Regge processes and chromodynamics

V. A. Abramovskiĭ and O. V. Kancheli
Institute of Physics, Georgian Academy of Sciences

(Submitted 28 August 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **32**, No. 7, 498–501 (5 October 1980)

A scheme, in which the rapidity density of partons is small in the wave function of a fast hadron and the real hadrons are produced via the decay of color strings, is proposed. The basic predictions of Reggistics are preserved and a correlation with QCD and with the additive quark model is established.

PACS numbers: 12.40.Bb, 12.40.Mm

Until now, the energy range in which Reggistics can be used and the "natural" values of its parameters have been unclear. It is clear that Reggistics must be correlated with QCD and both its scale and parameters probably must be determined in this way. In addition, there are several points, which are difficult to fit in the context of multiperipheral Reggistics and which indicate the changes that must be introduced.

1. First, it is difficult to correlate "large" multiplicity $\bar{n} = b \ln s \equiv bY$ with "small" α'_p and with the transverse momenta of secondary hadrons $\langle k_\perp \rangle$. The diffusion relation $b = 22\alpha'_p \langle k_\perp^2 \rangle$ holds in the ladder in which the number of partons is equal to the number of hadrons, and in the experiments $b \approx 2$–3, but $\alpha'_p \langle k_\perp^2 \rangle \approx 0.1$. Thus, we need a scheme 1) in which the hadron multiplicity bY is much greater than the parton multiplicity $\nu(Y) \approx 2\alpha'_p \langle k_\perp^2 \rangle Y$. Second, the interaction amplitudes of partrons in QCD are $\sim S$; i.e., the partons that are far apart in rapidity also interact. Therefore, the hadron cross sections increase as $\sigma(s) \sim \nu(Y)$ (or faster) in the perturbation theory when screening of distant partons is not evident—this shows that $\nu(Y)$ and $\partial \nu(Y)/\partial Y$ are small. Third,[1] the $\langle k_{i\perp} \rangle$ of the partons in the perturbation theory increase as $\sim \exp[c\sqrt{\nu(Y)}]$, where $c \sim 1$—this, together with the experimental constraint of $\langle k_{i\perp} \rangle$, shows that $\partial \nu(Y)/\partial Y$ is small. Fourth, the parton density $\Delta^{-1} = \nu/Y$ can be estimated in QCD by using the WKB method: $\Delta^{-1} = 2/\pi \int dk_\perp^2 k_\perp^2 \left[\frac{g^2(k_\perp)}{4\pi}\right] (k_\perp^2 + \lambda^2)^{-2}$ and by assigning the mass $\lambda \approx 0.6$–0.8 GeV to partons and gluons. Truncating this integral by (hadron radius)$^{-1} \approx 1/5$ and by (quark radius)$^{-1} \approx 1$, we obtain $\Delta \equiv \Delta_{\text{nucl}} \approx \frac{1}{3}\Delta_q \approx 8$–12.

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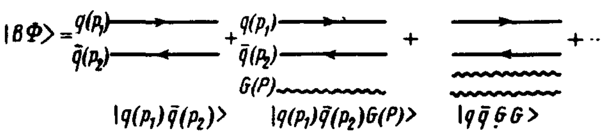
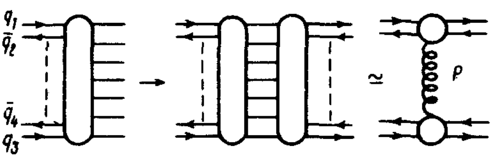
2. The formation and decay of color strings is a natural mechanism in QCD for the production of hadrons[2] which "fill" the gaps between the rare partons from the wave function (WF). We formulated[3] in parton language the basic properties of the picture of high-energy interactions[2]. It is a "three-step" picture: there are few partons in the WF before collision (valence quarks and one or two soft gluons with $E \sim 10^2$–10^3 GeV; the average rapidity gap before the first gluon is $\Delta \sim 10$). A color exchange occurs as a result of collision, followed by a longitudinal scattering of color charges and the formation of a color-electric field tube (string), that breaks into sections that form hadrons.[2] If this picture is translated into Regge language, then the basic properties of the scheme with a pomeron, nonvacuum Reggeons, and lowest basic branching can be reproduced.

3. We describe the properties of a pomeron (P) and of the branching. The WF (of a meson) is represented by the series



of the valence quarks and gluons. A simple contribution to P with $\alpha_p' = 0$ occurs because of interaction of the components of the $|q_1\bar{q}_2\rangle \otimes |q_3\bar{q}_4\rangle$ gluon (G) exchange and because of decay of the gluon string. 3) This can be schematically represented as follows:



A multiple G exchange between $|q_1\bar{q}_2\rangle$ and $|q_3\bar{q}_4\rangle$ does not change the total color charges of dispersed hadrons, i.e., the same color string appears. We note that the pomeron residues are factorized to an accuracy of the 1 G exchange. Taking into account the higher components $|q\bar{q}G\rangle$, $|q\bar{q}GG\rangle$, ... in the WF gives $\alpha_p' \neq 0$—it increases the average color charges because of multiple exchange and gives rise to pomeron branching.

Our approach involves expansion of the amplitudes in terms of the components in the WF and in terms of the G exchanges; the expansion is likely to converge more quickly at existing energies. An expansion in Reggeon diagrams with $\alpha_p' \neq 0$ is more customary. It is easy to establish a correlation between these approaches. For example, a simple and probably dominant contribution to the $2P$ branching comes from a $2G$ exchange in the $|q\bar{q}G\rangle \otimes |q\bar{q}\rangle$ configuration. The double, dispersing gluon charges can occur in this case. As in the case of the $1G$ exchange,[3] where we summed over the transverse position of the quark strings, here we must sum over the $x_{i\perp}$ positions of the two gluon (4 quark) strings. The contribution of the ordinary $2P$ branching corresponds to a large $|x_1 - x_2'|_\perp$; the AGK relations in this limit are valid for the absorption parts. However, the gluon tubes in the dominant configurations strongly overlap each other transversely and interact with each other.[3] This corresponds to large, diagonal vertices of the pomeron interaction $r(2P\to 2P)$, $r(3P\to 3P)$.... Therefore, in terms of the Reggeon-diagram method, the summing[5] of diagrams with large diagonal and small ($\sim 1/\Delta$) nondiagonal vertices is more adequate.[4]

Since the $\phi(k)$ spectra of gluons in $|q(p_1)\bar{q}(p_2)G(k)\rangle$ are bremsstrahlung spectra at $k \ll p_i$ $\phi(k) \sim 1/k$, the ends of the gluon strongs attached to G are uniformly distributed in rapidity; i.e., we have only the enhanced $2P$ branching.[5] The higher branching is analogous to it.

4. Three-Reggeon limit. If the interaction occurs in the $|q(p_1)\bar{q}(p_2)G(k)\rangle \otimes |q(p_3)\bar{q}(p_4)\rangle$ configuration, where $k \ll p_i$ with a $2G$ (colorless) exchange, then the gluon string will stretch only between (p_1p_2) and (k). Thus, the region characteristic of the three-Reggeon configuration in the rapidity space is filled with hadrons. Since the G distribution is of the type $dk/k\Delta$, we obtain $d\sigma_{\text{t.r.}} \sim (1-x)^{-1}$ and also $\sigma_{\text{t.r.}}/\sigma_{\text{tot}} \sim r_{3P} \sim 1/\Delta$. For the simplest configuration $\alpha'_p = 0$; the higher contributions $|q(p_3)\bar{q}(p_4)G\rangle$,...lead to "Reggeization."

5. Increase of total cross sections. The value $\partial\sigma/\partial Y$ is usually determined by the branching. However, since the vertices of $r(2P\to 2P)$,... are large, the usual estimate is unreliable. An estimate in terms of the change of the WF, however, is simple: the cross sections increase because the average number of soft partons (gluons) increases. If $\nu_i(Y) \approx \nu_{0i}(1 + J_i/\Delta_q)$ is the average number of partons in the states $|1\rangle \otimes |2\rangle$, where $y_1 + y_2 = Y$, then $\partial\sigma/\partial Y \approx \sigma/\Delta_q$, which is consistent with the experiment at $\Delta_q \approx 20$–30.

The inclusive density of produced hadrons in the central region $f(Y,y,k_\perp)$ increases with Y, since the average number of components in the WF increases; i.e., the average exchangeable color charge and hence the average number of strings increase; we obtain $(1/f)\dfrac{\partial f}{\partial Y} \sim \sigma_{\text{in}}/\pi R^2\Delta \sim 1/\Delta$, where R^2 is the hadron radius.

If the value of α'_p is defined by the "Brownian" expression $\alpha'_p \approx 1/2\ \Delta\lambda^2$ in terms of the gap Δ in the hadron and in terms of the gluon "mass" λ, then we can estimate $\alpha'_p \approx 0.1$–0.2. It is more reasonable, however, to estimate it in terms of the hadron radius $\alpha'_p \approx (1/4)\partial R^2(Y)/\partial Y \sim R^2/8\Delta \approx 0.3$ at energies when the WF has about one parton-gluon. The α'_p arising in this manner is generally not universal (like the other quantities in the higher orders in G).

The total cross sections (and other P vertices) are very sensitive to the confinement physics and to the breakdown of chiral symmetry, although an estimate based on the simple diagrams gives qualitatively reasonable values in the style of the additive quark model.

6. Our scheme can be used at least to $Y \approx 2\Delta - 3\Delta$ (i.e., to 10^{15}–10^{20} eV).

It is conceivable that at larger Y the spacing Δ between the soft gluons decreases to ~ 1. This would lead to larger α'_p and to more "multiperipheral" Reggistics.

At $Y \gg \Delta$ the configurations with large $\langle k_\perp\rangle_{\text{patron}}$ and $\alpha_p(0) \approx 1 + \dfrac{12}{\pi}\ln(g^2/2\pi)$ can be the main configurations. If there are no reductions with the contributions from higher orders in g^2, then a complicated picture with Fruassar cross sections and a multiplicity $\bar{n} \sim \exp[c(\ln s)^{1/4}]$ or faster can occur.

It was previously predicted[6] that at $E \sim 10^{13}$–10^{15} eV the spectrum $f(x)$ for $x \sim 1$ is reconstructed because of merging of the "parton ridges" from different valence quarks. In our case it is somewhat different: 1) there are no ridges attached to the quarks; 2) if the average multiplicity of the color exchange increases with increasing E, then only two quarks tubes can be coupled to the valence quarks in a fast meson [therefore $f(x)$ is unchanged at $x \sim 1$]; 3) only a transition from two-quark tubes to three-quark tubes is possible in a nucleon (i.e., f changes slightly); 4) $f(x)$ can change considerably in a fast nucleus at $x \approx 1$.

It is very important to determine the value of Δ, since it may turn out that the dominant processes are described by simple QCD diagrams in the "experimentally permissible" region (up to 10^{20} eV).

The authors thank V. N. Gribov and E. G. Gurvich for discussions.

[1)]If we assume that the partons are resonances, then we obtain only a factor of 2–3. We also assumed that the partons are heavy clusters which break up softly. But this assumption does not correspond to QCD.

[2)]Some aspects of this approach were pointed out earlier.[4]

[3)]This amplitude is purely imaginary, since the separation of color charges is "always" accompanied by a string that gives a multiparticle state.

[4)]Most Regge evaluations of the experiments, therefore, seem suspicious to us at present.

[5)]Because of distortion of the spectrum $\phi(k) \neq 1$, an unenhanced $2P$ branching also appears at $k \sim p_i$, but it is small.

[1]E. A. Kuraev, L. N. Lipatov, and V. S. Fadin, Zh. Eksp. Teor. Fiz. **72**, 377 (1977) [Sov. Phys. JETP **45**, 199 (1977)].

[2]J. Kogut and L. Suskind, Phys. Rev. **D10**, 732 (1974); E. G. Gurvich, Phys. Lett. **B87**, 386 (1979); A. Casher, H. Neuberger, and S. Nassinov, Phys. Rev. **D20**, 179 (1979).

[3]V. A. Abramovskiĭ and O. V. Kancheli, Pis'ma Zh. Eksp. Teor. Fiz. **31**, 566 (1980) [JETP Lett. **31**, 532 (1980)].

[4]F. Low, Phys. Rev. **D12**, 163 (1975); S. Nussinov, Phys. Rev. Lett. **34**, 1286 (1975); S. Brodsky and J. Gunion, Phys. Rev. Lett. **37**, 402 (1976).

[5]V. N. Gribov, Materialy X zimneĭ shkoly LIYaF (Proceedings of the 10th Winter School, LIYaF [Leningrad Inst. Of Nucl. Phys.]), Vol. 1, 1975, p. 5.

[6]V. V. Anisovich and V. M. Shekhter, Yad. Fiz. **28**, 1079 (1978) [Sov. J. Nucl. Phys. **28**, 554 (1978)].

Translated by Eugene R. Heath
Edited by S. J. Amoretty