A mechanism for filling the diffraction minima in the inelastic scattering cross sections of protons by nuclei

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It is shown that allowance for the t-dependence of the ratio of the real part to the imaginary part of the nucleon-nucleon amplitude makes it possible to improve the description of the diffraction minima in the elastic and the inelastic cross sections for scattering of 1-GeV protons by nuclei.

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The elastic and inelastic scattering of 1-GeV protons by nuclei has recently been effectively used to study nuclear structure.[1] The existing Glauber-Sitenko theory of multiple scattering accurately describes the scattering cross section and makes it possible to extract fine details of the distribution of nuclear matter from an analysis of data for the scattering of high-energy protons by nuclei. At the same time, the scattering process of fast protons has not been fully resolved. The puzzling (without a diffraction minimum) cross section of excitation of the 3^- level ($E_{ex} = 9.64$ MeV) in ^{12}C nuclei by 1-GeV protons until now has not been fully accounted for.[2]

We showed[3] that the t-dependence of the ϵ-ratio of the real part to the imaginary part of the amplitude of the proton-nucleon scattering is a probable cause for filling of the diffraction minimum in the cross sections for elastic scattering of protons by the lightest nuclei (^{3}He and ^{4}He). We might ask how an allowance for the t-dependence of the value ϵ can influence the depth of the minima in the inelastic scattering cross sections and is it possible to fully explain the observed filling of the minima in terms of this dependence? So far as we know, this problem has not been examined in the literature. In this paper we calculate the cross section for elastic scattering of 1-GeV protons by ^{12}C and ^{40}Ca nuclei and the cross section for inelastic scattering, which is accompanied by excitation of the 3^- level in ^{12}C and the 5^- level in ^{40}Ca. The proton-nucleus scattering amplitudes were calculated by using a numerical integration method and the exact formulas of Glauber-Sitenko (see, for example, Ref. 1). The proton-nucleus Coulomb interaction was taken into account in the usual way. The proton-nucleon scattering amplitude, averaged over the pp and pn interaction, was parametrized in the form

$$f = \frac{k\sigma}{4\pi}(i + \epsilon)\exp(\beta t/2), \qquad (1)$$

$$\epsilon = \epsilon_0 + \epsilon_1 t + \epsilon_2 t^2, \qquad (2)$$

where k is the wave vector, σ is the total cross section for proton-nucleon interaction ($\sigma = 4.4$ F^2), β is the slope parameter ($\beta = 0.21$ F^2), $t = -q^2$, and q is the momentum

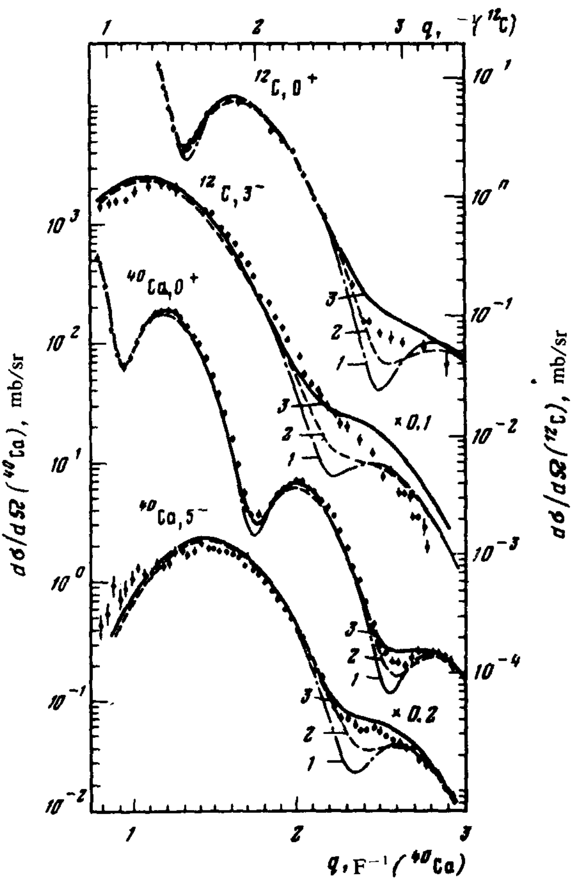

FIG. 1. Elastic (0^+) and inelastic (3^-, $E_{ex} = 9.64$ MeV; 5^-, $E_{ex} = 4.49$ MeV) cross sections for scattering of 1-GeV protons ^{12}C and ^{40}Ca nuclei. Curves 1, 2, and 3 correspond to calculations disregarding the t-dependence in the ratio of the real part to the imaginary part of the nucleon-nucleon amplitude (1) and allowing for the linear (2) and the quadratic (3) terms in t (the calculated cross sections were normalized to the experimental cross sections).

transfer. The many-particle transition densities and the ground-state densities of the ^{12}C and ^{40}Ca nuclei were represented as the products of the corresponding single-particle densities (this corresponds to disregarding the nucleon correlations). The single-particle transition densities of the nuclear matter were of the form

$$\rho_{LM}(\mathbf{r}) = \delta_L Y_{LM}(\mathbf{r})\, \partial/\partial r\ \rho_1(\mathbf{r}),$$

The single-particle, ground-state densities $\rho_0(r)$ and the $\rho_1(r)$ densities were parametrized by the Fermi distribution:

$$\rho_i(r) \sim [1 + W_i (r/R_i)^2]/\{1 + \exp[(r - R_i)/a_i]\}, \quad (i = 0, 1).$$

We used the following parameters in the calculations[1)]: $R_0 = R_1 = 2.16$ F,

$W_0 = W_1 = -0.11$, $a_0 = 0.55$ F, $a_1 = 0.68$ F, $\delta_3 = 0.47$ F for ^{12}C and $a_0 = a_1 = 0.60$ F, $W_0 = W_1 = -0.1$, $R_0 = 3.66$ F, $R_1 = 3.40$ F, $\delta_5 = 0.27$ F for ^{40}Ca. Note that the elastic specific choice of the density parameters influences the location of the minima and the height of the maxima, but has a relatively small effect on the depth of the minima. Figure 1 shows the results of calculations with the following proton-nucleon amplitude parameters: 1, $\epsilon_0 = -0.24$; $\epsilon_1 = 0$; $\epsilon_2 = 0$; 2, $\epsilon_0 = -0.18$ F^2; $\epsilon_2 = 0$; 3, $\epsilon_0 = -0.21$; $\epsilon_1 = 0$; $\epsilon_2 = 0.012$ F^4. The calculated cross section were compared with the experimental data.[4] The values of ϵ_0 in case 1 was chosen on the basis of an optimum description of the depth of the first minimum in the cross section for elastic scattering of protons by ^{40}Ca nuclei. We can see that in this case the calculated depth of the first minimum in the elastic scattering cross section for ^{12}C is larger than the experimental value. In case II and III, when the t-dependence was taken in to account in the value ϵ, we could describe the depth of the first minimum in the elastic scattering cross sections for both ^{40}Ca and ^{12}C. As far as the shape of the minima at high momentum transfer is concerned, we can see that allowance for the t-dependence of the value ϵ leads (for the values of ϵ_1 and ϵ_2) to a large filling of the minima. Thus, our calculations show that the dependence of the ratio of the real part to the imaginary part of the nucleon-nucleon amplitude on the momentum transfer is one of the major reasons for filling of the diffraction minima at high q in the cross sections for elastic and inelastic scattering of 1-GeV protons by nuclei.

Unfortunately, there is no information on the actual behavior of the pn amplitude, because a complete experiment on pn scattering is difficult to perform. The problem examined in this paper makes it possible to raise the question of determining the t-dependence of the ratio of the real part to the imaginary part of the nucleon-nucleon amplitude directly from the data for the scattering of protons by nuclei. In fact, the filling of diffraction minima in the elastic and inelastic cross sections for scattering of protons by nuclei is very sensitive to the value of ϵ_0 and to the t-dependence of ϵ. We must take into account, however, that other factors such as nucleon correlations[2] can also influence the filling of the minima. These effects can be separated by performing experiments at different proton energies. Thus, at an energy $E_p = 24$ GeV a deep diffraction minimum can be observed in the elastic cross section for scattering of protons by ^4He nuclei.[5] Therefore, the filling of this minimum at an energy $E_p = 1$ GeV cannot be attributed to the structure of the ^4He nucleus. A measurement of the inelastic differential scattering cross section with excitation of the 3^- level in the ^{12}C nuclues at an energy $E_p \approx 20$ GeV would make it possible to isolate contribution in the cross section minimum due to nucleon correlations. This would facilitate a further study of the structural singularities of the ^{12}C nucleus.

[1)]Here we give the parameters of the "quenched" densities that take into account the finite size of the nucleon.

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