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LETTER TO THE EDITOR

ON THE (^{3}He,t) CHARGE EXCHANGE REACTION*

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Experimentally there is a difference in the position of the delta (1232) peak in the proton with respect to the one in the carbon. Various possible explanations are discussed and their failure has led to the suggestion that the confinement size of the delta resonance in nuclear matter is larger than in the free space.

In quest for the missing Gamow-Teller strength, (p,n) and, in particular, (^{3}He,t) charge-exchange reactions have been studied experimentally at the LNS, Saclay[1] (600 MeV to 2.3 GeV) and the JINR, Dubna[2] ($P_{^3\mathrm{He}} = 4.4$, 6.81, 10.79 and 18.3 MeV/c) allowing the excitation of the $\Delta_{33}(1232)$ peak. The results reveal the $A^{1/3}$ scaling implying the expected surface character of the reaction. The Dubna experiment, except for the proton, involved only ^{12}C as a nuclear target. Tritons were detected at almost zero degrees ($\Theta \leq 0.4°$) implying specific kinematics with the purely longitudinal momentum transfer $p_{\parallel}$ related, for a given energy transfer Q, as

$$Q = \frac{p_{\parallel} (2p_i - p_{\parallel}) c^2}{2E_i}. \qquad (1)$$

p_i and E_i are incident momenta and energy, respectively.

The data for p (^{3}He,t) Δ^{++} are well understood as a single-step one-pion exchange process in the eikonal approximation[3]. In the case of ^{12}C as a target, differences (summarized in Table 1) with respect to the proton case were found.

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TABLE 1.

	Δ peak position (MeV)		FsWHM	
$P_{^3He}$ (GeV/c)	p (^{3}He, t)	^{12}C (^{3}He, t)	p (^{3}He, t)	^{12}C (^{3}He, t)
4.4	322 ± 2.5	274 ± 2.5	138	182
6.81	327 ± 1.5	295 ± 1.5	129	204
10.79	327 ± 2	305 ± 2	129	257

Essentially, the peak position is shifted downwards with respect to the free rest mass difference of the nucleon and the delta resonance and the full width at half maximum (FWHM) is considerably increased. Whereas the last fact can be understood because of the presence of the N$\Delta \to$ NN process in nuclear matter, the shift in the peak position is not explained by reasons such as Fermi motion, effective mass, pion absorption cross section, which would first come to mind[2,3]. Two possibilities are then left: either the surface of the carbon is coarsely grained (cluster formation) or the collective delta-hole mechanism is at work. Cluster formation is likely for densities of about half the nuclear matter density[4]. Higher recoiling mass would shift downward the position of the delta peak, but because of the small probability of cluster formation[5], the cross section would be smaller than the experimental one.

For simplicity, to study the role and the effect of the delta-hole excitations, nuclear matter will be considered. The free spin-isospin response is then given by the Lindhard function

$$R_{\Delta}^{(0)}(\vec{q}, \omega) = \frac{16}{9} \frac{f_{\Delta}^2(q^2)}{m_{\pi}^2} \left\{ \int \frac{d^3 p}{(2\pi)^3} \frac{n(\vec{p})}{\varepsilon_{\Delta}(\vec{p} + \vec{q}, \omega) - \varepsilon(p) - \omega} + \begin{bmatrix} \omega \to -\omega \\ \vec{q} \to -q \end{bmatrix} \right\}. \tag{2}$$

Units are $\hbar = c = 1$. With $\omega_{\Delta} = M_{\Delta} - M_N$,

$$\varepsilon_{\Delta}(p, \omega) = \omega_{\Delta} + \frac{p^2}{2M_{\Delta}} - i\Gamma_{\Delta}(\omega)$$

and $n(\vec{p})$ is the occupation probability. With neglect of the width $\Gamma_{\Delta}(\omega)$ of the delta resonance for small momentum transfers, the free response (2) becomes

$$R_{\Delta}^{(0)}(q, \omega) = \frac{8}{9} \frac{f_{\Delta}^2(q^2)}{m_{\pi}^2} \frac{\omega_{\Delta}}{\omega_{\Delta}^2 - \omega^2} \varrho, \tag{3}$$

where ϱ is the nuclear matter density and the Chew-Low value $f_{\Delta}(q^2) = 2f_N(q^2)$ will be taken. The particle-hole interaction will be one-pion exchange with the Landau-Migdal g_0' piece taking care of the short-range repulsion:

$$V(q, \omega) = \frac{f_{\pi}^2}{m_{\pi}^2} \left[g_0' + \frac{q^2}{\omega^2 - q^2 - m_{\pi}^2} \right]. \tag{4}$$

The ring-diagram summation[6] with neglect of the exchange terms gives the full response as

$$R_\Delta (q, \omega) = \frac{R_\Delta^{(0)} (q, \omega)}{1 + V (q, \omega) R_\Delta^{(0)} (q, \omega)} \tag{5}$$

whose poles

$$V (q, \omega) R_\Delta^{(0)} (q, \omega) = -1$$

are solutions. With ϱ_0 the normal nuclear density and $g_0' = 0.7$, the solutions are at $q \to 0$

$$\omega_+ = \omega_\Delta \left[1 + 0.42 \frac{\varrho}{\varrho_0} \right]^{1/2},$$

$$\omega_- = \omega_q .$$

Clearly, $\omega_+ > \omega_\Delta$, which implies an upward shift of the delta peak. However, the delta resonance propagates in nuclear matter and it is quite possible that the confinement size for the delta in this case be different from the nucleon one. In fact, in the MIT bag model, $\omega_\Delta \propto R^{-1}$ (R, radius) and in the chiral soliton model[7] approximating the chiral angle as a straight line $\omega_\Delta \propto R^{-1}$ as well.

If, then, the confinement size of the delta resonance is larger than the confinement size of the nucleon, ω_Δ in nuclear matter would be smaller than in the free space and the collectivity in the spin-isospin delta-hole propagation will work. In the end one should note that similar conclusions in a different context[8] are reached. Taking the surface instead of the volume response[9] does not change conclusions. For further elucidation of the problem, it would be of utmost importance to have a less inclusive experiment detecting pions besides tritons.

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O (^{3}He, t) REAKCIJI S IZMJENOM NABOJA

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Razmatrana je razlika u poziciji delta (1232) vrha na protonu i ugljiku nađena eksperimentalno. Diskutirajući moguće uzroke predloženo je moguće pojašnjenje promjernom veličine zasužnjenja delta rezonance u nuklearnoj materiji.