INFLUENCE OF FORM FACTORS ON PIONIC DEUTERON DISINTEGRATION

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In a recent paper [1] we have presented a microscopic model for the process

$$\pi + d \longrightarrow p + p'. \qquad (1)$$

For the resonant p-wave absorption, we calculated the amplitude for (1) by summing Feynman graphs corresponding to the absorption on a single nucleon line (impulse approximation) and to the rescattering of both π and ρ mesons through the 33 resonance. For the s-wave πN rescattering we used the zero range $\pi\pi NN$ interaction of Koltun and Reitan[2]. Reid's soft core potential was used for the deuteron wave functions [3]. Without introducing form factors and using a rather strong ρ meson coupling constant $f_{\rho N} = f_\rho(1+\kappa_\rho)$ with $f_\rho = 1.0$ and $\kappa_\rho = 6.6$, we obtained a reasonable agreement with the experiment.

To investigate the effect of hadronic form factors, we include at each of the two vertices of the rescattered meson a monopole form factor:

$$F_{iNN}(k^2) = F_{i\Delta N}(k^2) = \frac{\Lambda_i^2}{k^2 + \Lambda_i^2} \quad . \qquad (i = \pi,\rho) \qquad (2)$$

Here k is the transferred momentum. The form (2) is consistent with our use of a nonretarded meson propagator (see ref.1. A transfer of half the incident pion energy by the exchanged meson, as used by Goplen et al.[4], increased our results by less than 10%.) In the following we shall only discuss p-wave absorption which dominates the resonance region.

The dashed curves in Fig. 1 show the absorption cross section σ for the case where only a pion is rescattered. A cut-off mass of $\Lambda_\pi \simeq m_\rho$ already reduces the value of σ obtained without cut-off to less than the experimental value. This is in contrast to the findings of Goplen et al.[4] who needed cut-offs of less than 400 MeV in order to fit the experiment.

The inclusion of the ρ meson further cuts down the cross section, as already shown in ref. 1. If pion cut-offs below 1 GeV were used together with the ρ exchange, the peak value of σ would be less than half the experimental value. The solid line in Fig. 1 shows the result obtained with ρ exchange and setting $\Lambda_\pi = \Lambda_\rho = 1.5$ GeV (and $\kappa_\rho = 3.7$). This latter curve is not meant to be a fit; it rather defines some lower limits for the pion cut-off mass. (A variation of Λ_ρ between 1.5 and 2 GeV affected the results by less than 10%.)

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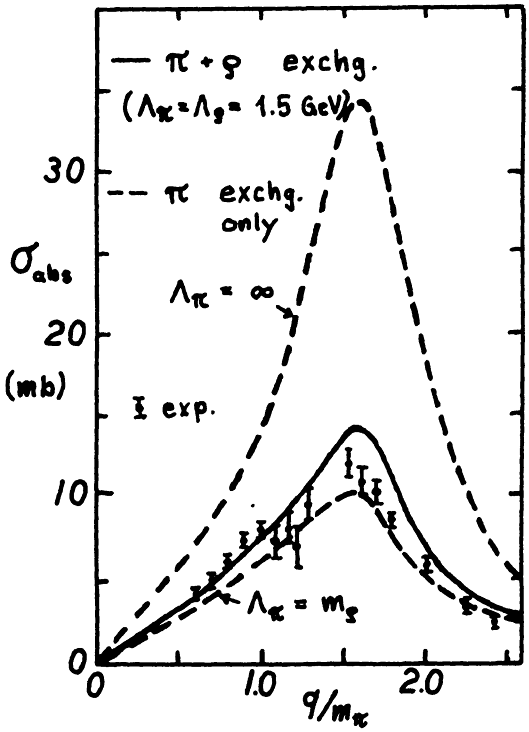

Fig. 1. Pion absorption cross section on deuteron as function of the incoming pion momentum q.

Our conclusions are thus opposite to those of ref. 4: After inclusion of the ρ meson, only very short ranged form factors give a reasonable agreement with experiment, especially for the larger values of κ_ρ = 5.5 - 6.6 found in recent analyses [5,6]. The low mass cut-offs of $\Lambda_\pi \simeq$ 700 MeV obtained from analyses of πN scattering data [7,8] seem to be incompatible with our calculations, even if we allow for an overall uncertainty in σ of 30 - 40% (mainly due to the uncertainty in the ρ meson coupling constant).

If pion cut-off masses lower than 1 GeV are to be believed, we have to look for further mechanisms which could enhance the cross section for the process (1), such as double rescattering or the exchange of higher mass bosons. Other improvements of the model, taking into account the momentum distribution of the deuteron, nonstatic vertex corrections, or the mass distribution of the ρ meson, will probably lead to minor corrections only.

Although many questions remain to be answered before we reach a quantitative understanding of the process (1), its extreme sensitivity to the pion cut-off energies may challenge new attempts to put the determination of form factors on a more rigorous theoretical basis.

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CALCULATION OF THE PION PRODUCTION REACTION $^3He(p,\pi^+)^4He$

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ABSTRACT

The differential cross section for the reaction $^3He(p,\pi)^4He$ has been calculated in a distorted wave impulse approximation model. Results are presented for incident proton lab energies of 415 and 716 MeV and centre-of-mass pion angles of 0° to 100°.

Recently there has been much interest in the reaction A(p,π)A+1 where the final nucleus is left in a definite state. These reactions are interesting because in principle they probe details both of π-nucleus interactions and of high momentum components of nuclear wave functions. Most data so far, except for some on deuterium, have been at threshold, though more medium-energy data are to be expected soon from the new meson facilities. In particular, the reaction $^3He(p,\pi)^4He$ has been studied and preliminary data are to be reported at this conference.[1] As the reaction d(p,π)t was described fairly successfully in a DWIA calculation[2] the same model has been extended to $^3He(p,\pi)^4He$.

The model used expresses the cross section for A(p,π)A+1 in terms of the cross section for pp→dπ and a form factor which is basically a Fourier transform of the overlap of initial and final wave functions. Spin and antisymmetrization effects are included and distortion effects are put in via Glauber approximation. Details are as in Ref. 2.

The above model was used to calculate dσ/dΩ for $^3He(p,\pi)^4He$ at proton lab energies of 415 and 716 MeV for $0° \leq \theta_\pi^{cm} < 100°$. The effective momentum transfer in this range is 300-500 MeV/c at 415 MeV and 350-700 MeV/c at 716 MeV. It was found that the calculations were quite sensitive to the nuclear wave functions used. The form factor calculated in this model is somewhat similar to the charge form factor. Both Gaussian and Irving-Gunn S-state wave functions were tried. The former reproduce the charge form factor up to the first dip but are much too low beyond that, while the latter are too high over the first dip but reproduce the second maximum. As seen in the figure, the presence of higher momentum components in the Irving-Gunn wave functions leads to a cross section which decreases more gradually from forward direction than with the Gaussian wave functions.

The results shown here include distortion in the p^3He and the π^4He systems as in Ref. 2. Such distortions alter the shape of the cross sections to some extent, but primarily affect the normalization. An alternative way of putting in the distortion[2] or reasonable changes in the parameters can increase or decrease the overall normalization by factors of 2-3. The overall distortion effect is somewhat smaller at 716 MeV than at 415 MeV because of the smaller NN and πN cross sections at this energy.

At the time of this writing, only very preliminary data are available.[1] At 415 MeV both the normalization and shape of this data are reproduced well using the Irving-Gunn wave functions. At 716 MeV the shape is still in acceptable agreement with the data, but the normalization seems low by about a factor of 5. At both energies results with Gaussian wave functions decrease too rapidly, as would be expected, and give results sometimes as much as an order of magnitude too low at the larger angles.

Further refinements of the calculations are planned. Since the results are sensitive to the details of the wave functions, the calculations will be repeated using wave functions which better reproduce the charge form factors. Also as the D-states in the nuclear wave functions were significant in the d(p,π)t calculations, serving to increase the cross sections at high momentum transfers,[2] they may be even more important in the ^{3}He(p,π)^{4}He calculations where the momentum transfer is greater. Results of these calculations will be reported at a later date.

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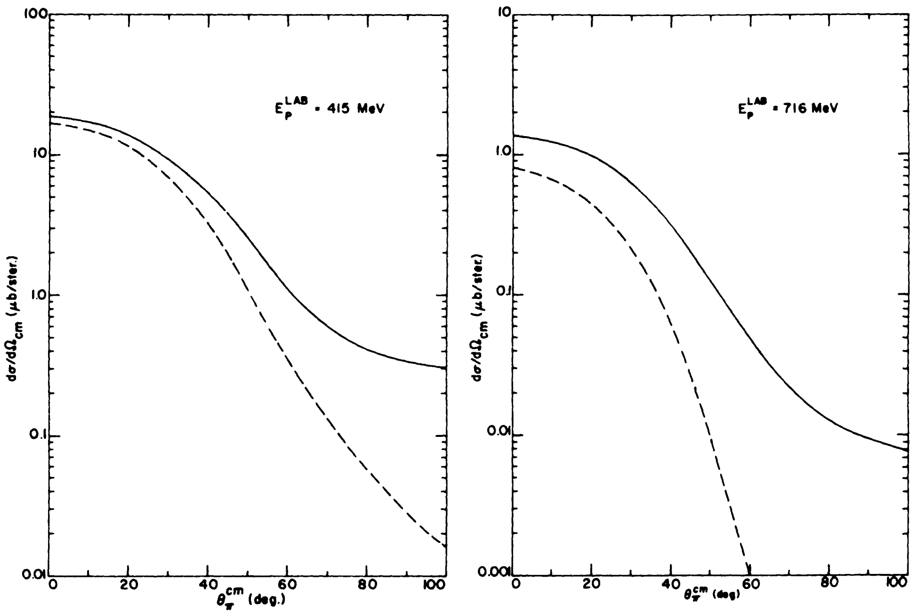

Fig.1. DWIA differential cross section for ^{3}He(p,π)^{4}He using Irving-Gunn (solid line) and Gaussian (dotted line) wave functions.

$^3He(p,\pi^+)^4He$ REACTION AT 415 AND 716 MeV

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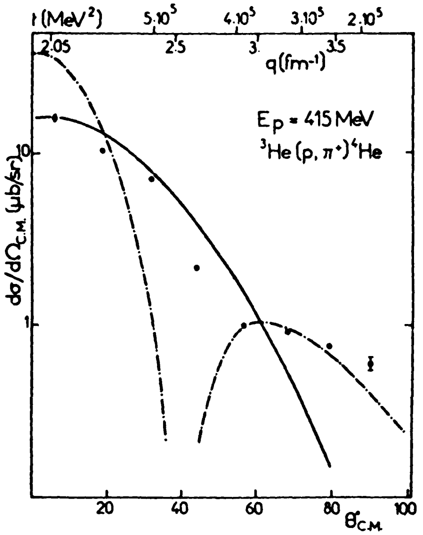
Due to the high momentum components involved, the pion production induced by intermediate energy protons on light targets is expected to be an interresting reaction to investigate the role of Δ components. For very light nuclei ($A \leqslant 4$), the S state component of the wave functions is rather wellknown, so that a comparison of experimental results from $^3He(p,\pi^+)^4He$ with classical calculations may reveal exotic components of the wave functions.

The differential cross sections for the $^3He(p,\pi^+)^4He$ reaction have been measured at 415 MeV and 716 MeV using the Saturne synchrotron proton beam[3] over a wide angular range (up to 100° CM). A liquid target (143 mg/cm^2), built by the IPN cryogenic service[4], has been used. The positive pions were detected by means of the SPES I facilities[5], essentially composed of a spectrometer and several drift chambers, scintillator counters and Cerenkov detectors. The beam intensity was monitored by a secondary electron chamber and calibrated with ^{11}C activity measurements from $^{12}C(p,pn)^{11}C$. Very good reproductibility has been observed through different measurements at the same angle and same energy. Except for the smallest and the largest angles the statistical accuracy (plotted on the experimental results) was < 5%. An additional uncertainty, whose maximum value may be as large as ± 20%, is essentially due to the uncertainties on detectors efficiencies, solid angle and for a smaller part on target thickness, beam monitoring and muon contamination. The results are plotted in Fig. 1 and Fig. 2. When extrapolating the data, good agreement with the two previous measurements[1,2] is obtained.

Elementary calculations in the plane wave approximation have been done using one-nucleon and two-nucleon mechanisms. In the one-nucleon description which corresponds to a neutron stripping, the transition form factor corresponds to the neutron wave function in a zero range approximation. This function has been deduced from the nuclear density $\rho(r)$ corresponding to the elastic electron charge form factor $F(q)$. The computer code Piuck of Rost and Kunz has been used. For the two-nucleon mechanism calculation Ruderman's method, developped by Ingram[7], was followed. The experimental $p(p,\pi^+)d$ cross sections of ref. 8 are introduced for the direct elementary process with the phase space term given by the Fearing's formula[9]. The energy of the incident proton for the elementary cross section is given by the Ingram's kinematical prescription. At Ep=415 and 716 MeV respectively this method gives an effective energy of 629 and 1040 MeV. For this last value the $p(p,\pi^+)d$ cross-section is very small. We have considered the interaction of the incident proton on a nucleon moving in the same (and not opposite) direction, which allows us to fix the energy of the elementary process at the energy (616 MeV) corresponding to the maximum of the cross section. Harmonic oscillator wave functions for ^3He and ^4He nuclei are used with parameters adjusted in order to give good values of the charge root mean square radii (such wave functions do not



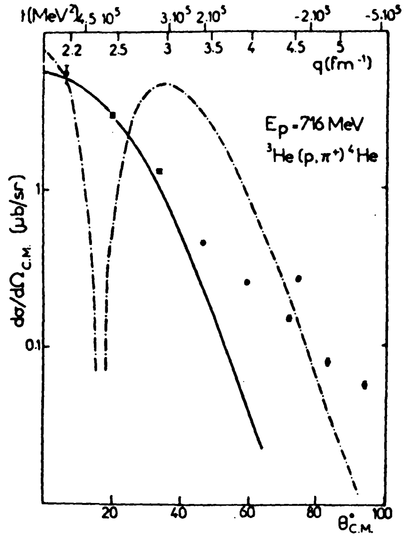


Fig. 1 — The dotted-dashed lines correspond to the 1N mechanism and are multiplied by .2
The full lines correspond to the 2N mechanism and are multiplied by 1.5 — Fig. 2

reproduce correctly the charge form factors at large momentum transfers.

The results corresponding to both calculations are shown in Fig. 1 and 2 (with a normalization factor). We note a deep minimum in the 1N case, at the zero of the Fourier transform of the neutron captured wave function $\varphi(r)$. In the 2 N case the angular distribution, except for backward angles, reproduces rather well the experimental results. A change of 8 % of one H.O. parameter does not change the angular shape but the normalization changes by a factor of 40 %.

The 1N and 2N amplitude cannot be simply added especially due to the unknown relative phase. More complete calculations with S and D states giving a good description of both ^{3}He and ^{4}He nuclei are needed in order to study the role of isobars in the reaction mechanism.

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SOFT-PION PRODUCTION IN N-N COLLISIONS

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ABSTRACT

The matrix element for s-wave pion production nn $\leftrightarrow \pi^- d$, is examined as a function of the external pion mass. Quite unexpectedly, in view of the well-known failure of soft pion theory for this reaction, it is found to be constant within a few per cent. Both the reason for this result and its implications are briefly discussed.

INTRODUCTION

It has been known for some time that soft-pion theory, despite its successes elsewhere, fails quite badly for s-wave pion production in nn $\leftrightarrow \pi^- d$ [1]. For real pions, the impulse approximation gives anomalously small results, owing to a "chance" cancellation of matrix elements leading to the S- and D-wave components of the deuteron. (A cancellation which led to suggestions of using this reaction to constrain P_D [2].)

More recently there has been a suggestion [3] that using PCAC one can put a model-independent constraint on the cross-section for μ-capture on nuclei leading to low-energy neutrinos. For such a process at small neutrino momentum, the cross-section is proportional to $|\underline{A}|^2 + |A_0|^2 + |\underline{V}|^2$, where A and V are the familiar axial-vector and vector currents. Using the standard PCAC arguments, the matrix element of A_0 is the amplitude for absorption of an s-wave "pion" of mass $\mu = m_\mu$ (the muon mass). Unfortunately the anomalous behaviour at the real mass ($\mu = m_\pi$), which we described above, makes one very dubious about the reliability of extrapolating from m_π to m_μ.

RESULTS

We have investigated this extrapolation by extending the model of Refs. 4 (and Ref. 2), with remarkable results -- summarized in Table 1. [The subscripts B-S and RSC refer to the Bryan-Scott (P_D = 5.38%) and Reid Soft Core (P_D = 6.47%) deuteron and $^3P_1$ wavefunctions, and M(μ) is the invariant matrix element for nn $\leftrightarrow \pi^- d$ as a function of the external pion mass "μ".] We notice the following: i) As already stated, the sensitivity to P_D at $\mu = m_\pi$ is due to the difference in the single scattering contribution SS (i.e. no pion rescattering) in that case. ii) As μ decreases, this difference decreases (column four), and the SS contribution grows relative to the term in which the pion rescatters once, DS (see columns five and six). iii) The shift of importance from DS to SS is such that the invariant matrix element is essentially a constant (first two columns)!

Table 1

Variation of the invariant matrix element for s-wave nn $\leftrightarrow$ $\pi^- d$, with the external pion mass (μ). [$\Delta \equiv \{|M|^2_{BS} - |M|^2_{RSC}\}/\{|M|^2_{BS} + |M|^2_{RSC}\}$.]

	$\|M(\mu)\|^2/\|M(m_\pi)\|^2$		$\frac{M^{SS}(\mu)}{M^{SS}(\mu) + M^{DS}(\mu)}$		
μ(MeV)	B-S	RSC	Δ	B-S	RSC
m_π	1.00	1.00	8.8%	16%	-3%
130.0	1.01	1.03	7.6%	21%	4%
120.0	0.98	1.03	6.5%	24%	10%
m_μ	0.97	1.04	5.0%	30%	20%
90.0	0.97	1.07	3.9%	39%	32%

SUMMARY

While investigations are continuing, we can make the following comments. First, the extrapolation of the matrix element of A_0 from m_π to m_μ can be carried out rather accurately (within ±5%) by assuming it is constant! Second, the close relationship of P_D to the OPEP tensor force suggests that there may be a conspiracy afoot. Further investigation of this phenomenon is clearly required -- particularly in the region $\mu \to 0$.

It is a pleasure to acknowledge conversations on this subject with M. Ericson and T.E.O. Ericson.

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