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LARGE-ANGLE SCATTERING AND THE QUARK STRUCTURE OF HADRONS

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In a paper[1] on the basis of automodelity or scale invariance hypothesis and dimensional quark counting the following predictions have been made:

a) The differential cross section of exclusive two-body scattering at fixed angles $z = \cos\vartheta_s = 1 + \frac{2t}{s} = -\left(1 + \frac{2u}{s}\right) \neq \pm 1$ obeys the following scaling law:

$$\frac{d\sigma}{dt}(ab \to ab) = \frac{1}{s^{2(n_a+n_b-1)}} \; f_{ab}(z). \tag{1}$$

The valence quark representation for hadrons gives the following energy dependence for definite processes

$$\frac{d\sigma}{dt}(pp \to pp) \sim \frac{1}{s^{10}}, \quad \frac{d\sigma}{dt}(\pi p \to \pi p) \sim \frac{1}{s^{8}}, \quad \frac{d\sigma}{dt}(ep \to ep) \sim \frac{1}{s^{6}}.$$

b) The EM form factor of a hadron a in the limit of large momentum transfers behaves as

$$F_a(t) \sim \frac{1}{t^{n_a - 1}}, \tag{2}$$

where n_a is a minimum number of hadron constituents. Using the valence quark representation for mesons and baryons we predict the monopole asymptotic behaviour for mesons $F_M(t) \sim \frac{1}{t}$ $(M = \pi, K, \ldots)$ and the dipole one for baryons $F_B(t) \sim \frac{1}{t^2}$ $(B = p, \Sigma, \Delta, \ldots)$.
The agreement of this predictions with experiment gives a dynamical (non group-theoretical) support for composite nature of hadrons.

The purpose of this paper is to obtain an explicit expression for the angular distribution function $f_{ab}(z)$ in deep region $s, |t|, |u| \to \infty$ by means of the dimensional quark counting rule based on the dynamical interpretation of quark diagrams. On the basis of automodelity or scale invariance hypothesis it is reasonable to expect that invariant amplitudes at high energy and large momentum transfers should have a simple asymptotic form

$$f(s,t,u) \sim s^{\alpha} t^{\beta} u^{\gamma}$$

Dimensional quark counting arguments fixed unambiguously the sum of the exponents

$$\alpha+\beta+\gamma = -(n_a+n_b)+2$$

which results in the scaling law (1). To obtain an explicit form of the angular distribution function $f_{ab}(z)$ it is necessary to know the value of the exponents α, β, γ separately. This information can be obtained by dynamical interpretation of quark diagrams for definite two-body reactions.

Let us start from the consideration of the simplest case of kaon-nucleon scattering, where only one topology of quark diagrams contributes (Fig.1):

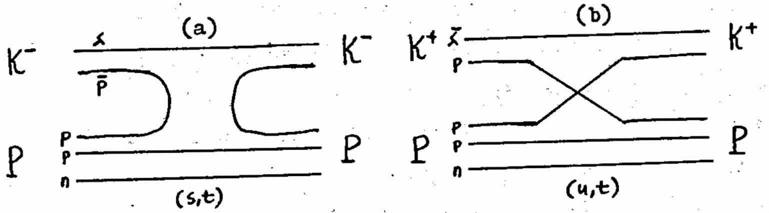


Fig.1. Kaon-nucleon quark diagrams.
(a) in $K^-p \to K^-p$ only (s,t) topology contributes
(b) in $K^+p \to K^+p$ only (u,t) topology contributes.

In the case of $K^-p \to K^-p$ scattering the number of quarks in s direction and t direction are $n_s=2$ and $n_t=3$ respectively. The corresponding diagram in Fig.1(a) has asymptotic behaviour $\frac{1}{s^{n_s-1}t^{n_t-1}} = \frac{1}{st^2}$. For $K^+p \to K^+p$ scattering the numbers are $n_u=2$ and $n_t=3$ and hence the diagram on Fig. 1(b) behaves as $\frac{1}{u^{n_u-1}t^{n_t-1}} = \frac{1}{ut^2}$. In general $n_s+n_t = n_a+n_b$ (and $n_u+n_t = n_a+n_b$) and hence these rules are in agreement with general dimensional considerations, developed in[1].

In practice the inclusion of spin effects is important for the calculation of angular distribution function $f_{ab}(z)$ although it does not affect the energy dependence of the differential cross section. The meson-baryon scattering amplitude can be represented in a standard form

$$f^s_{\lambda'\lambda} = \bar{u}_{\lambda'}(p')\{-A+\gamma\cdot Q\,B\}\,u_{\lambda}(p).$$

From the condition of γ_5- invariance at high energies[2] it follows, that $A^s \simeq 0$. Hence only the B-amplitude gives a dominant contribution and is connected with the helicity non-flip amplitude by the relation $f^s_{++}(s,t) = \sqrt{su}\,B(s,t)$. The S-channel helicity amplitude can be represented in the form:

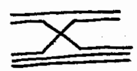
$$f^s_{++}(s,t) = \cos\frac{\vartheta_s}{2}\, f(s,t) + \cos\frac{\vartheta_s}{2}\, \bar{f}(s,t)$$

and respectively u - channel amplitude reads

$$-f^u_{++}(s,t) = \cos\frac{\vartheta_s}{2}\, \bar{f}(s,t) + \cos\frac{\vartheta_u}{2}\, f(u,t).$$

The invariant functions $f(s,t)$ and $f(u,t)$ are free of kinematical zeros and singularities and are determined by the quark exchanges, corresponding to (s,t) and (u,t) topology quark diagrams. Then for the differential cross section for meson-baryon scattering we obtain

$$\frac{d\sigma}{dt}\sim\frac{1}{s^2}\Big|\cos\frac{\vartheta_s}{2}$$

$$+\cos\frac{\vartheta_u}{2}$$

$$\Big|^2. \qquad (3)$$

For the simplest case of kaon-nucleon scattering from (3) it follows

$$\frac{d\sigma}{dt}(K^-p\to K^-p)\sim\frac{1}{s^2}\left|\frac{u}{s}\right|\left(\frac{2}{st^2}\right)^2=\frac{4\sigma_K}{s^8}\,\frac{(1+z)}{(1-z)^4}, \qquad (4)$$

$$\frac{d\sigma}{dt}(K^+p\to K^+p)\sim\frac{1}{s^2}\left|\frac{s}{u}\right|\left(\frac{2}{ut^2}\right)^2=\frac{64\sigma_K}{s^8}\,\frac{(1+z)}{(1-z^2)^4}. \qquad (5)$$

The constant σ_K has dimension m^{12}. From (4) and (5) we prediot the ratio

$$\frac{d\sigma(K^-p\to K^-p)}{d\sigma(K^+p\to K^+p)}\sim\left(\frac{u}{s}\right)^4=\left(\cos\frac{\vartheta_s}{2}\right)^8=\frac{1}{16}\Big|_{\vartheta_s=90^\circ}. \qquad (6)$$

By means of $s\leftrightarrow t$ crossing we obtain from (4) the annihilation cross section

$$\frac{d\sigma}{dt}(\bar{p}p\to K^+K^-)\sim\frac{1}{s^2}\left|\frac{u}{t}\right|\left(\frac{2}{ts^2}\right)^2=\frac{8\sigma_K}{s^8}\,\frac{(1+z)}{(1-z)^3} \qquad (7)$$

and for the ratio

$$\frac{d\sigma(\bar{p}p\to K^+K^-)}{d\sigma(K^-p\to K^-p)}\sim\left|\frac{t}{s}\right|=\left|\sin^2\frac{\vartheta_s}{2}\right|=\frac{1}{2}\Big|_{\vartheta_s=90^\circ}. \qquad (8)$$

In the case of pion-nucleon scattering both (s,t) and (u,t) topologies contribute. We have

$$f_{++}^{\pi^-p}(s,t)=\cos\frac{\vartheta_s}{2}\,\frac{2}{st^2}+\cos\frac{\vartheta_u}{2}\,\frac{1}{ut^2}$$

$$f_{++}^{\pi^+p}(s,t)=-\cos\frac{\vartheta_s}{2}\,\frac{1}{st^2}-\cos\frac{\vartheta_u}{2}\,\frac{2}{ut^2} \qquad (9)$$

$$f_{++}^{\pi^-p\to\pi^0n}=\frac{3}{\sqrt{2}}\left[\cos\frac{\vartheta_s}{2}\,\frac{1}{st^2}+\cos\frac{\vartheta_u}{2}\,\frac{1}{ut^2}\right].$$

The differential cross seotion, and the corresponding annihilation cross section are given in Table I, where $\sigma_\pi=\sigma_K$ in SU(3) limit.

In the case of nucleon-nucleon scattering differential cross seotion can be represented from γ_5-invariance arguments [2] in the form:

$$\frac{d\sigma^{pp}}{dt}(pp\to pp)=\frac{1}{s^2}\,\frac{1}{(ut)^6}\left\{(\alpha u^2+\beta t^2)^2+(\alpha t^2+\beta u^2)^2+\left[\frac{s}{u}(\bar\alpha u^2+\bar\beta t^2)+\frac{s}{t}(\bar\alpha t^2+\bar\beta u^2)\right]^2\right\} \qquad (10)$$

where only (u,t) and (t,u) topology diagrams in Fig.2 contribute.

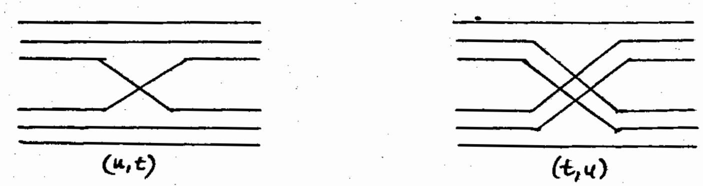


Fig.2. Nucleon-nucleon quark diagrams.

The result is presented in Table I. The differential cross section for $\bar{p}p \to \bar{p}p$ process can be obtained from here by $s \leftrightarrow u$ crossing.

The predictions, which are collected in Table I, can directly be compared with experiment and theoretical results of papers[3,4]. A more complete discussion of these results will be given elsewhere.

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Table I

Reaction	$\frac{d\sigma}{dt}$
$pp \to pp$	$\frac{\sigma_p}{s^{10}}\frac{1}{(1-z^2)^6}\left[\left\{\left[\alpha(1+z)^2+\beta(1-z)^2\right]^2+(z\to -z)\right\}+\left\{\frac{2}{1+z}\left[\bar{\alpha}(1+z)^2+\bar{\beta}(1-z)^2\right]+(z\to -z)\right\}^2\right]$
$\pi^+p \to \pi^+p$	$\frac{\sigma_\pi}{s^8}\frac{(1+z)}{(1-z)^4}\left[1+\frac{8}{(1+z)^2}\right]^2$
$\pi^-p \to \pi^-p$	$\frac{\sigma_\pi}{s^8}\frac{(1+z)}{(1-z)^4}\left[2+\frac{4}{(1+z)^2}\right]^2$
$\pi^-p \to \pi^0n$	$\frac{9\sigma_\pi}{2s^8}\frac{(1+z)}{(1-z)^4}\left[1+\frac{4}{(1+z)^2}\right]^2$
$K^+p \to K^+p$	$\frac{64\sigma_K}{s^8}\frac{(1+z)}{(1-z)^4}$
$K^-p \to K^-p$	$\frac{4\sigma_K}{s^8}\frac{(1+z)}{(1-z)^4}$
$\bar{p}p \to \bar{p}p$	$\frac{\sigma_p}{4s^{10}}\frac{1}{(1-z)^6}\left[\left(\bar{\alpha}+\bar{\beta}\frac{(1-z)^2}{4}\right)^2+\left(\bar{\alpha}\frac{(1-z)^2}{4}+\bar{\beta}\right)^2+\left\{\frac{1+z}{2}\left(\alpha+\beta\frac{(1-z)^2}{4}\right)-\frac{1+z}{1-z}\left(\alpha\frac{(1-z)^2}{4}+\beta\right)\right\}^2\right]$
$\bar{p}p \to \pi^+\pi^-$	$\frac{\sigma_\pi}{2s^8}\frac{(1+z)}{(1-z)^3}\left[2+\left(\frac{1-z}{1+z}\right)^2\right]^2$
$\bar{p}p \to \pi^0\pi^0$	$\frac{\sigma_\pi}{4s^8}\frac{(1+z)}{(1-z)^3}\left[1+\left(\frac{1-z}{1+z}\right)^2\right]^2$
$\bar{p}p \to K^+K^-$	$\frac{2\sigma_K}{s^8}\frac{(1+z)}{(1-z)^3}$

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