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THE K^+-NUCLEUS INTERACTION

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ABSTRACT

The K^+-nucleus system is reviewed and comparison with data is made. The principal conclusions are that the theoretical uncertainties in relating the K^+-nucleus interaction to the K^+-nucleon interaction are very small and hence the positive kaon makes an excellent probe of the nucleus. It is suggested that this particle may be more sensitive to non-nuclonic degrees of freedom (especially quarks) than classical probes.

INTRODUCTION

Among particle probes the K^+ holds a very special position. Because the antiquark in its constitution is strange and since there are no (valence) strange quarks in the nucleon, a quark-quark annihilation is not possible. Thus the system cannot couple to a 3-quark object. The K^+-nucleon system is a true 5-quark quantity and, presumably because of this, there are no presently known K^+N resonances below 1 GeV/c. For this reason the interaction has two important properties: it has a slow energy dependence, and it is very weak -- the weakest of all known strong interactions.

THE NUCLEON VIEW

The implications of this feeble interaction for K^+-nuclear scattering are significant. Distortion effects are small, so that an approximate treatment of them is of even greater utility than in the case of pion and nucleon projectiles. The lack of a strong energy dependence is very important for theories which are to treat the scattering and distortion effects because the (almost) direct use of measured phase shifts is possible. In contrast, in the case of pion projectiles near the (3,3) resonance for example, the binding of the nucleons introduces complications in the construction of an effective nuclear potential from the phase shifts. Since the principal partial wave is s (not p-wave as for pions) nucleon recoil effects are much smaller. Since there is less multiple scattering, the finite range of the interaction plays a less important role. Having made these qualitative statements we are left with the question: "How small are these medium correction effects?"

We have recently finished a study[1] to quantify the errors caused by these possible corrections. The multiple scattering

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theory used is a form of the optical potential developed for pseudoscalar meson scattering by many workers over the past decade[2]. Pauli blocking effects, so important in nucleon and pion scattering from nuclei, are totally negligible for incident momenta ~ 800 MeV/c, where the present differertial cross section data exist. The blocking will become noticeable for kaon momenta less than ~300 MeV/c.

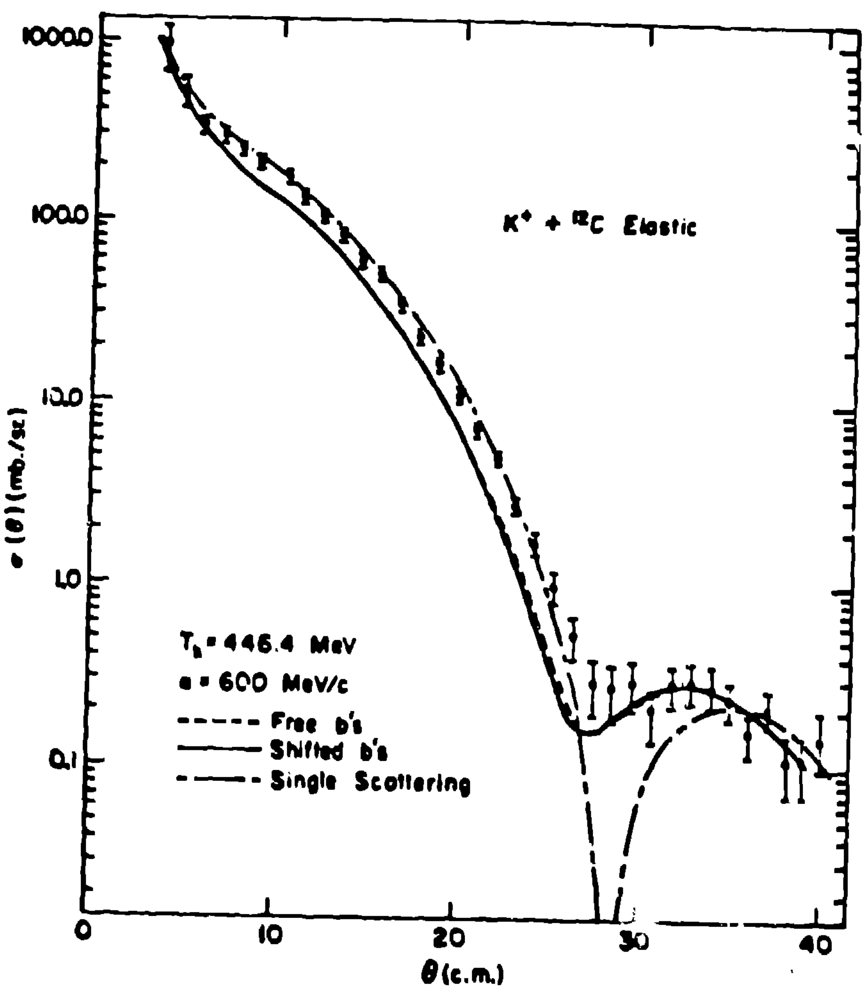

Fig. 1 Effects of the Energy Shifts. The quantity "α" is the off-shell range.

Fig. 1 shows t.e result of the correction to the kaon-nucleon amplitudes caused by the fact that the nucleon interaction with the kaon is bound in a finite nuclear well. This correction is significant in pion scattering and reactions but is seen to be of no consequence in the K^+ case. Also shown is the recent data of Marlow et al.[3] As might be expected the Born approximation gives a reasonable representation of the data and the full calculation follows the data well, but is far from perfect.

The effect of the finite size of the K^+-nucleon system in off-shell scattering also comes into play to the degree that multiple scattering is important. The inclusion of this correction is also very important in the pion-nucleus interaction. Fig. 2 shows the variation of the differential cross secton due to our uncertainty as to the value of the off-shell range. We see that there is, in fact, some sensitivity to this quantity in the minimum.

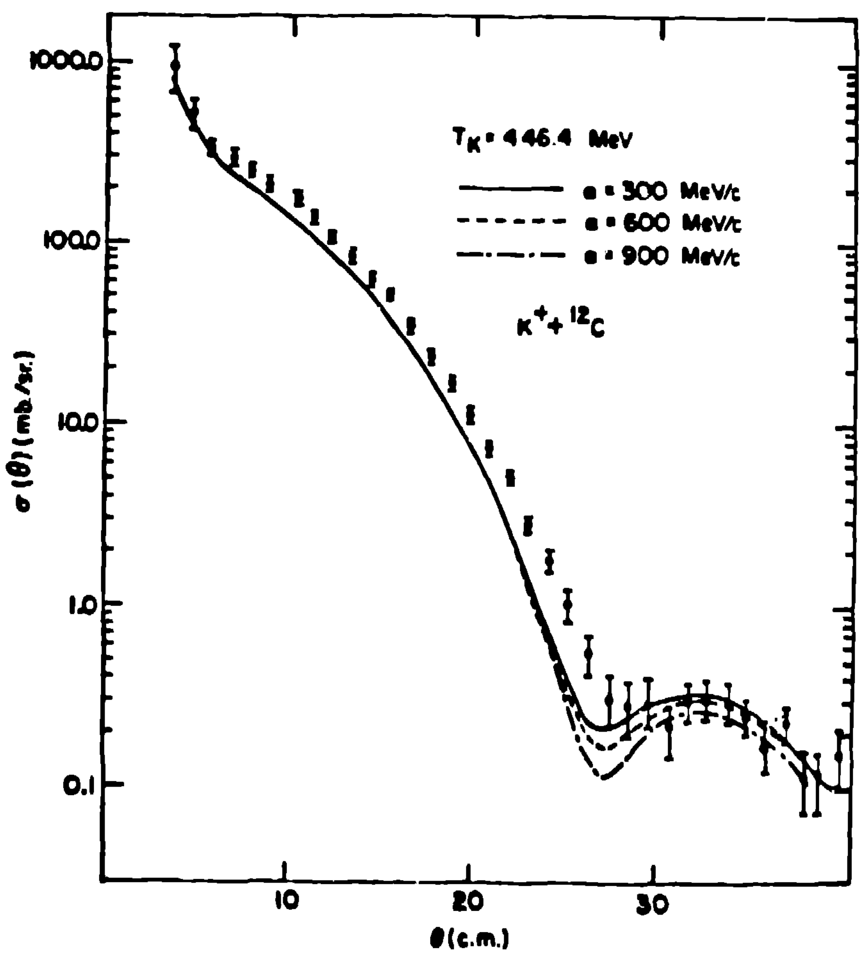

Fig. 2. Effect of the off-shell range on the differential cross section for elastic scattering.

It is important to take into account, not only the s- and p-waves, but the d- and f-waves of the K^+-nucleon interaction as well. We find that the contribution of these higher partial waves is of the order of 15%. In the work presented in Ref. 1 they have been included in a distorted wave approximation. We estimate the error in the differential cross section due to this approximation to be less than 4% except in the minimum of the angular distribution. To do better than this one must include these small partial waves exactly.

In summary, the K^+-nucleus interaction can be constructed from the K^+-nucleon interaction with much greater reliability than any other strongly interacting particle. The present contribution from the theoretical corrections are to be characterized by a number around 4%. The error is considerably less in the forward direction (2%) and larger in the minima. Hard work on the theory may be expected to decrease the errors to the order of 1%.

This analysis does not include uncertainties in the K^+-nucleon phase shifts. A study of these errors was made by Coker et al.[4]. Fig. 3 shows their results. The present uncertainties in these phase shifts is clearly significant and better K^+-nucleon data is needed.

All of this assumes, of course, that the relevant degrees of freedom of the nucleus are entirely nucleonic. We will return to this question later.

Another result of the weakness of the interaction of the K^+ is that it penetrates deeply into the nucleus. Thus the whole nuclear volume is sampled, not just the

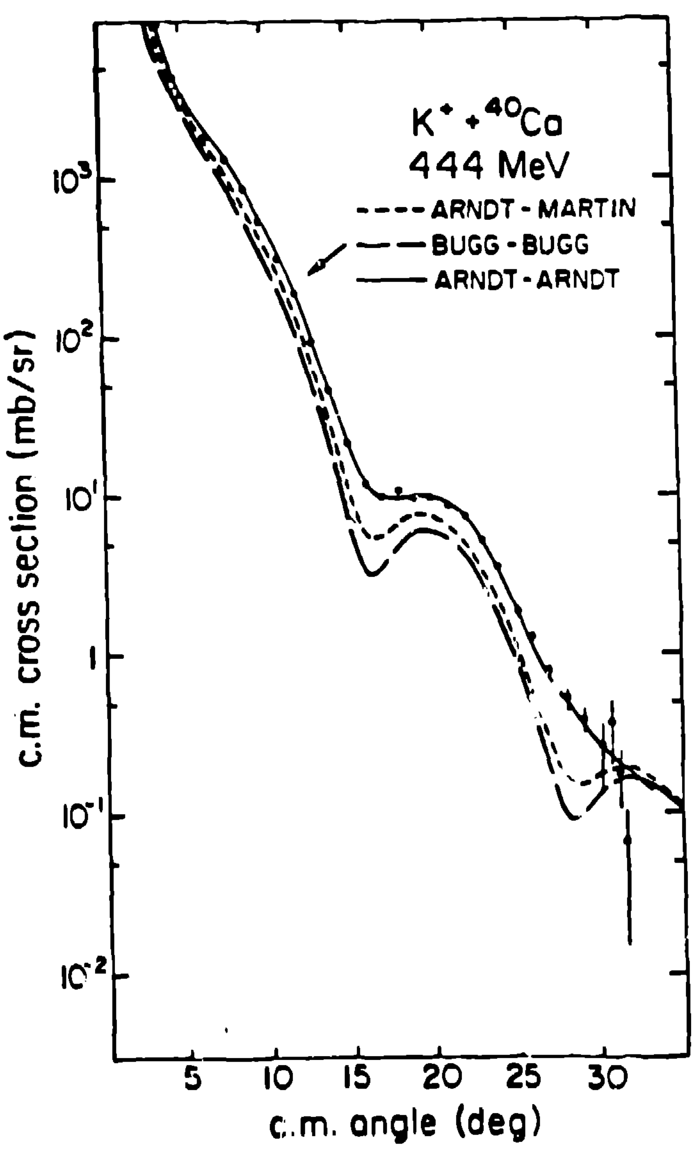

Fig. 3. Calculations using different phase shifts for the K^+-nucleon amplitudes. This figure is from Ref. 4.

surface, as is the case for the resonant pions, or to a lesser extent, protons. This allows us to obtain a more complete picture of the nucleus. Since the interaction of the K^+ with neutrons is about the same as with protons, the comparison of K^+ scattering with a proton distribution inferred from electron scattering provides the best known means for studying the neutron distribution in nuclei. As shown by Coker et al.[4], the K^+ is superior to the proton for probing neutron densities inside the nuclear surface.

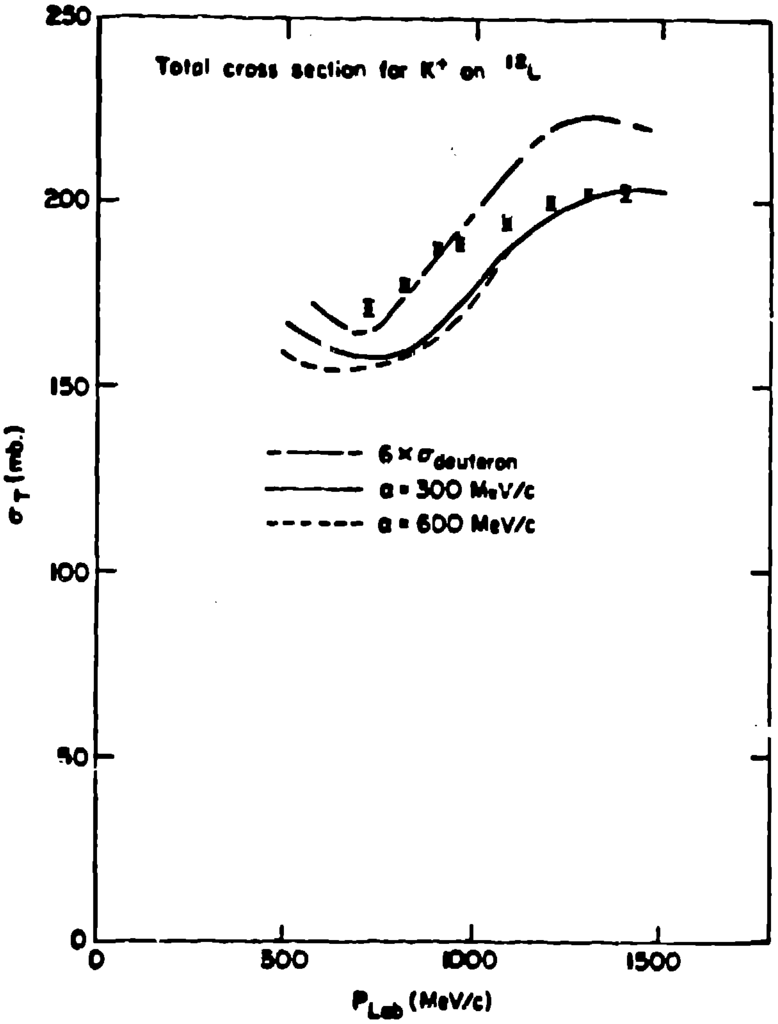

Fig. 4. Comparison of the ^2H and ^{12}C total cross section showing the shadowing expected. The two values of the off-shell range show the theoretical uncertainties expected.

From comparison with data in the first three figures one has the impression that a clear discrepancy between theory and experiment exists. Indeed there does seem to be a problem. We undertook a study of experimental unknowns[1] to see if the discrepancy is well established. Of particular interest are the effect of the normalization uncertainty, the finite angular resolution and the beam momentum uncertainty of the data. The combination of these variables allowed us to achieve a χ^2/data point of less than one for the ^{40}Ca elastic data but ≥ 1.4 for the ^{12}C. Thus, I would say that evidence for a discrepancy is present but not very strong.

An interesting comparison that can be made is the total cross section for K^+ on deuterium and ^{12}C, both of which were measured some time ago[5]. One expects almost no shadowing for the deuteron because of its few nucleons at low density. The shadowing in ^{12}C is not expected to be large but one should expect the ^{12}C total cross section to be slightly less than 6 times the corresponding deuteron cross section. It may be seen from Fig. 4 that the multiple scattering calculations show just such an effect, being about 10% smaller than 6Xd. The ^{12}C data agrees with this amount of shadowing at the highest energy shown, but for the lower energy is actually bigger than 6Xd! This result is difficult to reconcile with our present models of the nucleus and we may be led to suspect the data, but there are cross-checks which which tend to make errors in the data unlikely. Does this suggest that ^{12}C is not just 12 nucleons?

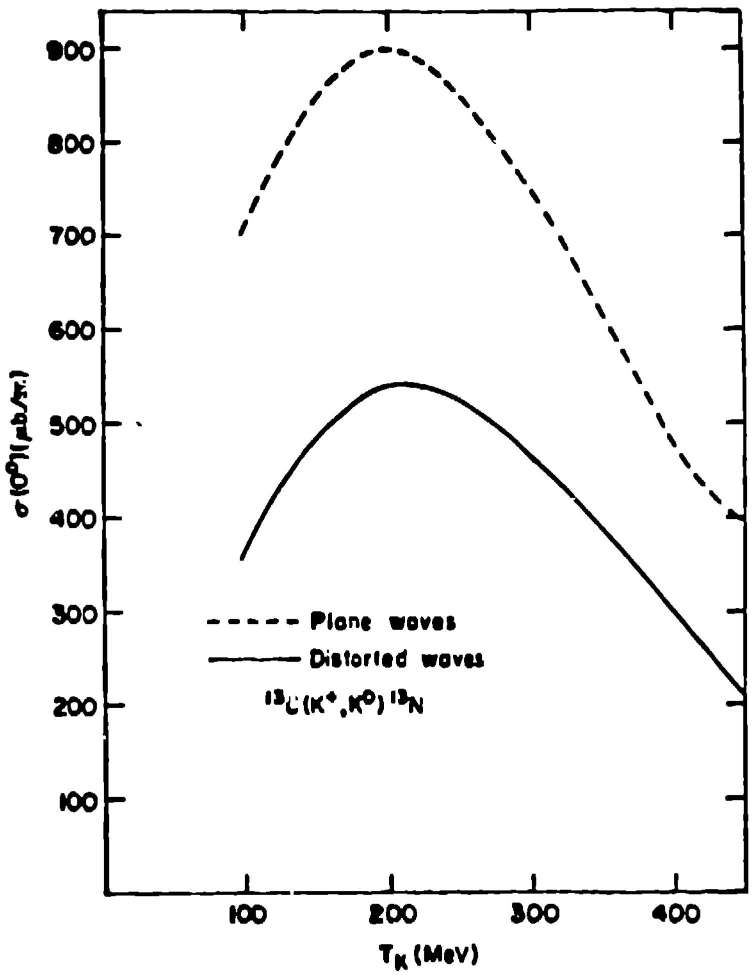

Fig. 5. The K^+ charge exchange reaction. As it may be seen, the distortion effects are substantial even for a probe this weak.

Valence neutron distributions can also be studied with the charge exchange reaction (K^+,K°), the K° also being weakly interacting for the same reasons as the K^+. The distortion effects in this reaction are much smaller than the corresponding pionic case so that the nuclear structure information can be extracted with much greater confidence. The calculated[1] zero degree cross section for kaon charge exchange on ^{13}C is shown in Fig. 5. The magnitude is about the same as the corresponding pion cross section. Because of the rapid decrease in the angular distribution however, the integrated cross section is much smaller than in the pion case.

The selective nature of the K^+ has also been studied[6]. Because of its special characteristics, different states will tend to be excited than with other probes. As expected for a weakly absorbed probe, there is selective excitation of low spin states at low momentum transfer and high spin states for high momentum transfer.

THE QUARK VIEW -- COMPLEMENTARY PROBES

The above discussion was based on a picture of the nucleus composed only of nucleons. We now know that this oversimplified view requires modification. Should the K^+ see more or less of the non-nucleonic components than, say, a pion? The answer seems to be, very likely, more.

To see why, let us compare the case of coherent single charge exchange for pions and K^+'s. The π^+ and K^+ have roughly similar mass and both are pseudoscalar mesons. Experimentally the situation is similar, a secondary meson beam is produced, steered onto a isospin-non-zero target and the final neutral meson (π° or K°) is detected by measuring its two-body decay ($\gamma\gamma$ or $\pi^+\pi^-$). Even on a quark level there are some similarities. The π^+ ($u\bar{d}$) must find a ($\bar{u}d$) quark pair or exchange its u quark for a d quark to become a π° (linear combination of $u\bar{u}$ and $d\bar{d}$) and the K^+ ($u\bar{s}$) must do the same thing to become a K° ($d\bar{s}$).

Here the similarities end. The pion is very likely to exchange a u for a d-quark with a nucleon since it forms resonances with nucleons readily and thus spends more time in their vicinity. The K^+ only spends a short time near the nucleon so that the probability of exchanging a d-quark in the area of baryonic center is not much greater than anywhere else (except of course for the fact that the d-quark density is higher there). Thus while either pions or K^+'s can be regarded as probing the quark distribution in nuclei the weighting function for pions (due to the baryonic resonances) distorts the picture greatly while the K^+ sees a cleaner view of the quarks in the nucleus.

The accuracy of the nucleonic picture of K^+-nucleus scattering has been established. We may search for quark (or mesonic) degrees of freedom by looking for deviations from the nucleonic model. The questions are now clear.

On the theoretical side: What is the magnitude of possible quark effects in nuclei? Some simple pictures immediately come to mind. If the K^+ sees a "small" nucleon then, if the nucleon swells in the nucleus (Noble, Shakin) or if quarks, in fact, percolate between nucleons (Stephenson, Goldman) then the space between the nucleons may be filled in with quarks. Either one of these will have an effect on the total and differential cross sections. What a golden opportunity to test these kinds of predictions! Are the effects large enough to be seen?

On the experimental side: To what level can the limits of non-nucleonic theories to be pushed? Can we actually see such effects? Have we already seen some indications of non-nucleonic effects but at a marginal level? This is clearly a challenge for experimentalists and machines alike.

Note that this picture of probing quark distributions is quite different from that presented in the first part of the talk on measuring neutron distributions. Both pictures can't apply at the same time. It is clear that we can never be sure what distribution is being measured without using at least one more probe. E. g., electrons measure a charge distribution which can only be interpreted as a proton density if quark effects (meson exchange currents) can be neglected. (This certainly does not seem to be justified in the three-body case.) If one, however, does make this assumption and uses a second probe, say the proton or pion or K^+, again assuming only nucleonic degrees of freedom a neutron distribution can be inferred. This procedure is unlikely to be correct (or even defined), at some deeper level. There is no way in which the proper degrees of freedom of the nucleus (whatever they may turn out can be measured without the use of a number of probes equal to (preferably greater than) the number of components necessary to make a complete description of the nucleus in terms of these degrees of freedom.

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