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K_s–MESON REGENERATION ON NUCLEI IN THE COLOUR QUARK MODEL

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1. The interest in the K_S-meson regeneration on nuclei is excited in part by a possibility of getting some new information about space-time structure of strong interaction at high energies. Such information differs from that obtained in the hadron-nucleus elastic scattering, because the $K_L \to K_S$ transformation picks up same configurations in the incident K-meson wave function which have a small weight.

It is known that inelastic shadowing corrections increase the transparency of nuclear matter for the incident hadron. If one calculates the K_S regeneration cross section and takes into account the inelastic corrections only of the type shown in fig. 1 one obtains a theoretical curve above the experimental points/1/. This means that other inelastic corrections of the type shown in fig. 2, should decrease the K_S regeneration cross section, i.e., "darken" the nucleus. This fact confirms the conclusion /2/ that diffractive dissociation amplitude has a negative sign. Unfortunately any correct calculation of the inelastic shadowing of type shown in fig. 2 is impossible now.

Nevertheless, it is possible to sum up the inelastic corrections of all the types by means of the eigenstate method /3/. When the wave function of incident hadron is decomposed into the eigenstates of interaction, each of this states scatters on the nucleus without any inelastic shadowing. Thus the problem is reduced to finding out the eigenstate spectrum and the scattering amplitude eigenvalues. This can be done in the framework of some model only. In the parton model, for instance, the eigenstates of interaction are the states of incident hadron with a definite number of wee partons. In the constituent quark model each valence quark has its own parton wave function, which can be decomposed into the eigenstate series. The hadron-nucleus elastic scattering amplitude in such an approuch has been considered in paper /3/. In this way there has been calculated also the amplitude of K_S- meson regeneration on nuclei /4/. It has been assumed there that d-quark in the K-meson, which is coupled to ω-reggeon, is slow enough to be active, i.e., to have one wee parton at least. The calculations/4/ showed a good agreement with experimental data/1/.

2. Another example of eigenstate spectrum has been found in quantum chromodynamics /5/. If one neglects the gluon contri-

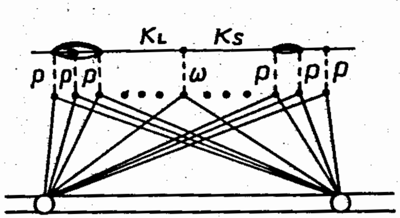

Fig.1. Example of the first type inelastic corrections: K_L or K_S diffractively dissociates on one of the nucleons. The reverse transition into initial state takes place on another nucleon.

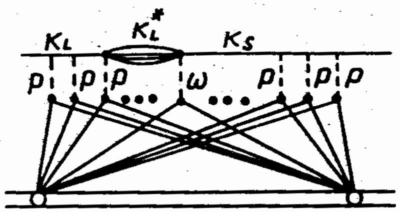

Fig.2. Example of the second type inelastic corrections: K_L diffractively dissociates on one of the nucleons and then the produced jet transits into K_S on another nucleon.

bution to the hadron wave function, then the eigenstates of interaction are the states of hadron with a definite interquark distance in the impact parameter plane. In the Born approximation, when only a two gluon exchange is included /6,7/, the scattering amplitude of a two quark system with a relative transverse distance ρ is imaginary and has the form

$$f(\rho) = i\frac{8\pi\alpha_S^2}{3\ln 2\ \lambda^2}\left[1+C-e^{-z^2/4}+\ln\left(\frac{z^2}{4}\right)\mathrm{Ei}\left(-\frac{z^2}{4}\right)\right]. \qquad (1)$$

Here $z=\lambda\rho$; the parameter λ is connected with a nucleon two-quark form factor, which is taken in the Gaussian form $\langle\exp[i\vec{k}(\vec{r}_1-\vec{r}_2)]\rangle_N = \exp(-k^2/\lambda^2)$ ($\lambda^2=3.2\ \phi m^{-2}$).

The averaging here is taken over the nucleon quark coordinates r_i (i=1,2,3).

The quark-gluon coupling α_S is fixed by the value of total cross section $\sigma_{tot}^{\pi N}=16\pi\alpha_S^2/3\lambda^2$.

It is easy to see that amplitude (1) is the increasing function of interquark distance ρ. Indeed, a colourless hadron can interact with a gluon field of a target only through its own transverse colour dipole momentum, which is proportional to ρ.

Let us now make a digression about Born approximation to quantum chromodynamics. In spite of its oversimplification the two gluon exchange contribution surprisingly well describes all the known hadronic cross sections /6/ data and the diffractive dissociation also /7/. It seems that this is not a happy coincidence, but a consequence of an important property inherent to the Born approximation: scattering amplitude strongly depends on transverse dimension of hadrons. It may be that corrections of higher order on α_S do not change this conclusion.

Indeed, the calculation of ladder gluon graphs /8/ in the leading logarithm approximation showed that the scattering amplitude asymptotics is governed by a fixed singularity in the j -plane which is placed to the right from unity. This means that the scattering amplitude is large only in the region of impact parameter values of the order of hadronic radius. Too rapid increase of the amplitude with energy in this region will be stopped after addition of the unitarity corrections.

Accidental fluctuations in the value of interquark distance are slowed down by Lorenz transformation of the time scale. So if a hadron has the energy $E \gg \mu^2 R_A$ (μ is a characteristic mass at about 1 GeV), then while it passes through a nucleus of radius R_A its transverse interquark distance can be regarded as fixed. Then the scattering amplitude of the two quark system with fixed relative transverse distance ρ on a nucleus can be calculated in the Glauber approximation, because no other intermediate state of this system in a nucleus can arise.

The partial hadron-nucleus scattering smplitude at a given impact parameter b is equal to /5/

$$f^{el}_{hA} = \int d^2\rho\,|\Psi(\rho)|^2\{1-\exp[if(\rho)\,T(b)]\}. \qquad (2)$$

Here $\Psi(\rho)$ is a radial part of the quark wave function of meson h. $T(b)=\int_{-\infty}^{\infty} dz\,\sigma_A(b,z)$ is the nucleus profile function. $\sigma_A(b,z)$ is nuclear density depending on impact parameter b and longitudinal coordinate z.

The optical approximation is used in expression (2) for simplicity.

It is worth while noting that the averaging over ρ in the formula (2) is made for the whole hadron-nucleus amplitude, in contrast to the Glauber approximation where only the amplitude $f(\rho)$ in the exponent is averaged over ρ. The difference of amplitude values calculated in these approaches is equal to the sum of all the inelastic shadowing corrections /3/.

3. The conclusion about the dependence of absorbtion strength of a hadron in a nucleus on the interquark distance in a hadron is very important for the K_S regeneration process. Indeed the valence d -quark of K -meson must interact with one of the nucleons by means of the ω -reggeon exchange (s -quark is coupled only to ϕ -reggeon, which has too low intercept). The space-time picture of this process looks as follows: the $K_L \to K_S$ conversion picks out those rear fluctuations in the incident K -meson, where valence d -quark is slowed down long way of regeneration point (at distance about E/μ^2), by means

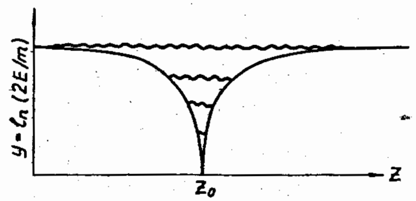

Fig.3. The dependence of d-quark rapidity on the longitudinal coordinate z. CP-charge exchange takes place at the point z_0.

of successive virtual gluon emission. When it becomes slow enough it interacts with a nucleon, changing the CP-quantum number and then by absorbing successivly the gluons it becomes fast again. This process is shown graphically in fig. 3.

It is important here that while the d-quark is slowed down it diffuses in impact parameter plane to a distance of about

$$\rho^2 = 4\alpha'_\omega \ln(2E/m). \qquad (3)$$

The slope parameter of the ω-trajectory $\alpha'_\omega \approx 0.75$ $(GeV/c)^{-2}$ is large. Consequently the K_S- regeneration process at high energies picks out mainly those components of K meson, that have a radius with much more than the average value. This results in stronger absorbtion on K-meson in nuclear matter in the regeneration process than in the elastic scattering.

In real calculations one should bear in mind that the interquark distance ρ is changed while K-meson passes through a nucleus, and the value (3) corresponds to maximal value of ρ (in average), which is achived in the regeneration point. In the region of this point the value of ρ changes very steeply, because quark rapidity $y = \ln(2E/m)$ depends on the distance from regeneration point in the way shown in fig. 3. The size of this region is about 1 f, i.e., internucleon distance in nucleus.

At larger distance from regeneration point the changing of K-meson radius is gently sloping, so one can consider it to be constant and substitute E in the expression (3) by $E/L\mu$, where L is a distance, which is passed by K-meson in nuclear matter. We put approximately $L = T(b)/\sigma_0$, where $\sigma_0 \approx 0.15$ f^{-3} is a nuclear density. So the average value of K-meson radius in the regeneration process on a nucleus at impact parameter b is equal to

$$R^2(b) = R_0^2 + 4\alpha'_\omega \ln\left[\frac{2E\sigma_0}{\mu^2 T(b)}\right]. \qquad (4)$$

Here $R_0^2 = 0.26$ f^2 is the average value of K-meson radius squared.

Now one can write the expression for the K_S-regeneration amplitude on a nucleus

$$|f^A_{LS}| = |f^N_{LS}|_\omega A_{eff}, \qquad (5)$$

where

$$A_{eff} = \int d^2b \frac{T(b)}{R^2(b)} \int d^2\rho \exp\left[if(\rho)T(b) - \frac{\rho^2}{R^2(b)}\right] \qquad (6)$$

$(f^N_{LS})_\omega$ is ω-reggeon contribution to f^N_{LS} and is equal to

$$(f^N_{LS})_\omega = \beta_\omega \frac{1 - e^{-i\pi\alpha_\omega}}{\sin\pi\alpha_\omega} (2m_N E)^{\alpha_\omega - 1}. \qquad (7)$$

Here [9] $\alpha_\omega = 0.44$; $\beta_\omega = 10.46$ mb $(GeV)^2$.

The expressions (5), (6) contain no free parameter, so the amplitude f^A_{LS} can be calculated. The nuclear density $\sigma(r)$ was taken in the Woods-Saxon form with parameters from paper [10]. The results of calculations are shown in fig. 4. It is seen that theory describes well experimental points, especially if one remembers the absence of free parameters. There is a small difference between the phases of amplitudes f^A_{LS} and f^N_{LS} which is due to more steep energy dependence of f^A_{LS}. This difference has been calculated in paper [4].

4. Thus those nuclear reactions at high energies, which are realized by means of secondary reggeon exchange are characterized by larger radius of incident hadron than in elastic hadron-nucleus scattering. This property should be manifested in more strong absorbtion of hadron in nuclear matter. The good description of experimental data, achieved above, confirms significant role of hadronic size for the cross section value.

There are other known effects in the processes with reggeon exchange, which can be investigated on nuclear targets. For instance real part of the elastic hadron-nucleus scattering amplitude, polarization phenomena in hadron-nucleus scattering, etc.

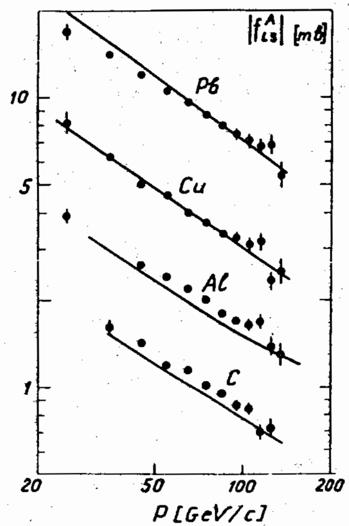

Fig.4. Comparison of the calculation results with experimental points [1] for the nuclei Pb, Cu, Al, C.

It is worth noting in conclusion that the growth of the hadronic total cross sections with energy may also be connected directly with the growth of the interaction radius. If such connection exists, then the following relation should be executed

$$\frac{1}{\sigma_{tot}} \frac{d\sigma_{tot}}{d(\ell n E)} = \frac{1}{B} \frac{dB}{d(\ell n E)}, \qquad (8)$$

where $B \approx 10\ (GeV/c)^{-2}$ is the value of diffraction slope in the elastic hadron-hadron scattering. $dB/d(\ell n E) = 2\alpha'_P \approx 0.5 (GeV/c)^{-2}$. The left-hand side of relation (8) is equal in accordance with experiment to $d(\ell n\,\sigma_{tot})/d(\ell n\,E) \approx 0.06$. Thus relation (8) is fulfield with a good accuracy.

REFERENCES

1. Gsponer A. et al. Phys.Rev.Lett., 1979, 42, p. 13.
2. Zamolodchikov Al.B. et al. JETP, 1979, 77, p. 451.
3. Kopeliovich B.Z., Lapidus L.I. JETP Lett., 1978, 28,p.664; in "Proc. of V Seminar on High Energy Phys. Problems", JINR, D1,2-12036, Dubna, 1978, p. 469.
4. Kopeliovich B.Z., Nikolaev N.N. Z.Phys.C, Part. and Fields, 1980, 5, p. 333.
5. Kopeliovich B.Z., Lapidus L.I., Zamolodchikov Al.B. JINR, E2-81-251, Dubna, 1981.
6. Gunion J.F., Soper H. Phys.Rev., 1977, D15, p. 2617.
7. Levin E.M., Ryskin M.G. Yad. Fizica, 1981, 34, p. 421.
8. Balitsky Ya.Ya., Lipatov L.N., Fadin V.S. In "Proc. of XIV Winter School LNPI", Leningrad, 1979, p. 109.
9. Bertocchi L., Treliani D. Nuovo Cimento, 1979, A50, p. 338.
10. Murthy P.V.R. et al. Nucl.Phys., 1975, B92, p. 269.

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