INTERFERENCE BETWEEN COULOMB AND NUCLEAR SCATTERING AT HIGH ENERGIES

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Interference between Coulomb and nuclear scattering is considered in the quasi-classical approximation. Results of calculations are presented for scattering of 8.7-Bev protons on light and heavy emulsion nuclei. The magnitude and sign of the real part of the amplitude for scattering of protons on protons are discussed.

THE amplitude of elastic scattering of nucleons on nucleons and nuclei has, in the general case, the form

$$f(\vartheta) = A(\vartheta) + (B\sigma_i, \vartheta), \quad (1)$$

where $A(\vartheta)$ is some complex function, and $B(\sigma_i, \vartheta)$ is the part of the amplitude dependent on the spins of the interacting particles. At high energies it is usually assumed that the real part of $A(\vartheta)$ and the term $B(\sigma_i, \vartheta)$ in expression (1) are equal to zero. Experiments on elastic scattering of 8.7-Bev protons on hydrogen[1] and on emulsion nuclei[2] apparently indicate that this assumption is incorrect. However, the results of these experiments, in essence, only raise the question of taking into account the real part of $A(\vartheta)$ and the spin dependence of the nuclear forces, but do not give any clue as to their role in the interaction. In the present article we consider the interference between nuclear and Coulomb scattering, the study of which can give the magnitude and sign of Re A.

In the quasi-classical approximation for spin-zero particles the scattering amplitude has the form

$$A(\vartheta) = ik\int_0^\infty [1 - e^{2i\beta(\rho)}] J_0(k\vartheta\rho)\,\rho d\rho, \quad (2)$$

where $\beta(\rho)$ is the sum of the Coulomb and nuclear scattering phase shifts. Thus the Coulomb interference is determined by the value and sign of the nuclear phase shifts. In the optical approximation, the latter depends in turn on the magnitude and sign of the real part of the nucleon—nucleon forward scattering amplitude, Re $f_{NN}(0)$.

Formula (2) is approximately valid also for the case of the scattering of particles with spin on spin-zero nuclei, for example, for the scattering of protons on light emulsion nuclei (C^{12}, N^{14}, O^{16}). Strictly speaking, the spin-orbit interaction should be taken into account in this case, but it does not play an important role in the small-angle region.

We used expression (2) to calculate the interference between Coulomb and nuclear scattering of 8.7-Bev protons on light and heavy (Ag, Br) emulsion nuclei.* The phase shifts of the nuclear scattering were calculated by the usual method (see, for example, reference 2). The Coulomb scattering phase shifts were obtained from the formula of Bethe.[3] The magnitude of Re $f_{NN}(0)$, according to the data of Markov, Tsyganov, Shafranova, and Shakhbazyan (see reference 4), was set equal to 14.4×10^{-13} cm. The results of the calculations are shown in Fig. 1. In order to obtain the differential cross section for the mixture of emulsion nuclei, it is necessary to combine the cross sections for the light and heavy nuclei with respective weights of 0.58 and 0.42.

The differential cross section was also calculated from the approximate formula of Bethe:[3]

$$d\sigma/d\Omega = |g_n(0) - (2n/k\vartheta^2)e^{2i\eta}|^2 F^2(k\vartheta a),$$
$$n = Ze^2/\hbar v, \qquad \eta = n(0.058 - \ln ka - \ln\vartheta), \quad (3)$$

where $g_n(0)$ is the forward nuclear scattering amplitude, a is the mean square radius multiplied by $\sqrt{2/3}$. The form factor was taken in the form $F = \exp\{-(k\vartheta a)^2/4\}$. Here we wished to consider the degree of applicability of this approximate formula in connection with the critical remarks of Batty.[5] As a result of the calculations, it turned

*We neglect the spin of the heavy nuclei as it does not play an important role in the scattering process. This is connected with the fact that the ratio of the spin of heavy nuclei to their mass number is small.

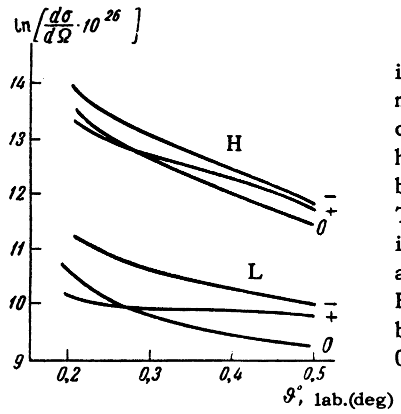

FIG. 1. Interference in the case of emulsion nuclei. The curves calculated for light and heavy nuclei are denoted by the letters L and H. The curves corresponding to positive, negative, and zero values of Re $f_{NN}(0)$ are denoted by the symbols +, −, and 0. ($d\sigma/d\Omega$ in cm^2)

out that the difference between the cross sections obtained from the approximate formula and the quasi-classical approach is no greater than a few percent for light nuclei.

In the case of scattering of 8.7-Bev protons on protons, it was assumed that the effect of their spins can be neglected.* The differential cross section was calculated from formula (3). The form factor in the same form as for the nuclei was calculated for $a = 0.86 \times 10^{-13}$ cm — the value taken from the data of Preston.[4] The results of the calculations (in the c. m. s.) are shown in Fig. 2. It is seen that the choice of the value Re $f_{NN}(0) = 13.5 \times 10^{-13}$ cm does not contradict the experimental results if its sign is positive. This statement, however, should not be considered conclusive, since the errors on the histogram are large, and the assumptions made above are based on insufficiently accurate experimental data.

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*Some basis for this assumption may be found in the fact that comparison of the scattering of 8.7-Bev protons on hydrogen[1,4] and on emulsion[2] indicates that the effect of the spin-dependent interaction is small.

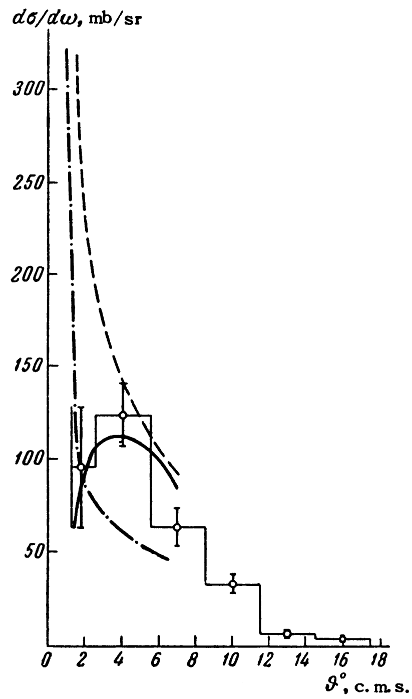

FIG. 2. Interference in the case of hydrogen. The solid, dashed and dot-dash lines refer to the positive, negative, and zero values of Re $f_{NN}(0)$. The histogram represents the experimental results of Markov et al.

[1] Lyubimov, Markov, Tsyganov, Cheng Pu-Ying, and Shafranova, JETP 37, 910 (1959); Soviet Phys. JETP 10, 651 (1960).

[2] Bannik, Grishin, Danysz, Lyubimov, and Podgoretskiĭ, JETP 37, 1575 (1959); Soviet Phys. JETP 10, 1118 (1960).

[3] H. Bethe, Ann. Phys. 3, 190 (1958).

[4] V. I. Veksler, Report at the 9th International Conference on High Energy Physics, Kiev, 1959.

[5] C. J. Batty, Proc. Phys. Soc. (London) A 73, 185 (1959).

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