ON SOME PROBLEMS IN DESCRIBING ^{4}He(e,e′) REACTION

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Inelastic ^{4}He(e,e′) energy spectra and response functions together with realistic calculations are considered. It was found that at the threshold region models predict far less cross section and response functions strength than are experimentally observed.

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1. INTRODUCTION

A striking feature observed in inelastic (e,e′) electron scattering spectra from nuclear targets is the broad "quasifree" peak (QFP), which results from the scattering of electron from a single nucleon, moving within the nucleus. The QFP maximum position would occur at a scattered electron energy loss ω_{max}~$q_\mu^2/2M^*$ (q_μ- 4- momentum transfer, M*- nucleon effective mass) and the observed width of the peak can be attributed to the Fermi motion of the nucleons inside the nucleus.

If Lorenz covariance, parity invariance and current conservation are assumed, the (e,e′) cross section depends [1] on only two response functions: the L- longitudinal (R_L) and T- transverse (R_T). When using unpolarized targets and electrons the response functions depend on two independent variables**:** 3- momentum transfer q = |**q**| and ω. In this approximation the differential cross section contains a mixture of L- and T- contributions. The QFP cross section value, shape and location are determined by the sum of the L- and T- parts of the cross sections. All these take the opportunity to investigate the quasifree cross sections both with the point of view of $d^2\sigma/d\omega d\Omega$ cross sections and in terms of $R_L(q,\omega)$ and $R_T(q,\omega)$ that contain all the nuclear structure information.

The goal of this paper is to look for the "white spots" in (e,e′) scattering from ^{4}He target in the QFP region. By other words we investigate kinematical conditions with weak or contradictory experimental ensuring, problems in describing full cross sections or L- and T- response functions. Besides a presentation of the experimental results the work concentrates on a description of the scattering results within the modern nuclear models.

2. EXPERIMENTAL DATA. COMPARISON WITH CALCULATIONS

First of all we have considered the double differential cross sections obtained at forward (θ<90°) scattering angles. Accurate results for inclusive electron scattering in ^{4}He for initial energy E=465.3; 596.8 MeV in the QFP region at θ=60° (q in the QFP maximum q_{max}=425, 535 MeV/c respectively) were obtained in [2]. The data were compared with the simple quasifree prediction and realistic model calculations. In the first case expressions for the cross section are given in terms of integrals over the nucleon momentum distribution. Realistic momentum densities were used. Second version is a direct connection with the single-nucleon spectral function for the A(e,e′N)B reaction. The spectral function for ^{4}He was calculated separately for each possible final state: (ppnn), p^3H, n^3He, pnd, dd). The (e,e′) cross section is obtained by integrating over both nucleon momentum and removal energy. Both models used the plane wave impulse approximation in the final state (PWIA). The comparison shows that theoretical predictions for all q at $\omega<\omega_{max}$ lie systematically below experimental points.

More complex model calculations of the ^{4}He(e,e′) cross sections at forward angles [1,3,4] (q_{max}=337…640 MeV/c) also have shown serious deviations from the experimental points at the low ω side of the QFP. Typical picture is displayed in Fig. 1.

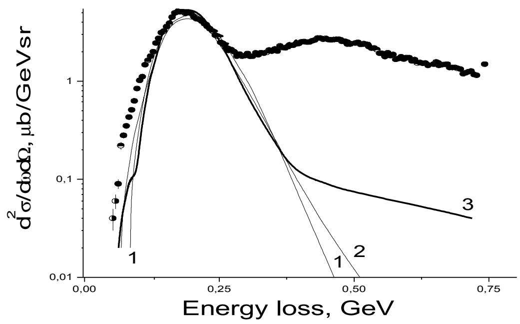

Fig. 1. *Cross section for ^{4}He as a function of energy loss (E=1169 MeV, θ=30°,* q_{max}=588 MeV/c *[3]). Curves 1-3 are described in the text*

The curves 1 and 2 are the results of calculations in the framework of harmonic oscillator model and approach [4] in which main attention is paid to covariance and conservation of electromagnetic current by including the vertex functions, that take into account the structure of the ^{4}He, for Urbana potential. It is so-called Lorentz-Calibration-Invariable Approach (LCIA). Curve 3- calculations with nucleon momentum distribution derived by the variational ATMS method [5] for Reid soft core potential. It uses a three-body force to get the correct binding energy. Comparison shows that there are problems in describing ^{4}He(e,e′) cross section at small energy loss.

Thus different simple approximations and more fundamental theoretical approaches give a substantial excess of the experimental cross section compared to all model predictions for region of interest. Apparent violation of the impulse approximation has led to a conclusion: other physical processes are important here.

Even more impressive picture can be seen when comparing the experimental differential cross section of ^{4}He(e,e′) reaction at backward θ>90° angles with model calculations. One of the spectra [1] (q_{max}=530 MeV/c) is demonstrated in Fig. 2 together with the theoretical analysis. The dashed and dotted curves are the L- and T- contributions [1], the solid curve is the full cross section. The calculation sums over all possible (e,e′N) states using the PWIA in the final state. The ^{4}He wave function (WF) was calculated by ATMS method [5]. Final state interactions (FSI), effects of meson exchange currents and real pion production were not taken into account. Note that the transverse contribution dominates in the cross section. In addition, in Fig. 2 by the dash-dotted curve is presented the prediction of approach [4].

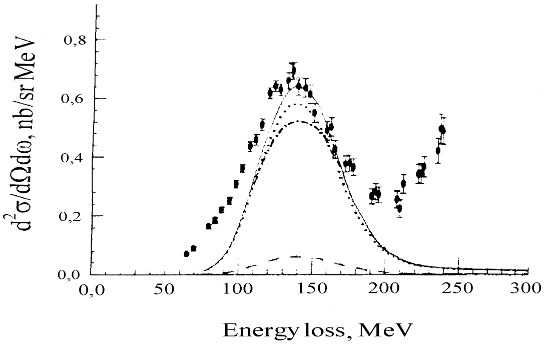

Fig. 2. *^{4}He. Cross section as a function of energy loss at E=328 MeV, θ=134.5° [1] together with theoretical curves (see the text)*

Figs. 1,2 and the results of data interpretation [1-4] have unequivocally showed a significant breakdown of the quasifree picture. It proves that above mentioned models, based on a quasifree reaction mechanism, are rather simple ones for describing the nucleon knockout process at low energy loss side of the QFP at intermediate energies.

During the past few decades a series of electron scattering experiments on ^{4}He have been performed with a goal of the measured double differential cross sections separation into L- and T- response functions at constant momentum transfers. R_L(q,ω) and R_T(q,ω) response functions were extracted [1] at q=300…500 MeV/c. Some later Rosenbluth separations into L- and T- response functions at q=const were made for q=300…600 MeV/c in [6]. The most accurate data for these responses in the region of the QFP were determined via analysis of the world's cross section data [7] for q=300…700 MeV/c.

It turned out that the results of different model calculations [6] are in reasonable agreement with the R_L(q,ω) data. The best description was achieved in [8] for q=300 and 400 MeV/c. Authors have used Green function Monte Carlo method and realistic Hamiltonian containing two- and three-nucleon potentials. So we concentrated our attention on T- response functions.

T- response functions [1] at q=300…500 MeV/c and the modern calculations results are displayed in Fig. 3.

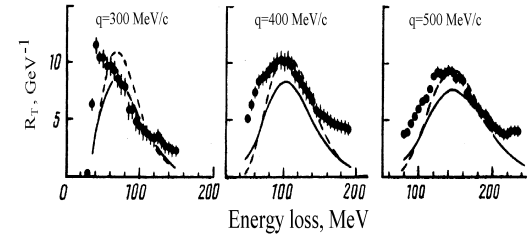

Fig. 3. *^{4}He. Transverse responses [1] as a function of energy loss. Curves: PWIA [1] (dashed line), LCIA [4] (solid line)*

The data R_T(q,ω) are significantly wider and there is more strength at low ω side than what is predicted. In general the calculations describe poorly the data. T- responses extracted in [6] and theoretical interpretation is presented in Fig 4.

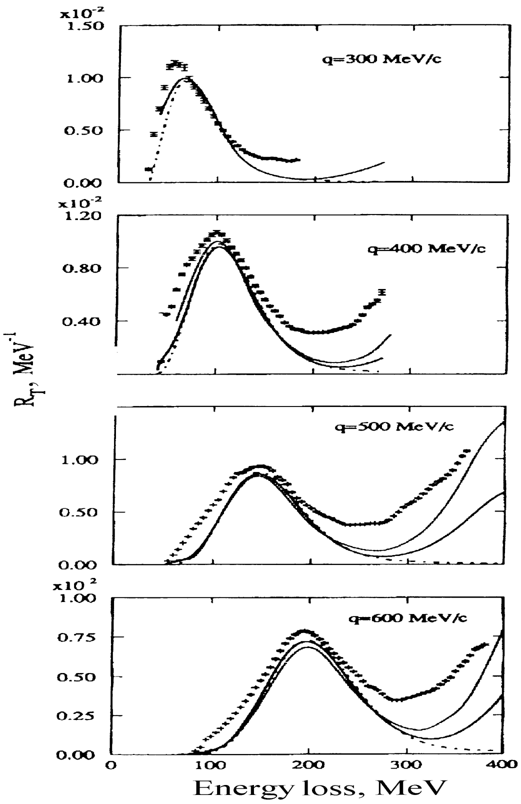

Fig. 4. *^{4}He. Transverse responses [6] as a function of energy loss. Curves: PWIA (DWIA) [10,11] - dash-dotted (solid) line; Laget calculations [9] (dotted line)*

In spite of high quality of electron beams and experimental facility in both scientific centers [1,6] there are small differences in measured (e,e′) spectra and obtained T- response functions. R_T(q,ω) dependence obtained at low q [1,2] is shifted to lower energy loss and is quite asymmetric. This fact is explained by an enhancement in these spectra from FSI or excitation of the broad inelastic states between 20…30 MeV excitation energies. At the same time R_T(q,ω) obtained in [6,7] shows practically smooth shape without any anomalies. In experiment [6] at q=300 MeV/c R_T(q,ω) value is ~10% larger. Secondly, modern theoretical approaches do not describe the low energy loss side in both cases.

T- response functions [6] have been compared to calculations with three different models [9] and [10,11] (two versions). In the calculations of [9] the WF of ^{4}He employed was determined by a variational method using the Argonne NN potential; three-nucleon forces were taken into account; FSI, exchange currents and pion production are included.

In calculations [10,11] have been used two models of the spectral function for ^{4}He; for small nucleon momenta ($p \leq 300$ MeV/c) the WF calculated by a variational method and for high momenta and removal energies the WF was obtained through a convolution integral of the momentum distributions describing on one hand the relative motion of the two correlated nucleons and on the other hand the center-of-mass motion of this correlated pair. FSI were taken into account through an optical potential (DWIA).

The origin of the excess strength observed in the threshold region of the transverse response functions under different kinematical conditions q=const=300… 600 MeV/c are not convincingly explained.

3. CONCLUSIONS

When studying the ^{4}He(e,e′) cross sections and transverse response functions in the QFP region one finds the kinematical region, which have weak experimental ensuring. Besides, modern theoretical models cannot explain the data in particular in the low energy loss side of the QFP and T- response functions. Without doubt this region remains interesting both for experimentalists and theorists.

To understand reasons of such behavior of the ^{4}He(e,e′) cross sections and $R_T(q,\omega)$ dependences one needs in additional theoretical and especially accurate experimental studies (as it was stressed in [7] "in part, the slow progress was due to the confusing experimental picture, that some time obfuscated the interpretation of the data"). At the same time pure transverse cross sections can be obtained (not a traditional) by a direct way - measuring the inclusive spectra at 180°.

High quality electron beam at the future NSC KIPT Electron Accelerator, high-resolution spectrometer that will be able to measure scattered electrons at 180°, effective many-channel detectors will allow measuring transverse cross sections at low energy loss side and threshold region, avoiding measurements of the energy spectra under different kinematical conditions and Rosenbluth procedure of L- and T- response functions separation. Such kind of data is practically absent.

Another field of experimental activity may be the resonant electroexcitation of low-lying levels, magnetic transitions above the nucleon threshold and giant resonances in middle weight and heavy nuclei.

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О НЕКОТОРЫХ ПРОБЛЕМАХ ОПИСАНИЯ РЕАКЦИИ ^{4}He(e,e′)

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Анализируются неупругие энергетические спектры и респонс функции реакции ^{4}He(e,e′) совместно с реалистическими расчетами. Показано, что в пороговой области модели предсказывают существенно меньшие величины сечения и респонс-функций, чем наблюдается экспериментально.

ПРО ДЕЯКІ ПРОБЛЕМИ ОПИСУ РЕАКЦІЇ ^{4}He(e,e′)

Е.Л. Купленніков, А.А. Немашкало, Ю.М. Ранюк

Аналізуються непружні енергетичні спектри та респонс функції реакції ^{4}He(e,e′) сумісно з реалістичними розрахунками. Знайдено, що у поріговій області моделі передбачають значно менші величини перерізу і респонс-функцій, ніж спостерігаються в експерименті.