Total multiplicities in the photoproduction and electroproduction on nuclei

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It is shown that the total multiplicities have a specific abrupt dependence on the virtual-photon mass $\sqrt{Q^2}$ in interactions with nuclei, in spite of the fact that the total multiplicities are the same in photoproduction and electroproduction on nucleons ($Q^2 = 0$ and $Q^2 \neq 0$). The magnitude of the predicted effects reaches 30–40%.

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In parton and multiperipheral models, the longitudinal distances over which the interaction takes place increase in proportion to the momentum:

$$\Delta z \approx P/m^2 . \tag{1}$$

As was emphasized by Kancheli,[1] this growth of the longitudinal distances can be verified in interactions between high-energy hadrons and nuclei. The two-phase mechanism of particle generation in intranuclear cascades, which follows from the growth of the longitudinal distances and was developed in[2], is adequately confirmed by experiment (see also the review[3]). In hadron interactions, however, the logitudinal distances can be varied only by varying the energy, and this changes also the characteristics of the elementary interaction between the incident hadron and the nucleons of the nucleus.

From the point of view verifying the space-time picture of the interaction, the electroproduction reactions are much more convenient. The point is that in this case[4]

$$\Delta z \approx P/Q^2 + m^2 . \tag{2}$$

By varying the photon mass at a fixed photon momentum we can control the longitudinal distance over which the interaction takes place. A direct proof of the growth of the longitudinal distances with increasing energy was obtained by Ioffe[4] precisely from an analysis of experimental data on electroproduction. It will be shown in this paper that the change of Q^2 and, accordingly, the change of the longitudinal distances that play a significant role in the interaction, leads to effects of the order of 30–40% in the generation of particles in intranuclear cascades.

Owing to the growth of the longitudinal distances, the interaction of a photon with hadrons can be represented as proceeding in two stages.[5] First the photon goes over into a hadronic state, which then interacts with the target. As shown in[6,3], only a small part of the hadronic states into which the virtual photon goes over can interact strongly with the target. This, however, does not affect the multiplicity. All that matters is that the parton wave function of the photon is similar to the parton wave function of the hadrons and does not depend on Q^2. This can be verified by following the analysis given in[6,3] for the structure of the hadronic

states into which the photon goes over. The independence of the parton wave function of the photon of Q^2 is confirmed also by the fact that in experiment the multiplicities are equal in photoproduction and electroproduction on nucleons.

When $\Delta z > R$ (R is the radius of the nucleus), the hadrons into which the photon goes over are scattered by the nucleus in the customary diffraction manner. From the point of view of particle generation in an intranuclear cascade, the important fact here is that the absorption takes place on the surface of the nucleus, as in ordinary hadron-hadron interactions. Particle generation takes place over a length on the order of the nuclear diameter, and it follows from the similarity of the parton wave functions of the photon and the hadron that

$$<n>_{\gamma A} \;\widetilde{\;\lessgtr\;}\; <n>_{bA} . \tag{3}$$

In experiment, the photoproduction cross section has a diffraction character already at photon energies $E \gtrsim 5{-}10$ GeV,[7] Relation (3) should also be satisfied starting with these very same energies.

In the case of electroproduction, diffraction scattering occurs at low values of the scaling variable $x = Q^2/2m\nu$:

$$x \lesssim x_d A^{-1/3} , \tag{4}$$

which correspond to large longitudinal distances

$$\Delta z \approx 1/mx \gtrsim R . \tag{5}$$

On the other hand, in the region of large values of x

$$P_x \lesssim x \tag{6}$$

the longitudinal distances are smaller than the internucleon distances, and the interaction with the individual nucleons of the nucleus will be incoherent. Since the parton wave function does not depend on Q^2, the multiplicities in electroproduction and in the photoproduction will be the same in the diffraction region:

$$<n>_{\gamma A} \approx <n>_{\gamma^* A} , \qquad x \lesssim x_d A^{-1/3} . \tag{7}$$

The absence of nucleon screening at $x \gtrsim x_d$ means

that the points of the first interaction are uniformly distributed over the entire diameter of the nucleus. Accordingly, the particle generation in the cascade will take place in the mean over a length on the order of half the nuclear diameter. Since the parton wave function does not depend on Q^2, the mechanism of cascade development will be the same as in photoproduction or in the diffraction region. Therefore the entire change of the total multiplicity in the transition from the diffraction region to the region of incoherent scattering, due to increased Q^2 at fixed ν, will be due entirely to the difference between the longitudinal distances over which the interaction takes place at different Q^2.

We have estimated numerically the dependence of the multiplicity on the photon energy ν and on its mass squared Q^2 within the framework of the two-phase parton model of particle generation in an intranuclear cascade; this model was developed and used successfully in[2] to describe hadron-nuclear interactions. Figure 1 shows the expected energy dependence of the ratio $R_A \langle n \rangle_A / \langle n \rangle_N$ of the total multiplicities in the case of interaction with a nucleus and a nucleon for different nuclei. The curves drawn through the symbols $\triangle$, $\blacktriangledown$, $\blacklozenge$, $\blacksquare$, and $*$ pertain to $A^{1/3} = 2$, 3, 4, 5, and 6, respectively. The solid curve corresponds to photoproduction and electroproduction in the diffraction region and was obtained using relation (3). The dashed curve corresponds to electroproduction in the incoherent-scattering region. It was calculated in the model of[2] for interactions of hadrons with nuclei under the assumption that the points of the first inelastic interaction are uniformly distributed over the entire diameter of the nucleus. This curve can be used at $Q^2 \gtrsim 1$ GeV^2, when the scattering already has a scaling character. At a given fixed Q^2 the dependence of R_A on the photon energy ν follows the dashed curve up to energies $\nu \lesssim Q^2 / 2mx_d$, and at energies $\nu \gtrsim Q^2 A^{1/3}/2mx_d$ the ratio R_A follows the solid curve. The character of the change in the regime at $Q^2 = 8$ GeV^2 is shown qualitatively by the dashed curve of Fig. 1. In the calculation, use was
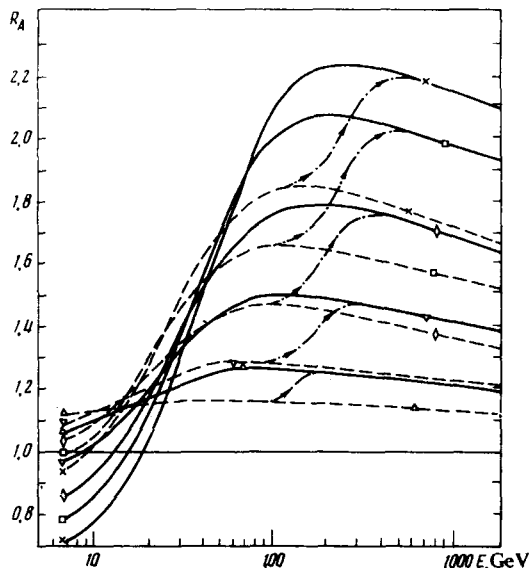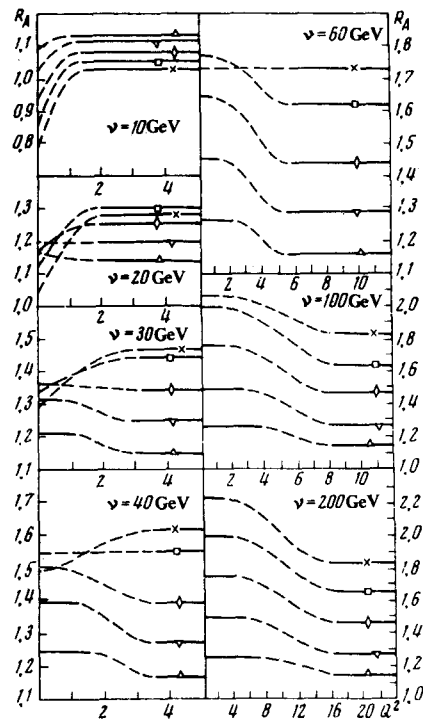

FIG. 2.

made of the fact that the analysis given in[6,3] indicates that $x_d = 0.03$ to 0.05.

Figure 2 shows the expected dependence of R_A on Q^2 at fixed photon energies ν for different nuclei. At $Q^2 \lesssim 2m\nu x_d / A^{-1/3}$, in the diffraction-scattering region, R_A does not depend on Q^2. With further increase of Q^2 we go over into the region of incoherent scattering, and starting with $Q^2 \gtrsim 2m\nu x_d$ the multiplicities are again independent of Q^2. A measure of particle generation in a cascade is the deviation of R_A from unity. It is seen that $R_A - 1$ changes by more than 30–50% with changing Q^2. The predicted effects are large and can be observed in experiments on deep inelastic scattering of muons and in neutrino experiments (obviously, all the discussed effects pertain equally well to electroproduction and to neutrino reactions). Experiments at Fermilab energies would be particularly interesting, since the predictions are numerically most reliable at energies $E \gtrsim 40$–60 GeV.

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FIG. 1.

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