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Nuclear form factor sensitivity in the reaction $^3He(\pi^-,\pi^0)^3H$

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Charge exchange angular distributions for the reaction $^3He(\pi^-,\pi^0)^3H$ are calculated using realistic nuclear form factors obtained from electron scattering experiments in the Glauber multiple scattering formalism. It is found that the charge exchange scattering is not very sensitive to the magnetic form factors at low q and, in particular, is not sensitive to changes in the mean square magnetic radius at the $\pm 5\%$ level. Calculations are also compared with the most recent experimental results.

[NUCLEAR REACTIONS $^3He(\pi^-,\pi^0)^3H$, nuclear structure form factors, Glauber multiple scattering theory.]

We have used the Glauber multiple scattering formalism to investigate the nuclear structure dependence of pion scattering from the $A = 3$ nuclei. The mass 3 system is ideal for studying structure questions because it is the simplest system which allows the full complement of pion elastic and charge exchange scattering to a bound final state. The Glauber elastic and charge exchange amplitudes are expressed in terms of the nuclear charge and magnetization densities and, thereby, directly related to the four experimental electron scattering form factors. We find that charge exchange scattering, which is strongly dependent upon the ^3H and ^3He magnetic form factors, is not very sensitive to variations of the form factors within experimental uncertainties at low momentum transfers. The charge exchange reaction may, however, provide a means of refining our knowledge of the magnetic form factors at higher momentum transfer.

Early theoretical calculations[1-3] in the $A = 3$ nuclei were concerned primarily with determining the relative importance of contributions to the cross section arising from the different terms in the pion-nucleon interaction, and used simple descriptions of the structure. Nevertheless, agreement with the existing large angle charge exchange data was not unreasonable. This is in contrast to the situation in ^{13}C where the best charge exchange calculations are not in accord with experimental results.[4] The extent to which this disagreement in heavier elements is a structure or reaction theory problem is not known. Some resolution of this question might result from a thorough investigation of the structure sensitivity in the mass 3 system.

Previous attempts to assess the importance of nuclear structure for pion scattering from the $A = 3$ nuclei have used a Glauber formalism with model wave functions[5] or an optical potential formalism with phenomenological form factors.[6,7] Until recently, however, the amount of data available for comparison with theoretical results has been small. It has not been possible, therefore, to draw any firm conclusions about structure effects.

The π^0 spectrometer group at LAMPF has now acquired forward angle ^3He charge exchange cross section data at 200 MeV.[8] When combined with previous back angle time-of-flight data,[9] this yields the first complete charge exchange angular distribution. Also newly available are the ^3He data from the UCLA group.[10] These data are the lowest energy $A = 3$ charge exchange data to date and, when taken in conjunction with elastic data obtained by the same group, permit the very first test of the isospin triangle inequality. By making more stringent tests of theory possible, these developments greatly enhance the prospects of extracting structure information.

The calculation presented here uses the Glauber multiple scattering formalism. While more primitive in some respects than the optical model, the Glauber formalism is not without its advantages, especially in the lighter nuclei where it is also difficult to justify use of an optical potential. Further, most of the cross section is due to the single scattering term, which for practical purposes, is equivalent in the Glauber and first order optical potential formalisms. The π-N amplitudes are obtained using the $l = 0$ and $l = 1$ phase shifts from Roper *et al.*[11] and only terms linear in $\vec{\sigma}\cdot\hat{n}$ are retained in the higher order spin-flip terms.

For the nuclear structure, realistic form factors are used to describe the single particle nuclear

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densities. The experimental charge and magnetic form factors of McCarthy *et al.*[12] are used for ^{3}He, and those of Collard *et al.*[13] are used for ^{3}H. In each case the experimental density is fitted with the functional form

$$f(q^2) = (1 + a_1 q^2 + a_2 q^4 + a_3 q^6) \exp(-a_4 q^2) . \quad (1)$$

To facilitate the calculation, the parameter a_4 in the Gaussian function is kept the same for all four form factors. In general the quality of the fits is very good.

The Glauber scattering amplitude is then expressed in terms of four "fundamental densities"[14] each of which is composed of linear combinations of the ^{3}He and ^{3}H charge and magnetic form factors. This procedure is exact for the first order scattering terms but, in higher order terms, encounters an important difficulty. Since the charge and magnetic density operators are single particle operators, the form factors yield only one body in-

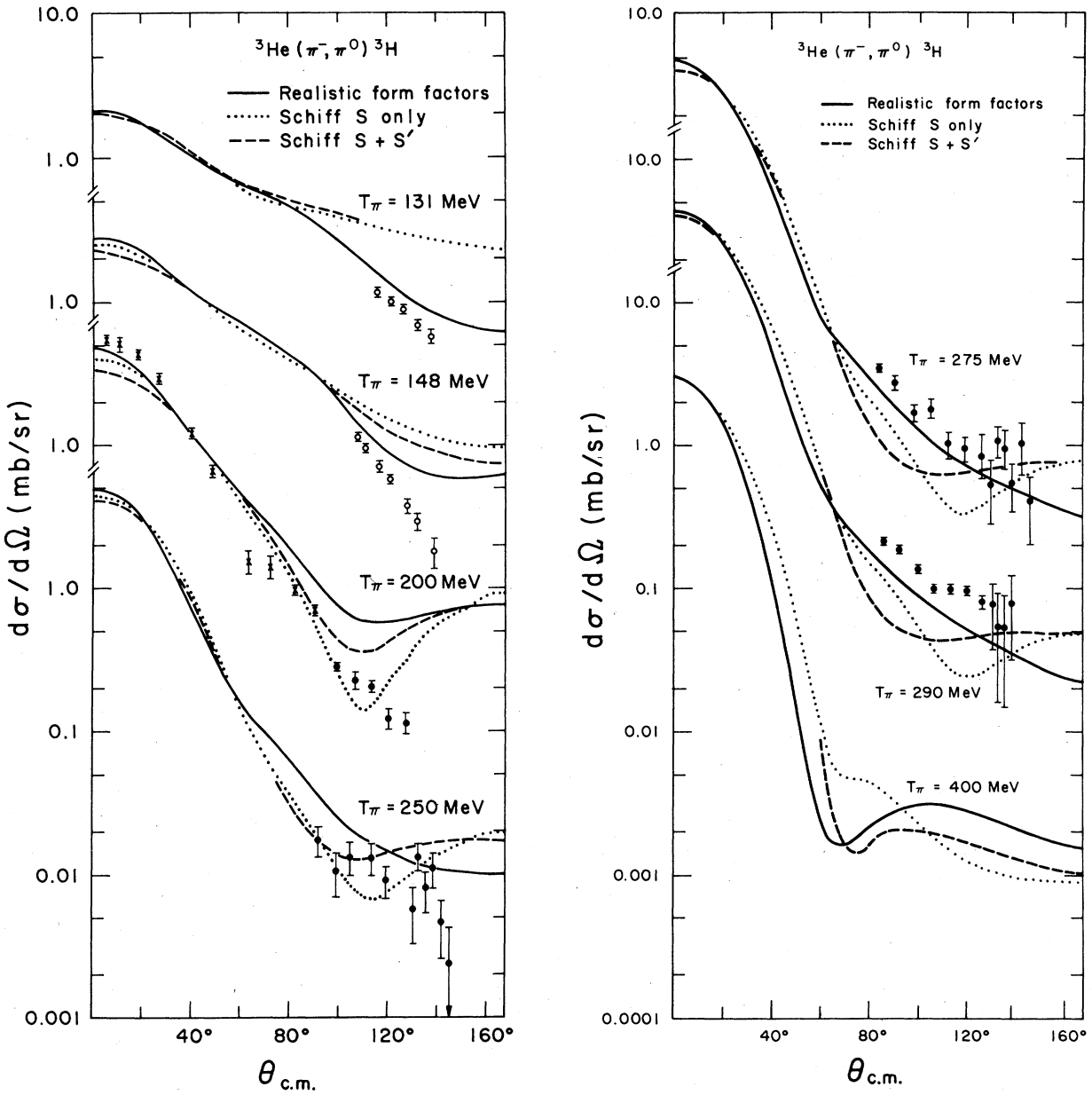

FIG. 1. Comparison of theoretical ^{3}He(π^-, π^0)^{3}H angular distributions with existing data as a function of center of mass angle. The solid curves use realistic form factors. The dotted curves use the Schiff spatially symmetric (S) wave function. The dashed curves use the Schiff $S+S'$ wave function.

formation. Some prescription for the nucleon-nucleon correlation information needed in the multiple scattering terms must be introduced. In this calculation we have assumed a correlation function identical in form to that given by the Schiff symmetric wave function[15] which incorporates only the center of mass correlations. Neglected from the calculation are the meson exchange contributions to the magnetic form factors which are believed to be small,[16] and the Coulomb energy difference between ^{3}He and ^{3}H, which is also small.

Figure 1 shows the results of the calculation for the best fit to the electron scattering form factors. Also shown are the results of a Glauber calculation using the Schiff wave function[15] with and without the mixed symmetry, S' contributions. The circled data points are those of the UCLA group.[10] The crossed data points are the π^0 spectrometer data from LAMPF (Ref. 8) and the dotted points are from Källne *et al.*[9] The calculated curves are in good agreement with the forward angle π^0 spectrometer results. The situation in the backward direction is not as good. The predictions lie above the data at 200 MeV, but fair agreement is obtained for energies 250, 275, and 290 MeV. It can be seen that S' contributions in the Schiff wave function are needed to make the shape of the angular distributions correspond more closely to the data. The realistic form factor calculation appears to exhibit the best shape and overall agreement with the existing data.

The calculation of Lohs and Mandelzweig[5] is similar to ours, except that they use the Jackson-Elliot wave function and include all orders of spin flip. Their results are similar to our Schiff $S+S'$ wave function curves. It can be seen from Fig. 1 that the charge exchange reaction can distinguish between model wave functions and realistic structure determined by electron scattering over a wide range of energies and angles. At lower energies, differences due to structure are greatest at backward angles where the Glauber procedure is least reliable. At higher energies significant differences occur even at forward angles.

At energies greater than about 150 MeV, the discrepancy between model wave functions and realistic form factor calculations is due primarily to first order spin flip contributions which dominate the cross section from around 60° to 120°. First order spin-flip terms are directly related to the magnetic form factors, which are independent of the charge form factors when realistic form factors are used to describe the nuclear structure. On the other hand, when model wave functions are used, the charge and magnetic form factors are not independent of each other. This dominance of first order spin-flip processes over some energy and

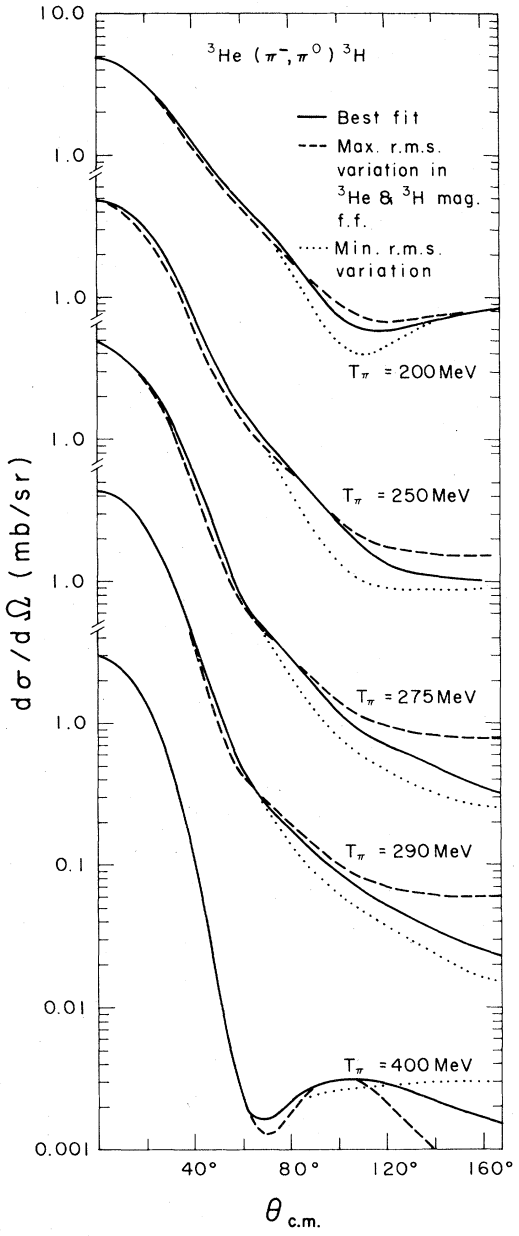

FIG. 2. Effect of variations in the ^{3}He and ^{3}H magnetic form factors at low q^2. Solid curves use the best fit form factors. Dashed curves use fits which increase the magnetic rms radii of both ^{3}He and ^{3}H by 5%. Dotted curves correspond to a decrease in the magnetic rms radii of both ^{3}He and ^{3}H by 5%.

angular interval means that the Glauber formalism can be used to reliably extract information about the $A = 3$ magnetic form factor using pion charge exchange scattering.

Landau[6,7] has computed ^{3}He(π^-, π^0)^{3}H differential cross sections in an optical potential formalism. His "lower limit fit to the ^{3}He magnetic form fac-

tor" curves exhibits the same shape as our realistic form factor curves, while his "upper limit fit to the ^{3}He magnetic form factor" lies close in shape to the Schiff spatially symmetric (S) wave function curves. In his calculation Landau uses the parametrization of the experimental ^{3}He magnetic form factor obtained by McCarthy *et al.*[12] By varying these parameters within the stated error, which in turn alters the magnetic rms radius by ±5%, Landau concludes that charge exchange scattering is extremely sensitive to the magnetic radius. This procedure greatly overstates the sensitivity to the magnetic radius because the uncertainties in the fit parameters of McCarthy *et al.*[12] are correlated. Using extreme values for these parameters causes the analytic form factor to diverge dramatically from the experimental data beyond $q^2 = 2$ fm^{-2}. Distortion effects in an optical model formalism make the cross section sensitive to higher q^2 and it is, therefore, incorrect to attribute changes in the charge exchange angular distribution solely to changes on the magnetic radius.

A more realistic assessment of the changes of the charge exchange angular distribution when the magnetic radius is varied by ±5% can be seen from Fig. 2. The magnetic form factors used in these calculations are obtained by constraining a_1 and a_4 in Eq. (1) to give the best fit rms magnetic radius increased or decreased by 5% and then varying the other parameters a_2 and a_3 to give a best fit to the data. This procedure causes the form factor to heal to the higher q^2 data. The final form factor generally remains within the uncertainty of the measured value for all data points and has a χ^2 per degree of freedom which exceeds the best fit value by less than one.

Figure 2 shows that when the magnetic radii are changed by ±5%, the cross section varies only by about a factor of 2 at 90° for energies between 200 and 300 MeV. The variation is even less when the magnetic radius of ^{3}He is changed while holding the ^{3}H magnetic radius fixed. It seems, therefore, that electron scattering will remain the best means of determining the magnetic radius. At higher pion energies, however, where the charge exchange reaction is acutely sensitive to the magnetization densities through first order spin-flip dominance, it will be possible to place limits on the magnetic form factors for momentum transfers at which they have not yet been measured or have large experimental uncertainties. The higher energy charge exchange curves shown here require extrapolation of the best fit to the electron scattering form factors beyond the measured region. Selective variation of the form factors in this region is not difficult in this procedure which utilizes the form factors in the form of a Gaussian multiplied by a polynomial in q.

As a structure tool, charge exchange scattering is, however, not without its own set of difficulties. Frequently the charge exchange amplitudes are calculated from the elastic amplitudes using isospin relationships. Neglected meson exchange currents and other effects which could lead to isospin breaking make for uncertainties in this procedure. This makes it extremely important to experimentally check the isospin triangle inequality as has been done by the UCLA group. While uncertainties in the cross sections preclude the drawing of any firm conclusion from checks of the triangle inequality at this time, it does appear that the experimental precision is on the threshold of being able to make important tests of charge symmetry assumptions. Further tests with greater experimental precision would be very helpful, preferably at some higher energy.

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