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POSSIBILITY OF SPIN MECHANISM OF TOTAL CROSS SECTION GROWTH

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The most consistent investigation of the dynamics of strong interactions can be made on the basis of the quasipotential approach[1] in which a dynamical equation for the scattering amplitude was obtained.

Within this approach the standard eikonal representation[2] for the scattering amplitude can be found by using the hypothesis of smoothness of the local quasipotential[3]

$$T(s,t) = is \int \rho \, d\rho \, J_0 (\rho \Delta) (1 - e^{2i \chi(\rho, s)}). \qquad (1)$$

This eikonal representation was obtained for the first time in quantum mechanics[4]. The eikonal phase χ is connected with the global hadron structure.

The energy dependence of observables specific for the small-angle scattering (the total cross section, the slope of the diffraction peak, the ratio of the real part to the imaginary part of the scattering amplitude and so on) can be investigated on the basis of the representation (1).

The experimentally observed growth of the total cross sections is usually connected with the growth of an interaction radius and with the particle "transparency" changes with growing energy[5]. The first of these mechanisms is called the geometrical scaling model[6] and the second the factorized eikonal model[7]. There are, e.g., some other models in which the total-cross-section growth is explained by the highest possible growth of a central-part radius[8].

In this paper we investigate a possibility of a new mechanism of the total cross-section growth, connected with the spin effects, we have found in ref.[9]. It takes place, when spin effects decrease slowly with growing energy. We shall consider the spin mechanism of the total cross-section growth in the case of the nucleon-nucleon scattering and discuss some effects which can be observed in this case.

Let us consider the scattering of two particles with spin 1/2 on the basis of the quasipotential equation for the wave function which can be written as follows[10]:

$$[E - I \otimes \hat{H}(-i\vec{\nabla}) - \hat{H}(i\vec{\nabla}) \otimes I + \gamma_0 \otimes \gamma_0 \hat{V}(E, \vec{r})] \Psi(r) = 0. \qquad (2)$$

Here

$\hat{H}(i\vec{\nabla}) = m\gamma_0 + i\vec{\alpha}\vec{\nabla}$,

E is the total energy in the c.m.s.

The quasipotential $\hat{V}$ can be determined in the matrix form [11]

$$\hat{V}(E,\vec{r}) = A(E,\vec{r}) + B(E,\vec{r})[I \otimes \hat{n}(-\vec{e}) + \hat{n}(\vec{e}) \otimes I] + D(E,\vec{r})\,\hat{n}(\vec{e}) \otimes \hat{n}(-\vec{e}), \quad (3)$$

$$\hat{n}(\vec{e}) = \gamma_0 - \vec{\gamma}\vec{e}/|\vec{e}|, \qquad \vec{e} = (\vec{p} + \vec{k})/2,$$

where $\vec{p}$ and $\vec{k}$ are the particle momenta before and after the scattering process. It was shown in ref. [11] that the standard eikonal representation for the helicity amplitudes of nucleon-nucleon scattering is valid when

$$A(s,\vec{r}) \sim B(s,\vec{r}) \sim D(s,\vec{r}) \lesssim \text{const}.$$

In this case the total cross section is constant or grows logarithmically with energy and the spin-effect contributions to the differential cross sections decrease as follows

$$\frac{|T_{++,+-}(s,t)|}{|T_{++,++}(s,t)|} \sim \frac{1}{\sqrt{s}}.$$

In the case when the quasipotential A and B have anomalous terms [9], it is possible to obtain slow changes of spin effects with energy typical for the models [12]. The quasipotential (3) takes the form:

$$\hat{V}(s,\vec{r}) = a(s,\vec{r}) + \frac{\sqrt{s}}{2}\alpha(s,\vec{r}) + [I \otimes \hat{n}(-\vec{e}) + \hat{n}(\vec{e}) \otimes I]\,(b(s,\vec{r}) + \frac{\sqrt{s}}{2}\beta(s,\vec{r})) + \hat{n}(\vec{e}) \otimes \hat{n}(-\vec{e})\; d(s,\vec{r}). \quad (4)$$

The quasipotentials in (4) can logarithmically depend on energy. A special investigation of this case was carried out in ref. [9] for the meson-nucleon scattering.

The solution of equation (2) with the quasipotential (4) can be obtained by the same method. Here we only write the solutions for nucleon-nucleon helicity amplitudes valid in the case $\alpha, \beta \ll 1$

$$T_{++,++}(s,t) = i\int \rho\, d\rho\, J_0(\rho\Delta)\,[1 - e^{\chi_0(s,\rho)}]$$

$$T_{++,+-}(s,t) = -\int \rho\, d\rho\, J_1(\rho\Delta)\,\chi_1(s,\rho)\, e^{\chi_0(s,\rho)}, \quad (5)$$

where

$$\chi_0(s,\rho) = -\frac{2}{i}\int_{-\infty}^{\infty} dz\,[\,d(s,r) - \frac{\sqrt{s}}{2}(\beta^2(s,r) + \frac{\alpha^2(s,r)}{16})],$$

$$\chi_1(s,\rho) = \frac{1}{2i}\int_{-\infty}^{\infty} dz\, \frac{d\beta(s,r)}{d\rho}.$$

Quasipotentials a and b contribute to the subsequent terms of $1/P$ -expansions of helicity amplitudes. The double spin-flip amplitudes are suppressed in this case by a power.

Expressions similar to (5) were obtained in the case of meson-nucleon scattering [9]. Expressions (5) have the eikonal form. However, χ_0 contains rapidly growing terms proportional to α^2 and β^2. These terms are absent in the standard eikonal representation.

It is obvious that these anomalous terms of the quasipotential become important when s is growing. It has been shown [9] that this effect leads to the total cross-section growth.

So, the scattering amplitude (5) has two different mechanisms of the total cross-section growth. The first mechanism works in the energy region where the anomalous terms of the quasipotential are unimportant

$$\frac{\sqrt{s}}{2}\,(\beta^2(s,r) + \frac{\alpha^2(s,r)}{16}) \ll d(s,r). \quad (6)$$

It has a standard character and is connected with the interaction radius growth and the particle "transparency" changes.

The second mechanism takes place in the superhigh energy region where the anomalous terms mainly contribute to the eikonal phase. This mechanism has a spin character. Its plysical nature is the following. The main contribution to the non-spin-flip amplitude comes from the terms with double change of the spin of one or two particles proportional to $\beta^2(s,r)$ or $\alpha^2(s,r)$ when the quasipotential (4) contains the anomalous terms. The quasipotential equation permits us to sum up these terms. As a result, they become exponential and contribute to the eikonal phase χ_0.

Let us consider now the energy dependence of the scattering amplitude at $t=0$ and possible effects connected with the spin mechanism of the total cross section growth. This can be done on the basis of some model with anomalous terms (for example, [13]) in the most consistent manner.

However, we shall use the simple gaussian form of the eikonal phase. Taking into account the $s \to u$ crossing symmetry of the main asymptotic term of the scattering amplitude, we obtain for χ_0:

$$\chi_0(s,\rho) = -x e^{-\rho^2/4a(s)} - (1 - i)\frac{\sqrt{s}}{2}\lambda e^{-\rho^2/2b(s)},$$

$$a(s) = a_0\kappa(s); \quad b(s) = b_0\kappa(s); \quad \kappa(s) = (1 + \alpha(\ln s - \frac{i\pi}{2})) \quad (7)$$

and

$x = 1, \quad a_0 = 3{,}4\ \mathrm{GeV}^{-2}, \quad a = 0{,}075.$

With these parameters we have a good description of σ_{tot} in the ISR energy region.

The radius of anomalous terms is unknown and depends on the model. Note that in /13/ and in some models /12/ the anomalous terms have a peripheral character and are determined by the two-pion exchange in the t-channel. In this case their radius is equal to/or larger than a, the radius of the main term of eikonal phase. So, let us suppose that

$$a \le b \le 2a.$$

The coupling constant of the anomalous term can be determined from the condition that the total cross-section for pp-scattering does not exceed the $p\bar{p}$ total cross-section at the CERN $p\bar{p}$ collider energy $\sqrt{s} \approx 540$ GeV. In this case

$$\lambda_{b=a} = 2{,}4\ 10^{-3}; \qquad \lambda_{b=2a} = 1{,}0\ 10^{-3}. \tag{8}$$

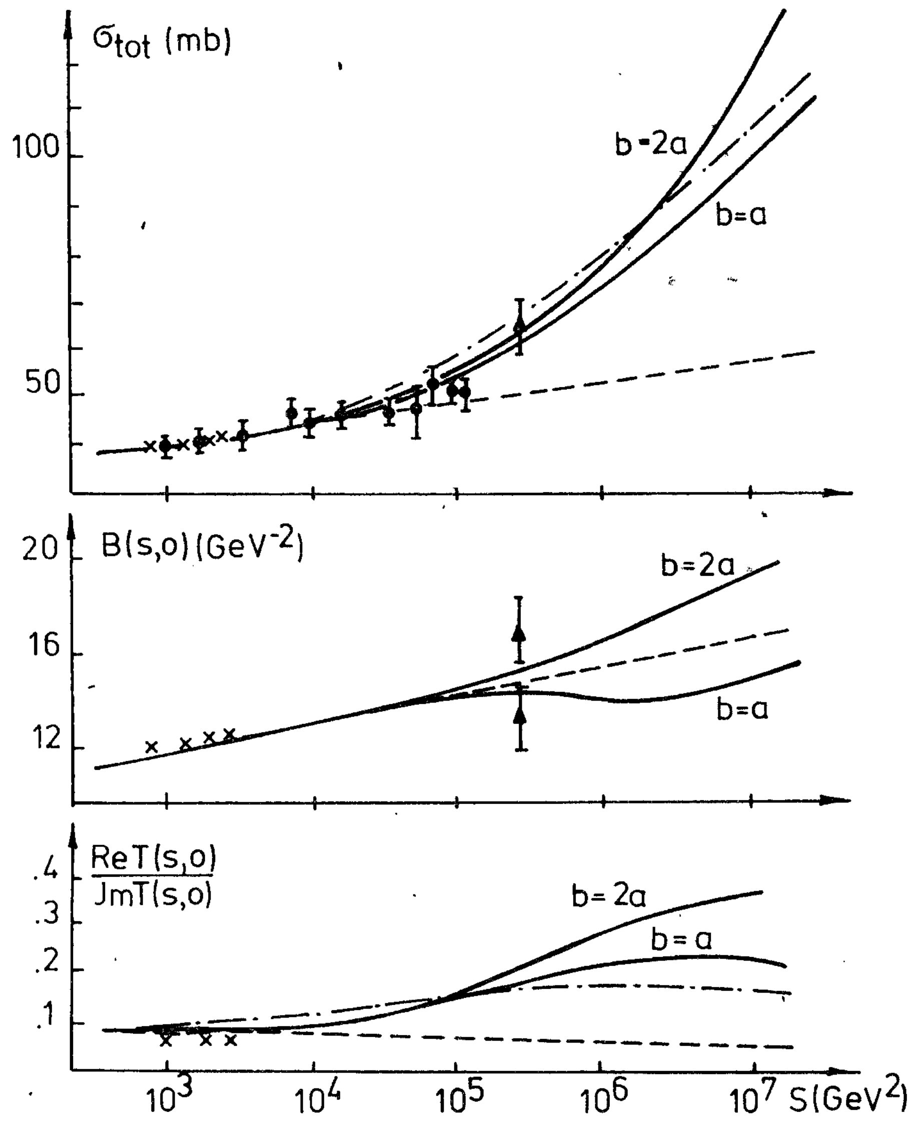
The Figure shows the total cross-section, the diffraction peak slope B(s,0) and the ratio Re T(s,0) / Im T(s,0), obtained in the model with and without spin mechanism of the total cross-section growth ($\lambda=0$), the results of model /8/, and experimental data from accelerators /14–16/ and cosmic data /19/. It can be seen from the picture that the spin mechanism of the total cross section growth appears at an energy $s \approx 10^5\ \mathrm{GeV}^2$ for the λ determined in (8). The main contribution to the total cross section growth at lower energy comes from the standard mechanism. It is easy to see that results of this simple model with the spin mechanism are similar to predictions of the model /8/ without spin effects up to an energy $s \approx 10^7\ \mathrm{GeV}^2$.

As has been shown, the spin mechanism is connected with slowly changing spin effect that is in the case:

$$\frac{T_{++,+-}(s,t)}{T_{++,++}(s,t)} = f(s,t),$$

where f(s,t) is a logarithmic function of energy. Appearance of the contributions of this kind can be checked in polarization experiments. In this case polarization must be large and slowly change with energy in the diffraction minimum region (see /12/).

Another typical effect determined via the spin mechanism is a rapid energy change of the eikonal phase χ_0. It is well known



Energy dependence of $\sigma_{tot}(s)$, B(s,0), $\frac{\mathrm{Re}\,T(s,0)}{\mathrm{Im}\,T(s,0)}$ in the model - - - - without spin mechanism, ——— - with spin mechanism of the total cross section growth; —·— results of the model /8/; Δ - data from CERN $p\bar{p}$ collider /14,15/; × - accelerator data /16/; ɸ - consmic data.

that a similar dependence in the factorized eikonal model leads to the ratio growth

$$\frac{d\sigma}{dt}\Big|_{2-ndmax} \Big/ \frac{d\sigma}{dt}(0) = f(s) \qquad (9)$$

with growing energy. In the geometrical scaling model the ratio (9) does not depend on energy. Measurement of this ratio at superhigh energies is an indirect indication of the spin mechanism of the total cross section growth. So, in this paper a possibility of the spin mechanism is established for the total cross-section growth which may be important at very high energies. We discuss here some physical effects which must be typical in this case. These can be estimated within a dynamical model with this mechanism (for example, [13]).

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О возможном существовании спинового механизма роста полных сечений

Указано на возможность существования спинового механизма роста полных сечений, обсуждены эффекты, к которым он должен приводить.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Possibility of Spin Mechanism of Total Cross Section Growth

A possibility of the spin mechanism is indicated to exist for the growth of total cross sections, and related physical effects are discussed.

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

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