сообщения
объединенного
института
ядерных
исследований
дубна

E4-83-663

A.N.Antonov, I.Zh.Petkov*

ON THE QUASIELASTIC ELECTRON SCATTERING FROM NUCLEI

* Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, 1184 Sofia, Bulgaria

1983

1. INTRODUCTION

The scattering of high-energy electrons from nuclei is a powerful tool in the investigation of the nuclear structure. The interaction of electrons with the nuclear charge and current densities is well known, it is relatively weak and it gives a possibility of obtaining a more direct and reliable nuclear information. An additional advantage of the electron experiments is, that the three momentum transfer to the nucleus $\vec{q}$ and the energy loss of the electron ω can be considered as variables with the only requirement: $q^2 = \vec{q}^2 - \omega^2 > 0$.

It is shown in [1,2] that if one detects only the final electron, then any electrodynamic processes associated with the one-photon exchange between the nucleus and the electron can be described by means of only two form factors $W_{1,2}(\vec{q}^2, \omega)$. The quasielastic electron scattering is a process of this type and has been first considered in [2-5]. Czyz and Gottfried pointed out [5] that the high energy-loss tail of the quasielastic peak contains information on the short-range nucleon-nucleon correlations.

The main characteristic of the quasielastic scattering is that electrons scatter on individual nucleons ejected afterwards from the nucleus. This picture is simply incorporated by Moniz [6] in the Fermi-gas model, where the electron scatters elastically on a single nucleon in the Fermi sea, the recoiling nucleon lying outside the Fermi sphere because of the exclusion principle. The model of Moniz has been successfully applied to the quasielastic electron scattering on a wide range of nuclei, at various energies and angles [7-9]. It has been possible to extract from these analyses the values of the parameters: the Fermi momenta (k_F) and the average separation energies ($\bar{\epsilon}$) (or the effective mass M^*). The general behaviour of the quasielastic region is reproduced well, but however, there is a systematic underestimation of the observed cross sections at very large and small energy loss ω. Furthermore, the data of high-energy electron scattering from ^{6}Li and ^{12}C ($E \geq 2$ GeV) cannot be reproduced by this model [10].

More sophisticated approaches, in which the nucleon-nucleon interaction was included, have been developed (see, for example, Refs. [11,12]).

One of the most significant experimental results obtained recently was the separation of the longitudinal and transverse response functions in the quasielastic electron scattering [13,14]. It was demonstrated [13,15] that the calculated transverse response function is in a qualitatively good agreement with the experimental one, while the calculated longitudinal response function exceeds the experimental curve by about a factor of 2. It means that the standard Fermi-gas model fails to explain the data.

Noble assumed, that the effect of nuclear matter on nucleon structure increases the nucleon charge radius and quenches the anomalous magnetic moments, and on this basis, some relativistic Fermi-gas calculations have been carried out [15]. As a result a good fit for the longitudinal response function and a qualitatively good agreement for the transverse response function in the region of small energy loss has been achieved.

It was shown in [16,17] that the meson exchange current gives small contributions in the case of the longitudinal response function. These contributions get larger in the case of the transverse one.

Celenza et al. [18] adopted the point of view, that the behaviour of the longitudinal response function can be explained if one assumes that an amount of the longitudinal strength is to be found at high energies and that the depletion of strength at the lower energies is a measure of the reduction of the shell-model orbital occupation probability due to short-range correlations.

The purpose of the present paper is to propose a new approach to the study of the quasielastic electron scattering from nuclei. It is based on the coherent fluctuation model (CFM), which has been recently developed [19,20]. The essential idea underlying the model is to represent the density distribution by a superposition of spherical distributions of nucleons confined in a sphere with a given radius. The weighting factor of these spherical distributions is expressed in terms of the local nucleon density distribution $\rho(r)$. In this picture definite nucleon-nucleon correlations with a collective nature are effectively taken into account. The mixed density matrix $\rho(\vec{r},\vec{r}')$ satisfies the condition $\rho^2 \neq \rho$.

CFM has been applied to the description of the nucleon momentum distribution in nuclei [19-21] and of various processes of particle-nuclei interaction [22]. The spectral functions of hole nuclear states and some quantities related to them (such as single-particle widths, centroid energies, quasiparticle effective mass, etc.) have also successfully described in the framework of CFM [23].

In this paper we investigate the influence of the nucleon-nucleon correlations (which are effectively taken into account in CFM) on the quasielastic electron cross section and the response functions.

In Sect.2 we summarize the method we use for calculations of quantities related to the quasielastic electron scattering. In Sect.3 we present the results of our calculations and compare them with the experimental data and other approaches. The discussion of the results is given in the same section.

2. QUASIELASTIC ELECTRON SCATTERING

1. The quasielastic electron scattering cross section in the one-photon exchange approximation is usually written in the form:

$$\left[\frac{d^2\sigma}{d\Omega_2 dE_2}\right]_{lab.} = \frac{Z^2}{M_T}\left[W_2(\vec{q}^{\,2},\omega) + 2W_1(\vec{q}^{\,2},\omega)\,tg^2\frac{\theta}{2}\right], \qquad (1)$$

where M_T is the target (nuclear) mass, Z is the nuclear charge, $\vec{q}$ is the three momentum transfer to the nucleus in the lab. frame, $\omega = E_1 - E_2$ is the electron energy loss, the Mott cross section is given by

$$\sigma_M = \frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E_1^2 \sin^4\frac{\theta}{2}}, \qquad (2)$$

and $E_1(E_2)$ is the initial (final) electron energy.

The longitudinal and transverse resonse functions are defined by

$$R_L(\vec{q}^{\,2},\omega) = \frac{Z^2}{M_T}\frac{\vec{q}^{\,2}}{q^2}\left[-W_1(\vec{q}^{\,2},\omega) + \frac{\vec{q}^{\,2}}{q^2}W_2(\vec{q}^{\,2},\omega)\right], \qquad (3)$$

$$R_T(\vec{q}^{\,2},\omega) = \frac{Z^2}{M_T}\,2W_1(\vec{q}^{\,2},\omega). \qquad (4)$$

The expressions for the nuclear form factors W_1 and W_2 in the Fermi-gas model are given in [6].

2.. Having in mind the application of CFM to the description of the quasielastic electron scattering from nuclei we generalize the form factors W_1 and W_2 from [6] by the following superpositions: .

$$W_1(\vec{q}^{\,2},\omega) = \int_0^\infty dx\,|f(x)|^2\,W_1(\vec{q}^{\,2},\omega,x), \qquad (5)$$

$$W_2(\vec{q}, \omega) = \int_0^\infty dx |f(x)|^2 W_2(\vec{q}, \omega, x). \qquad (6)$$

The form factors $W_i(\vec{q}^{\,2}, \omega, x)$ $(i = 1,2)$ have the form of Eq. (10) in /6/, in which the momentum distribution $\theta(k_F - k)$ is replaced by $\theta(k_F(x) - k)$. Here $k_F(x)$ is the Fermi-momentum of the flucton in CFM /20/:

$$k_F(x) = \left(\frac{3\pi^2}{2}\rho_0(x)\right)^{1/3}; \quad \rho_0(x) = 3A/4\pi x^3. \qquad (7)$$

The weight function $|f(x)|^2$ of CFM can be expressed by the local density distribution $\rho(r)$ /19,20/:

$$|f(x)|^2 = -\frac{1}{\rho_0(x)} \frac{d\rho(r)}{dr}\Big|_{r=x}. \qquad (8)$$

3. RESULTS OF THE CALCULATIONS. DISCUSSION

The cross sections of the quasielastic electron scattering have been calculated by means of Eqs. (1,5-7). The standard "dipole fit" was used for the nucleon form factors:

$$G_E^p = \frac{G_M^p}{2.79} = \frac{\overline{4M^2}}{q^2} \frac{G_E^n}{1.91} = \frac{G_M^n}{-1.91} = \left(1 + \frac{q^2}{0.71\,(\mathrm{GeV}/c)^2}\right)^{-2}, \qquad (9)$$

where

$$G_E = F_1 - \frac{q^2}{2M} F_2; \quad G_M = F_1 + 2MF_2. \qquad (10)$$

The weight function $|f(x)|^2$ was calculated from (8) using the symmetrized Fermi-type distribution /24/:

$$\rho_{SF}(r) = \rho_0\left[\left(1 + \exp\frac{r-R}{b}\right)^{-1} + \left(1 + \exp\frac{-r-R}{b}\right)^{-1} - 1\right]; \qquad (11)$$

$$\rho_0 = \frac{3A}{4\pi R^3[1 + (\pi b/R)^2]}.$$

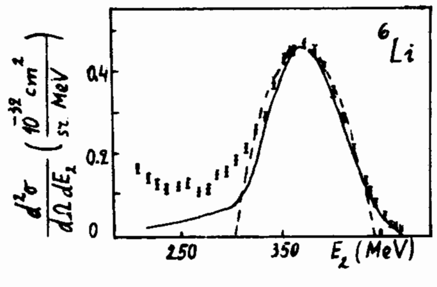


Fig.1. Cross section of quasielastic scattering of 500 MeV electrons at 60° from ^{6}Li. The solid line is the result of the present calculations. The dashed line represents the result of the Fermi-gas calculations /6-8/. The experimental data were taken from /8/.

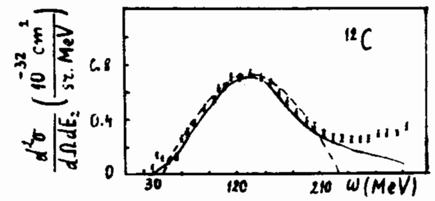


Fig.2. The same as in Fig.1 for ^{12}C. The experimental data are from /7/.

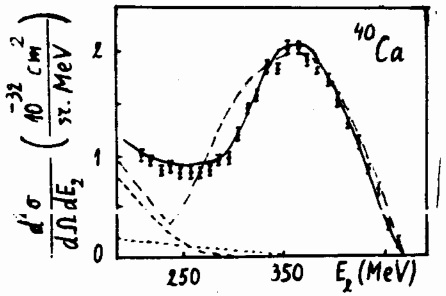


Fig.3. Cross section of quasielastic scattering of 500 MeV electrons at 60° from ^{40}Ca. The dotted line and the small-amplitude dashed line are the s-wave π-production and the isobar excitation contributions respectively; the large-amplitude dashed line is the total result in the Fermi-gas model /8/. The solid line is the result of the present calculations in CFM to which the π-production and isobar excitation contributions from the Fermi-gas model /8/ have been added.

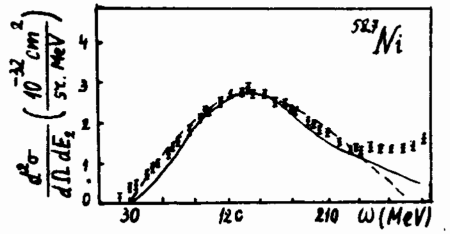


Fig.4. The same as in Fig.1 for ^{58,7}Ni. The experimental data are from /7/.

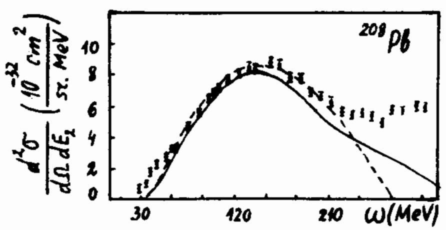


Fig.5. The same as in Fig.1 for ^{208}Pb. The experimental data are from /7/.

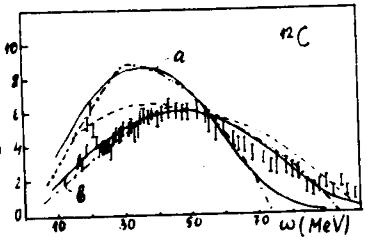


Fig.6. Cross section of quasi-elastic scattering of 148,5 MeV electrons at 135° from ^{12}C. The solid curves a) and b) are the results of the present calculations with $M^* = M$ and $M^* = M/1,4$ respectively. The dot-small amplitude dashed curve and the dot-large amplitude dashed curve are the Fermi-gas results with $M^* = M$ and $M^* = M/1,4$ respectively /6/. The dashed line is for harmonic oscillator momentum distribution from /6/.

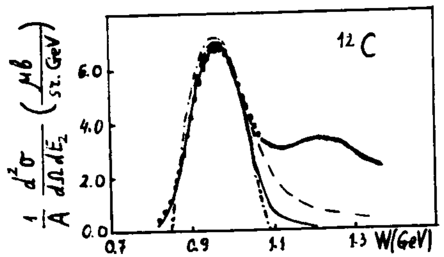


Fig.7. Cross section of 2 GeV electron scattering at 15° versus the invariant mass W for ^{12}C. The solid line is the result of the present calculations. The dot-dashed curve is the Fermi-gas result with parameters $k_F = 221$ (MeV/c) and $\bar\epsilon = 30$ MeV. The experimental data and the dashed curve are from /25/.

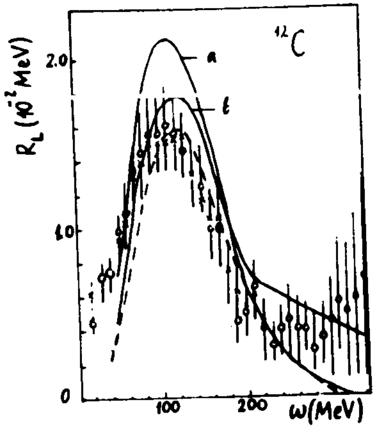


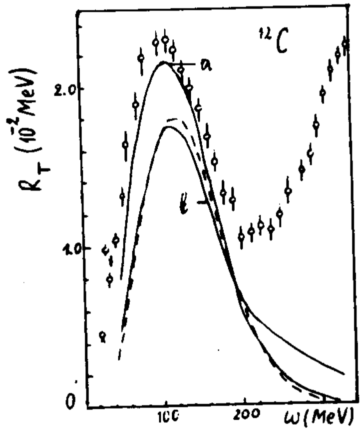
Fig.8. The longitudinal response function $R_L(\vec q^2, \omega)$ for inelastic electron scattering from ^{12}C. The solid curves a) and b) are the results of the present calculations with $M^* = M$ and $M^* = M/1,4$ respectively ($\bar\epsilon = 25$ MeV). The dashed curve is the result from /18/. The experimental data were taken from /14/. The 4-momentum transfer square $q^2 = (400\ \mathrm{MeV/c})^2$.

The parameters R and b have been obtained from the best fit to the elastic electron scattering experimental data /24/.

Following a convenient prescription given by Moniz /6/, we use an average separation energy $\bar\epsilon$ and a nucleon effective mass M^* (only in the case of $\frac{|\vec q|}{k_F(x)} < 2$).

The results of the calculations have been compared with the experimental data for quasielastic electron scattering and with other approaches and are presented on Figs.1-7.

Fig.9. The same as in Fig.8 for the transverse response function $R_T(\vec q^2, \omega)$.



The calculations for the response functions $R_L(\vec q^2, \omega)$ and $R_T(\vec q^2, \omega)$ are presented in Figs.8-9 and are compared with the results of Celenza et al. /18/ and with the experimental data.

Our calculations for the quasielastic cross sections were carried out with the parameters $M^* = M/1,4$ and $\bar\epsilon$, the optimal fit for the latter is given in the Table.

The values of $\bar\epsilon$ for various nuclei are in agreement with the conclusion stated in /11/, namely that $\bar\epsilon \simeq 30$ MeV is fairly constant across the nuclear table except for the light nuclei.

Here we would like to emphasize the fact that the values of $\bar\epsilon$ given in the Table are in good agreement with the ones obtained from the relation /11/:

$$\bar\epsilon(\vec q) = (\vec q^{\,2} + M^{*2})^{1/2} - M^* - \vec q^{\,2}/2M, \quad (|\vec q| \geq 2k_F) \qquad (12)$$

for $M^* = M/1,4$ and for different values of $\vec q$, which are characteristic for a given experiment. In this way the number of the free parameters is actually reduced to one parameter only, namely the effective mass M^*.

It was shown in /11/ that the value of $M^* \simeq M/1,4$ is, in fact, an average over the nucleus of the local effective mass $M^*(r)$ in the nuclear field approach /26,27/.

The function $M^*(k)/M$ (where the various k are the momenta attached to the hole nuclear states) can be determined in CFM /28/:

$$\frac{M^*(k)}{M} = \frac{\int_0^{a/k} dx\,|f(x)|^2}{|\mu| \int_0^{a/k} dx\,|f(x)|^2 \Big/ \frac{h^2 k_p^2(x)}{2M}}, \quad a \equiv \left(\frac{9}{8}\pi A\right)^{1/3}. \qquad (13)$$

This function is shown in Fig.10 for ^{40}Ca and ^{58}Ni. We note, that here the value of $M^* \simeq M/1,4$ can be considered also as an average value of the function $M^*(k)$.

Table

Values of the parameter $\bar{\epsilon}$

Nuclei	E_1 (MeV)	θ (deg)	$\bar{\epsilon}$ (MeV)	Nuclei	E_1 (MeV)	θ (deg)	$\bar{\epsilon}$ (MeV)
^{6}Li	500	60	20	^{40}Ca	500	60	28
^{12}C	148,5	135	0	^{58,7}Ni	500	60	30
	500	60	25	^{208}Pb	500	60	30
	2000	15	30				

In order to investigate the influence of the possible flucton size dependence of the effective mass M* on the cross section and response functions we performed methodical calculations for all cases of interest. The following dependence of the function $M^*(x)/M$ on x was chosen:

$$\frac{M^*(x)}{M} = \begin{cases} 0.428 & x \le x_0 - \Delta \\ \frac{0.286}{\Delta}(x - x_0) + 1/1.4\,, & x_0 - \Delta \le x \le x_0 + \Delta \\ 1 & x \ge x_0 + \Delta \end{cases} \qquad (14)$$

where x_0 is the value of the argument, at which the function $|f(x)|^2$ has a maximum, 2Δ is the region of x, in which the weight function $|f(x)|^2$ essentially differs from zero ($2\Delta \simeq 3$ fm). We note that the results differ insignificantly from the ones obtained using the average value $M^* = M^*(x_0) = M/1.4$.

The comparison of the cross sections calculated in the framework of CFM with the experimental data shows a better agreement, than those calculated in the Fermi-gas model (Figs.1-5,7) for large and small energy loss ω (or invariant mass W) and small and large E_2, respectively. We have added the s-wave π-production and the isobar excitation contributions calculated in [8] to our calculations of the quasielastic electron scattering cross section in the case of ^{40}Ca (cf. Fig.3). It is seen that the total result (solid line) describes much better the enhancement of the cross section at small E_2, than the Fermi-gas model calculations (large-amplitude dashed curve).

The improvement of the agreement with the experimental data, and especially the enhancement of the cross section in the region of large ω in comparison with the Fermi-gas model calculations can be considered as a result of short-range correlations effectively taken into account in CFM.

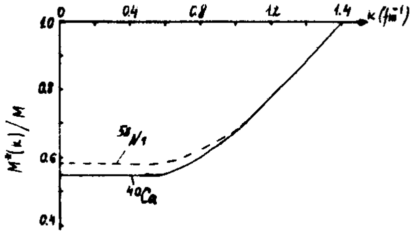


Fig.10. Effective mass M*(k) in CFM (cf. Eq. (13)).

The calculations for the longitudinal and transverse response functions R_L and R_T for ^{12}C (Figs. 8 and 9) with $M^* = M$ (curves a/) show the well-known picture of the impulse approximation: a qualitative agreement for the transverse response function R_T and larger values than the experimental data for the longitudinal response function R_L. The calculations with $M^* = M/1.4$ (curves b/) show the improvement of the agreement for R_L and a disagreement for R_T.

The CFM results for the longitudinal and transverse response functions at $M^* = M/1.4$ (curves b/) are close to those obtained in the modified impulse approximation [18], in which the decrease of R_L at lower energies is related to the reduction of the shell-model orbital occupation probability, due to short-range correlations.

REFERENCES

1. Drell S.D., Walecka J.D. Ann.Phys., 1964, 28, p. 18.
2. de Forest T.Jr., Walecka J.D. Adv.Phys., 1966, 15, p.1.
3. Sitenko A.G., Gur'ev V.N. JETPh, 1960, 39, p. 1260.
4. Czyż W. Phys.Rev., 1963, 131, p. 2141.
5. Czyż W., Gottfried K. Ann.Phys., 1963, 21, p. 47.
6. Moniz E.J. Phys.Rev., 1969, 184, p. 1154.
7. Moniz E.J. et al. Phys.Rev.Lett., 1971, 26, p. 445.
8. Whitney R.R. et al. Phys.Rev., 1974, C9, p. 2230.
9. Brieva F.A., Dellafiore A. Nucl.Phys., 1977, A292, p. 445.
10. Heimlich F.H. et al. Nucl.Phys., 1974, A231, p. 509.
11. Rosenfelder R. Ann.Phys., 1980, 128, p. 188.
12. Korchin A.Ju. Yad. Fiz., 1982, 35, p. 1162.
13. Altemus R. et al. Phys.Rev.Lett., 1980, 44, p. 965.
14. Barreau P. et al. Nucl.Phys., 1981, A358, p. 287.
15. Noble J.V. Phys.Rev.Lett., 1981, 46, p. 412.
16. Donnely T.W. et al. Phys.Lett., 1978, 76B, p. 393.
17. Kohno M., Ohtsuka N. Phys.Lett., 1981, 98B, p. 335.
18. Celenza L.S. et al. Phys.Rev., 1982, C26, p. 320.
19. Antonov A.N., Nikolaev V.A., Petkov I.Zh. Bulg.J.Phys., 1979, 6, p. 151.
20. Antonov A.N., Nikolaev V.A., Petkov I.Zh. Z.Phys., 1980, A297, p. 257.
21. Antonov A.N., Nikolaev V.A., Petkov I. Zh. and Hodgson P.E. Preprint Nucl.Phys.Lab., Oxford Univ., No. 23/82, Oxford, 1983.

22. Antonov A.N., Nikolaev V.A., Petkov I. Zh. Izv. AN SSSR, ser.fiz., 1983, 47, 134 (and references therein).
23. Antonov A.N., Nikolaev V.A., Petkov I.Zh. Z.Phys., 1982, A304, p. 239.
24. Burov V.V. et al. JINR, E4-8029, Dubna, 1974.
25. Glawe U. et al. Phys.Lett., 1979, 89B, p. 44.
26. Walecka J.D. Ann.Phys., 1974, 83, p. 491.
27. Serr F.E., Walecka J.D. Phys.Lett., 1978, 79B, p. 10.

Received by Publishing Department
on September 20,1983.

SUBJECT CATEGORIES OF THE JINR PUBLICATIONS

Index	Subject
1.	High energy experimental physics
2.	High energy theoretical physics
3.	Low energy experimental physics
4.	Low energy theoretical physics
5.	Mathematics
6.	Nuclear spectroscopy and radiochemistry
7.	Heavy ion physics
8.	Cryogenics
9.	Accelerators
10.	Automatization of data processing
11.	Computing mathematics and technique
12.	Chemistry
13.	Experimental techniques and methods
14.	Solid state physics. Liquids
15.	Experimental physics of nuclear reactions at low energies
16.	Health physics. Shieldings
17.	Theory of condenced matter
18.	Applied researches
19.	Biophysics

Антонов А.Н., Петков И.Ж. E4-83-663

О квазиупругом рассеянии электронов ядрами

Модель когерентных флуктуаций ядерной плотности /МКФ/ применяется к квазиупругому рассеянию электронов ядрами. Исследуется влияние нуклон-нуклонных корреляций, которые учитываются в модели, на сечения квазиупругого рассеяния электронов и на функции отклика. Проведено вычисление дифференциальных сечений реакции (e,e′) на ^{6}Li, ^{12}C, ^{40}Ca, ^{57}Ni, ^{58}Ni, ^{208}Pb в широком интервале энергий и углов. Рассчитаны также продольная и поперечная функции отклика для ядра ^{12}C при значении квадрата четырехмерного переданного импульса $q^2 = /400$ МэВ/с/^{2}. Результаты расчетов сравниваются с экспериментальными данными и с другими подходами. В МКФ получено улучшение согласия с экспериментальными данными о сечениях реакции (e,e′) при больших переданных энергиях по сравнению с моделью Ферми-газа, а также и с данными о продольной функции отклика.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1983

Antonov A.N., Petkov I.Zh. E4-83-663

On the Quasielastic Electron Scattering from Nuclei

The model of coherent nucleon density fluctuations (CFM) is applied to the quasielastic electron scattering by nuclei. The influence of nucleon-nucleon correlations (which are effectively taken into account in the model) on the quasielastic electron cross sections and the response functions is studied. Calculations of the differential cross sections of the reaction (e,e′) in the cases of ^{6}Li, ^{12}C, ^{40}Ca, ^{58,7}Ni, ^{208}Pb, at different energies and angles are carried out. The longitudinal and transverse response functions for ^{12}C at $q^2 = (400\ \mathrm{MeV/c})^2$ are calculated. The results of the calculations are compared with the experimental data and other approaches. In CFM an improvement of the agreement of the theoretical results with the experimental data for the reaction (e,e′) at large energy loss in comparison with the Fermi-gas model results is obtained.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1983