Electromagnetic effects in the diffraction scattering of hadrons

B. Z. Kopeliovich, L. I. Lapidus, L. L. Frankfurt,[1)] and V. A. Khoze[1)]

Joint Institute for Nuclear Research
(Submitted February 10, 1975)
Zh. Eksp. Teor. Fiz. **69**, 422–428 (August 1975)

The role of electromagnetic effects in diffraction processes is discussed in the strong and weak pomeron-interaction variants. It is found that the interference of the diagrams with exchange of a γ quantum and vector V mesons shifts the position of the vacuum pole by an amount $\Delta^{\gamma V} \sim 10^{-3}$. A correction is also found for the three-pomeron coupling constant, and is connected by a simple relation (3) with $\Delta^{\gamma V}$. It amounts to several percent of the experimental value. It is shown that in the case of strong coupling the contributions of these two effects to the position of the vacuum pole can cancel each other. At the same time, the pure electromagnetic corrections always shift the pole to the right of unity.

PACS numbers: 12.40.Mm, 13.40.Ks

INTRODUCTION

When theories are developed for diffraction processes, it is customary to neglect electromagnetic effects.[1,2] It is known, however, that the cross sections of certain electromagnetic processes increase with energy (see, e.g.,[3-5]). The purpose of this paper is to ascertain the order of magnitude of the effects resulting from allowance for electromagnetic corrections. The analysis is limited here to radiative corrections for the position of the vacuum pole, and to the value of the three-pomeron coupling constant.

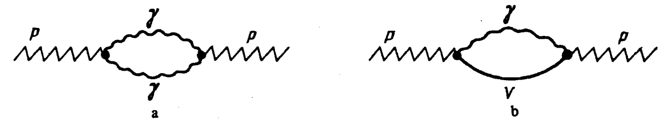

FIG. 1

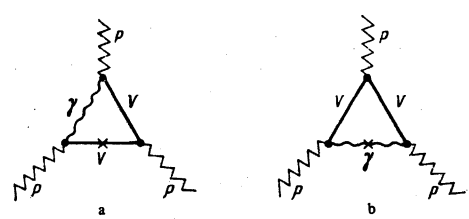

FIG. 2

The electromagnetic shift of the position of the vacuum pole from the self-energy part shown in Fig. 1a was discussed in[5]. If the bare pomeron P has $\alpha_P(0) = 1 + \Delta^h$, then, owing to absence of reggeization of the photon, two poles are produced, $\alpha_\pm(0) = 1 + \Delta^h \pm \Delta_\pm^{\gamma\gamma}$, where

$$\Delta_\pm^{\gamma\gamma} = -\Delta^h/2 \pm [(\Delta^h/2)^2 + \Sigma^{\gamma\gamma}]^{1/2}, \tag{1}$$

$$\Sigma^{\gamma\gamma} = (1/4\pi^3 R^2)(\sigma_{tot}^{\gamma N})^2/\sigma_{tot}^{NN}. \tag{2}$$

Here $\sigma_{tot}^{\gamma N} \approx 0.1$ mb and $\sigma_{tot}^{NN} \approx 40$ mb are the total nucleon photoabsorption the nucleon-nucleon interaction cross sections; $R^{-2} \approx 0.5\ (\mathrm{GeV}/c)^2$ is a parameter that determines the dependence of the cross section of deep inelastic scattering on t. It is seen from (1) that regardless of the sign of Δ^h we have $\alpha_+(0) > 1$, $\alpha_-(0) < 1$.

A shift of the vacuum pole is also possible as a result of interference between the electromagnetic and strong interaction. An example of the self-energy part of this type is shown in Fig. 1b, where V denotes the vector mesons ρ and ω. The quantity $\Delta^{\gamma V}$ was calculated in[6,7]. When finding $\Delta^{\gamma V}$ in the present paper, the integration regions in the diagram of Fig. 1b were subdivided in accord with the value of the energy for V-exchange. It was shown that the main contribution to $\Delta^{\gamma V}$ is made by the integration region where the V exchange is not reggeized, and a value $\Delta^{\gamma V} \approx 10^{-3}$ was obtained.

The radiative correction to the three-pomeron coupling constant, brought about by the diagram of Fig. 2a, is estimated in Sec. 2 (the crosses show the manner in which the diagrams are cut). It has turned out that the corresponding correction to the three-pomeron vertex is connected by a simple relation with the shift of the pole[2)]:

$$g_{PPP}^{\gamma V} = \Delta^{\gamma V} \sigma_{tot}^{VN} / \sqrt{\sigma_{tot}^{NN}}. \tag{3}$$

In Sec. 3 we compare the calculated quantities with the experimental data and discuss the result from the point of view of the variants of the strong[2] and weak[1] interactions of the pomerons.

1. CALCULATION OF $\Delta^{\gamma V}$

As a result of the shift of the vacuum pole by an amount $\Delta^{\gamma V}$, the total hadron-interaction cross section will depend, in first order in $\Delta^{\gamma V}$, on the energy in the following manner:

$$\sigma_{tot} = \sigma_{tot}^h + \sigma_{tot}^{int}, \quad \sigma_{tot}^{int} = \Delta^{\gamma V} \sigma_{tot}^h \ln(s/M^2), \tag{4}$$

where M^2 is the minimum value of s at which pomeron exchange is meaningful. The first term σ_{tot}^h of (4) is due to strong interaction, and the second σ_{tot}^{int} is the result of the contribution of the interference of the electromagnetic and strong interactions—diagrams of the type of Fig. 3.

For the differential cross section of the NN interaction with production of two particle showers we have in this case[6]

$$\frac{d^3\sigma^{int}}{dq^2\,ds_1\,ds_2} = \frac{1}{(2\pi)^3 s^2} \frac{1}{q^2(q^2+m_V^2)} \sum_V \operatorname{Im} T_{\mu\nu}^{\gamma N\to VN}(s_1, t, q^2)|_{t=0} \times \operatorname{Im} T_{\mu\nu}^{\gamma N\to VN}(s_2, t, q^2)|_{t=0}. \tag{5}$$

Here q^2 is the square of the 4-momentum transfer; s_1 and s_2 are the squares of the effective masses of the showers; $T_{\mu\nu}^{\gamma N\to VN}(s_1, t, q^2)$ is the amplitude for the photoproduction of a vector meson; t is the square of the 4-momentum transferred from γ to V.

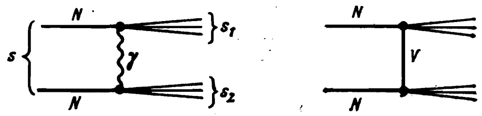

FIG. 3

If we use vector dominance and neglect the cross section for the absorption of the longitudinal vector mesons and γ quanta, we obtain

$$\operatorname{Im} T_{\mu\nu}^{\gamma N\to VN}(s_1,t,q^2)|_{t=0}=\frac{s_1}{1+q^2/m_V^2}\left(16\pi\frac{d\sigma^{\gamma N\to VN}}{dt}\Big|_{t=0}\right)^{1/2}\times\left(g_{\mu\nu}-\frac{p_\mu q_\nu+p_\nu q_\mu}{pq}+q^2\frac{p_\mu p_\nu}{(pq)^2}\right), \tag{6}$$

where $d\sigma^{\gamma N\to VN}/dt|_{t=0}$ is the cross section for the forward production of V on a nucleon and p_μ is the nucleon 4-momentum. Changing over in (5) from the variables s_1 and s_2 to s_1 and $q_m^2 = s_1s_2/s$ (the minimal value of q^2), we substitute (6) in (5) and carry out one integration with respect to s_1. We obtain

$$\frac{d^2\sigma^{int}}{dq^2dq_m^2}=\frac{4}{\pi^2}\sum_V\frac{m_V^4}{(q^2+m_V^2)^3}\frac{d\sigma^{\gamma N\to VN}}{dt}\Big|_{t=0}\left(2\frac{q^2}{q_m^2}+\frac{q_m^2}{q^2}-2\right)\ln\left(\frac{s}{M^2}\right). \tag{7}$$

At low values of q_m^2, the energy going to V exchange is large and it is necessary to reggeize V. The propagator $(q^2 + m_V^2)^{-1}$ must then be replaced by the energy multiplier

$$\left(\frac{m_V^2}{q_m^2}\right)^{\alpha_V(q^2)-1}\frac{\pi}{2}\alpha_V'\operatorname{tg}\left(\frac{\pi\alpha_V(q^2)}{2}\right)\alpha_V(q^2), \tag{8}$$

where $\alpha_V(q^2) = \alpha_V(0) - \alpha_V' q^2$ is the V-reggeon trajectory; $\alpha_V(0) \approx 1/2$, $\alpha_V' \approx 1$ (GeV/c)$^{-2}$. The factors $\alpha_V(q^2)$ in (8) are naturally expected from the exchange degeneracy of ρ and A_2 (see, e.g.,[9]). At large values of q^2 the quantity $\tan(\pi\alpha_V(q^2)/2)$ contains poles that must be cancelled out. We confine ourselves instead to the region $q^2 \le m_V^2$ of integration with respect to q^2; this corresponds to the multiperipheral kinematics.

Thus, by breaking up the region of integration with respect to q_m in (8) into two intervals, we have

$$\sigma_{tot}^{int}=\sum_V\frac{4m_V^2}{\pi^2}\frac{d\sigma^{\gamma N\to VN}}{dt}\Big|_{t=0}(I_1+I_2)\ln\left(\frac{s}{M^2}\right), \tag{9}$$

where I_1 is the contribution from the region where V is not reggeized and is equal to

$$I_1=\int_{y_0}^{\infty}dy\int_{y}^{\infty}\frac{dx}{(1+x)^3}\left(2\frac{x}{y}+\frac{y}{x}-2\right). \tag{10}$$

We have put here $x = q^2/m_V^2$ and $y = q_m^2/m_V^2$. The region of integration with respect to x and y has been continued to infinity, since the integrand decreases rapidly there. The quantity

$$I_2=\int_0^{y_0}dy\int_y^1\frac{dx}{(1+x)^2}y^{1-\alpha_V(m_V^2x)}\left(2\frac{x}{y}+\frac{y}{x}-2\right)\frac{\pi}{2}\alpha_V' m_V^2\operatorname{tg}\left(\frac{\pi\alpha_V(m_V^2x)}{2}\right) \tag{11}$$

is the integral over the region where V is reggeized.

Starting from the condition for matching the two integration regions, we put $y_0 = 1$. Then

$$I_1=0.85, \quad I_2=0.03. \tag{12}$$

After substituting (12) and also the cross section values[10]

$$\frac{d\sigma^{\gamma N\to\rho N}}{dt}\Big|_{t=0}\approx 0.1\text{ mb},\quad \frac{d\sigma^{\gamma N\to\omega N}}{dt}\Big|_{t=0}\approx 0.01\text{ mb}.$$

we obtain

$$\sigma_{tot}^{int}=0.024\ [\text{mb}]\ \ln(s/M^2). \tag{13}$$

From this and from (4) we obtain the shift of the pole

$$\Delta^{\gamma V}\approx 0.6\cdot 10^{-3}. \tag{14}$$

For comparison, we note that the value[3)] obtained in[6,7] is $\Delta^{\gamma V} = 2.3 \times 10^{-3}$.

The procedure for calculating $\Delta^{\gamma V}$, even when account is taken of two integration regions, contains a number of uncertainties and must be regarded only as an estimate. There are here unaccounted-for contributions to Δ^{int} from the electromagnetic interactions. Nonetheless, Eq. (14) does give the order of magnitude of the effect, since the vector dominance makes it possible to describe semiquantitatively the electromagnetic interaction at low energies.

2. RADIATIVE CORRECTIONS TO THE THREE-POMERON COUPLING CONSTANT

To calculate the contribution of diagram 2a to the three-pomeron vertex, we consider the scattering of a pomeron P by a nucleon N as shown in Fig. 4. The calculations are carried out here in the same manner as for the NN scattering on Fig. 3. The difference is that on Fig. 4a, in the upper shower, it is necessary to take into account only the cases when the system of the produced particles has a low effective mass. Confining ourselves to the eikonal approximation, we find that the contribution of diagram a of Fig. 4 to the total pomeron-nucleon interaction cross section σ_{tot}^{PN} is connected with the value of σ_{tot}^{int} obtained in Sec. 1 in the following manner:

$$(\sigma_{tot}^{PN})^{\gamma V}=\pi\frac{\sigma_{tot}^{VN}}{\sigma_{tot}^{NN}}\frac{\sigma_{tot}^{int}}{\ln(s/M^2)}. \tag{15}$$

We note that all the uncertainties contained in the calculation of the PN-interaction cross section are included in the quantity σ_{tot}^{int}.

By substituting in (3) the values $\sigma_{tot}^{VN} \approx 30$ mb[11] and $\Delta^{\gamma V} \approx 10^{-3}$ we obtain

$$g_{PPP}^{\gamma V}\approx 10^{-2}\ (\text{Гэв}/c)^{-1}. \tag{16}$$

The existing experimental data on the reaction p + p → p + X do not contradict the result that the quantity g_{PPP} lies in the interval of values 0.25–0.5 (GeV/c)$^{-1}$.[8,12] Thus, the obtained correction (16) amounts to several per cent of g_{PPP}.

There are also other electromagnetic contributions to the vertex g_{PPP}. One of the examples is shown in Fig. 2b.

It is interesting that in the case of a theory of the vector-dominance type, rather large values of the transverse momenta, $q_\perp^2 \sim m_\rho^2$, play an important role in the diagram of Fig. 2b. One can expect this effect to manifest itself in the inclusive spectrum of the γ quanta in the reaction $p + p \to \gamma + X$ as a change in the form of the spectra at $q_\perp^2 \gtrsim m_\rho^2$.[4)] This example shows that at

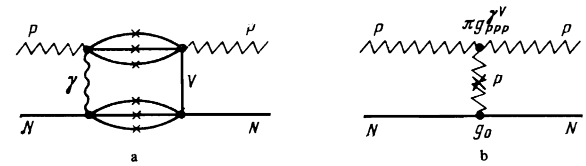

FIG. 4

short distances the γ-quantum spectrum is sensitive to the parton structure of the hadron wave function (to the structure of the initial multiperipheral ladder).

3. DISCUSSION OF RESULTS

The obtained estimates of the radiative corrections (14) to $\alpha_P(0)$, and (16) to g_{PPP} show that at the presently attainable energies these corrections are small. It is nevertheless useful to assess the role played by electromagnetic interactions at asymptotic energies.

1. Strong pomeron interaction.[2] From the point of view of the possible influence of the electromagnetic processes, this variant of the theory is of greatest interest, since we have here a small parameter, the three-pomeron coupling constant.

To satisfy the condition $\alpha_P(0) = 1$ after turning on the three-pomeron interaction, the spectrum of the unrenormalized pomeron must have a gap

$$\Delta^h \approx -\frac{(g^h_{PPP})^2}{32\pi\alpha_P'} \ln \frac{(g^h_{PPP})^2}{32\pi\alpha_P'} \approx 1.5\cdot 10^{-2}.$$

The additional shift produced in the position of the pole by the self-energy part shown in Fig. 1a is equal to

$$\Delta_{+}^{\gamma\gamma} \approx \Sigma^{\gamma\gamma}/\Delta^h \approx 1.7\cdot 10^{-4}. \tag{17}$$

Together with $\Delta^{\gamma V}$ from (13), the electromagnetic corrections amount to about 10% of Δ^h.

It must be emphasized that the question of whether corrections such as Δ^{int} to the trajectory of the vacuum pole are included in Δ^h has not been solved in principle, and it must be considered separately. In any case, it is not excluded that the increase of the bare gap by an amount $\Delta^{\gamma V}$ is offset by the increase of the three-pomeron constant by the amount g^V_{PPP}. This compensation takes place if

$$-\frac{g^h_{PPP}}{16\pi\alpha_P'}\frac{\sigma^{\rho N}_{tot}}{\sqrt{\sigma^{NN}_{tot}}} \ln \frac{g^h_{PPP}}{16\pi\alpha_P'} = 1. \tag{18}$$

Within the limit of the uncertainty of g^h_{PPP}, the relation (18) is satisfied.

We note that the shift $\Delta^{\gamma\gamma}$ cannot be offset by a contribution of the three-pomeron interaction. Therefore at $e^2 \ln(s/s_0) \lesssim 1$ the effective $\alpha_P(0)$ exceeds unity because of the contribution of the electromagnetic interactions.

It is interesting that the screening calculated in[2], which results from exchange of the vacuum branch cuts, does not change the situation. This is easiest to discern in four-dimensional space of the transverse momenta, followed by continuation in the dimensionality of space, in analogy with the procedure used in[2]. We consider first the screening of the interference contribution Δ^{int}. When account is taken of the three-pomeron interaction, the electromagnetic correction can increase because of the change of the Green's function of the pomeron. In first order in Δ^{int}, the correction to the Green's function G takes the form

$$\delta G = \Delta^{\text{int}} G^2(l, k^2), \tag{19}$$

where $G = \beta(l)/[\omega + k^2 R^2(l)]$, $l = \ln(1/\omega_m)$, $\omega_m = \max(\omega, k^2)$ (all the symbols are taken from[2]). However, after the screenings of the type shown in Fig. 5 are taken into account, Eq. (19) is altered and takes at $k^2 = 0$ the form

$$\delta G = \Delta^{\text{int}}/\omega^2, \tag{20}$$

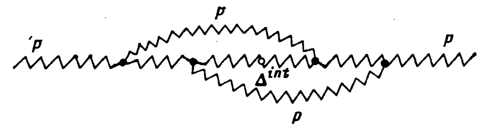

FIG. 5

i.e., the contributions of the three-pomeron interaction were cancelled out.

The validity of (20) can be easily verified by noting that the screening of Δ^{int} coincides with the screening of Γ_0', for which the relation $\beta^2\Gamma'/\Gamma_0'$ holds, where Γ_0' and Γ' are the unrenormalized and renormalized vertices for particle emission by a reggeon.[2]

It is clear that the same reasoning holds also for two-photon exchange. Thus, electromagnetic effects in the strong-coupling variant lead to an increase of the hadron-interaction cross section.

2. Weak pomeron interaction.[1] In this case $g^h_{PPP} = 0$. The question of the estimate of the radiative corrections to g_{PPP} becomes less definite, since it is known that the vanishing of g_{PPP} means that it is incorrect to separate in it contributions of individual diagrams.

Concerning the influence of the interference of the electromagnetic and strong interactions on the position of the vacuum pole, we are left with the previous question: is it necessary to separate this contribution from the contribution of the strong interactions? The purely electromagnetic contribution $\Delta^{\gamma\gamma}$ is singled out as before and leads to a change in the asymptotic form.

---

1) Nuclear Physics Institute, USSR Academy of Sciences.

2) We chose for gppp the normalization assumed in [8].

3) Owing to a numerical error in the course of the transition from formula (21) to (27), the result for $\Delta^{\gamma V}$ is overestimated in [6] by a factor of four.

4) At smaller values of $q_\perp$, the principal role is played by γ quanta from π^0-meson decay.

1. V. N. Gribov, Yad. Fiz. **17**, 603 (1973) [Sov. J. Nuc. Phys. **17**, 410 (1973)]; Proc. XVI Int. Conf. on High Energy Physics, Chicago, 1972, **3**, ed. National Accelerator Laboratory, Batavia (1973), p. 491.
2. A. A. Migdal, A. M. Polyakov, and K. A. Ter-Martirosyan, Zh. Eksp. Teor. Fiz. **67**, 848 (1974) [Sov. Phys.-JETP **40**, 420 (1975)]; H. D. I. Abarbanel and J. B. Bronzan, Phys. Rev. **D9**, 2397 (1974).
3. H. Primakoff, Phys. Rev. **81**, 899 (1951).
4. I. Ya. Pomeranchuk and I. M. Shmushkevich, Nucl. Phys. **23**, 452 (1961).
5. L. L. Frankfurt, Zh. Eksp. Teor. Fiz. **61**, 45 (1971). [Sov. Phys.-JETP **34**, 23 (1972)].
6. B. Z. Kopeliovich and L. I. Lapidus, JINR **R2**-7462, Dubna (1973).
7. M. Suzuki, Nucl. Phys. **B65**, 70 (1973).
8. A. B. Kaĭdalov, V. A. Khoze, Yu. F. Pirogov, and N. L. Ter-Isaakyan, Phys. Lett. **B45**, 493 (1973).
9. E. M. Levin, Usp. Fiz. Nauk **111**, 29 (1973) [Sov. Phys.-Usp. **16**, 600 (1974)].
10. J. Ballam et al. (LBL-SLAC collaboration), Phys. Rev. **D7**, 3150 (1973).
11. H. Alvensleben et al., Phys. Rev. Lett. **24**, 786 (1970).
12. Yu. M. Kazarinov, B. Z. Kopeliovich, L. I. Lapidus, and I. K. Potashnikova, Proc. of the XVII Int. Conf. on High Energy Physics, London, 1974, ed. J. R. Smith, Rutherford High Energy Laboratory, England (1975).

Translated by J. G. Adashko
44