LA-UR -91-514

LA-UR--91-514

DE91 008536

MAR 1 1 1991

TITLE: HYPERNUCLEAR SPECTROSCOPY WITH THE (pi,K) REACTION

AUTHOR(S): J. Millener, BNL
M. B. Johnson, MP-DO and J. McGill, MP-DO

SUBMITTED TO: pi,K Physics Workshop
Los Alamos, NM
Oct. 9-11, 1990

HYPERNUCLEAR SPECTROSCOPY WITH THE (π,K) REACTION

J. Millener
Brookhaven National Laboratory, Upton, New York 11973

Mikkel B. Johnson and J. McGill
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

What are the advantages of (π, K) experiments at PILAC over hypernuclear physics studies at other facilities? The experiments at other facilities will take a long time, with counting rates comparable to those achieved at Brookhaven, whereas those at PILAC will run relatively fast. Coincidence experiments may be possible at PILAC but not at CEBAF (beyond the coincidences already necessary for the $(e, e'K^+)$ reaction). The kinematics of (γ, K) and (π, K) reactions are very similar. In terms of the reaction mechanism, spin-flip amplitudes dominate over nonnegligible $\Delta S = 0$ amplitudes in the elementary (γ, K) process, while the converse is true for the elementary (π, K) process. Also, the spin-flip contributions to (π, K) reactions are suppressed at small angles. This may be an advantage for separating two states that lie within the experimental resolution, if the one-body density-matrix elements for producing the two states have differing amounts of spin flip. At small angles, the state with the larger $\Delta S = 0$ amplitude will dominate, while at large angles, the state with the greater amount of spin flip will be relatively enhanced. There was a general feeling that the (π^-, K^0) experiments would be interesting and so there should be room made for a K^0 detector. This reaction transforms a proton into a Λ and can reach hypernuclei that are inaccessible via the (π^+, K^+) reaction (e.g., ${}^{9}_{\Lambda}$Li). It should be possible to install a K^0 detector in conjunction with PILAC.

The energy splittings of multiplets formed by coupling a Λ to a nuclear core carry fundamental information on the effective ΛN interaction. If the Λ is in an s orbit, only spin-dependent forces (e.g., spin-spin, spin-orbit, and tensor) contribute to doublet splittings. It is important to overdetermine the information on these contributions in order to assess the need for, and role of, possible three-body ΛNN forces. If the Λ is in a p (or higher) orbit, the $Q \cdot Q$ component of the dominant spin-independent central interaction can act and will generally give rise to larger splittings than would be obtained from the spin-dependent forces alone. For example, such interactions will give rise to fine structure in the peaks, due to the population of simple particle-hole (doorway) configurations, which dominate (π^+, K^+) spectra. Good resolution will enable studies of the single-particle structure, including fine structure, of hypernuclei to be extended to heavy targets such as ^{208}Pb, where the interleaved series of states based on the $i_{13/2}$ and $h_{9/2}$ neutron-hole states must be disentangled. Generally, states between the nucleon and Λ thresholds will decay by nucleon emission (Auger transitions) and thus possess escape widths, which have been estimated to be small compared with the spacing between Λ orbits. States involving p_Λ orbits may be particle stable, particularly in heavy hypernuclei, and are thus candidates for γ-decay coincidence studies. Nevertheless, the bottom line is that a lot can be done without polarization and coincidences.

Can one separate spin-orbit doublets? An example illustrates the problem. Consider a Λ in a $p_{1/2}$ or $p_{3/2}$ orbit coupled to ^{27}Si ground state with $J^\pi = 5/2^+$. Of the six resulting states, the two 3^- states should be strongly populated in the $^{28}\mathrm{Si}(\pi^+, K^+)^{27}_{\Lambda}\mathrm{Si}$ reaction. Unfortunately, the separation of the 3^- states is likely to be mainly due to the $Q \cdot Q$ interaction referred to above. The same is true for the corresponding 2^+ states in $^{12}_{\Lambda}$C. These states have a measured separation of 750 keV, which can be accounted for without any contribution from the spin-orbit splitting of the Λ p orbits. The Λ would need to be coupled to a well isolated 0^+ core state for a direct measurement to have a chance of working. In heavier nuclei, additional complications arise because of fragmentation. Also, p_Λ states in light nuclei are generally above particle thresholds so that the states will possess escape widths. Can we pick examples where the spin-orbit splitting can clearly be read from the spectrum? $^{13}_{\Lambda}$C provides one such example of bound p_Λ states where structure calculations show that the separation of the $1/2^-$ and $3/2^-$ states indeed provides a measure of the Λ spin-orbit splitting. Unfortunately, the $1/2-$ state is difficult to populate with the (π^+, K^+) reaction because of the low multipolarity of the transition.

What can one do with polarization? Hypernuclei can be produced with substantial polarizations in (π^+, K^+) reactions away from 0°. The amount of polarization can be very sensitive to configuration mixing. The exact way in which this is to be exploited remains to be developed. Generally, the polarization must be measured or utilized in coincidence experiments, such as the measurement of angular distributions of pions or protons following weak decay of the hypernucleus. Magnetic moments may be probed by using polarized hypernuclei.

How can we use coincidences? Various types include γ-ray coincidences and Auger coincidences (cascades by nucleon emission). Does the duty factor of PILAC work against coincidences? We cannot use a (π, K) trigger, unless the time structure of the beam is retained, because there are too many π's. We could use a K trigger. The duty factor can be overcome by a large solid angle. Doing this is not a difficult in principle, rather it is a matter of money. Coincidences are also needed for studying both mesonic and nonmesonic weak decays.

We may use γ cascades to improve resolution when the energy-level splitting is small. How high in A can one push γ-ray experiments? Heavy targets mean lots of gammas from many fragments, so the desired γ may be hard to pick out. It was pointed out that one should look for strong γ's from collective states in this case. In Auger cascades, it may be possible to see levels that would not be visible in one-step excitation. With segmented arrays, good count rates could be achieved. Experiments should be designed to look for specific signals.

It was stated that lifetime experiments are not interesting because to first approximation all lifetimes are about 200 ps. However, in rebuttal the point was made that Adams has shown that lifetimes vary from one nucleus to another across shell structure. PILAC will have a 20-30-ps bunch, so this might be used if sufficient thought is given to what would be learned. Branching ratios were felt to be more important than lifetime measurements: Γ_n, Γ_p, Γ_{π^-}, Γ_{π^0}, etc.

It was suggested that these ideas should be evaluated, keeping in mind that some of them could be done now with the 2-GeV line and H-particle spectrometer at Brookhaven. At this line, the number of (π, K) events/100 h-μb/sr = 25,000/A. The $\delta p/p = 0.5\%$, implying 3.5 MeV/c. For example, for ${}^{13}_{\Lambda}\mathrm{C}(P_\Lambda\text{-}S_\Lambda)$ transition with a $\Delta\Omega = 30\%$ of 4π, the number of γ-ray counts per 100 h is about 1000 events.

One should look for ways to enhance the signal of the Λ in its role as an impurity. The following ideas are speculative. Little has been done in the way of calculation, and it may not be possible to devise practical experiments to test the ideas.

What happens to collective motion when a Λ is inserted into the nucleus? In the case of rotational motion, it was asked which γ's need to be observed to extract the desired information from rotational levels. Perhaps the low-energy part of the spectrum, which has associated strong γ's, would be sufficient.

One might look for a collectivity that would not exist in the absence of the Λ. For example, this could be done by putting the Λ into valence shells in which there is already a lot of collectivity. Otherwise, the introduction of the Λ is a A^{-1} effect. Another way to magnify the effect is to insert a Λ into a nucleus that is soft or floppy. One can look for enhanced E2 transitions to see whether there are large structural changes. The effect of the Λ on modification of structure may be more prominent than A^{-1} on superconducting properties. The pairing barrier might be modified. It was pointed out that the effect on the pairing barrier has never been calculated. Although it was believed that this physics is quite interesting, there was a general feeling that these studies would be too difficult for the first experiments.

The properties of collective states, such as giant resonances, might be changed by a Λ impurity. Another interesting possibility would be (π, K) leading to fission. The Λ might modify the fission barrier, i.e., raising or lowering it.