INELASTIC DIFFERENTIAL CROSS SECTIONS AT HIGH ENERGIES AND DUALITY

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We consider the collision of two hadrons with 4-momenta p_a and p_b, resulting in the production of one particle with 4-momentum p and of a beam {X} of an arbitrary number of particles with total mass $v^{1/2}$, where $v = (p_a + p_b - p)^2$. If $s = (p_a + p_b)^2 >> m^2$ and $s >> v$, then the total differential cross section $d^3\sigma/d\vec{p}^3$ of sucha process can be expressed in terms of the amplitude $U_{\alpha_1\alpha_2}$ for the scattering of a reggeon by a particle. It will be shown below that the hypothesis that $U_{\alpha_1\alpha_2}$ has dual properties makes it possible to draw a number of conclusions concerning the behavior of $d^3\sigma/dp^3$.

When $s >> v$ we can write [1] the amplitude of the process $p_a + p_b \to p + k + ... + k_n$ (see Fig. 1) in the Regge form

$$A_n(p_a + p_b \to p + k_1 + ... + k_n) = \sum_{\{\alpha\}} g_\alpha(t)\, G_\alpha(s,t)\, Y_\alpha^{(n)}(t, v; k_i)\, \theta_\alpha(t), \tag{1}$$

where $G_\alpha(s,t) \simeq (s/s_0)^{\alpha(t)}$ is the Green's function of the reggeon α, $\theta_\alpha(t)$ is the signature factor, $t = (p_a - p)^2$, and $Y_\alpha^{(n)}$ is the amplitude for the transition of the reggeon α and of the particle p_b into a beam of n particles with momenta k_i and total mass $v^{1/2}$. Starting from (1), we write down an expression for the total differential cross section:

$$\frac{d^3\sigma}{dp^3} = \frac{1}{(2\pi)^3 2\epsilon}\,\frac{1}{4|p_a|\sqrt{s}} \sum_{\{\alpha_1\alpha_2\}} g_{\alpha_1}(t)\, g_{\alpha_2}(t)\, G_{\alpha_1}(s,t)\, G_{\alpha_2}(s,t)\, \theta_{\alpha_1}(t) \times \theta^*_{\alpha_2}(t)\, \tilde{U}_{\alpha_1\alpha_2}(v,t), \tag{2}$$

$$U_{\alpha_1\alpha_2}(v,t) = \frac{(2\pi)^4}{2} \sum_{n=1}^{\infty} \int \prod_{i=1}^{n} \frac{d^3k_i}{(2\pi)^3 2k_{i0}}\, \delta^4\Big(p_a + p_b - p - \sum_{i=1}^{n} k_i\Big)\, Y_{\alpha_1}^{(n)}(t, v; k_i) \times Y_{\alpha_2}^{*(n)}(t, v; k_i) \tag{3}$$

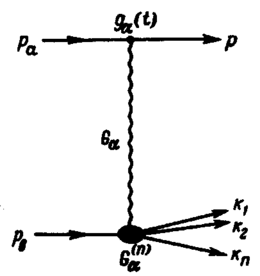


Fig. 1

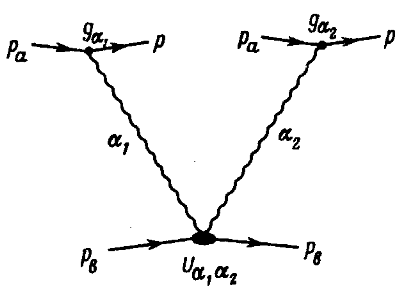


Fig. 2

is the absorption part, with respect to v, of the amplitude of the transition (b) + (α_1) → (b) + (α_2) with zero momentum transfer [2]. The terms in the sum (2) over {α_1, α_2} correspond to the diagram in Fig. 2.

At large values of v, the behavior of $U_{\alpha_1\alpha_2}(v, t)$ is also Regge-like:

$$U_{\alpha_1\alpha_2}(v,t) / (v/s_0)^{-\alpha_1(t)-\alpha_2(t)} \sum_{\{\beta\}} \gamma^{\beta}_{\alpha_1\alpha_2}(t)\, G_\beta(v, 0) g_\beta(0)\, \theta_\beta(0). \tag{4}$$

The factor $(v/s_0)^{-\alpha_1-\alpha_2}$ in (4) has a kinematic character and is connected with the definition of $\tilde{U}_{\alpha_1\alpha_2}$ assumed above (see [2]). We note that it is precisely this factor which ensures the correct transition to the multireggeon regime [1] for the processes in Fig. 1. Let us assume that $\gamma^{\beta}_{\alpha_1\alpha_2}$ are the vertices of the transition of reggeons α_1 and α_2 into the reggeon β are real, since they enter in (4) at values of the arguments below the thresholds of the production of real particles, and let us neglect the singularities connected with the thresholds for the production of several reggeons; we then obtain

$$\tilde{U}_{\alpha_1\alpha_2} \approx (v/s_0)^{-\alpha_1-\alpha_2} \sum_{\{\beta\}} \gamma^{\beta}_{\alpha_1\alpha_2} G_0 g_\beta \operatorname{Im}\theta_\beta(0).$$

Substituting $\tilde{U}_{\alpha_1\alpha_2}$ in (2) with s >> v and v >> m^2, we get:

$$\frac{d^2\sigma}{dv\,dt} = \frac{1}{2\pi^2} \sum_{\{\alpha_1\alpha_2\beta\}} \left(\frac{s}{s_0}\right)^{\alpha_1(t)+\alpha_2(t)-2} \left(\frac{v}{v_0}\right)^{\beta(0)-\alpha_1(t)-\alpha_2(t)} \times$$

$$\times [g_{\alpha_1}(t) g_{\alpha_2}(t) \gamma^{\beta}_{\alpha_1\alpha_2}(t)\, g_\beta(0)][\theta_{\alpha_1}(t)\, \theta^*_{\alpha_2}(t) \operatorname{Im}\theta_\beta(0)]. \tag{5}$$

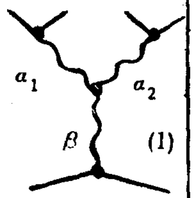
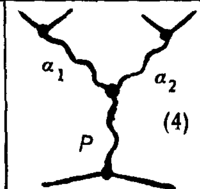
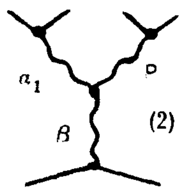
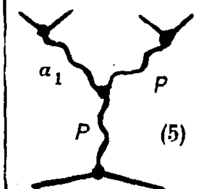
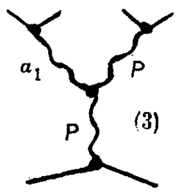
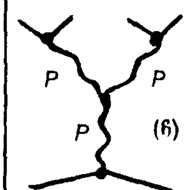
Let us assume that $U_{\alpha_1\alpha_2}$ has dual properties analogous to the approximate dual properties of a four-point diagram with real particles [3]. This means that the Regge contributions (4) determine the resonant part of the amplitude $U_{\alpha_1\alpha_2}$ in the "v-channel." The contribution of the Pomeranchuk pole (P) to (4) should be singled out and corresponds to the background in the "v-channel" [4]. We also assume [3, 5] that $U_{\alpha_1\alpha_2}$ is determined by expression (4), in the mean, also in the region of small v. Separating, in addition, P from $\{\alpha_1, \alpha_2\}$, we arrive at the classification listed in the table for the contributions of (5) to $d^2\sigma/dvdt$.

Let us consider first processes of non-diffractive character, when $\{\alpha_1, \alpha_2\}$ cannot contain P, for example $\pi^\pm N \to \pi^0\{X\}$, $\pi^\pm N \to K^\pm\{X\}$, $\pi^\pm p \to p\{X\}$, etc. It follows from (5) that

$$\frac{d^2\sigma(\text{resonances})}{dv\,dt} \Big/ \frac{d^2\sigma(\text{back})}{dv\,dt} \sim v^{\beta(0)-\alpha_P(0)} \sim v^{-1/2}$$

and does not depend on s. On the other hand, the behavior of the resonant and phonon parts of $d^2\sigma/dvdt$ depends strongly on s and on the type of reaction. Thus, the background in the reaction $\pi^\pm N \to \pi^0\{X\}$ depends little on v, but in $\pi^- p \to p\{X\}$ (back-scattering) the background is a growing one. In the latter case α_1 and α_2 are Δ trajectories, $\beta = (\rho, \omega, f, A_2)$, and from (5) we obtain $\sigma(\text{background}) \sim v^{0.7-1}$ and $\sigma(\text{resonances}) \sim v^{0.2-0.5}$, depending on the value of $\alpha_\Delta(0) \sim 0.15 - 0$. The boson spectrum with respect to v, obtained in [6] for the reaction $\pi^- p \to p\{X\}$ at $|p_\pi|$ = 16 GeV/c is qualitatively of this type.

The resonance production cross section, which is given by the contributions of the diagrams of the first column of the table, includes both the resonances lying on the principal trajectories and, generally speaking, also on the

Diagram	Interpretation of contribution	Diagram	Interpretation of contribution
	Nondiffraction resonance production		Nondiffraction background
	Interference resonance production		Interference background
	Diffraction resonance production		Diffraction background

daughter trajectories in the "v-channel." Therefore $2v_0^{1/2}\Gamma(v_0)d^2\sigma(\text{res})/dv_0dt$ gives, in order of magnitude, the cross section for the production of this resonance and its daughter resonances ($\Gamma(v_0)$ is the width of the resonance with mass $v_0^{1/2}$). It follows hence that the cross section for the production of resonances lying on degenerate trajectories (ρ, ω, f, A_2), in the reactions $\pi^{\pm}N \to (\rho, \omega, f, A_2)N$, as a function of the mass M is $d\sigma(M)/dt \sim \Gamma(M^2)$, ($t \sim 0$). The cross section for the production of the same resonances backwards ($u \sim 0$, fermoin exchange) in the reaction $\pi^{\pm}N \to N(\rho, \omega, f, A_2)$ is a growing one, $d\sigma(M)/dt \sim \Gamma(M^2)M^{1.4-2}$, ($t \sim 0$).

We now proceed to processes whose $\{\alpha_1, \alpha_2\}$ may contain P, such as $\pi^{\pm}N \to \pi^{\pm}\{X\}$, etc. Added to the contributions considered above are also the contributions of diagrams (2), (3), (5), and (6) of the table. Diagrams (2) and (3) describe resonance production. Since P has vacuum quantum numbers, these resonances lie on the same trajectories as the particles (p_b); in real experiments these are π, K, and N. Diagram (6) yields the diffraction background, which dominates at large values of s and its contribution to $d^2\sigma/dvdt$ is proportional to $(\gamma_{PP}^{P}(t)/v)(s/v)^{2\alpha' Pt}$. The ratio $\sigma(\text{diffr. res.})/\sigma(\text{diffr.backgr.})$ is proportional to $v^{-1/2}(\gamma_{PP}^{f}/\gamma_{PP}^{P})$, but apparently $\gamma_{PP}^{f}/\gamma_{PP}^{P} \ll 1$. The interference production of resonances (diagram 2) is also suppressed, owing to the approximate exchange degeneracy of the trajectories and of the vertices of the reggeons (ρ, ω, f, A_2).

Writing down $d^2\sigma/dvdt$ from (5) in the form Ae^{-at}, we obtain $a \sim \alpha' \ln s/v$, i.e., the cone in the distribution with respect to t expands with increasing v, a feature characteristic of the existing experimental data. We have assumed above that the effects of the renormalization of $\gamma^{\beta}_{\alpha_1\alpha_2}$ as a result of the interaction with the reggeons are small. This, however, may not be correct for the vertex γ_{PP}^{P} (see [2]). In particular, it is possible [2] that $\gamma_{PP}^{P}(t) \sim t$. This is reflected in the behavior of the background in $d^2\sigma/dvdt$ as $t \to 0$ and at large s and v.

In conclusion, we note the advantage of the non-diffraction processes for the study of the production of heavy resonances at large values of s by the missing-mass method. This follows from the fact that, as demonstrated above, at large values of s the ratio σ(resonances)/σ(backgr.) is small in the diffraction reactions and is not small in non-diffraction reactions.

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SUBBARRIER ALPHA PARTICLES EMITTED BY NUCLEI WITH LARGE ANGULAR MOMENTA

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The interaction of heavy ions with nuclei is of considerable interest from the point of view of the influence of the large angular momentum of the compound nucleus on the process of the relaxation of the excitation by emission of various types of particles and γ quanta.

A description of the behavior of highly-excited systems is possible on the basis of the statistical theory. Using the classical cascade approach developed in [1, 2], the authors of [3 - 5] calculated the emission of particles from nuclei with large angular momenta with allowance for the consecutive change of the characteristics of the excited nucleus during the evaporation process. These calculations, in general, can be reconciled with the experimental data, with the possible exception of the excessively large fraction of α particles with energies below the Coulomb barrier in the experimental distributions.

In all the calculations, however, either no account or very approximate account was taken at all of the γ-quantum emission, whereas the competition between the emission of α particles and γ quanta plays the decisive role at the final stage of the process of excitation relaxation, as shown by Grover and Gilart [6]. Their calculation scheme was based on the statistical model of successive evaporation of the particles with allowance of dipole and quadrupole γ emission. The calculation shows a large yield of subbarrier α particles, revealing thereby a complicated structure of a subbarrier α spectrum consisting of three components. An experimental verification of the form of the spectrum would be the best confirmation of the applicability of the evaporation model and of the calculation scheme itself. With this in mind, we have performed an experiment with Ag nuclei on the U-300 heavy-ion cyclotron[1)] with energy 175.4 MeV. The target, 1.2 mg/cm^2 thick, consisted of a natural mixture of Ag isotopes and 99.99% pure. The reaction products were identified with the aid of a telescope consisting of one thin (ΔE) and one thick (E) silicon detector measuring the ionization losses of the particles and the residual energy. The thickness of the thin detector was 13.3 μ, and the energy resolution of the quantity E + ΔE

[1)]We investigated the characteristics of the α particles (differential spectra at various angles) from the interaction of Ne^{22} ions.