Quark-parton model of the interaction of hadrons with nuclei

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An eigenstate method (ESM) is proposed for the calculation of the cross sections of the interaction of hadrons with nuclei. It is shown that the ESM is equivalent to the multiple-scattering model in which inelastic screening is taken into account. It is shown in the quark-parton model that the valent quarks in a hadron have a 50% probability of being in a passive state that contains only fast partons.

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1. The increase, with increasing energy, of the longitudinal distances over which the interaction of hardrons takes place, is being investigated of late in processes of multiple production of particles on nuclei.[1-3] We consider here manifestations of this effect in elastic hadron–nucleus scattering.

Consider a hadron with momentum P satisfying the condition

$$P/\mu^2 >> R_A . \tag{1}$$

Here P/μ^2 is the longitudinal length characterizing the interaction with the target; μ is a certain characteristic mass; R_A is the radius of the target nucleus. Since the interaction region exceeds the dimension of the nucleus, it is impossible to separate the elastic and inelastic intermediate states inside the nucleus as is done in the multiple-scattering model (MSM). This separation corresponds to contributions of different Feynman diagrams and must not be taken literally.

2. We consider a method of expanding the wave function $|\Psi\rangle$ of the hadron in the eigenstates $|\Psi_k\rangle$ of the interaction Hamiltonian (the ESM–eigenstate model)[4,5]

$$|\Psi> = \sum_K c_k |\Psi_k> , \tag{2}$$

where

$$<\Psi_i|\Psi_k> = \delta_{ik} , \tag{3}$$

$$\sum_K c_k^2 = 1 , \tag{4}$$

$$\hat{f}|\Psi_k> = f_k|\Psi_k> . \tag{5}$$

Here $i\hat{f}$ is the scattering-amplitude operator. The amplitudes f_k are assumed to be real. The amplitude of elastic scattering of the hadron h by a nucleus takes, according to

(2)–(5), the form

$$f^{hA} = \langle\Psi|\hat{f}|\Psi\rangle = \sum_K c_k^2 f_k^{hA}. \qquad (6)$$

It is assumed here that condition (1) is satisfied, i.e., the states $|\Psi_k\rangle$ are not intermixed during the time of the interaction. To calculate the amplitudes f_k^{hA} we can use the usual Glauber model.[6] It will be shown below that for the scattering of a fast quark by a "black" nucleus this difference amounts to about 100%.

3. We shall show that the ESM is equivalent to the MSM with account taken of elastic and inelastic intermediate states. Consider the screening correction to the amplitude of scattering by a deuteron. According to (6)

$$(\Delta f^{hd})_{\rm ESM} = \sum_k c_k^2 (f_k^{hN})^2. \qquad (7)$$

The Glauber correction is equal to

$$(\Delta f^{hd})_{el} = (\sum_k c_k^2 f_k^{hN})^2. \qquad (8)$$

We express the inelastic correction in the form[7]

$$(\Delta f^{hd})_{in} = \sum_k \langle\Psi_k|\hat{f}|\Psi\rangle^2 - \langle\Psi|\hat{f}|\Psi\rangle^2 = \sum_k c_k^2 (f_k^{hN})^2 - (\sum_k c_k^2 f_k^{hN})^2. \qquad (9)$$

It is seen that the sum of (8) and (9) is indeed equal to (7). The proof can be easily generalized to include the case of an arbitrary nucleus.

4. Consider now the quark–parton model, according to which the fast hadron consists of valent quarks, each of which carries its own parton sea. The states $|\Psi_k\rangle$ in the model are the states $|k\rangle$ with a definite number k of slow partons ($k = 0,1,2,...$),[8,9] since only slow partons interact with the target.[10] By the number of slow partons we mean the number of "combs" that contain partons with $P = \mu$. Since the weight c_0^2 of the passive component ($k = 0$) cannot decrease with increasing energy[9] we can expect c_0^2 to be large at high energies and the passive component of the hadron to play an important role.

5. We consider now the diffraction dissociation of a quark q (u and d quarks) on a proton

$$\sigma_{\rm diff}^{qp} = (1 - P_q)(\sigma_{el}^{qp} + \sigma_{\rm diff}^{qp}) + P_q^2 \int d^2b (\langle f^2\rangle_{\rm act} - \langle f\rangle_{\rm act}^2). \qquad (10)$$

Here $P_q = \Sigma_{k=1} c_k^2$ is the weight of the active component of the wave function of the q-quark; b is the impact parameter, and $\langle f\rangle_{\rm act} = \Sigma_{k=1} c_k^2 f_k$. If we neglect the dispersion of the amplitude f_k in the active component, i.e., the second term of (10), then calculation of σ_{el}^{qp} and $\sigma_{\rm diff}^{qp}$ yields for P_q a value $P_q \gtrsim 0.5$. An estimate of the second term in (10) has shown that it makes a contribution of the order of 8% to $\sigma_{\rm diff}^{qp}$. In this case $P_q \lesssim 0.55$. Thus, the main contribution to the diffractive dissociation is made by the passive component of the quark.

6. The total cross section $\sigma_{\rm tot}^{pA}$ will be written in the optical approximation in the

form

$$\sigma^{pA}_{\text{tot}} = 3P_q(1-P_q)^2 I_1 + 3P_q^2(1-P_q)I_2 + P_q^3 I_3 , \tag{11}$$

where

$$I_n = 2\int d^2b\left[1-\exp\left(-\frac{n}{2P_q}\sigma^{qN}_{\text{tot}}\;T(b)\right)\right] . \tag{12}$$

Here $\sigma^{pN}_{\text{tot}} \approx 17$ mb; $T_A(b)$ is the profile function of the nucleus. Comparing (11) and (12) with the data for σ^{pA}_{tot} at 240 GeV (Ref. 11), we obtain the values of P_q Listed in Table I:

TABLE I.

A	C^{12}	Al^{27}	Cu^{64}	Pb^{207}
P_q	0.4	0.45	0.5	0.67

It appears that the increase of P_q with increasing A is due to the fact that the energy 250 GeV is low for heavy nuclei from the point of view of (1). This is confirmed by the fact that σ^{pA}_{tot} decrease with energy in the case of lead.[11]

7. Thus, the ESM, together with a correct interpretation of the space–time picture of the hadron–nuclear interactions, makes it possible to obtain interesting information on the structure of the hadron. We have explained here, that a fast quark spends approximately half its time in a passive state. Therefore the asymptotic expression does not contain a universal hadron cross section, and there are no absolutely "black" objects.

Detailed calculations of hadron–nuclear cross sections, and also an analysis of the data on the hadron–hadron interactions in the ESM, will be published separately.

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