AL

**Coulomb-nucleon phase
and spin effects in the diffraction dip domain**

O.V.Selyugin

swg647

Division de Physique Théorique¹, Institut de Physique Nucléaire, 91406 Orsay Cedex
and LPTPE, Université P.&M.Curie, 4 Place Jussieu, 75252 Paris Cedex 05, France

and

BLTPh*, Joint Institute for Nuclear Research, 141980 Dubna, Moscow region.
Russia

IPNO/TH 96-40

SEPTEMBER 1996

¹ Unité de Recherche des Universités Paris 11 et Paris 6 Associée au CNRS

*Permanent address.

ABSTRACT - The total phase of the Coulomb-hadron interaction is calculated with the true hadron scattering amplitude and with the Coulomb amplitude including the form factor of hadrons. This phase includes also the contribution of the phase of the pure coulomb interaction of hadrons taking into account the hadron form factors. The analyzing power A_N is calculated in the whole diffraction dip domain of high-energy elastic hadron scattering with the Coulomb-hadron interference effects.

At present, the spin effects owing to the Coulomb-hadron interference at very small transfer momenta are widely discussed in the aspect of future spin experiments at RHIC and LHC. These effects are worse understood in the domain of the diffraction dip. In many respects, this is due to the fact that we do not know the Coulomb-hadron interference phase for not small transfer momenta and its impact on the magnitude of the spin effects. The spin phenomena in diffraction processes can give important information about the structure of scattering amplitudes in the nonperturbative region.

A number of models [1, 2] predicts the existence of a nondisappearing spin-flip amplitude at high energies in the diffraction-peak region. Possibility for appearing this amplitude at $\sqrt{s} = 540 \text{ GeV}$ in the proton-antiproton scattering has been shown in [3]. At present, new experiments are proposed on high precision investigations of polarization phenomena in the diffraction region of the proton-proton scattering at RHIC (see, for example, [4, 5]). There also we need exact knowledge of the contribution of the Coulomb amplitude.

In this paper, we will consider the phenomena of interference of Coulomb spin amplitudes with the elastic nonflip hadronic amplitude and their contributions to the spin correlation parameters A_N around the diffraction minimum. A majority of theoretical models describe the hadron scattering at small angles with the eikonal approximation for the scattering amplitude

$$F(s, t) = \frac{1}{2i} \int_0^\infty \rho d\rho J_0(\rho\Delta)(1 - e^{-2i\delta(\rho)}); \quad (1)$$

where the eikonal phase $\delta(\rho)$ includes the Coulomb and hadron parts and is spin-dependent:

$$\delta(s, \rho) = \int_0^\infty d^2\Delta e^{-i\vec{\Delta}\vec{\rho}} F^{Born}(\Delta, s, \vec{s}); \quad (2)$$

The interaction potential of charged hadrons is a sum of Coulomb and nuclear

interactions

$$F^{Born}(s, \Delta, \vec{s}) = F_c^{born}(\Delta, \vec{s}) + F_h^{Born}(s, \Delta, \vec{s}).$$

So, after the eikonal summation, terms with the Coulomb and nuclear interactions appear. The phase of the Coulomb-hadron interaction has been calculated and discussed by many authors [6, 7] and has the form [8]

$$\varphi(s, t) = \mp[\gamma + \ln(B(s, t)|t|/2) + \ln(1 + 8/(B(s, t)\Lambda^2)) + \nu_c. \quad (3)$$

where $B(s, t)$ is the slope of the nuclear amplitude; Λ is a constant entering into the dipole form factor and ν_c is an additional part coming from the pure Coulomb interaction and calculated in [8] for small t .

In [10], the phase ν_s of the pure Coulomb amplitude in the second Born approximation with the form factor in the monopole and dipole form has been calculated in a wide region of transfer momenta. It was shown that the behaviors of ν_s at not small t sharply differ from the behaviors of ν_c obtained in [8]. Now, we show how one can calculate the total Coulomb-hadron phase that can be used in the whole diffraction range of elastic hadron scattering.

Let us expand (1) in powers of eikonal Coulomb and hadron phases. following the procedure in [7]:

$$F(s, t) = \frac{1}{2i} \int_0^\infty \rho d\rho J_0(\rho q) (2i\delta_c + 2i\delta_h - \frac{(2i\delta_c)^2}{2} - \frac{(2i\delta_h)^2}{2} - \frac{2i\Delta_c 2i\delta_h}{2} - \frac{2i\delta_h 2i\delta_c}{2} \dots). \quad (4)$$

Now let us very carefully collect the terms with Coulomb and hadron phases and mixed terms:

$$F(s, t) = F_c(s, t) + F_h(s, t) - 2 \int_0^\infty \delta_c(\rho) (1 - e^{-2i\delta_h(\rho, s)}) \rho d\rho J_0(\rho q) \quad (5)$$

We obtain the total hadron and Coulomb amplitudes and the interference term in the second Born approximation. If we combine this interference term with the

hadron term, we obtain:

$$F(s, t) = F_c(s, t) + F_h(s, t) \left[1 - \frac{2}{F_h(s, t)} \int_0^\infty \delta_c(\rho) (1 - e^{-2i\delta_h(\rho, s)}) \rho d\rho J_0(\rho q) \right] \quad (6)$$

The representation (6) is an equivalent of the formula obtained in [9] in the diagram technique. Taking into account the pure Coulomb phase obtained in [10] we can rewrite (6) in terms of the Coulomb-hadron phase

$$F(s, t) = F_c e^{i\alpha(\varphi_{ch} + \varphi_c)} + F_h(s, t). \quad (7)$$

The Coulomb phase can be calculated with the hadron form factor in the second Born approximation [8, 10]

$$\varphi_c = \ln \frac{\lambda^2}{\Delta^2} + \nu \quad (8)$$

Here, $\lambda \rightarrow 0$ is the effective photon mass. Note that the divergent logarithmic term appears only in the second Born approximation. Hence, if we take the Coulomb amplitude in first order, this term will be absent.

For the calculation of the Coulomb part in the Coulomb-hadron eikonal, let us expand the nucleon form factor in inverse powers of $\lambda^2 + \Delta^2$:

$$\begin{aligned} G^2(\Delta^2) &= \left[\frac{\Lambda^2}{\Lambda^2 + \Delta^2} \right]^4 \\ &= 1 - \frac{\Delta^2}{\Lambda^2 + \Delta^2} - \frac{\Delta^2 \Lambda^2}{(\Lambda^2 + \Delta^2)^2} - \frac{\Delta^2 \Lambda^4}{(\Lambda^2 + \Delta^2)^3} - \frac{\Delta^2 \Lambda^6}{(\Lambda^2 + \Delta^2)^4} \end{aligned} \quad (9)$$

In accordance, we obtain for the Coulomb part of the Coulomb-hadron eikonal:

$$\begin{aligned} \delta_c(\rho) &= \alpha(K_0(\rho\lambda) - K_0(\rho\Lambda) - \frac{\Lambda\rho}{2\Gamma(2)}K_{-1}(\rho\Lambda) - \frac{\Lambda^2\rho^2}{4\Gamma(3)}K_{-2}(\rho\Lambda) \\ &\quad - \frac{\Lambda^3\rho^3}{8\Gamma(4)}K_{-3}(\rho\Lambda). \end{aligned} \quad (10)$$

Here K_i are MacDonald functions and $\Gamma(n)$ is a gamma function. The first term gives the eikonal without the nucleon form factor and others give the corrections that play an important role when t goes from zero. For the first two terms the

integral is calculated, the term with λ is cancelled with the same term of δ_c , and we obtain for the total Coulomb-hadron phase:

$$\varphi = \ln \frac{\Delta^2}{4} + 2\gamma + \frac{2}{F_h(s, \Delta)} \int_0^\infty \tilde{\delta}_c(\rho) (1 - \exp(-2i\delta_h(\rho, s))) J_0(\rho\Delta) d\rho. \quad (11)$$

with

$$\tilde{\delta}_c(\rho) = 2\rho \ln \rho + 2\rho K_0(\rho\Lambda) \left[1 + \frac{5}{24}\Lambda^2 \rho^2\right] + \frac{\Lambda\rho}{12} K_1(\rho\Lambda) \left[11 + \frac{5}{4}\Lambda^2 \rho^2\right] \quad (12)$$

The calculated phase (11) is the eikonal analog with taking account of the hadron form factor of the expression obtained by West and Yennie [9] from the Feynman diagram.

If we take the Born term of the hadron amplitude in the Regge form

$$F_h^B(s, \Delta) = h \exp(-B(s, \Delta)\Delta^2), \quad (13)$$

and only the first term of (11) that corresponds to the Coulomb amplitude without the form factor, we obtain the ordinary representation for the total Coulomb-hadron phase in the region of small transfer momenta

$$\varphi \simeq \ln \frac{B(s, \Delta)\Delta^2}{2} + \gamma. \quad (14)$$

However, our eikonal for the Coulomb-hadron phase (11) is true in a wide region of transfer momenta. If we take the true hadron scattering eikonal that describes the experimental differential cross sections including the domain of the diffraction dip, we can calculate the Coulomb-hadron phase for that region of transfer momenta. This phase will have a real and a not small imaginary part. The phase can be very important for the calculation of spin correlation parameters owing to the Coulomb-hadron interference effects in the domain of the diffraction dip. In this region, the imaginary part of the scattering amplitude has zero and these effects can be not small. Beforehand, we don't know how large they will be and how the Coulomb-hadron phase affects their magnitudes. Of course, the largest effects will be in the

energy range where the diffraction minimum has a strictly defined form and, thus, the real part of the nonflip scattering amplitude will be small.

Let us take, for example, the eikonal of the spin-nonflip hadron scattering amplitude obtained in [1] that gives a quantitative description of high-energy experimental data:

$$-2i\delta_h(s, \rho) = h_1 e^{-\mu\sqrt{\rho^2+b^2}} (1 - h_2 e^{-\mu\sqrt{s^2+b^2}}). \quad (15)$$

As this model is based on the crossing symmetry of the scattering amplitude, the parameters in this eikonal are complex and, hence, the obtained scattering amplitude has a real and an imaginary part. Using this eikonal we can calculate the total Coulomb-hadron phase, for example, for $\sqrt{s} = 30$ (GeV). Note that our results depend weakly on the model for the hadron spin-nonflip eikonal. Different models should give the same $\sigma_{tot}, \rho(s) = ReF(s, 0)/ImF(s, 0)$ and differential cross sections in a wide region of energies and momenta transfer. The calculated total Coulomb-hadron phase is shown in Fig.1. It is clear that the phase in the domain of the dip is large in magnitude with a positive maximum of the real part at $-t = 1.25$ GeV² and a negative maximum, at $-t = 1.45$ GeV². The imaginary part has one negative maximum at the point of the minimum of the diffraction dip.

Using the obtained phase, let us calculate, for example, the analysing power in the dip domain of the proton-proton elastic scattering

$$A_N \frac{d\sigma}{dt} = -4\pi Im[(F_1 + F_2 - F_3 - F_4) F_5^*]. \quad (16)$$

For the Coulomb helicity amplitudes, one takes the usual one-photon approximation (see [11]) with our Coulomb-hadron phase calculated for the whole diffraction range. As a result, the total helicity amplitudes can be written as $F_i(s, t) = F_i^h(s, t) + F_i^c(t)exp(i\alpha\phi)$. The calculated analyzing power is shown in Fig.2. It is in form similar to the Coulomb-hadron phase. The analysis shows that the impact of the Coulomb-hadron phase leads to the increase of the analyzing power approximately

by 50% of the effect. Hence, if this impact were negative, the effect of the Coulomb-hadron interference on the analyzing power becomes very small.

We obtain the eikonal form for the Coulomb-hadron interference phase. Using this representation, the Coulomb-hadron phase was calculated in a wide region of transfer momenta. Now we can calculate the spin correlation parameters for the domain of the diffraction minimum. The calculation of the analysing power shows that the Coulomb-hadron phase increases the spin effect by about 50%. This order of magnitude of the effect can be obtained for the double-spin correlation parameter A_{NN} . As a result, we obtain, in the domain of the diffraction minimum, not small spin correlation effects due to the interference of the spin-nonflip elastic scattering amplitude and the Coulomb spin-flip amplitude that can be measured in modern high-energy experiments with polarized beams.

Acknowledgment. The author thanks Prof. D.Vautherin for the kind hospitality at IPN Orsay and LPTPE Paris. He also thanks P.Gauron, M.Islam and B.Nicolescu for useful discussions.

References

- [1] S. V. Goloskokov, S. P. Kuleshov, O. V. Selyugin, *Zeitschr. fur Phys.* **C 50**, 455 (1991).
- [2] M. Anselmino, S. Forte, *Phys. Rev. Lett.* **71**, 223 (1993).
- [3] O. V. Selyugin, *Phys. Lett.* **B 333**, 245 (1994).
- [4] O. V. Selyugin, In Proceedings "Spin-95", Protvino (1995).
- [5] N. Akchurin, N. H. Buttmore, A. Penzo, *Phys. Rev.* **D 51** 3944 (1993).
- [6] H. Bethe, *Ann. Phys.* **3**, 190 (1958).
- [7] M.M.Islam, *Phys.Rev.*, **162** 1426 (1967).
- [8] R. Cahn, *Zeitschr. fur Phys.* **C 15**, 253 (1982).
- [9] G. B. West, D. R. Yennie, *Phis. Rev.* **172**, 1414 (1968).
- [10] O.V. Selyugin. preprint JINR. E2-96-58, Dubna, 1996.
- [11] N. H. Buttmore, E. Gotsman, E. Leader. *Phys. Rev.* **D 35**, 407 (1987).

Fig. 1. The total Coulomb-hadron interference phase in the domain of the diffraction dip at $\sqrt{s} = 50 \text{ GeV}$ (dashed and full lines are real and imaginary parts of φ).

Fig. 2. The asymmetry A_N owing to the Coulomb-hadron interference (dashed and full lines are without and with the Coulomb-hadron interference phase).