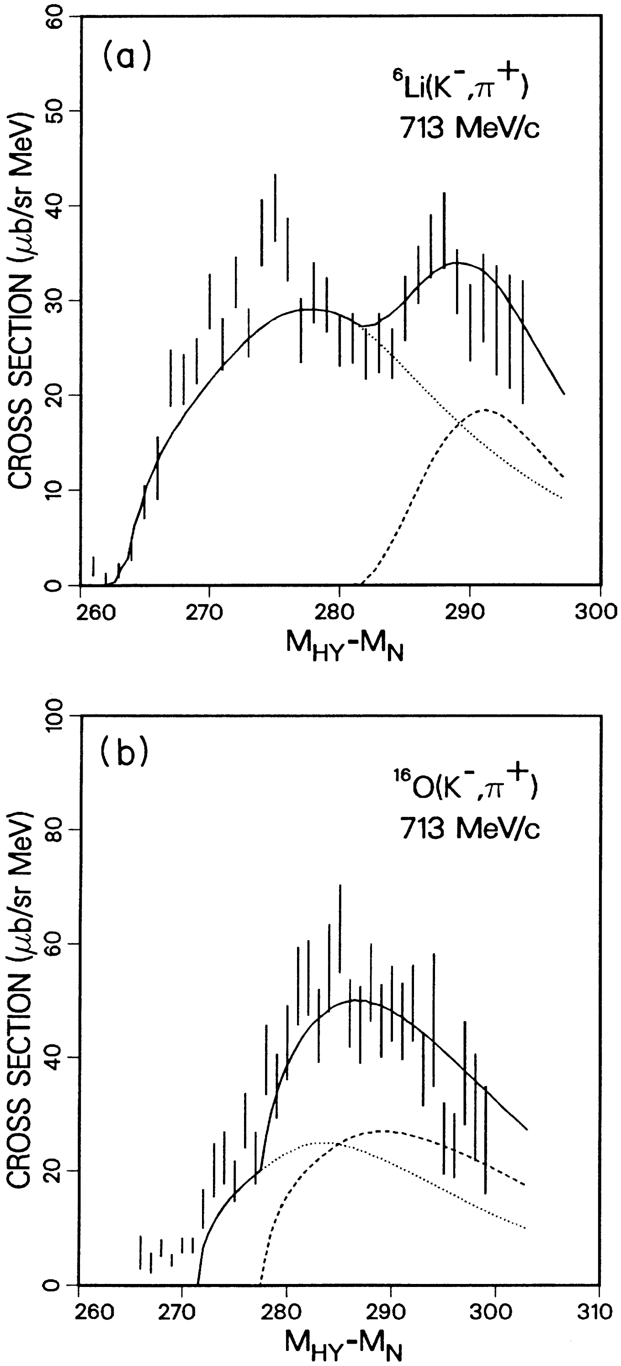

FIG. 2. Missing mass spectra for (K^-,π^+) reactions on ^{6}Li and ^{16}O as obtained at BNL (Ref. 11). The hole-state strengths of the residual nucleus are seen mirrored in the data. In (a) the $p_{3/2}$ (dotted) and s (dashed) components are separately shown, as is the sum (solid line). In (b) the $p_{1/2}$ (dotted) and $p_{3/2}$ (dashed) components are shown.

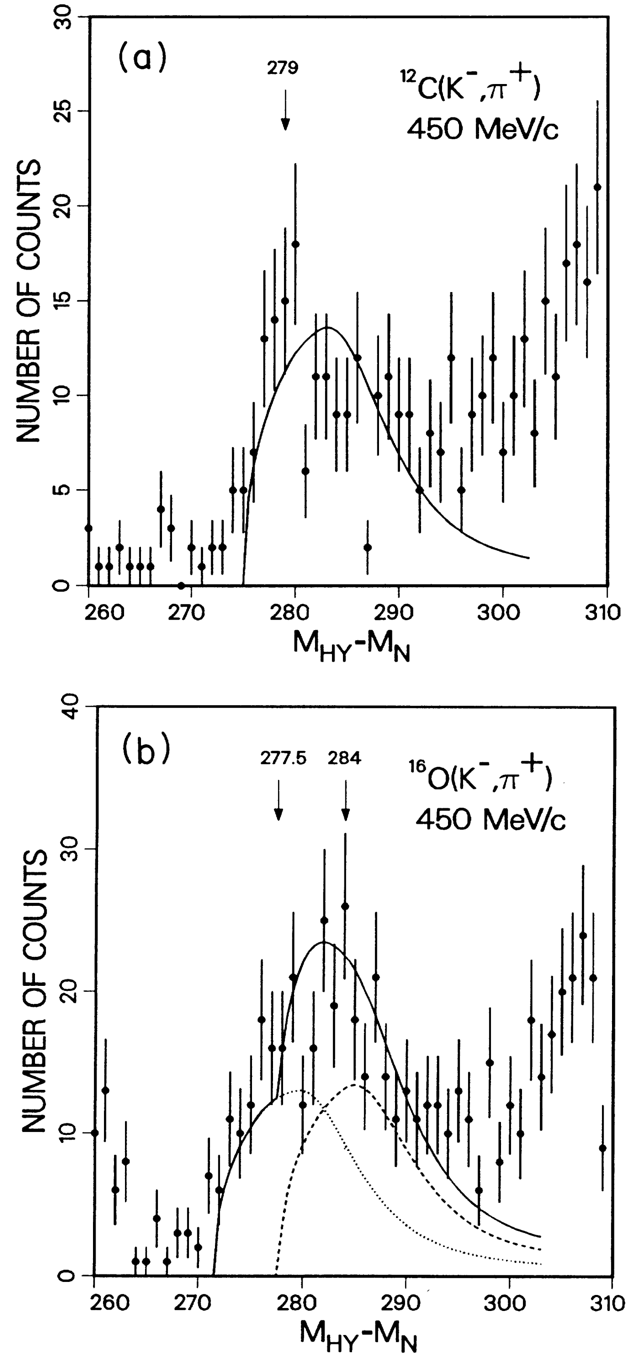

FIG. 3. Data from CERN (Refs. 2 and 3) studies are shown, along with the present quasifree calculations. In (a) the hole-state strength is assumed to be all in the ^{11}B ground state, while in (b) the $p_{1/2}$ (dotted) and $p_{3/2}$ (dashed) components are shown. The arrows show the positions of the proposed narrow states. The increasing background above $M_{HY}-M_N=290$ is primarily due to three-body kaon decay.

appears, the Y*(1520). This resonance has the effect of narrowing the quasifree distribution.

Several examples of comparing the present calculations to experimental data are shown in Fig. 2. We restrict the present discussion, for purposes of brevity, to the (K^-,π^+) data. Figure 2 shows a comparison to BNL data[11] for ^{6}Li and ^{16}O. We observe that the calculation adequately reproduces structure which can be associated with the

$p_{3/2}$ and s-proton hole strengths in the former case, and with the $p_{1/2}$ and $p_{3/2}$ hole strengths in the latter. Because of the peripheral nature of the (K,π) reaction, the appearance of the s-hole state is manifested only for the lightest p-shell hypernuclei.

In Figs. 3(a) and (b) we show comparisons to the experimental data of CERN.[2,3] As in Fig. 2 previously, the calculation has been normalized arbitrarily, since a calculation of the effective number of participating nucleons is beyond the scope of the present analysis.

It is clear from Figs. 2 and 3 that the present calculation accounts adequately for the shapes of the continuum. Similar calculations have been performed for (K^-,π^-) data in the continuum region reported for Λ and Σ hypernuclei at various momentum transfers. These calculations reproduce the continuum shape adequately in all cases. A complete description of the calculation and fits to known data will be published.

The positions of the narrow Σ states observed in the CERN studies are also shown in Fig. 3. These presumed states formed the basis of estimates on the Σ-nuclear spin-orbit splitting.[2,3] The conclusion of the present analysis is that it is essential to perform a proper correction for the underlying continuum, in order to evaluate the peak positions and intensities of the proposed structures, before drawing any conclusions about the shell model structure of Σ hypernuclei.

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