MESON PRODUCTION IN COLLISIONS OF HIGH-ENERGY NUCLEONS

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It was shown in the report of D. I. Blokhintsev[1] at the CERN symposium that at energies of several Bev it is possible to distinguish between central and periphery collisions of nucleons and to evaluate the latter by the Weizsäcker-Williams method (see Ref. 2). In this note a more detailed consideration of the periphery collisions of nucleons is given, making more precise the results of Blokhintsev.

Firstly, terms from mesons of different charges are calculated. It follows from the hypothesis of charge independence that virtual $\pi^{\pm}$ and π^0-mesons are in the nucleon cloud with relative probabilities of 2/3 and 1/3. Therefore the energy carried by the π^0-meson cloud of a fast nucleon is

$$E^0 = \frac{2\pi}{3}\int_r^\infty b\,db \int_{-\infty}^{\infty} v\,[\nabla_x \varphi(b, x, t)]^2_{x=0}\,dt,$$

where r is the radius of the nucleon core,[1] and the integrand is the current density of the energy of the meson field of the nucleon, moving with velocity v along the x-axis, at a point on the plane x = 0.

$$\varphi(b, x, t) = \frac{\gamma g}{\sqrt{4\pi}}\left(\frac{m}{2M}\right)(\sigma\nabla)\frac{\exp\left[-R^{-1}\sqrt{b^2+\gamma^2(x-vt)^2}\right]}{\sqrt{b^2+\gamma^2(x-vt)^2}}$$

is the function of the meson field of the fast nucleon in a non-relativistic approximation for the nucleon; m and M are the masses of the π-meson and nucleon,

$$R = \hbar/mc, \quad \gamma = (1-\beta^2)^{-1/2}, \quad \beta = v/c.$$

Expanding $\nabla_x\varphi(b,x,t)$ at x = 0 in a Fourier integral,[2] we obtain

$$E^0 = E\frac{m}{M}g^2\int_0^\infty z\,Q^0(r, z)\,dz,$$

where

$$Q^0(r, z) = \frac{1}{3}\frac{z}{2\pi}\{2uK_0(u)K_1(u) + r^2[K_0^2(u) - K_1^2(u)]\}, \quad u = \left(\frac{r}{R}\right)\sqrt{1+\left(\frac{M}{m}z\right)^2}$$

is treated as a spectrum of virtual π^0-mesons accompanying the fast nucleon. Here $K_0(u)$, $K_1(u)$ are the modified Bessel functions, $z = \epsilon/\beta E$, where E is the total energy of the nucleon and ϵ is the energy of the virtual π-meson.* The spectra of $\pi^{\pm}$-mesons accompanying the proton and neutron, respectively, are equal to $Q^+ = Q^- = 2Q^0$.

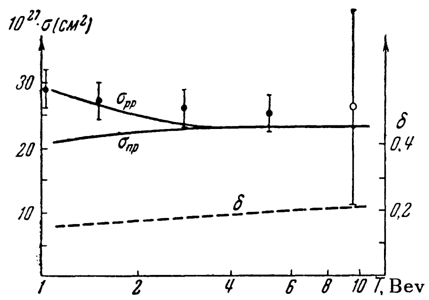
The effective cross sections for production of mesons and the relative energy losses of the fast nucleon in the interaction of its cloud with the core of the stationary nucleon [(π,K)-interaction] are equal, respectively, to[2]

$$\sigma_1 = g^2\frac{m}{M}I_1; \quad I_1 = \frac{1}{\beta}\int_0^{z_{max}}[\sigma^{\pm}(\beta Ez)\,Q^{\pm}(r, z) + \sigma^0(\beta Ez)\,Q^0(r, z)]\,dz,$$

$$\delta_1 = \frac{\Delta E}{E} = \frac{I^2}{I_1}; \quad I_2 = \int_0^{z_{max}}[\sigma^{\pm}(\beta Ez)\,Q^{\pm}(r, z) + \sigma^0(\beta Ez)\,Q^0(r, z)]\,z\,dz,$$

where $\sigma^{+,-,0}(\epsilon)$ with different indices are the total cross sections for scattering of the corresponding π-meson by the nucleon (proton or neutron) where, corresponding to the hypothesis of charge independence, $\sigma^0(\epsilon) = \frac{1}{2}[\sigma^+(\epsilon) + \sigma^-(\epsilon)]$ and $\sigma^+(\epsilon)$ and $\sigma^-(\epsilon)$ are taken from experiment.[4] The use of the experimental cross section for $\sigma_{\pi K}(\epsilon)$ is possible only if the (π,π)-interaction of the nucleon clouds with each

*The cut-off of the meson spectrum $z_{max} = \epsilon_{max}/\beta E$, where $\epsilon_{max} = E - \sqrt{(E + Mc^2)(Mc^2/2)}$ corresponds to the loss by the fast nucleon losing all its kinetic energy in the center-of-mass system of the colliding nucleons.



Relative energy losses δ and effective cross sections for meson production in the periphery collisions of nucleons: σ_{pp} — proton with proton; σ_{np} — neutron with proton. Experimental points are taken from Ref. 6.

other[1] is assumed small which, it appears, is valid for nucleons of energy $E \leq 10$ Bev, since the interaction cross section of such nucleons $\sigma_{NN} \approx 30 \times 10^{-27}\,cm^2 < \pi(2R)^2$.

Secondly, the interaction of the core of the fast nucleon with the cloud of the stationary one[3] by (K, π) – interaction was take into account. In the rest system of the fast nucleon this interaction occurs as (π, K) – interaction with cross section σ_1. Here the relative energy losses of the fast nucleon, expressed in the laboratory system, are made up of the losses $\delta_2^{\pi} \approx \gamma(1-\beta)\delta_1 \approx \delta_1/2\gamma$ in the production of π-mesons and $\delta_2^N \approx \delta_1^2/2\gamma(1-\delta_1)$ in nucleon recoil.

Since the meson field functions employed correspond to the exchange of one π-meson by the interacting nucleons, the cross sections for production of π-mesons in both processes are added together, and the relative energy losses are averaged

$$\sigma = 2\sigma_1; \quad \delta = (\delta_1/2)\,[1 + 1/2\gamma\,(1-\delta_1)].$$

The best agreement with experiment is obtained for a radius of the nuclear core $r = \hbar/m_K c \approx 2\hbar/Mc$ and a coupling constant $g^2 = 15$ (see figure). Here the cross section for central collision of the nucleons (with impact parameter ($b \leq r$) $\delta_{KK} \approx \pi r^2 = 5.6 \times 10^{27}\,cm^2$ constitutes about 20% of the total cross section for inelastic collisions, which coincides with the experimental estimate of Smorodin and others.[5] The relative energy losses of the fast nucleon in the periphery collisions also agrees with experiment.[5] It is essential that they are completely independent of the magnitude of the coupling constant.

In conclusion I should like to express deep gratitude to Prof. D. I. Blokhintsev for valuable advice and interest in this work.

[1] D. I. Blokhintsev, CERN Symposium, Geneva (1956).

[2] W. Heitler and H. W. Peng, Proc. Roy. Irish Acad. **49A**, 101 (1943).

[3] W. Heitler, Proc. Roy. Irish Acad. **50A**, 155 (1945).

[4] S. I. Lindenbaum and L.C.L. Yuan, Phys. Rev. **100**, 306 (1955); Cool, Piccioni, and Clark, Phys. Rev. **103**, 1082 (1956).

[5] Iu. A. Smorodin et al., Report at Third All-Soviet Conference on Cosmic Rays (1954).

[6] Proceedings of the Sixth Rochester Conference (1956); M. M. Dubrovin, Diploma Thesis, Moscow State University (1955).

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REMARKS ON ELASTIC SCATTERING OF RELATIVISTIC PARTICLES IN MATTER IN THE STEADY STATE

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LET us consider a steady stream of some type α of positive-rest mass particles scattering in a substance by means only of elastic collisions. These particles are unstable and can be absorbed by the substance. Ordinarily the velocities of the particles comprising the substance are much less than those of the particles of type α. Let us therefore assume that the particles of matter are at rest. Under these