SCATTERING AND STOPPING OF HADRONS IN NUCLEAR MATTER

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ABSTRACT

We have observed, in the 180 litre xenon bubble
chamber, that when hadrons with kinetic energy
higher than the pion production threshold fall
on a layer of nuclear matter - on an atomic nuc
leus in other words - in many cases they can
pass through it without causing particle produc
tion but they are deflected through some deflec
tion angles; if the energy is lower than a few
GeV and the nuclear matter layer is thick eno -
ugh, the hadrons can be stopped in it. The amo-
unt of the deflection at a given incident hadron
energy varies with the way the hadron strikes
the atomic nucleus; the probability of the occur
rence of stopping depends on the incident hadr-
on identity and energy, and on the way the had-
ron passed through the nucleus, as well.

1. Introduction

Almost 75 years ago H. Geiger and E. Marsden, two of
E. Rutherford students, directed a beam of alpha particles
onto a thin foil of gold. With a screen of fluorescent ma-
terial they then counted the number of particles scattered
at various angles as a result of encounters with the gold
atoms, Geiger H. and Marsden E. (1909). It was E. Ruther -
ford who supplied the interpretation of findings obtained
in the experiments; in the interpretation he had also int-
roduced a method whose importance is indiminished today,
Rutherford E. (1911).
I would like to communicate, in this paper, that now
it is possible to perform similar experiments in which in-
stead of the metallic foil the "foil" of nuclear matter of
definite thickness will be used, and the projectiles emp -
loyed will be the strongly interacting particles, pions or
protons for example, raised to high energy by an accelera-
tor.
In contrast to the Geiger-Marsden-Rutherford experi -
ments, where the scattered alpha particles have been obser
ved only, in the experiments with nuclear matter foils   an

emission of nucleons from the "foil" is observed always and three general kinds of events occur against the background of this emission: a) Events in which the projectile is deflected only, without causing the particle production, Strugalski Z., Pluta J. (1974), Strugalski Z., Pawlak T., Pluta J. (1982). b) Events in which incident hadron is stopped completely without causing the particle production, Strugalski Z., Pluta J. (1974), Strugalski Z., Pawlak T., Pluta J. (1982). c) Events in which particles are produced.

The emitted nucleons are of kinetic energy from about 20 up to about 400 MeV, as it has been seen experimentally, Strugalski Z., Pawlak T., Pluta J. (1982).

2. A Massive Atomic Nucleus as the "Foil" of Nuclear Matter

Any of the atomic nuclei massive enough can be regarded as the lens-shaped "foil" or "slab" of nuclear matter, if the thickness $\lambda(b)$ of the nuclear matter layer at any distance b from the nucleus center is measured in units of number of nucleons per some area S fm^2, like the Earth atmosphere thickness is expressible usually in grams/cm^2, Strugalski Z. and Pawlak T. (1981).

Such a "slab" should be characterized generally by the maximum thickness of the nuclear matter layer - λ_{max}, the mean thickness $<\lambda>$, and the thickness $\lambda(b)$ at any distance b from the nucleus center; the values of these quantities for many nuclei can be found in one of our works, Strugalski Z. and Pawlak T. (1981).

Results of experimental studies of the nucleon emission process in hadron-nucleus collisions, Strugalski Z., Pawlak T., Pluta J. (1982), prompt to us the procedure by which we can determine the quantity $\lambda(b)$; it has been concluded that relation exists between the multiplicity of the emitted nucleons n_N and $\lambda(b)$ ·expressed in nucleons per S $\approx$ 10 fm^2:

$$\lambda(b) \cdot S = n_N \qquad (1)$$

When the multiplicity n_p of the emitted protons is measured only, relation (1) should be rewritten:

$$\lambda(b) \cdot S \cdot \frac{Z}{A} = n_p \qquad (1')$$

where Z and A are the charge and mass numbers of the target nucleus, and S = πD_o^2 fm^2, and D_o is the nucleon diameter, Strugalski Z. (1985).

3. Experiment

Experimental information about pion deflection in its passage through nuclear matter was obtained by means of the 26 and 180 litre xenon bubble chambers, Kanarek T.I. et al. (1959), Kusnetsov E.V. et al. (1970). The small chamber was exposed to the pion beam from the synchrophasotron of the Joint Institute for Nuclear Research at Dubna, 2.34 GeV/c;

the larger chamber was exposed to the beam of negatively charged pions of 3.5 GeV/c momentum from the accelerator of the Institute of Theoretical and Experimental Physics in Moscow. The massive nucleus of the xenon 131 atom was used as the nuclear matter slab, Strugalski Z., Pawlak T., Pluta J. (1982).

4. Results

It has been found experimentally that: a) A definite simple relation exists between the incident pion deflection angle Θ_π and the average multiplicity n_p of emitted protons; in other words – a definite simple relation exists between the pion deflection angle Θ_π and the thickness in protons/S of the nuclear matter layer traversed by this pion. b) The mean value of the cosine of the pion deflection angle, $<\cos\Theta_\pi>$, depends definitely and simply on the number n_p of emitted protons; in other words, the deflection angle of the incident pion increases in a definite manner with increasing the thickness λ of the nuclear matter layer traversed by the pion.

The analysis of experimental data, Strugalski Z.(1982), leads to the recognition: a) The observed deflection angle distribution is a result of two sorts of hadron deflections in nuclear matter – one is due to a multiple scattering from objects with the rest mass as large approximately as the pion rest mass is, the second one is due to a single scattering from massive objects with the rest mass as large as the rest mass of the nucleon. b) The multiple scattering may be described quantitatively by simple formula with a simple physical meaning, Strugalski Z. (1982):

$$< \Theta_\pi >^2 \ = <\vartheta_\pi>^2 \cdot \lambda \qquad\qquad (2)$$

where $<\Theta_\pi>$ is the mean deflection angle occurred on the thickness λ nucleons/S, $<\vartheta>$ is the mean deflection angle occurred on the thickness $\varkappa = 1$ nucleon/S. Formula (2) is similar to the Rutherfords formula, Rutherford E. (1911).

When the incident hadron energy is smaller than a few GeV, events occur in which the hadron is stopped, Strugalski Z., Pluta J. (1974), Strugalski Z., Pawlak T., Pluta J. (1982). In pion-xenon nucleus collisions, the "stopped" events occur when the incident pion energy is smaller than about 4 GeV.

Simple relation exists between the range R_h of the hadron in nuclear matter and its kinetic energy E_h, Strugalski Z. (1983):

$$R_h \ = \frac{E_h}{\epsilon_h} \qquad\qquad (3)$$

where R_h is in nucleons/S, E_h in GeV, ϵ_h is experimentally determined coefficient in GeV/(nucleon/S) –for pions

$\epsilon_h = \epsilon_\pi \approx 0.18$ GeV/(nucleon/S) and for protons $\epsilon_h = \epsilon_p \approx$ 0.36 GeV/(nucleon/S).

5. Conclusions

Hadron deflections and hadron stoppings were observed experimentally. These phenomena are observed clearly at energies smaller than a few GeV. Many effects occur due to these phenomena - energy dependence of the mean multiplicity $\langle n_N \rangle$ of the emitted nucleons, for example. At energies high enough these phenomena do not influence on the observed outcomes in h-A collisions.

It should be noted that the energy spectra, the longitudinal and transverse momentum distributions of the emitted nucleons do not depend on the hadron deflection angle, at angles not larger than about 60 degrees; they are independent of the hadron range in nuclear matter as well.

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