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NUCLEAR STRUCTURE SENSITIVITY IN THE REACTION $^3He(\pi^-,\pi^o)^3H$

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In the last few years, a certain progress has been reached in both the experimental and theoretical investigation of the reaction $^3He(\pi^-,\pi^0)^3H$. In a series of papers, Landau [1-4] analysed $\pi\ ^3He$ scattering using the optical model. Introducing several simplifying assumptions, he extracted the nuclear structure input from the electron scattering experiments. It follows from such calculations that the differential cross section of $^3He(\pi^-,\pi^0)\,^3H$ and to a lesser extent also of the $^3He(\pi^-,\pi^-)\,^3He$ reactions are enormously sensitive to the shape of magnetic form factors of the trinucleon system. Further, Landau [1-3] suggested to use the pion scattering data on the trinucleon system for extracting the value of ^3He magnetic radius $R_m(^3He)$ and to remove in this way the existing discrepancy between the experimental values $R_m(^3He)= 1.74+0.10$ fm and $R_m(^3He) = 1.95+0.11$ fm obtained by Collard et al. [5] and McCarthy et al. [6], respectively.

In our previous paper [7] we analysed pion elastic scattering on ^3He using a similar version of the optical model as Landau. The relationship was carefully examined between the nuclear form factors, which can be extracted from the electron scattering experiments and those, which enter the optical potential. A method was developed of subtracting the meson-exchange contribution (inherent in electron scattering) from magnetic form factors before using them as an input in optical model calculations. Utilizing such a realistic model for nuclear body form factors, we check here the sensitivity of the $^3He(\pi^-,\pi^0)\,^3H$ cross sections to variations in nuclear structure input.

The nuclear structure enters our optical potential via four body form factors

$$h_j(q) = \frac{\langle 0(JT)|\exp(i\vec{r}_1\vec{q})\,\Omega_j\,|0(JT)\rangle}{\langle 0(JT)|\,\Omega_j\,|0(JT)\rangle}\ , \qquad (1)$$

$j = 0$, T, S and ST, and the two normalization constants

$$a_S = \langle 0(JT)|\,\Omega_S\,|0(JT)\rangle\ ,\quad a_{ST} = \langle 0(JT)|\,\Omega_{ST}|\,0(JT)\rangle\ , \qquad (2)$$

where $\Omega_0 = 1$, $\Omega_T = \tau_3$, $\Omega_S = \sigma_3$ and $\Omega_{ST} = \sigma_3\tau_3$. The operators Ω_S, Ω_T and Ω_{ST} act on the spin and isospin projection of the nucleon labelled by 1. The symbol $0(JT)$ stands for the nuclear wave function taken in its maximal projections ($J_z = J$ and $T_z = T$).

In terms of the charge ($F_{^3He}(q)$, $F_{^3H}(q)$) and magnetic ($G_{^3He}(q)$, $G_{^3He}(q)$) nuclear form factors, the body form factors can be expressed as

$$3h_0(q) = [\,2F_{^3He}(q) + F_{^3H}(q)\,]\ /\ g(q)\ , \qquad (3)$$

$$h_T(q) = [\,2F_{^3He}(q) - F_{^3H}(q)]\ /g(q), \qquad (4)$$

$$a_S\,h_S(q) = \frac{\mu_{^3He}G_{^3He}(q) + \mu_{^3H}G_{^3H}(q) - Y_{^3He}(q) - Y_{^3H}(q)}{(\mu_p + \mu_n)\,g(q)} \qquad (5)$$

$$a_{ST}\,h_{ST}(q) = \frac{\mu_{^3He}G_{^3He}(q) - \mu_{^3H}G_{^3H}(q) - Y_{^3He}(q) + Y_{^3H}(q)}{(\mu_p - \mu_n)\,g(q)}\ , \qquad (6)$$

where $g(q)$ is the form factor of a nucleon. Further, $Y_{^3He}(q)$ and $Y_{^3H}(q)$ are the meson-exchange contributions to the magnetic scattering of electron by ^3He and ^3H, respectively. We parametrized the four electromagnetic form factors according to McCarthy et al. [6]. When the sensitivity of CEX-reaction is studied with respect to variations in $R_m(^3He)$, special attention has been paid to not to change the shape of $G_{^3He}(q)$ substantially.

In Fig.1 the results are shown for energies of 200, 250 and 290 MeV and for three different values of $R_m(^3He)$. It can be concluded that the calculated cross sections are not very sensitive to variations in $R_m(^3He)$ and that the theoretical curves lie systematically below the experiment. The discrepancy becomes more serious with increasing pion energy. Finally, the deepest minimum in the cross section corresponds to the lowest value $R_m(^3He) = 1.73$ fm. The results reported here disagree with those of Landau in two important aspects. Firstly, we observed much weaker sensitivity with respect to the variation in $R_m(^3He)$ and secondly, Landau's calculations exhibit reversed trends when the magnetic radius of ^3He is changed. His lowest curve corresponds to the biggest value of $R_m(^3He)$.

In order to explain the afore-mentioned disagreement, we briefly repeat the essence of the method with the help of which Landau obtained the nuclear body form factors. He started from Gibson parametrization [8]

$$F_{^3He}(q) = g(q)\,[\,F_{1c}(q) - \frac{1}{2}F_{2c}(q)\,]\ , \qquad (7)$$

$$F_{^3H}(q) = g(q)[F_{1c}(q) + F_{2c}(q)] , \qquad (8)$$

$$\mu_{^3He} G_{^3He}(q)/g(q) = \mu_p F_{2m}(q) + \mu_n [F_{1m}(q) + F_{2m}(q)] , \qquad (9)$$

$$\mu_{^3H} G_{^3H}(q)/g(q) = \mu_p [F_{1m}(q) + F_{2m}(q)] + \mu_n F_{2m}(q) , \qquad (10)$$

where F_{1c}, F_{2c}, F_{1m} and F_{2m} are related to S, S′ and D components of the trinucleon wave function as

$$F_{1c}(q) = P_S^2 F_{SS}(q) + P_D^2 F_{1,DD}(q) , \qquad (11)$$

$$F_{2c}(q) = P_S P_{S'} F_{SS'}(q) + P_D^2 F_{2,DD}(q) , \qquad (12)$$

$$F_{1m}(q) = P_S^2 F_{SS}(q) + P_S P_D F_{1,SD}(q) + P_D^2 F_{3,DD}(q) , \qquad (13)$$

$$F_{2m}(q) = P_{S'} P_S F_{SS'}(q) + P_S P_D F_{2,SD}(q) + P_D^2 F_{4,DD}(q) . \qquad (14)$$

Since the magnetic form factor $G_{^3H}(q)$ is not known very well from the experiment, Landau preferred to express it in terms of $F_{^3He}(q)$, $F_{^3H}(q)$ and $G_{^3He}(q)$. To this end he neglected all the terms in eqs. (11-14), which are proportional to P_D^2 and assumed, further, that $F_{1,SD}(q) = F_{2,SD}(q)$. The four electromagnetic form factors are interrelated by such a procedure, thus the variation in $R_m(^3He)$ leads automatically

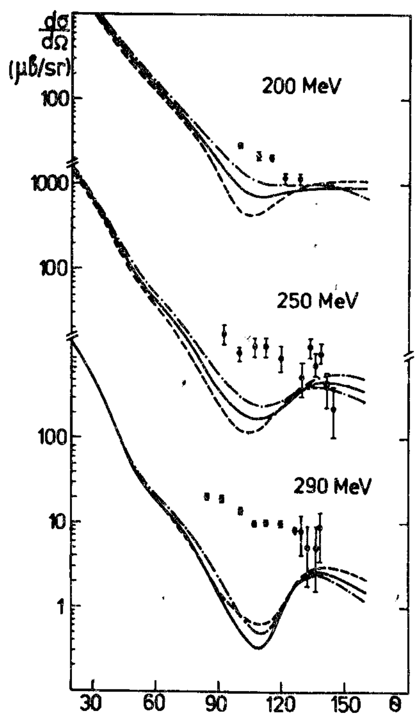

Fig.1. Differential cross section of the reaction $^3He(\pi^-,\pi^0)\,^3H$. Effect of variation in ^3He magnetic radius. —— $R_m(^3He) = 1.93$ Fm - - - $R_m(^3He) = 1.75$ Fm, –·–· – $R_m(^3He) = 2.17$ Fm. Experimental data of Källne et al. [11] were used.

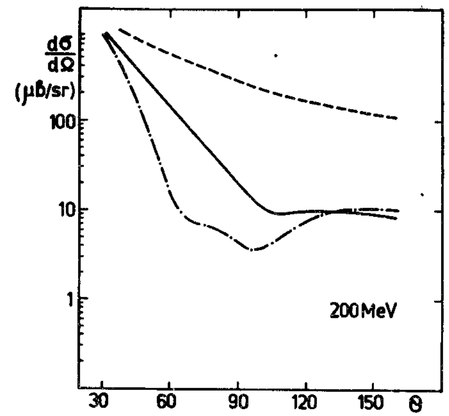

Fig.2. Effect of variation in ^3He magnetic radius. Nuclear form factors were calculated according to Landau [1]. The meaning of the curves is the same as in Fig.1.

to a variation in $R_m(^3H)$ too. This is one reason for large sensitivity of charge-exchange reaction to the value of ^3He magnetic radius, which has been reported by Landau.

Because of $P_S \gg P_D$, the neglect of P_D^2 terms seems to be a quite reasonable procedure. However, the terms $F_{i,DD}(q)$, $i = 1,\dots,4$, are normalized to unity for $q = 0$, while $F_{1,SD}(0) = F_{2,SD}(0) = 0$. Therefore, the neglect of P_D^2 terms with respect to $P_S P_D$ ones is not very justified in the low transferred momentum region, we work in. Using Elliott-Jackson wave function, we have shown some time ago [9] that the effect of P_D^2 and $P_S P_D$ terms is of comparable magnitude in the case of elastic $\pi^-\,^3He$ scattering.

In order to demonstrate that the discrepancy between our and Landau's results are due to his use of simplified relationship between the body and electromagnetic form factors, we repeated the calculation of $^3He(\pi^-,\pi^0)\,^3H$ cross sections using Landau's procedure for obtaining the nuclear structure input. As it can be seen from Fig.2, the sensitivity to the variation in magnetic radius greatly increases and bigger value of $R_m(^3He)$ corresponds to smaller differential cross section of the charge-exchange reaction.

Similar trends and sensitivities as in our Fig.1 were reported by Gerace et al. [10]. They realized that the variation of magnetic radius within the experimental errors overstates the sensitivity of the charge-exchange cross section. A more appropriate procedure consists in fitting all of the parameters on which the magnetic form factor depends, when $R_m(^3He)$ is changed.

It can be concluded that in the framework of the first order optical model and using realistic nuclear form factors derived from electron scattering experiments, the differential cross sections of the reaction $^3He(\pi^-,\pi^0)\,^3H$ are not very sensitive to the variation in magnetic radius of ^3He nucleus. The calculated cross sections lie systematically below the experimental data. The charge-exchange reaction on ^3He cannot be fully accounted for without making a step beyond the first order optical model.

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REFERENCES

1. Landau R.H. Ann.Phys., 1975, 92, p.205.
2. Landau R.H. Phys.Rev., 1977, C15, p.2127.
3. Landau R.H. In: TRIUMF Workshop on the Future of Pion-Nucleus Interaction TRI-79-2, Vancouver, 1979.
4. Landau R.H. In: Proc. ICOHEPANS, Vancouver, 1979.
5. Collard H. et al. Phys.Rev., 1965, 138, p.B57.
6. McCarthy J.S. et al. Phys.Rev.Lett., 1970, 25, p.884.
7. Falomkin I.V. et al. Nuovo Cim., 1980, 57A, p.111.
8. Gibson B.F. Phys.Rev., 1965, 139, p.B1153.
9. Mach R. Nucl.Phys., 1976, A258, p.513.
10. Gerace W.J. et al. Phys.Rev., 1980, C22, p.1197.
11. Källne J. et al. Phys.Rev.Lett., 1979, 42, p.159.

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Чувствительность ядерной структуры
в реакции $^3He(\pi^-,\pi^\circ)^3H$

В оптической модели вычислены дифференциальные сечения для реакции $^3He(\pi^-,\pi^\circ)^3H$. Показано, что такая реакция перезарядки практически не чувствительна к изменению магнитного радиуса ^3He.

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Nuclear Structure Sensitivity
in the Reaction $^3He(\pi^-,\pi^\circ)^3H$

Differential cross sections for the reaction $^3He(\pi^-,\pi^\circ)^3H$ are calculated using the optical model. It is shown that the charge-exchange scattering is not very sensitive to changes in magnetic radius of ^3He nucleus.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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