ABOUT OBSERVATION OF THE MESON EXCHANGE CURRENT IN INELASTEC ELECTRON SCATTERING ON ^{4}He NUCLEUS

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The problem of the experimental detection of meson exchange current contribution in inelastic electron scattering on ^{4}He nucleus is examined. The upper limit of this contribution is finded for q = 0.75 - 1.50 fm^{-1}.

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1. INTRODUCTION

As it is known, the strong interaction of nucleons occurs through the interchange of virtual mesons. The motion of these mesons is called the meson exchange current (MEC). In the case of charged mesons their current produces the magnetic field that accompanies the strong interaction. So the magnetic field of MEC has to influence on the electromagnetic structure of the atomic nucleus, that is the association of strongly interacting nucleons.

The experimental investigation of MEC is complicated by the fact that the assumed influence of these currents on the nuclear structure is not large relatively to the nucleon charge interaction and strong interaction itself. So, the MEC contribution to the calculated form-factor of the ground and the excited nuclear states is ~1÷10% and is summed up with a number of other contributions of such order. Therefore, even if such multicomponent calculation agrees with the experimental data this maybe the casual consent only, i.e. this assent relates to the sum of contributions one of which is MEC but doesn't prove definitely the reality of MEC.

For more definite determination of MEC contribution the studding of electronuclear sum rule calculations [1] is very attractive.

2. MEC AND SUM RULES FOR ^{4}He NUCLEUS

The double-differential cross section $d^2\sigma(E,\omega,\theta)$ for electron scattering can be separated into the transverse and the longitudinal components according to the polarization of the virtual photons and can be represent by the transverse $R_T(q,\omega)$ and the longitudinal $R_L(q,\omega)$ response functions correspondingly.

$$d^2\sigma(E,\omega,\theta)\,(\sigma_M(E,\theta)\,G^2(Q^2))^{-1} = \lambda^2 R_L(q,\omega) + [\lambda/2 + \tan^2(\theta/2)]R_T(q,\omega), \quad (1)$$

where E and θ are the initial energy and the scattering angle of electron, ω is the energy transferred to the nucleus, $\sigma_M(E,\theta)$ is the Mott cross section, $G(Q^2)$ is proton electric form factor, q and Q are three and four momentum transferred correspondingly, $\lambda = Q^2/q^2$. The integral

$$S_{T/L}(q) = \int_0^\infty R_{T/L}(q,\omega)\,d\omega\ , \quad (2)$$

not including itself the form factor of the ground state of the nucleus, is called the inelastic zero moment of response function.

The moments $S_T(q)$ and $S_L(q)$ of ^{4}He, according to [1], can be represented with accuracy of about 1% as

$$S_T(q) = S_T^{QES}(q) + S_T^{PCC}(q) + S_T^{MEC}(q) \text{ and} \quad (3a)$$
$$S_L(q) = S_L^{QES}(q), \quad (3b)$$

where $S_T^{QES}(q)$ and $S_L^{QES}(q)$ are the contributions of the quasi-elastic scattering (QES) of electrons on the nuclear nucleons, $S_T^{PCC}(q)$ is the contribution of the scattering on the proton convention currents (PCC) and $S_T^{MEC}(q)$ is the contribution of the scattering on MEC. In this article the expressions for calculation of $S_T^{QES}(q)$, $S_T^{PCC}(q)$ and $S_L^{QES}(q)$ was found. Let us denote the calculation of the sum $S_T^{QES}(q) + S_T^{PCC}(q)$ as $S^{th}(q)$, and the experimental value of moment $S_T(q)$ as $S_T^{exp}(q)$. Following expression (3a) we have

$$S_T^{MEC}(q) = S_T^{exp}(q) - S^{th}(q), \quad (4a)$$

or

$$S_T^{MEC}(q) = (D(q) - 1)\, S^{th}(q). \quad (4b)$$

in $S^{th}(q)$ units. Here the quantity $D(q) = S_T^{exp}(q)/S^{th}(q)$.

3. THE EXPERIMENTAL DETERMINATION OF MEC CONTRIBUTION

In article [2], using the method described in p. 2 and the experimental data of [3], the value of D for ^{4}He nucleus was found at the range of q = 1.5-2.5 fm^{-1}: $1.1 \le D \le 1.2$. In our article [4] $S_T^{exp}(q)$ for ^{4}He nucleus is measured at the range of q = 0.75 - 1.5 fm^{-1}. Let us consider these data.

As the measurements are always limited by some maximum value of the transferred energy ω_{max}, the experimental moment of the response function is written in the form:

$$S^{exp}_{T/L}(q) = \int_0^{\omega_{max}} R^{exp}_{T/L}(q,\omega)\,d\omega + \int_{\omega_{max}}^{\infty} R^{extr}_{T/L}(q,\omega)\,d\omega \quad ,(5)$$

where $R^{exp}_{T/L}(q,\omega)$ is the experimental value of the response function, $R^{extr}_{T/L}(q,\omega)$ is its extrapolation for $\omega > \omega_{max}$. In article [4] it was used the extrapolating form:

$$R^{extr}_{T/L}(q,\omega) = C_{T/L}(q)\,e^{-\alpha\omega}\,, \qquad (6)$$

where $C_{T/L}(q)$ is the parameter for the adjustment to the experimental response function, α is parameter, which, according to article [5], is independent from the transfer momentum and it is almost independent from the atomic number of nucleus. At the time when article [4] was published it was supposed that value of $\alpha = 3 - 4$ (see [5]), and so there the value of $S_T^{exp}(q)$ for $\alpha = 3$ and $\alpha = 4$ was presented. Since later it was found that $\alpha \cong 3$ (article [6]), we use $S_T^{exp}(q)$ for this value of parameter for calculation of D.

Article [1] proposes calculations of $S_{T/L}^{QES}(q)$ with using the unmodel sum rules (the term of this article) for $q \le 1.5$ fm^{-1} and the realistic nucleon potentials for $q > 1.7$ fm^{-1}. According to [1] the accuracy of first calculation is about 1%.

The calculation of $S_T^{PCC}(q)$ is not unequivocal because it contains the averaged kinetic energy $<T>$ of the intranuclear proton as a multiplier, and the diapason of well-known values of this characteristic is 56 - 78 MeV. Nevertheless as the contribution of $S_T^{PCC}(q)$ to $S^{th}(q)$ is little and it decreases monotonously with the increasing of the transfer momentum (about 17% for $q = 1$ fm^{-1} and 1% for $q = 2$ fm^{-1}) the uncertainty of the value of $S^{th}(q)$ connected with the quantity of $S_T^{PCC}(q)$ has not vital importance for the examining problem.

Table shows the values of the experimental and the calculated transverse moment. One can see that the ratio of these quantities D equal to 1 with accuracy to the experimental errors.

In order to determine the possible difference of D from unity, we have calculated the average value of these quantities at some interval of the transfer moment $q_1 \div q_2$: $\overline{D}_{q1-q2} = n^{-1}\sum D_i$ and

$$\Delta\overline{D}_{q1-q2} = \Delta_{sist}D + \frac{1}{n}\sqrt{\sum_i (\Delta_S D_i)^2}\,, \qquad (7)$$

where $\Delta_S D_i$ is the statistical error of D_i, $\Delta_{sist}D$ is the systematic (non-statistical) error, which is common for all n values of D. For the data of article [4] the error $\Delta_{sist}D = 0.05\,D$.

So, from the data of table one can find that $\overline{D}_{0.75-1.5} = 1.03 \div 1.07 \pm 0.08$. Here the first value corresponds to the calculation where $<T> = 78$ MeV, and the second one is for $<T> = 56$ MeV.

The errors of D values in article [2] are $\Delta D_i = 0.10 \div 0.15$. Let us estimate the error for the averaged value of quantity D that was found in this article. The systematic error of $S_T^{exp}(q)$ in article [3] is not smaller than 3%. Hence, we assume $\Delta_{sist}D = 0.03\,D$ and $\Delta_S D_i = \Delta D_i - \Delta_{sist}D$ for quantities D_i from [2], and using Eq. (7b) find $\Delta\overline{D}_{1.5-2.5} = \pm 0.09$.

Table. *Moment of transverse response function* ^{4}He*:* $S_T^{exp} \pm \Delta_S S_T^{exp}$ *is experimental data from* [4], S^{th} *is calculation on the basis of* [1] *(minus* MEC *contribution) and* $D \pm \Delta_S D$ *is theirs relation. First columns of* S_T^{exp} *and D values correspond to calculation with* $<T> = 56$ MeV, *second columns of theirs correspond to calculation with* $<T> = 78$ *MeV*

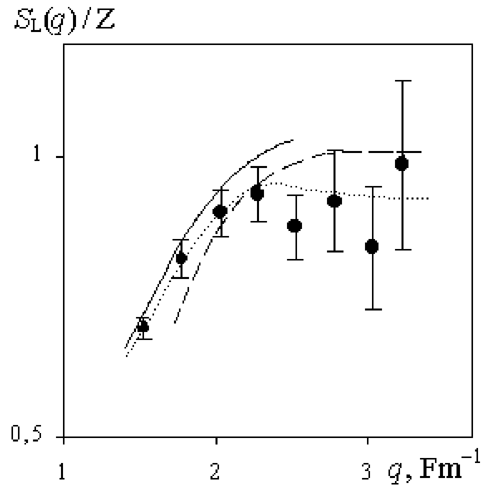
q fm^{-1}	S_T^{exp}	$\Delta_S S_T^{exp}$	S^{th}		D		$\Delta_S D$
0.750	0.158	0.014	0.153	0.168	1.033	0.940	0.087
0.875	0.266	0.028	0.237	0.252	1.122	1.056	0.115
1.000	0.403	0.027	0.347	0.363	1.161	1.110	0.076
1.125	0.507	0.041	0.486	0.502	1.043	1.010	0.083
1.250	0.659	0.053	0.651	0.667	1.012	0.988	0.080
1.375	0.863	0.071	0.839	0.855	1.029	1.009	0.084
1.500	1.153	0.100	1.047	1.062	1.101	1.086	0.095

4. DISCUSSION OF $S^{QEL}(q)$ CALCULATION

As one can see from Eq. (4a, 4b), the accuracy of detection of MEC contribution depends on the accuracy of $S^{th}(q)$ calculation. In the last one the contribution from QES dominates. I.e. the accuracy of $S^{th}(q)$ is mainly depends on the accuracy of $S_T^{QES}(q)$. As the equations for $S_T^{QES}(q)$ and $S_L^{QES}(q)$ are similar, we may consider the accuracy of the calculations with them to be equal.

In accordance with expression (2b), $S_L(q)$ moment contains one contribution only. Therefore the calculation of this moment can be examined by the comparison with the experimental value $S_L^{exp}(q)$.

The latest $S_L(q)$ measurements on ^{4}He [7] were realized in wide diapason of transfer energy. Therefore the extrapolation correction (second integral in Eq. (5)) for these data is little and its amount is estimated by us as 3% for $q < 2$ fm^{-1} and 5% for $q \geq 2$ fm^{-1}. These data with the mentioned estimation are shown in the figure. The curves calculated according to the equations of [1] are represented here too. One can see that these calculations agree badly with the experimental data for $q > 2$ fm^{-1}.



Inelastic moment of longitudinal response function ^{4}He*: the experimental data from* [7]; *solid and dashed lines are calculation on the basis of* [1] *for the unmodel sum rules and for the realistic nucleon potentials correspondingly; dotted line is the calculation of* [8] *including* NM *effect*

The possible cause of this is the effect of nucleon modification (NM), which was not accounted these calculations. The confirmation of this assumption is the agreement of the calculation (Eq. (12) of article [8]), which accounts NM effect, with the experimental data (see fig.). We have not the analogous calculation for $S_T^{QES}(q)$. However, as NM effect is small for $S_L^{QES}(q)$ calculation for $q < 1.7$ fm^{-1} and as it decreases proportionally of $\exp(-q^2)$ (following [8]) we may think that $S_T^{QES}(q)$ calculation used by us is enough exact for $q \leq 1.5$ fm^{-1}.

5. CONCLUSION

1. The accuracy of modern data is not enough for sure detection of MEC contribution in the electron scattering on ^{4}He nucleus.
2. Within the limits of approximation of Eq. (3a), value of $\overline{D}+\Delta\overline{D}=1.15$ determines the upper limit of MEC contribution for $q = 0.75$ - 1.5 fm^{-1} by means of Eq. (4b): $\overline{S}_T^{MEC} = 0.15\overline{S}^{th}$.

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