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QUASIPOTENTIAL DESCRIPTION OF pp - AND $\pi^{\pm}$p - SCATTERING AT LARGE ANGLES IN MODEL WITH DIMENSIONAL PARAMETER

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Квазипотенциальное описание pp- и $\pi^{\pm}p$-рассеяния на большие углы в модели с размерным параметром

Рассмотрено высокоэнергетическое pp- и $\pi^{\pm}p$-рассеяние на большие углы. Выражения для дифференциальных сечений рассеяния получены в кварковой модели, содержащей явный размерный параметр - массу кварка. Показано, что в рамках квазипотенциального подхода, при соответствующем выборе квазипотенциала, можно получить амплитуды адрон-адронных процессов, совпадающие с теми, что получаются в модели факторизующихся кварков. Полученные сечения содержат логарифмическое отклонение от чисто степенного поведения и хорошо описывают экспериментальные данные в широком диапазоне углов рассеяния.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Kuleshov S.P., Sidorov A.V., Skachkov N.B. E2 - 12688

Quasipotential Description of pp and $\pi^{\pm}p$ Scattering at Large Angles in Model with Dimensional Parameter

Elastic high-energy pp and $\pi^{\pm}p$ scattering is considered in a quark model with the dimensional parameter, quark mass. Expressions for cross sections, containing the logarithmic deviation from the purely power behaviour and successfully describing experimental data are obtained.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1979

The present experimental data indicate the power fall for the differential cross section of large-angle hadron-hadron scattering at asymptotic high energy[1]

$$\frac{d\sigma}{dt} \sim \frac{1}{s^n} f\left(\frac{t}{s}\right), \quad s \to \infty, \ \frac{t}{s} = \text{const}. \tag{1}$$

For instance, for the elastic $\pi^{\pm}p$ -scattering $n=8$ is observed and for the pp scattering - $n=10$. The power law (1) of the cross section decrease for fixed-angle hadron scattering is predicted by the dimensional quark-counting rules[2].

The behaviour of the elastic-hadron-hadron-scattering cross section in a wide range of scattering angles can be well described within the quasipotential approach[3,4].

In papers[5] the quasipotential equation was solved by the iteration method. Here the following expression for the cross section of large-angle-scattering was obtained:

$$\frac{d\sigma}{dt} \sim \frac{1}{s^2} |\phi(s,t,u)|^2. \tag{2}$$

The quasipotential was given in the form:

$$\phi(s,t,u) = s \int_0^\infty dx [x^{m_1} \rho_1(s,x) e^{xt} + x^{m_2} \rho_2(s,x) e^{xu}]. \tag{3}$$

It was shown in[5] that functions ρ_1 and ρ_2 satisfy the weak limit

$$\lim s^N \rho_1 (s, x = \frac{\eta}{s}) = \psi_1(\eta),$$

$$\lim s^N \rho_2 (s, x = \frac{\zeta}{s}) = \psi_2(\zeta), \tag{4}$$

$$0 < \eta, \zeta < \infty; \quad N > 0,$$

the scattering amplitude will depend on $s, t,$ and u by a power law.

It is worth noting that the observed analytic results well describe the experimental data in the range of asymptotic high energies. However, in the preasymptotic range one may expect a deviation from purely power behaviour of cross-sections.

In this connection our paper gives a special form of presentation (3) so that the amplitude of hadron-hadron scattering could depend by the power law not on s, t, and u, but on the quark scattering amplitudes on the effective potential. Without loss of generality, we choose a form of the amplitude which coincides, for instance, with the known expression for the amplitude of the hadron-hadron scattering. It can be obtained in the model of factorizing quarks [6] (MFQ). MFQ allows a clear physical interpretation for the amplitude of hadron-hadron scattering.

To express the scattering amplitude by formula MFQ (18)* the function $\phi(s,t)$ may be written in the following form:

$$\phi(s,t) = i \int_0^\infty dx \sum_{AB\to AB} , \qquad (5)$$

$$\sum_{pp\to pp} = a_1 \{ (\frac{x^5}{5!} + 5 g^2(u) \frac{x^3}{3!}) \exp[-\frac{x}{g(t)}] +$$

$$+ (\frac{x^5}{5!} + 5 g^2(t) \frac{x^3}{3!}) \exp[-\frac{x}{g(u)}] \} + \qquad (6)$$

$$+ a_2 S_p^4(t) \{ g \ \exp[-\frac{x}{g(t)}] + 5 \exp[-\frac{x}{g(u)}] \} ,$$

$$\sum_{\pi^+ p\to\pi^+ p} = a_1 \{ [\frac{x^4}{4!} + 2 \frac{x^2}{2!} g^2(u)] \exp[-\frac{x}{g(t)}] \} +$$

* The detailed discussion of the expression for the hadron-hadron scattering amplitude is given below.

$$+\alpha_2 S_\pi^3(t)\{G x \exp[-\frac{x}{g(t)}] + 2x\exp[-\frac{x}{g(u)}]\} +$$

$$+\alpha_3 S_\pi^3(u)\, 2x \exp[-\frac{x}{g(t)}],$$

$$\Sigma_{\pi^- p\to\pi^- p} = \alpha_1\{[\frac{x^4}{4!} + \frac{x^2}{2!} g^2(u)] \exp[-\frac{x}{g(t)}]\} + \quad (7)$$

$$+\alpha_2 S_\pi^3(t)\{6x\exp[-\frac{x}{g(t)}] + x\exp[-\frac{x}{g(u)}]\} + \alpha_3 S_\pi^2(u) x \exp[-\frac{x}{g(t)}]. \quad (8)$$

Now let us trace the production of amplitudes of hadron-hadron scattering within MFQ. This model assumes that the collision of two hadrons produces an effective potential, where quarks, constituents of hadrons, are scattered independently. As the probability of n-independent events is the product of probabilities of individual events, one may consider the amplitude of hadron scattering at angle θ (in the c.m.s.) to be proportional to the product of scattering amplitudes of individual quarks on the effective potential [7]

$$M_{AB\to AB} = \prod_i g_i^A(\theta) \prod_j g_j^B(\theta). \quad (9)$$

Formula (9) may be used only when identical quarks are absent in hadrons A and B. This formula takes into account only the contribution of diagrams of the a) type in figure 1.

Summing up all possible diagrams with the exchange of identical quarks (fig. 1 b, c, d) and following ref. [6] we present amplitudes of pp and $\pi^\pm p$ large-angle scattering (near 90°) in the form:

$$M_{pp}^{(1)} = g_p^6(\theta)[1+5r_p^2(\theta)+5r_p^4(\theta)+r_p^6(\theta)], \quad (10)$$

$$M_{\pi^+p}^{(1)} = g_{\pi^+}^5(\theta)[1+2r_\pi^2(\theta)],$$

$$M_{\pi^-p}^{(1)} = g_{\pi^-}^5(\theta)[1+r_{\pi^-}^2(\theta)], \quad (11)$$

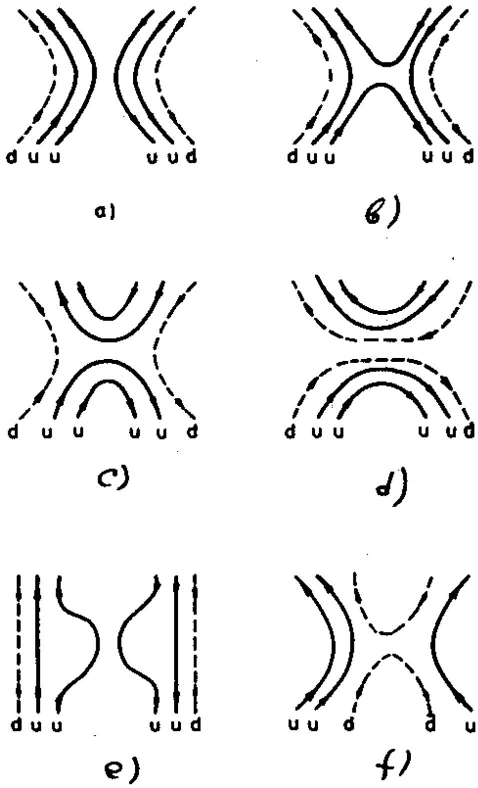

Fig.1. Examples of graphs, arising from the description of the elastic hadron-hadron scattering within MFQ.

where

$$r(\theta)=\frac{g(\pi-\theta)}{g(\theta)}. \qquad (12)$$

Formulae (10-12) correspond to the case when all the quarks of colliding hadrons are scattered on the effective potential and take into account the multiparticle interaction of quarks in a scattering process. In the present paper we calculate only two-body forces for small-angle scattering and elastic interaction of all quarks at large-angle scattering.

One can further see that this is quite sufficient for a successful quantitative description of the experimental data. For simplicity we also assume the forward hadron scattering $\theta_{c.m}\gtrsim 0°$ and the backward one $\theta_{c.m}\lesssim 180°$ to take place in reality on the same effective potential as in the case of two quarks (one from hadron A, and one from hadron B).

The contribution of the quarks at rest that do not interact is calculated by the spectator function $S(\theta)$. Then for the forward scattering [7] we obtain

$$M^{(2)}_{pp}= S^{4}_{p}(\theta)g^{2}_{p}(\theta)[9+5r^{2}_{p}(\theta)], \qquad (13)$$

$$M^{(2)}_{\pi^+ p}= S^{3}_{\pi}(\theta)g^{2}_{\pi}(\theta)[6+2r^{2}_{\pi}(\theta)], \qquad (14)$$

$$M^{(2)}_{\pi^- p}= S^{3}_{\pi}(\theta)g^{2}_{\pi}(\theta)[6+r^{2}_{\pi}(\theta)] \qquad (15)$$

and for the backward one [7]:

$$M^{(3)}_{\pi^+ p}= 2S^{3}_{\pi}(\theta)g^{2}_{\pi}(\theta), \qquad (16)$$

$$M^{(3)}_{\pi^- p}= S^{3}_{\pi}(\theta)\, g^{2}_{\pi}(\theta). \qquad (17)$$

We assume spectator functions to have the following form: for the forward scattering $S(\theta)=\exp\beta_1 t_q$, and for the backward one $S(\theta)=\exp\beta_2 u_q$.

The above-mentioned formulae for amplitudes were obtained under the prediction that the contribution of diagrams, containing quarks and antiquark annihilation, may be neglected (fig. 1, f). The total hadron-scattering amplitude is taken as the sum of amplitudes of all three types:

$$M_{AB\to AB} = \sum_{i=1}^{2,3} \alpha_i M^{(i)}_{AB\to AB} , \qquad (18)$$

where the coefficients α_i determine the contribution of amplitudes of each type and are obtained from the comparison with the experiment. We note that even without concretization of the function form $g(\theta)$, a factorizing quark model allows one to calculate a number of ratios of cross-sections of various hadron-hadron reactions [7], many of which are in good agreement with experiment.

In papers [8] there was assumed that the dimension of the quark interaction region is of an order of the quark Compton wave length. This resulted in the following expression for the quark scattering on the effective potential:

$$g_i(\theta) = \frac{M_q^2 \ln\left[1 - \frac{t_i}{2M_q^2} + \frac{1}{2M_q^2}\sqrt{t_i(t_i - 2M_q^2)}\right]}{\sqrt{t_i(t_i - 2M_q^2)}} . \qquad (19)$$

M_q are the quark masses; t_i is the momentum transfer per one quark: $t_i = c_0 t$. Assuming the momentum transfer to be equally distributed over the hadron valence quarks we obtained: $c_0 = \frac{1}{n^2}$; n being a number of valence quarks in a hadron.

Amplitude (19) contains the natural scale, the square of the effective quark mass M_q^2. In the asymptotic range $-t \to \infty$

$$g_i(t) \underset{-t\to\infty}{\sim} \frac{\ln \frac{|t_i|}{M_q^2}}{t_i / M_q^2} \qquad (20)$$

and for the amplitudes of pp and $\pi^{\pm}p$ scattering in the same asymptotic energy range for angles $\theta \sim 90°$ we obtain:

$$M^{(1)}_{pp} \sim \left(\frac{\ln \frac{|t_i|}{M_q^2}}{|t_i| / M_q^2}\right)^6 , \qquad (21)$$

$$M^{(1)}_{\pi^\pm p} \sim \left(\frac{\ln \frac{|t_i|}{M_q^2}}{t_i / M_q^2} \right)^5 , \qquad (22)$$
$-t \to \infty, \theta \sim 90^\circ$.

According to [5], within our approach we have the following expressions for differential cross sections of the elastic pp and $\pi^\pm p$ scattering.

$$\frac{d\sigma}{dt}_{pp} = \frac{|M_{pp \to pp}|^2}{s^2} , \qquad (23)$$

$$\frac{d\sigma}{dt}_{\pi^\pm p} = \frac{(1+z)\,|M_{\pi^\pm p \to \pi^\pm p}|^2}{s^2} , \quad z = \cos\theta_{c.m.} , \qquad (24)$$

where the amplitudes M_{AB} are derived from formula (18). Formula (23) is obtained under the prediction of vestor-, vector and axial-axial interaction [5] to be equal. This explains the absence of factors dependent on z.

As follows from figs. 2-4 , formulae (23), (24) are in a good agreement with experimental data[9]. The coefficients α and β, obtained from the comparison are given in the table. For the proton-proton scattering in the range of $7 < p_L < 31$ GeV : $\chi^2/\bar{\chi}^2 = 2.2$ and $M_q = (.305 \pm .004)$ GeV.

Table

	α_1	α_2	α_3	β_1(GeV^{-2})	β_2(GeV^{2})
$\pi^+ p$	9.8	2.6	120.	56.	68.
$\pi^- p$	21.	-12.	41.		
pp	21.	17.	-	2.1	-

There is observed a better agreement with experiment in the $\pi^\pm p$ scattering: $\chi^2/\bar{\chi}^2 = 1.3$. Here the quark mass is not defined directly from the fit, which gives only $M_q^2 / c_0 = 0.7$ GeV^2. Generally speaking, instead of the parameter c_0, one should introduce two parameters c_π and c_p that determine portions of the momentum transfer per each quark in a meson and a proton. For simplicity, we suppose $c_\pi = c_p = c_0$ and consider that c_0 for the πp scat-

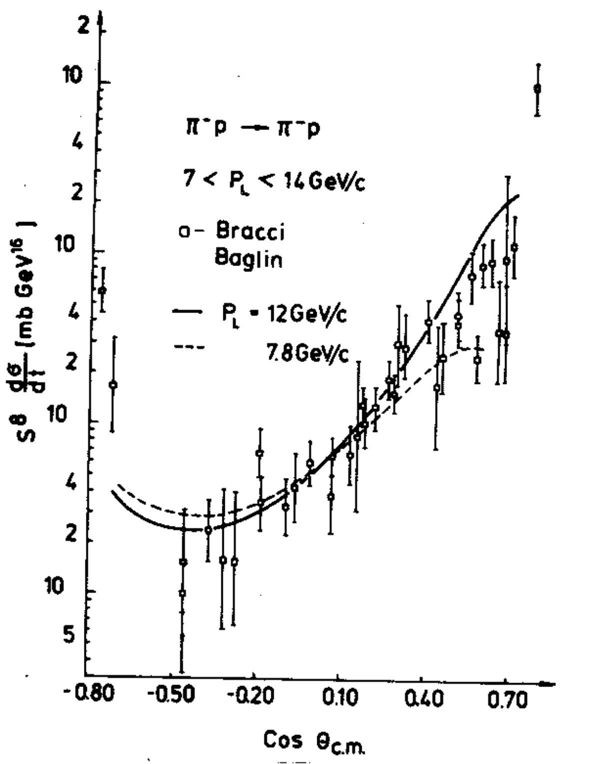

Fig. 2. The comparison of $s^8 \frac{d\sigma}{dt}$ with the experimental data on the elastic $\pi^- p$ scattering in the range of $0 < p_L < 14$ GeV/c.

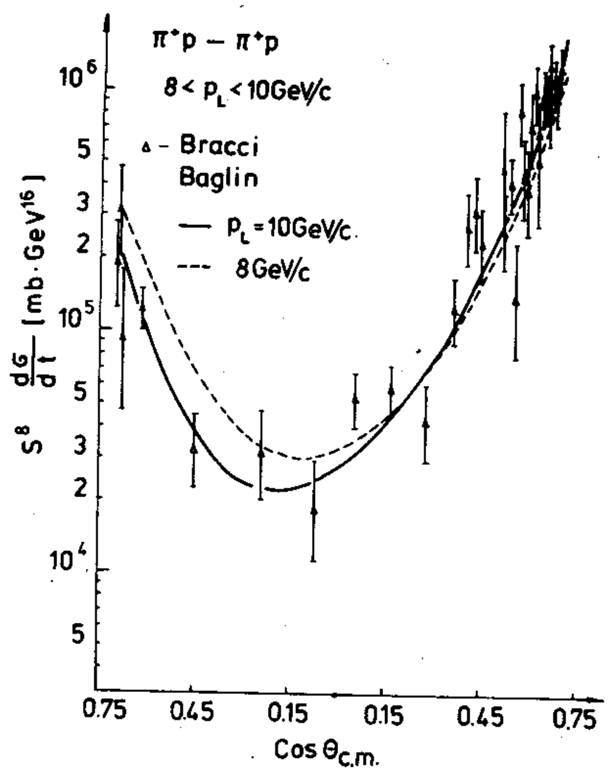

Fig. 3. The comparison of $s^8 \frac{d\sigma}{dt}$ with the experimental data on the elastic $\pi^+ p$ scattering in the range of $8 < p_L < 10$ GeV/c.

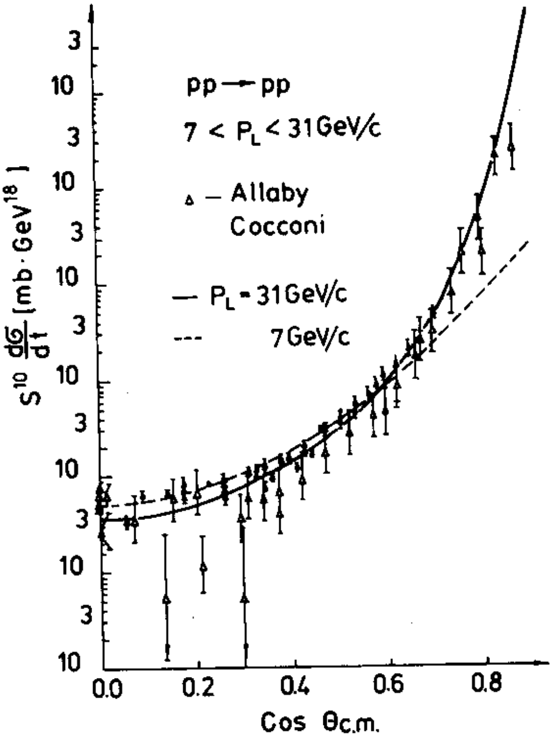

Fig.4. The comparison of $s^{10}\frac{d\sigma}{dt}$ with the experimental data on the elastic pp scattering in the range of $7 < p_L < 31$ GeV/c.

tering may be in the interval $\frac{1}{9} < c_0 < \frac{1}{4}$. Then for the quark mass we obtain: $0.28 < M_q < 0.42$ GeV. As one can see from graphs, theoretical curves for various p_L are different. This is a demonstration of the logarithmic deviation from the purely power behaviour of a cross section which is specific for our model.

Thus, the use of the mass parameter allowed us to describe the deviation from the power behaviour for the pp and $\pi^{\pm}p$ scattering cross section that indicates mass effects must be taken into account in the preasymptotic region.

REFERENCES

1. Barger V. Rapporteur's Talk at the XVII Int.Conf. on High Energy Phys., London, 1974.
2. Matveev V.A., Muradyan R.M., Tavkhelidze A.N. Nuovo Cim., 1973, 7, p. 719.
3. Logunov A.A., Tavkhelidze A.N. Nuovo Cim., 1963, 29, p. 380.
4. Kadyshevsky V.G., Tavkhelidze A.N. "Problems of Theoretical Physics". "Nauka", M., 1969, p. 261.
5. Goloskokov S.V. et al. JINR, P2-8211, P2-8337, Dubna, 1974; P2-9897, Dubna, 1976; Particles and Nucleus, 1977, 8, p. 969.
6. Kawaguchi M., Sumi Y., Yokomi H. Progr.Theor.Phys., 1967, 38, p. 1178; 1967, 38, p. 1183; Phys.Rev., 1968, 168, p. 1556.
7. Kawaguchi M., Yokomi H. Progr.Theor.Phys., 1977, 57, p. 470; 1977, 58, p. 596.
8. Pashkov A.F., Skachkov N.B., Solovtsov I.L. Sov.Pisma JETP, 1977, 25, p. 452; JINR, P2-10490, Dubna, 1977; P2-11211, Dubna, 1978.
9. Bracci E. et al. Compilation of Differential Cross Section II-Induced Reaction. CERN preprint CERN-HERA 75-2. 1975. Baglin C. et al. Nucl.Phys., 1975, B98, p. 365. Benary O. et al. NN and ND Interactions - A Compilation. Berkley Preprint, UCRL-20000 NN, 1970, Cocconi G. et al. Phys.Rev., 1965, 138, p. 165.

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