EXPERIMENTAL EVIDENCE OF THE DECREASE OF KINETIC ENERGY OF HADRONS IN PASSING THROUGH ATOMIC NUCLEI

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ABSTRACT

Hadrons with kinetic energies higher than the pion production threshold lose their kinetic energies monotonically in traversing atomic nuclei, due to the strong interactions in nuclear matter. This phenomenon is a crude analogy to the energy loss of charged particles in their passage through materials. Experimental evidence is presented.

1. Introduction

We have observed, in the 26 and 180 litre xenon bubble chambers that GeV pions can be deflected or absorbed in nuclei without causing particle production, without causing pion production in particular, when are falling on layers of nuclear matter thick enough, Strugalski Z. and Pluta J. (1974), Strugalski Z., Pawlak T., and Pluta J. (1982); the deflection or absorption is always accompanied by intensive emission of nucleons with kinetic energies from about 20 to about 400 MeV.

The energy and angular distributions of the protons in such deflected and stopped events are the same, and they are identical with the distributions of protons in collisions with particle production as well. It is remarkable and leads to the opinion that it is reasonable to think that hadrons lose their kinetic energies, in traversing nuclear matter, by causing nucleon emission.

The subject matter in this paper is to present shortly our results of experimental investigations of degradation of hadron energy through nuclei.

2. Experimental Evidence

We found experimentally that the number n_N of emitted nucleons which accompany the passage of a hadron through a nucleus along a path λ fm equals the number of nucleons contained within the volume $v = \pi D_o^2 \lambda$ fm^3 centered on λ in the target nucleus:

$$n_N = \pi D_o^2 \langle \rho \rangle \lambda , \qquad (1)$$

where $\langle \rho \rangle$ nucleons/fm^3 is mean density of nucleons in the target nucleus along λ, D_o is approximately as large as the nucleon diameter, Strugalski Z. (1978,1979), Pluta J. and Strugalski Z. (1985).

Relation (1) may be rewritten i a more convenient form:

$$n_N = \lambda S \qquad (2)$$

if the path length λ is expressed in nucleons per the area S, and $S = \pi D_o^2$; the number n_p of the emitted protons is:

$$n_p = \lambda S \frac{Z}{A} = \lambda' S \qquad (3)$$

where λ' is in protons per S, Z and A are the charge and mass numbers of the target nucleus.

The simplest observable effects which provide crucial evidence and support for formulas (1) - (3) are: a) At energies high enough, higher than a few GeV, the mean num - ber $\langle n_p \rangle$ of emitted protons in the deflected events is con stant and almost equals $\langle \lambda' \rangle$ S, where $\langle \lambda' \rangle$ is the mean thi ckness of the target nucleus in protons/S. b) At some pro - jectile energy, definite for a given incident hadron and a given target nucleus, the distribution of multiplicities of protons emitted in the stopped events is symmetrical and its maximum lies at the multiplicity n_p as large as D S, where D is the diameter of the target nucleus in protons/S. c) The probability of an appearance of the stopped events, in collisions of a given hadron with a given nucleus, decre ases with the increase of the incident hadron energy; at e- nergies high enough, the stopped events do not appear at all, only the deflected events present themselves in some portion of the collision events, Strugalski Z., Pawlak T. , Pluta J. (1984).

An analysis in details of the experimental facts led to the conclusion that: A hadron of kinetic energy E_h lar- ger than the pion production threshold loses its kinetic e- nergy in passing through nuclear matter; the fraction ΔE_h of the energy lost on the path length λ nucleons/s is:

$$\Delta E_h = \epsilon_h \cdot \lambda \qquad (4)$$

where ϵ_h MeV/(nucleon/S) is the measurable coefficient which depends on the hadron identity - for pions $\epsilon_h = \epsilon_\pi \approx 180$ MeV/(nucleon/S), for protons $\epsilon_h = \epsilon_p \approx 360$ MeV/(nucleon/S), Strugalski Z. (19~3).

In support for this conclusion, some additional experimental facts of the crucial value may be adduced: a) The mean number $\langle n_p \rangle$ of emitted protons in the stopped events is quantitatively predictable by simple relation

$$n_p = (E_h / \epsilon_h) \cdot S \qquad (5)$$

which is valid for such values of E_h when $(E_h/\epsilon_h)\, S \leq DS$ where D in nucleons/S is the target nucleus diameter times Z/A, Strugalski Z. (1983). b) The mean multiplicity $\langle n_p \rangle$ of emitted protons is energy-dependent at the incident hadron energies $E_h \leq D\,\epsilon_h$, and the energy-dependence is predictable quantitatively if formulas (3) and (4) are used for a given target nucleus and for a given incident hadron, Strugalski Z. (1984). c) Indirectly, the degradation of the incident hadron energy manifests itself in observed degradation of the kinetic energy and of the momenta of produced pions with the increase of the nuclear matter layer thickness $n_p = \lambda S$ the incident hadron of a given kinetic energy interacted with, as it is shown in Fig..

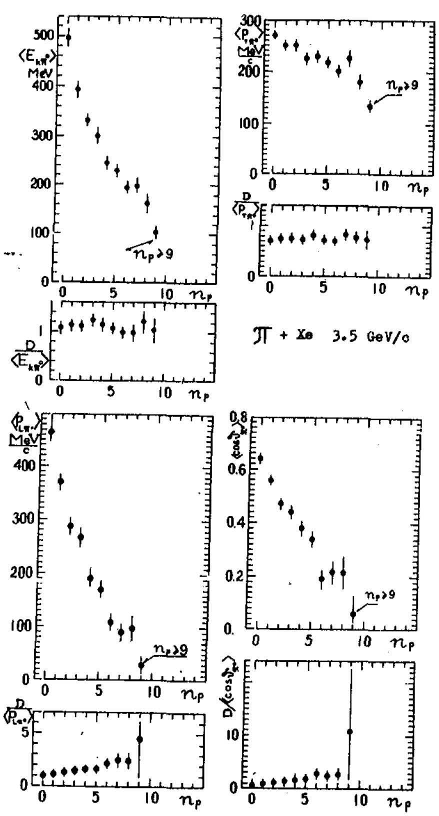

Fig. Mean kinetic energy $\langle E_{k\pi^o} \rangle$, mean longitudinal momentum $\langle P_{L\pi^o} \rangle$, mean transverse momentum $\langle P_{T\pi^o} \rangle$ and mean cosine of the pion' emission angle $\langle \cos\theta_{\pi^o} \rangle$ of neutral pions produced in pion-xenon nucleus collisions at 3.5 GeV/c momentum, in dependence on the multiplicity n_p of emitted protons; the multiplicity n_p is connected with the nuclear matter layer thickness λ the incident hadron interacted with as: $n_p = \lambda S$, where $S = \pi D_o^2 \approx 10$ fm^2 and D_o is the diameter of the nucleon. D/< > are the normalized dispersions of corresponding quantities.

3. Conclusions

It should be concluded that, in sudying hadron-nucleus collisions, we have met a phenomenon which may be regarded as a crude analogy to the phenomenon consisting in the energy loss of a charged particle in materials; simi larly, hadrons lose their energies in traversing nuclear matter. But, the newly observed energy loss of hadrons is due to the strong interactions of hadrons with nuclear matter.

In many cases, when particle-producing reactions occur, the nucleon emission and therefore the incident hadron energy loss, due to this emission, is going in advance of the particle-producing reaction; the incident hadron covers firstly some path in the target nucleus without particle-producing reaction and then it causes this reaction in the nucleus; in many cases it may happen on the end of the hadron path in the target nucleus.

The effects caused by the hadron energy loss are observed clearly when the incident hadron energy is not larger than $\epsilon_h D$, where ϵ_h is in GeV/(nucleons/S) and D in nucleons/S is the target nucleus diameter.

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