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III-7-13. Interaction of High Energy Nucleons according to Diagram Method View Point and Double Dispersion Relations*

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I. In the quantum field theory there exist two methods for treating strong interactions: double dispersion relations[1] (d.d.r.) and the diagram method. The latter one is employed effectively only in an one-meson approximation (o.m.a.), in which diagrams of inelastic interactions are being considered; they are of the type of Fig. 1[2] and 2**.

Both methods do not represent a closed theory, being to some extent phenomenological. Thus, in d.d.r. there appear unknown spectral functions $\rho(s, t)$ playing a fundamental role in theory, and in o.m.a. functions $D(k^2)$ and $\sigma(s, k^2)$.

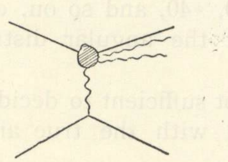

Fig. 1.

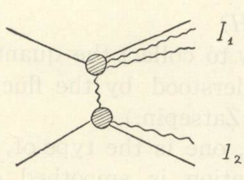

Fig. 2.

Here, k—4-momentum of an intermediate meson, see diagrams 1 and 2, s—square of energy in C. M. S., t—square of the 4-momentum transfer at the elastic interaction, $D(k^2)$—Green's function of π-meson; $\sigma(s, k^2)$—a function which at $k^2=-\mu^2$ is the cross-section of a real π-meson with a nucleon at an energy in their C.M.S., equal to $\omega_c=\sqrt{s}$; μ—mass of π-meson. Now, the problem arises of determining the behaviour of these unknown functions starting from experimental data.

In the present report the following questions are discussed.

1. What information on $\sigma(s, k^2)$ and $D(k^2)$ behaviour may be found on the basis of o.m.a., and of experimental data on N-N and π-N interactions at high energies.

2. To what extent interference between an amplitude of o.m.a. and amplitudes corresponding to other diagrams is essential. This question is highly actual, since o.m.a. has meaning only if corresponding interference terms are small enough (see, reference[4]).

The last question although referring to amplitudes of inelastic processes seems to be connected with the elastic N-N interaction. This circumstance allows to use d.d.r.

II. O.m.a. was applied for the description of nucleon-nucleon interactions at 9 GeV[3),4)] and 300 GeV[6)], and also of π-p interactions at 7 Gev[5)] (the last process being calculated ac-

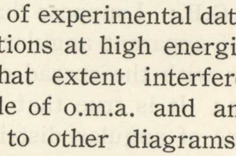

Fig. 3.

* This paper was not read due to the absence of authors.

** The pole approximation is a particular case of o.m.a., in which we put $\sigma(s, k^2)=\sigma(s, k^2=-\mu^2)$, $D(k^2)=\dfrac{1}{k^2+\mu^2}$ (here, we assume $k^2=\mathbf{k}^2-k_0^2$) however, this approximation is not true at $k^2\gg\mu^2$. Besides its validity for $0\le k^2\le\mu^2$ and high energy ($s\gg m^2$, where m—nucleon mass) needs discussion; o.m.a. would be valid at any values of k^2, if the absence of interference of matrix elements (see below) could be proved.

cording to the diagram of Fig. 3).

The total cross-section of inelastic *N-N* interaction at 9 Gev turns out to be $\sigma_{NN}=18$ mb. No restrictions on the virtuality k^2 were imposed; however, its effective value equals to $k^2 \leq (6\sim 7\mu)^2$.

The same holds for calculation of π^--N interactions at 7 GeV[5]. The comparison of computed characteristics with experimental data[7),8),9] testifies to the fact that o.m.a. describes correctly numerous details of inelastic processes, and consequently, one-meson processes contribute essentially. A charge asymmetry *p-n* interactions, or the occurrence of energetic π-mesons in π-*N* interactions, can hardly be explained by any scheme of a different type. At the same time in a one-meson scheme they find a rather simple, quantitatively satisfactory explanation.

Therefore, we concluded that:

1. The cross-section $\sigma(s, k^2)$ as a function of s and k^2 at small s, k, $s<6\,m^2$, $k^2 \leq (6\sim 7\,\mu)^2$, is a slightly changing function of k^2 and may be approximately assumed constant.

2. The contribution of an intergral

$$\int_{(3\mu)^2}^{\infty} \frac{\rho(x)dx}{k^2+x}$$

to the function $D(k^2)$ at $k^2 \leq (6\sim 7\,\mu)^2$ is small as compared to that of the pole term.

Similar calculations of *N-N* interactions at 300 GeV in o.m.a. show:

1. For large k^2 and $s(k^2 \geq (7\mu)^2$ and $s \gtrsim 100\,\mathrm{m}^2)$ $\sigma(s, k^2)$ should decrease and it cannot be considered constant. Otherwise, the cross-section calculated would exceed many times the observed one. The value of k^2 up to which it is possible to consider $\sigma(s, k^2)$ constant was estimated as $k^2 \leq (4\sim 5\,\mu)^2$ at $s \sim 40\,m^2$.

2. On this basis it was concluded that $\sigma(s, k^2)$ is not a multiplicative function of its variables and decreases, when k^2 increases, the more quickly, the greater is s. The same method was used for the determination of asymptotic properties $\sigma(s, k^2)$ at large values of k^2 and s. The *N-N* interaction was calculated at high energies according to diagrams of Figs. 1 and 2. Certain restrictions were imposed on the value of k^2, $k^2 \leq \alpha s$, $\alpha \ll 1$. Asymptotic behaviour of cross-sections under the restriction $k^2 \leq$const. was considered previously in[10].

Asymptotic properties of $\sigma(k^2, s)$ were obtained assuming that all cross-sections of real processes (*i.e.*, $\sigma_{NN}(s, m^2, m^2)$ and $\sigma_{\pi N}(s, \mu^2, m^2)$) are constant, at $s \to \infty$.

It turned out that:

1. If $\sigma(k^2, s) = f_1(k^2)\sigma_0(s)$ (*i.e.*, it is a multiplicative function) then at $k^2 \to \infty$, $f_1(k^2)$ must drop faster than $1/\sqrt{k^2}$. However, in this case σ_{NN} should depend logarithmically on s, thus contradicting the above assumption (this result agrees with that of reference[10),11]).

2. In general case, if $\sigma(s, k^2)$ is not a multiplicative function, it is hardly possible to find a definite asymptotic form; one can only say of firm that $\sigma(s, k^2)$ is a decreasing function either of k^2 or of s, or of k^2 and s simultaneously.

3. It is easy to give an example of a possible non-multiplicative form of σ-function, which would satisfy all the necessary conditions. This is

$$\sigma^2(k^2, s) = \frac{\sigma_0^2}{1+\left(\dfrac{k^2+\mu^2}{\mu^2}\right)^2 \ln \dfrac{s}{m^2}}$$

or

$$\sigma^2(k^2, s) = \frac{\sigma_0^2}{1+\left(\dfrac{k^2+\mu^2}{\mu^2}\right)\left(\ln \dfrac{s}{m^2}\right)^2}, \text{ etc.}$$

In this connection analytical properties of the function $\sigma(k^2, s)$ with respect to the variable k^2 were investigated.[12] The analyticity boundary was found. It was shown that it varies if s changes. From this it follows that $\sigma(k^2, s)$ cannot be the multiplicative function of its arguments.

III. Interference terms.

There are two kinds of such terms.

1. For the diagram of Fig. 2 there can arise interference terms due to the fact that wave functions of the first cone particles (state I_1) interfere with wave functions of the second cone particles (state I_2). A relative value of these terms depends on the character of angular distribution of secondary particles of the given cone in the system where their total momentum is equal to zero (further, $\mathfrak{M}$-system). In the majority of cases this relative value is small, if the ratio k^2/s is also small. At $k^2 \ll s$ and $s \to \infty$ the $\mathfrak{M}$-systems in C.M.S. move with high velocities and under small angles to the direction of primary particles. Therefore, the angular distribution of secondary particles in C.M.S. is essentially anisotropic, it consists of two

very narrow cones which do not overlap, thus securing small interference.

2. Interference terms of the second type are due to the interference between amplitudes of one-meson diagram and the multimeson one. Their value can be essential only if the angular distribution in multimeson diagrams is also of the two-cone character (in C.M.S.). It can hardly be expected that equally sharp angular distribution will take place if a number of intermediate mesons considerably exceeds one (we omit corresponding arguments). The problem of interference of one- and two-meson diagrams (see, Fig. 4) turns out to be very essential. It is possible to show that there is no such interference if the high energy elastic scattering is partly of diffraction type (as was stressed in many papers[13),14)]. "Diffraction", in particular, means that: a) The real part of the scattering amplitude is much smaller than the imaginary one. b) There is no charge-exchange scattering. c) There is no spin flip scattering.

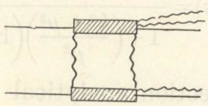

Fig. 4.

Let us consider what restrictions these conditions impose on quantum numbers of an intermediate π-meson cloud (namely: spin $\bar{J}$, isospin $\bar{T}$ and parity $\bar{I}$). According to d.d.r. these numbers must coincide with quantum numbers of a system consisting of a nucleon and antinucleon in a cross channel.

It is easy to show that the condition (b) (no charge-exchange) yields $\bar{T}=0$; further, for an imaginary part of the forward scattering amplitude (when momentum transfer $k_\nu=0$), condition (c) brings about $\bar{J}=0$, and $\bar{I}=+1$. Thus, due to the conservation of G-parity the diagrams with odd-number of intermediate mesons do not contribute to the forward diffraction scattering amplitude.

On the other hand, it is easy to show that a part of the total cross-section due to the interference between the diagrams of Fig. 1 and Fig 4 is proportional to an imaginary part of the forward scattering amplitude corresponding to the diagram with three intermediate mesons.

It follows that the interference between one-meson and two-meson diagrams at high energies vanishes, if scattering is of diffraction type.

In conclusion let us emphasize that the diffraction character of scattering and properties (a), (b), (c) at high energies are not experimentally established yet. Direct experiments aimed at finding a charge-exchange and (or) spin flip scattering and also measurement of energy dependance of the total cross-section would be highly desirable. These experiments in cosmic rays would be very important for the quantum field theory of elementary particles.

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