MASTER

PRESENT AND FUTURE PROSPECTS FOR KAON PHYSICS*

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* Invited talk presented at the LAMPF Workshop on Pion Charge Exchange Reactions, Los Alamos, New Mexico, January 22-24, 1979.

**Permanent Address: Brookhaven National Laboratory, Upton, NY; partially supported by the Department of Energy under Contract No. EY-76-C-02-0016.

***Partially supported by the National Science Foundation.

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Kaons offer unique possibilities for studies of both nuclear and hypernuclear structure physics. Pioneering experiments on the formation of hypernuclei via the (K^-, π^-) reaction at 0° have been done at CERN (1,2). More recently, a high resolution spectrometer for the study of kaon-induced reactions has gone into operation at the Brookhaven AGS; preliminary data for (K^-, π^-) angular distributions have shown interesting new phenomena (3). I will briefly survey the present status of these experiments and their theoretical interpretation. Some possible future directions for hypernuclear physics will be indicated. These include: a) the exploitation of the higher resolution capability to separate the dominant Λ particle-neutron hole configurations in the "analog" region, thereby yielding important information on the Λ -nucleon effective interaction in the nucleus; b) the study of hypernuclear states involving "core excitation", for example $^{11}\text{C}^* + \Lambda$; c) the search for collective "strangeness analog resonances" in heavier nuclei; d) the production of double hypernuclei via the (K^-, K^+) reaction.

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In the second half of this talk, I will discuss the virtues of the K^+ as a nuclear probe (4). Unlike π^+ and π^- , the strong interactions of K^+ and K^- with nucleons are quite different, because of the role of strangeness. The low energy K^-N interaction is dominated by the formation of Y^* resonances with $S = -1$. The propagation of such resonances (like the N^* 's in the πN system) in the nuclear medium is of considerable interest. The low energy K^+N interaction, on the other hand, is non-resonant, except for the possible existence of exotic Z^* resonances in the region above 800 MeV/c. These $S=1$ resonances are "exotic" because they cannot be composed of 3 quarks, unlike the Y^* 's. Thus the K^- is strongly absorbed in nuclei, whereas the K^+ is weakly absorbed and sensitive to different aspects of the nuclear density.

To exhibit these differences, we display in Fig. 1 the mean free paths $\lambda = 1/\rho\sigma_{av}$ as a function of momentum for various hadrons in nuclear matter ($\rho = 0.16 \text{ fm}^{-3}$). We see that the K^+ is the only hadronic probe that can "see" the whole nucleus, except possibly for low energy pions (50 MeV or less). On the other hand, the $\bar{p}$ is representative of the strong absorption limit; it annihilates into pions at the slightest hint of the presence of nuclear matter. The K^- is seen to have a much shorter mean free path than the K^+ .

The large difference in mean free path for K^- and K^+ is reflected in a qualitatively different optical potential $V_{opt}(r) = V(r) - iW(r)$ for K^- or K^+ incident on nuclei. In Figure 2, we plot $V(r)$ and $W(r)$ at $p_{lab} = 500 \text{ MeV/c}$. The K^- potential is strongly absorptive with an attractive real part (although its depth is uncertain); the K^+ potential should be weakly absorptive with a repulsive real part at low energy.

This characteristic difference in $V_{opt}(r)$ would show up in angular distributions for $K^\pm$ - nucleus elastic scattering, as shown in Figure 3. The K^+ distributions should be rather unstructured, while the K^- angular dependence should be oscillatory.

Now let us focus attention on K^- -induced processes. The study of K^- induced strangeness exchange reactions on nuclei will continue to be of great importance for the future of hypernuclear physics. The (K^-, π^-) reaction affords the best means of populating particular final states involving a single Λ (or Σ) in the nucleus. This is because the (K^-, π^-) reaction imparts small momentum transfers (6) to the nucleus; hence the "sticking probability" for the Λ is sizeable and the cross sections are of the order of tenths of mb for particular final states. Other ways of forming Λ hypernuclei, for instance via the (p, K^+) or $(p, p' K^-)$ reactions, are less favorable because of the larger momentum transfer (although beam intensities are much higher for p than K^-). The detailed hypernuclear spectroscopy (spins and parities) of the Λ in the nucleus can eventually be unraveled by a study of (K^-, π^-) angular distributions, or, in light nuclei, by the

(K^- , π^- γ) reaction (7). High energy resolution is essential for establishing the detailed spectroscopy, since final hypernuclear states of different spin and parity are in many cases predicted by the Λ shell model to be clumped together in energy. The level order of such clumps of states (for instance 2^+ , 0^+ , 2^+ in $^{12}\text{C}_\Lambda$) reveals important features of the ΛN effective interaction. It will also be very interesting to see whether or not collective excitations (8) involving a Λ develop in heavy nuclei ("strangeness analog states"); the A dependence of the energies and isospin splittings of these states are important quantities to measure.

The data on the (K^- , π^-) reaction with coarse energy resolution can be simply interpreted (1,2,9,10) in terms of the particle-hole model (Λ -particle and neutron hole). Such a model is reasonable for the broadest energy-averaged structures. The relevant configurations and their estimated excitation energies for the example of $^{12}\text{C}_\Lambda$ are shown in Fig. 4. The lowest lying configurations are the ground state doublet ($_\Lambda S_{1/2} n \bar{P}_{3/2}^{-1}$) $1^-, 2^-$ and the excited states ($_\Lambda P_{3/2} n \bar{P}_{3/2}^{-1}$) $0^+, 1^+, 2^+, 3^+$ and ($_\Lambda P_{1/2} n \bar{P}_{3/2}^{-1}$) $1^+, 2^+$. The method (9,10) for calculating the (K^- , π^-) cross sections at 0° to such ph configurations is sketched in Fig. 5. The key concept is that of "effective neutron number" N_{eff} . Due to the effect of strong distortion of the K^- and π^- wave functions, N_{eff} is greatly reduced with respect to the neutron number N . Experimentally, N_{eff} is of the order of $1/2$ and only weakly A dependent (1,2). In terms of the impact parameter b , Figure 5 shows that the contribution of small b is suppressed because of the attenuation factor $\exp(-\sigma T(b))$; only valence neutrons can contribute to the (K^- , π^-) reaction. This "surface localization" is typical of reactions to particular final states with strongly absorbed particles.

The DWIA formalism of Fig. 5 has been applied by a number of authors (9,10,11). The most extensive calculations are due to Bouyssy (10); his (K^- , π^-) "strength functions" at $\theta_L = 0^\circ$ are shown in Fig. 6 for $^{16}\text{O}_\Lambda$. The contributions of each ph configuration are shown separately. The "analog states" ($_\Lambda P_{1/2} n \bar{P}_{1/2}^{-1}$) 0^+ and ($_\Lambda P_{3/2} n \bar{P}_{3/2}^{-1}$) 0^+ are dominant at 0° as expected, since the momentum transfer is small (but nonzero). Some of the early CERN data (1) is shown in the inset. Two peaks presumably corresponding to the two predicted 0^+ states are seen. A more recent CERN experiment (2) has revealed two more peaks in $^{16}\text{O}_\Lambda$ with lower cross sections, corresponding to the predicted 1^- states ($_\Lambda S_{1/2}, n \bar{P}_{1/2}^{-1}$) 1^- and ($_\Lambda S_{1/2}, n \bar{P}_{3/2}^{-1}$) 1^- .

The ph model is thus capable of explaining the number of peaks in the coarse resolution (K^- , π^-) spectrum and also their

relative intensities. Absolute cross sections do not seem to be predicted correctly, but there is considerable disagreement in the experimental normalizations obtained by the CERN and BNL groups (3).

The DWIA formalism can be extended in order to predict (K^-, π^-) angular distributions (11). For $\theta_L \neq 0^\circ$, the cross section is no longer simply proportional to the elementary $K^-n\pi^-\Lambda$ cross section at θ_L ; the (K^-, π^-) angular distribution reflects the size of the nucleus and not the angular dependence of the elementary process. Some of the results of Dover, Gal and Walker (11) for the $^{12}\text{C}(K^-, \pi^-)^{12}\text{C}^*\Lambda$ reaction at 800 MeV/c are shown in Figs. 7 and 8.

The excitation of unnatural parity states in $^{12}\text{C}_\Lambda$ at 800 MeV/c ($1^+, 2^-, 3^+$) was calculated to be very small at all angles. The cross section to these states must rely on the relatively weak spin flip (K^-, π^-) amplitudes and must also vanish at 0° . As expected, the excitation of 0^+ states dominates 1^- and 2^+ near 0° , but the latter states grow quickly with angle, and peak at about 10° and 20° , respectively. Since the peaks for 0^+ , 1^- and 2^+ states are well separated in angle, a measurement with sufficient energy resolution to resolve individual ph states would also lead to relatively secure spin assignments from their characteristic signature in the angular distribution. The angle corresponding to the peak cross section for each state with $J \neq 0$ can be displaced a few degrees by modifications of the K^- and π^- optical potentials. For a fixed attractive K^- potential, we illustrate the effect in Figs. 7 and 8, where we have assumed three different well depths for the real part of the pion potential. The curves shown represent rather extreme variations from strong attraction ($\text{Re}V_\pi < 0$) to strong repulsion ($\text{Re}V_\pi > 0$). The familiar " t_p " approximation, which is of dubious validity for strongly absorbed probes, yields a repulsive V_π , although not as strong as the example in Figs. 7 and 8. Increasing the degree of attraction for the pion tends to shift the peak position to smaller angles. For 0^+ states, increased pion attraction augments the slope of $d\sigma/d\Omega$ near 0° ; if we fit a form $d\sigma/d\Omega = (d\sigma/d\Omega)_0 \exp(-b^2(q^2 - q_0^2))$ to the calculated curves, where $q_0 = |k_K - k_\pi| \approx 50$ MeV/c, we find that b varies from 1.2 fm ($\text{Re}V_\pi > 0$) to 1.8 fm ($\text{Re}V_\pi < 0$) for the models chosen. Preliminary BNL data (3) seem to favor $\text{Re}V_\pi < 0$, which gives better agreement both with the slope for the analog peak and also the peak position (about 10°) for the excitation of the ground state. Elastic scattering data for K^- and π^- would be very useful in pinning down the distorting potentials for use in the (K^-, π^-) reaction.

The energy resolution of the first CERN and BNL experiments

(1,2,3) was not yet sufficient to resolve the $(\Lambda^{P_{1/2}} n^{P_{3/2}^{-1}})_{2^+}$ and $(\Lambda^{P_{3/2}} n^{P_{3/2}^{-1}})_{0^+, 2^+}$ states predicted at around 11 MeV excitation. The predicted summed cross section to these states is shown in Fig. 8. The effect of the 2^+ states is to produce a "shoulder" in the angular distribution in the region from 15-20°. The BNL data (3) show some evidence for this characteristic signature, but higher resolution studies are required to firmly establish the 2^+ states.

In light hypernuclei such as $^{12}\text{C}_\Lambda$, there are relatively few configurations which are available to form narrow states. Mixing of the 0^+ particle-hole states is expected to be small, and there is little chance for significant collectivity to develop. In heavy nuclei, there is the intriguing possibility that collective 0^+ "strangeness analog states" will emerge, as discussed by Kerman and Lipkin (8), and more recently by Kisslinger and Gai (12).

Some future directions for hypernuclear physics are the following:

a) higher resolution (K^-, π^-) experiments to resolve overlapping ph structures ("gross structure"); use of angular distribution or ($K^-, \pi^- \gamma$) reaction in P-shell hypernuclei to determine spin assignments.

b) search for weaker lines of more complicated structure ("core excitations"). An example would be a 1^- state in $^{12}\text{C}_\Lambda$ arising from the coupling of $^{11}\text{C}^*(1/2^-)$ to the Λ in an $S_{1/2}$ orbit. The energy and relative intensity of this state have been predicted by Dalitz and Gal (7). There is some preliminary evidence for such an excitation in the BNL experiment (3).

c) search for Σ hypernuclear states. Such configurations are expected a priori to be very wide, and hence one would expect only a quasielastic peak corresponding to the processes $K^- + n \rightarrow \pi^- + \Sigma^0$ or $K^- + p \rightarrow \pi^+ + \Sigma^-$. The preliminary data does not show any narrow peaks (3), but there could be some surprises later.

Eventually, it may be possible to produce double hypernuclei via the (K^-, K^+) reaction. Such $\Lambda\Lambda$ or Ξ^- hypernuclei would be interesting for several reasons: a) a new strong interaction spectroscopy, b) provide further tests of the SU(3) structure of the baryon-baryon interaction, c) possibly test MIT bag model predictions of a new $S = -2$ dibaryon (13).

Experimentally, $\text{He}_{\Lambda\Lambda}^6$ and $\text{Be}_{\Lambda\Lambda}^{10}$ have been seen as single events in emulsion experiments (14). The $\text{He}_{\Lambda\Lambda}^6$ event is shown in Figure 9. $\text{He}_{\Lambda\Lambda}^6$ is a particularly stable structure, since the two Λ particles can both occupy the 1s orbit.

Recently, A. Gal and I have made rough cross section estimates (15) for the formation of $\Lambda\Lambda$ hypernuclei. The result for

the summed cross section at 0° ($\approx 4 \mu\text{b/st}$) is given in Figure 10. The cross sections for particular low-lying final states are expected to be much smaller ($\leq 1 \text{ nb}$), since processes as shown in Figure 10 tend to produce a slow Λ_1 and a fast Λ_2 ; the sticking probability of Λ_2 in a particular shell model orbital is thus very small.

A Ξ^- hypernucleus may be formed in one step $K^-p \rightarrow K^+\Xi^-$ process shown in Figure 11. The Ξ^- may subsequently decay via the strong process $\Xi^-p \rightarrow \Lambda\Lambda$. In principle, this could also lead to a given $\Lambda\Lambda$ hypernuclear final state, and interfere coherently with the process shown in Figure 10. However, these two ways of getting to the same $\Lambda\Lambda$ final state will peak at quite different values of p_{lab} . The summed cross section of $30 \mu\text{b/st}$. at 0° for direct Ξ^- formation (at 1.25 GeV/c) is not very much larger than for the second order process of Figure 10. This is because $K^-p \rightarrow K^+\Xi^-$ is dominated by u-channel baryon exchange, and hence backward peaked (in θ_{K^+}) in the c.m. system. Not far from threshold, the resulting lab cross section is focussed in a forward cone; however, the 0° lab cross section is still rather small, as per Figure 11. Again, cross sections for leaving the Ξ^- in a low-lying shell model orbital are small, since $p_{\text{lab}}(\Xi^-) \approx 500\text{-}600 \text{ MeV/c} \approx 2 \text{ pf}$.

The damping widths for Σ and Ξ hypernuclear states are estimated in Figure 12. In both cases, a strong conversion process is allowed, so a priori such states should be very wide. However, the Q value is only 30 MeV for $\Xi^-p \rightarrow \Lambda\Lambda$ and this process is mediated by very short range exchanges (dominantly $K^*(890)$), unlike $\Sigma^-p \rightarrow \Lambda n$, which has long range π exchange. The relevant quantity ($v\sigma$) for $\Xi^-p \rightarrow \Lambda\Lambda$ is only about $8\text{-}9 \text{ mb}$, estimated in perturbation theory, so we arrive at an upper limit $\Gamma(\Xi^-) \approx 16\text{-}18 \text{ MeV}$ for the $1s$ orbit (15). A Ξ^- bound in an orbit with $l \geq 1$ could possibly give rise to a narrow structure. Such structures are worth looking for experimentally. States with a Σ^- , on the other hand, have $\Gamma_{\Sigma^-} \approx 60 \text{ MeV}$ for the $1s$ orbit. Narrow Σ^- or Σ^0 hypernuclear states would only occur if some other selection rule comes to the rescue; the crude estimate of Figure 12 ignores selection rules and assumes a high density of states.

Now let us turn to a discussion of some theoretical predictions for K^+ elastic, inelastic, and charge exchange scattering from nuclei (4,5,16). There is as yet no data to test these predictions. Since the K^+ is the only hadron which is weakly absorbed in nuclei over a sizeable energy range ($p_{\text{lab}} \leq 0.8 \text{ GeV/c}$), it can be viewed as the "electron" of strong interaction physics. The theoretical description of the mechanism of K^+ induced reactions on nuclei is in many cases simple and controllable. This allows the extraction of nuclear structure information with a minimum of ambiguity, unlike the situation for strongly absorbed

probes such as the pion. In particular, we mention the following possibilities for K^+ studies on nuclei:

a. Extraction of neutron densities from measurements of elastic and total cross sections (5);

b. Inelastic and charge exchange scattering of K^+ to particular residual nuclear states (16). The excitation of high spin, unnatural parity states is particularly interesting, both from the nuclear structure point of view and as a means of discriminating between various models for the elementary K^+ -nucleon amplitudes. The K^+ could also effectively be used to explore the systematics of giant monopole and quadrupole resonances in nuclei, as well as the isospin splittings of giant resonances through kaon charge exchange reactions.

c. Quasiparticle properties of more deeply bound nucleon orbitals in the shell model via the (K^+, K^+p) reaction; also K^+ scattering with large energy loss ("deep inelastic" processes).

Since the K^+ is weakly absorbed, a density expansion of $V_{\text{opt}}(r)$ should converge rapidly, the dominant term being proportional to $f_{K^+n} \rho_n(r) + f_{K^+p} \rho_p(r)$. It thus should be a useful probe of neutron densities $\rho_n(r)$. In Figure 13, we show how total K^+ elastic and reaction cross sections σ_E and σ_R change when the radius and surface thickness of $\rho_n(r)$ are changed by ΔR and Δa (5). Measurements of σ_E and σ_R at the level of 1-2% should yield useful constraints on $\rho_n(r)$.

Inelastic scattering and charge exchange reactions of $K^\pm$ on nuclei look very promising both for nuclear structure studies and, in some cases, in furnishing constraints on the elementary amplitudes (16). In distorted wave impulse approximation (DWIA), the relevant formulae are displayed in Figures 14 and 15. From the decomposition of the inelastic amplitude into pieces with $\Delta S = 0, 1$ and $\Delta T = 0, 1$, one can easily discuss the spin and isospin flip nature of the strongest transitions. The main results are:

1. For K^+ , we expect a strong isospin selection rule $\Delta T = 0$ for $p_{\text{lab}} \leq 400$ MeV/c, since the elementary K^+N $I = 1$ amplitude dominates in most models.

2. For both K^+ and K^- , the $\Delta S = 0, \Delta T = 0$ term generally dominates, so we expect the largest cross sections to $J^\pi = 1^-, 2^+, 3^-$ natural parity $T = 0$ states, starting from a $0^+, N = 2$ target. Kaons could thus excite giant quadrupole (or monopole) resonances. Typical angular distributions (16) for K^+ inelastic scattering on ^{12}C at 800 MeV/c are shown in Figure 16.

3. Transitions to unnatural parity states are particularly interesting, since they reveal the isospin dependence of the spin flip amplitudes ($\Delta S = 1$). An example is shown in Figure 17 for the $4^-, T = 0, 1$ states in ^{12}C . The results at low momentum are seen to be very sensitive to the choice of the elementary K^+N

amplitude, since the leading $\Delta S = 0$, $\Delta T = 0$ term is absent. Transitions to angular momentum "stretch" configurations in heavier nuclei (6^- states in ^{28}Si , for instance) also deserve study.

4. Charge exchange reactions are also useful, since they enable us to unravel the spin dependence of isospin flip amplitudes ($\Delta T = 1$). For (K^-, K^0) , the $\Delta S = 0$ terms dominate near 800 MeV/c, so we expect to populate $1^-, 2^+ \dots$ natural parity states. Such reactions would be useful for studying the systematics of T_z components of giant dipole resonances, for instance. Typical charge exchange predictions (16) are shown in Figure 18. The (K^-, K^0) predictions, like those for (π^+, π^0) obtained in DWIA, are not very reliable, because of the strong distortion effects. The (K^+, K^0) reaction, on the other hand, is much more amenable to theoretical calculation, since the distortions are weak. This reaction may ultimately be quite useful for extracting information on nuclear wave functions, since the reaction mechanism should be well understood. Comparisons of the (π^+, π^0) and (K^+, K^0) reactions leading to the same final states may be very illuminating.

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Fig. 1

Fig. 2

Fig. 3

ENERGY LEVELS IN $^{12}_{\Lambda}\text{C}$

W. Brückner et al, Phys. Letters (1975)
(Povh group at CERN)

Fig. 4

CROSS SECTIONS FOR PRODUCTION OF HYPERNUCLEI IN (K^-, π^-) REACTION:

TO SPECIFIC STATE:

$$\frac{d\sigma^J}{d\Omega_B}(0^0) = N_{\text{eff}}^J \frac{d\sigma^{K^- n \rightarrow \pi^- \Lambda}}{d\Omega_L}(0^0)$$

$$N_{\text{eff}}^J = (2J+1) (2j_{\Lambda}+1) (2j_n+1) \left(\begin{matrix} j_{\Lambda} & j_n & J \\ 1/2 & -1/2 & 0 \end{matrix} \right)^2 |\langle n_{\Lambda} \ell_{\Lambda} | \hat{j}_J(r) | n_n \ell_n \rangle|^2$$

SUM RULE:

$$\sum_{j_{\Lambda} j_n N J} \frac{d\sigma^J}{d\Omega_L}(0^0) = N_{\text{eff}} \frac{d\sigma^{K^- n \rightarrow \pi^- \Lambda}}{d\Omega_L}(0^0)$$

$$N_{\text{eff}} = \int d^3r_{\Lambda} \rho_n(r) |\chi_{\pi^-}^{(-)}(r)|^2 |\chi_{K^-}^{(+)}(r)|^2$$

$$\approx \frac{N}{A} \int d^2b_{\Lambda} T(b) e^{-\bar{\sigma} T(b)}$$

$$\text{where } T(b) = \int_{-\infty}^{+\infty} \rho(r) dz, \quad \int d^2b_{\Lambda} T(b) = A$$

In plane wave approximation, $N_{\text{eff}} \rightarrow N$. Experimentally, $N_{\text{eff}} \approx 1/2$, roughly

independent of A.

Fig. 5.

(K^-, π^-) STRENGTH FUNCTION FOR $^{16}\text{O}_\Lambda$
 A. Bouyssy, Nucl. Phys. A290, 324 (1977)

Fig. 6

$^{12}\text{C}(\text{K}^-, \pi^-)^{12}\text{C}_\Lambda(1^-)$

800 MeV/c

DOVER, GAL, WALKER
(BNL preprint (1979))

Fig. 7

D. J. Prowse, Phys. Rev. Letters 17, 782 (1966)

$\text{He}_{\Lambda\Lambda}^6$ Double Hypernucleus
seen in $\text{K}^- + \text{Emulsion}$ (4-5 GeV)

- a) (K^-, K^+) to make Ξ^-
- b) $\Xi^- + {}^{12}\text{C} \rightarrow \text{Li}^7 + \text{He}_{\Lambda\Lambda}^6$
- c) $\text{He}_{\Lambda\Lambda}^6 \rightarrow \pi^- + \text{p} + \text{He}_{\Lambda}^5$
- d) $\text{He}_{\Lambda}^5 \rightarrow \pi^- + \text{p} + \alpha$

Fig. 9-

SUMMED FORMATION RATE FOR $\Lambda\Lambda$ HYPERNUCLEI:

$$\Sigma_f \left(\frac{d\sigma}{d\Omega_L} \right)_{0^+}^{\Lambda\Lambda, f} \approx \beta \left(\frac{d\sigma}{d\Omega_L} \right)_{0^+}^{K^- p \rightarrow \Lambda \pi^0} \left\langle \frac{1}{r^2} \right\rangle \left(\frac{d\sigma}{d\Omega_L} \right)_{0^+}^{\pi^0 p \rightarrow \Lambda K}$$

$\uparrow$ $\uparrow$ $\uparrow$
 0.76 mb/st 0.03 mb⁻¹ 0.65 $\frac{\text{mb}}{\text{st}}$

where

$$\beta \approx 8\pi^2 (1 - Q_0^{(1)}/v_{\pi L} E_{\Lambda 1L}) (1 - Q_0^{(1)}/v_{K^+ L} E_{\Lambda 2L}) \xi / 2k_{\pi L}$$

For $k_L^{K^-} \approx 1.1 \text{ GeV/c}$, $Q_0^{(1)} \approx 0.08 \text{ GeV/c} = k_{\Lambda 1L}$, $Q_0^{(2)} \approx 0.42 \text{ GeV/c} = k_{\Lambda 2L}$

$$\xi = \int \frac{d^2 Q}{(2\pi)^2} \left| \frac{t_1(\vec{Q})}{t_1(0)} \right|^2 \left| \frac{t_2(-\vec{Q})}{t_2(0)} \right|^2 \approx 0.02 \text{ mb}^{-1}$$

$$\beta \approx 0.28$$

$$\Sigma_f \left(\frac{d\sigma}{d\Omega_L} \right)_{0^+}^{\Lambda\Lambda, f} \approx 4 \text{ } \mu\text{b}$$

Fig. 10

FORMATION OF Ξ^- HYPERNUCLEI:

Kinematics:

$k_L^{K^-}$ (GeV/c)	k_{Ξ^-}	$(\frac{d\sigma}{d\Omega_L})_0^{K^- p \rightarrow K^+ \Xi^-}$
1.25	0.56	28 $\mu\text{b/st.}$
1.61	0.51	16

$$\sum_f \left(\frac{d\sigma}{d\Omega_L} \right)_0^{\Xi^-,f} \approx \left(\frac{d\sigma}{d\Omega_L} \right)_0^{K^- p \rightarrow K^+ \Xi^-} z_{\text{eff}}$$

$$z_{\text{eff}} \approx \int d^3x \rho_p(r) |\chi_{K^-}^{(+)}(r)|^2 |\chi_{K^+}^{(-)}(r)|^2$$

$$\approx \int d^3x \rho_p(r) e^{-L(b)/\hat{\lambda}} \approx 1 \text{ for He}^4$$

$$L(b) = \int_{-\infty}^{+\infty} \rho(b, z') dz' / \rho(0); \hat{\lambda} \approx \left(\frac{1}{\rho \sigma_{K^+}} + \frac{1}{\rho \sigma_{K^-}} \right) / 2 \approx 3 \text{ fm}$$

$$\sum_f \left(\frac{d\sigma}{d\Omega_L} \right)_0^{\Xi^-,f} \approx 30 \mu\text{b/st for } k_L^{K^-} \approx 1.25 \frac{\text{GeV}}{c}$$

Fig. 11

DAMPING WIDTHS OF Σ AND Ξ STATES:

$$\Gamma_{\ell j} \approx v\sigma \int_0^\infty dr \rho_p(r) u_{\ell j}^2(r)$$

1) observed $\sigma_{\text{TOT}}^{\Sigma^- p \rightarrow \Lambda n} \approx 150 \text{ mb}$ at $P_{\text{L}\Sigma} \approx 150 \text{ MeV/c}$

$\therefore (v\sigma)_{\Sigma^- p \rightarrow \Lambda n} \approx 30 - 100v \quad (v \leq 0.1)$

2) calculated $(v\sigma)_{\Xi^- p \rightarrow \Lambda n} \approx 8 - 9 \text{ mb}$

For uniform density $\rho_p(r) = 3Z/4\pi R^3 \quad r \leq R$

$$\Gamma_{\ell j} \approx v\sigma \frac{3Z/4\pi R^3 \int_0^R u_{\ell j}^2(r) dr}{\leq 1}$$

$$\Gamma_{1S} \approx (2 \text{ MeV/mb}) v\sigma$$

$\therefore \Gamma_{1S}^{\Sigma^-} \approx 60 \text{ MeV}$

$\Gamma_{1S}^{\Xi^-} \approx 16 - 18 \text{ MeV} \quad \leftarrow \ell \geq 1 \text{ could be narrow!}$

Fig. 12

K^+ as probe of neutron density
Sensitivity to changes in
radius ΔR and diffuseness Δa

$$\rho_n(r) = \rho_0 / 1 + e^{(r-R)/a}$$

$$R \rightarrow R + \Delta R$$

$$a \rightarrow a + \Delta a$$

Fig. 13

INELASTIC SCATTERING (more detail):

$$\frac{d\sigma}{d\Omega} (0^+ \rightarrow J^{\pi}) \sim |F|^2 \sim \left| \sum_{\substack{\ell_p \ell_h \\ j_p j_h}} \alpha_{ph} M_{ph} \right|^2$$

$$\pi = (-)^{\ell_p + \ell_h}$$

$$\text{Expand } \chi_E^{\ell} (p_i, k) = \sum_n a_{n\ell} (p_i) \delta(k_n - k)$$

$$M_{ph} \sim \sum_i a_{n\ell_a}^* a_{n\ell_b} (N + \hat{N})^{\alpha'}$$

$$N = \begin{pmatrix} \ell_p \ell_h J \\ 0 0 0 \end{pmatrix} \begin{pmatrix} A_{\Delta T}^{\Delta S} = 0 \\ B_{\Delta T}^{\Delta S} = 0 \end{pmatrix} + \begin{pmatrix} A_{\Delta T}^{\Delta S} = 0 \\ B_{\Delta T}^{\Delta S} = 1 \end{pmatrix}$$

$$\hat{N} = \sum_{\bar{J}} \begin{pmatrix} \ell_p \ell_h \bar{J} \\ 0 0 0 \end{pmatrix} \begin{pmatrix} \ell_p & 1/2 & j_p \\ \ell_h & 1/2 & j_h \\ \bar{J} & 1 & J \end{pmatrix} \begin{pmatrix} C_{\Delta T}^{\Delta S} = 1 \\ D_{\Delta T}^{\Delta S} = 1 \end{pmatrix}$$

SELECTION RULES:

$$N: \quad \pi = (-)^J \quad 0^+, 1^-, 2^+ \dots$$

$$\hat{N}: \quad \pi = (-)^{\bar{J}} \quad 1^+, 2^- \dots \quad (\text{also } 1^-, 2^+ \dots)$$

(spin-flip)

$$0^+ \rightarrow 0^- \quad \text{always forbidden}$$

INELASTIC SCATTERING OF SPIN 0, ISOSPIN 1/2 PROJECTILES:

$$A_{\Delta T=0}^{\Delta S=0} = \ell (f_{\ell-}^0 + 3f_{\ell-}^1) + (\ell+1) (f_{\ell+}^0 + 3f_{\ell+}^1)$$

$$B_{\Delta T=1}^{\Delta S=0} = \ell (f_{\ell-}^0 - f_{\ell-}^1) + (\ell+1) (f_{\ell+}^0 - f_{\ell+}^1)$$

$$C_{\Delta T=0}^{\Delta S=1} = \sqrt{\ell(\ell+1)} (f_{\ell+}^0 - f_{\ell-}^0 + 3f_{\ell+}^1 - 3f_{\ell-}^1)$$

$$D_{\Delta T=1}^{\Delta S=1} = \sqrt{2\ell(\ell+1)} (f_{\ell+}^0 - f_{\ell-}^0 + f_{\ell-}^1 - f_{\ell+}^1)$$

$$f_{\ell\pm}^I = \frac{Plab}{k} \frac{g_{\ell\pm}^I(k_n') g_{\ell\pm}^I(k_n)}{[g_{\ell\pm}^I(k)]^2} f_{\ell, j=\ell\pm 1/2}^{I, c.m.} \begin{matrix} \vec{\tau}_k + \vec{\tau}_N \\ \swarrow \end{matrix}$$

ISOSPIN SELECTION RULES:

- 1) If $|f^1| \gg |f^0|$, as for low energy K^+ then

$$|A|^2 / |B|^2 \approx g \rightarrow \Delta T = 0 \text{ favored}$$

- 2) If $|f^1| \ll |f^0|$, then $|A|^2 \approx |B|^2$

K^+ INELASTIC EXCITATION FUNCTION

(DOVER, WALKER BNL 25199)

- 1) natural parity states dominate
- 2) high momentum transfer $\rightarrow$ high spin

Fig. 16

INELASTIC SCATTERING TO
HIGH SPIN STATES

Fig. 17

$(K^-, \bar{K}^0)$ CHARGE EXCHANGE

EXAMPLE: $^{30}\text{Si} (K^-, \bar{K}^0) ^{30}\text{Al}$ at 300 MeV/c

- 1) $\Delta T = 1$ only
 $|B|^2$ dominates
- 2) make $T_>$ states

Fig. 18