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THE MEAN FREE PATHS FOR HIGH ENERGY HADRON COLLISIONS IN NUCLEAR MATTER

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1. INTRODUCTION

One of the main concepts which is useful in hadron-nucleus collision analysis is that of the mean free path λ; it always has a subscript denoting a particular process. The mean free path for a process is related to the cross section σ for that process; this relation is expressed in section 2. The cross section is a measurable quantity and,therefore,the mean free path is a measurable quantity too. The intelligent use of experimental data on cross sections, and hence of mean free paths, requires understanding of the methods and conditions used for their measurement, of the measurement results, and of the limitations of the methods and conditions.

It is not obvious a priori that the cross section for a process in hadron collisions with free nucleon is the same as that for hadron collisions with nucleon inside a target nucleus.The question: "What is the cross section or the mean free path for a process in hadron collisions with nucleon inside the atomic nucleus, e.g., in nuclear matter?" must find its answer primarily in experiment, although it must also be confronted with additional considerations of a theoretical or a philosophical nature.

The problem to be discussed in this paper is concerned with the methods of experimental determinations of the mean free paths for various processes in hadron collisions with objects inside target nuclei, and is also concerned with explanation of the relations between cross sections for hadron collisions with free nucleons and corresponding mean free paths in atomic nuclei.

2. HEURISTIC CONSIDERATIONS AND BASIC DEFINITIONS

To study hadron-nucleon collisions in detail, it is necessary to have a quantitative measure of the probability of a given collision. This quantity must be one of which can be measured experimentally and calculated in such a way that the theoretical and experimental values can be compared readily. The quantity that is most often used for this purpose is the cross section /1-3/ of a hadron for particular sort of collisions. If the nucleons are considered as spheres of radius R fm and the incident particles as point projectiles,then the target area, or cross section σ, of each nucleon is given by $\sigma = \pi R^2$ fm^2. A spacially limited sample of spherical shape of some number of nucleons distributed in a definite manner, met usually in nature as the atomic nucleus, we will call nuclear matter. A particle which passes normally through a thin sheet of nuclear matter of area s containing n nucleons has a probability $n\sigma/s$ of colliding with a nucleon provided that there is no "overlapping" of the nucleons or, in other words, that $n\sigma/s$ is small. The quantity n/s, which is the number of nucleons per cm^2 or the surface density of nucleons, can be expressed as ρt, where ρ is the number of nucleons per cm^3 and t is the thickness of the sheet. For a beam containing N incident particles per cm^3 moving with velocity v cm/s the number of particles passing through the sheet is Nv per cm^2 per second, and the collision rate expressed as collisions per cm^2 per second is equal to $nvN\sigma/s = Nv\sigma\rho t$; the collision cross section is then σ = (collisions per cm^2 per second)/$Nv\rho t$. The quantity Nv, which is the number of particles in the incident beam crossing one cm^2 of area each second, is called the particle flux. The term "collision" can be replaced by the appropriate term for any particle-nucleon reaction. For example, σ_s may be the cross section for scattering of a given kind of particle and may consist of two parts: σ_e - the cross section for elastic scattering, and σ_i - the cross section for inelastic scattering.

Although it is convenient and simple to introduce the cross section as a "target area" and to get a rough idea of its magnitude by calculating the geometrical cross section, this procedure must be taken only as some heuristic one. The experimental meaning of the cross section comes from its use as a measure of the number of collision events which occur under a given set of experimental conditions; values of these cross sections often differ greatly from the values of the geometrical cross sections. Under certain special conditions scattering cross sections and geometrical cross sections can be related directly, and the measured values of the scattering cross sections are then used to determine the size and the structure of nucleons. We use later 1 fm = 10^{-13} cm as the length unit.

The mean free path λ for a process is related to the cross section for that process:

$$\lambda \text{ fm} = \frac{1}{\rho\sigma}. \tag{1}$$

The scattering mean free path λ_s is given by λ_s fm = $1/\rho\cdot\sigma_s$, and is the path length travelled, on the average, in nuclear matter by the particle before being scattered. Relation (1) can be expressed as

$$\lambda\,(\text{fm})\ \rho\,(\text{nucleons/fm}^3) = \lambda\,(\text{nucleons/fm}^2) = \frac{1}{\sigma}, \tag{1'}$$

where λ nucleons/fm^2 is the mean free path expressed in units convenient in use when the nuclear matter density ρ nucleons/fm^3 varies markedly, as it is in fact when nuclear matter sheets at various distances from the nucleus center are in use[4-7].

Let us consider a particle flux I_0, incident on a layer of the thickness dt fm of nuclear matter. The differential intensity loss dI due to interactions is given by $dI = -I_0\sigma\rho dt$, and so $I = I_0 e^{-\sigma\rho t} = I_0 e^{-(t/1/\sigma\cdot\rho)} = I_0 e^{-t/\lambda}$. But, λ fm can be replaced by the λ in nucleons per fm^2, and t fm can be replaced by t in nucleons per fm^2 as well, and:

$$I = I_0 e^{-\frac{t}{\lambda}}. \tag{2}$$

Cross sections σ for particle-nucleon reactions are obtained in experiments when free nucleons are bombarded by various particles, and can be found, for example, in the well-known CERN-HERA tables[8]. The thickness t nucleons/fm^2 of a thin sheet of nuclear matter, on which a projectile particle falls on, is known, or can be known in principle, experimentally[7,9]. The thickness t, measured in nucleons per fm^2, of a layer of nuclear matter which a hadron falls on in almost any of hadron-nucleus collisions is known experimentally as well[9,10]; this thickness is determined by the number of emitted nucleons n_N of kinetic energy from about 20 to about 400 MeV or, in particular, by the number n_p of emitted protons only of the same kinetic energy, because almost all (more than 90%) of the hadron-nucleus collisions obey the relation

$$n_N = \pi \langle\rho\rangle D_0^2 t \tag{3}$$

as it is known experimentally[9,11-13], where D_0 is the nucleon diameter. Because the ratio between the proton Z and neutron A - Z numbers can be treated as constant inside atomic nuclei[7,14,15] being of the order of Z/A, formula (3) can be written for observed fast protons only:

$$n_p = \pi \langle\rho\rangle D_0^2 t \frac{Z}{A}. \tag{3'}$$

Let us consider now a sample of any type collisions of a definite hadron of definite kinetic energy with a definite target nucleus resting in the laboratory system. The sample we should think to be unlimited[16] but in practice it is limited sample large enough. This sample obtained in scanning of chamber photographs we call later the total sample of hadron-nucleus collisions. What is the common feature of the sample obtained in experiments performed using any technique - bubble chambers, nuclear photoemulsions, electronic arrangements, when one can treate it statistically as practically unlimited one? One common feature can be recognized, and we think it crucial: in games of chance in the collision processes we find events repeating themselves again and again. They are mass phenomena or repeative events; this unlimited repetition, this "mass character" is typically present in the case of all the events under studies.

The above discussion can be applied to any subsample of hadron-nucleus collision events, containing collision events of a specified category, for example - for the subsample of the collision events without particle production, if this subsample can be treated statistically as practically unlimited collection of appropriate collision events. But, we are confronted, in doing it, with the necessity of discussing populations of which we cannot examine every number. In such case the best we can do is to examine a limited number of individuals, called a sample, and hope that they will tell us, with reasonable trustworthiness, as much as we want to know about the population from which they come. The process of forming a sample is strict procedure described in the theory of statistics [16] and we will follow here this procedure.

It is of importance to emphasize that hadron-nucleus collisions in a sample under study are usually collisions of the hadron with identical target nuclei. In fact, regardless that each of the target nuclei is more or less destroyed in the collision, in any of collision events identical projectile falls on identical target nucleus. But, any target nucleus can be treated as a lens-shaped "slab" of nuclear matter [9,10]. Such "slab" should be characterized by the nuclear matter layer thickness t at any distance from the nuclear centre, by maximum thickness t_{max} of the nuclear matter layer, and by average thickness $\langle t \rangle$ of the "slab"; it is convenient to express these quantities in units of the number of nucleons n_N, or protons n_p, per the area $S = \pi D_0^2 = 10.292$ fm^2, where D_0 is the nucleon diameter.

In result of the above discussion, we can conclude that a sample of hadron-nucleus collision events can be treated as a collision of a beam of hadrons h with a layer of nuclear matter of the average thickness $\langle t \rangle$; in any of almost all of the collision events it is possible to determine which was the thickness of nuclear matter layer the incident hadron falled on. The advantage of using this treatment lies in the possibility of considering any hadron-nucleus collision experiment as an hadron absorption experiment [1,2], and of distinguishing collision events in which the incident hadron falls on definite nuclear matter layer thickness t. If hadron-nucleus collisions occur inside a track-sensitive medium, as it is the case in photonuclear emulsions or in heavy liquid bubble chambers, some of effects caused by incident hadrons in collisions with target nuclei can be visible and may be characterized by measurable quantities. In particular, the number N_0 of collision events in a sample can be treated as the incident hadron beam intensity I_0 in formula (2), and the number N_1 of events in a subsample containing the events in which a given process did not occur can be treated as the intensity I in formula (2). When t in formula (2) is known, λ can be determined simply and compared with that which follows from formula (1), if cross section for appropriate collision of the hadron with free nucleon is used in this formula.

It was not found necessary, in the light of the above-presented considerations, to demonstrate in more detail that the relation between the mean free path λ for a hadron collision with free nucleon expressed by formula (1) and the mean free path λ from formula (2) for this hadron collision in nuclear matter can be proved experimentally.

We try to perform it and we describe our results in the next section.

3. EXPERIMENTAL DETERMINATION OF THE MEAN FREE PATHS FOR HADRON COLLISIONS IN NUCLEAR MATTER

Let us observe a sample of pion-xenon nucleus collision events, at 3.5 GeV/c momentum of incident pions. If we distinct subsamples of events with definite numbers $n_p = 0,1,2,\ldots,8$ of emitted fast protons, we obtain subsamples of collisions in which the incident pion falled on the nuclear matter layers of the thicknesses $t = n_p$ protons per the area $S = \pi D_0^2$ fm^2, as it follows from formulas (3) and (3'); the maximum thickness for xenon nucleus is 8 protons/S.

In any of the subsample of events with definite n_p, or in the subsample corresponding to the incident pion beam falled on the nuclear matter layer of the thickness $t = n_p$ protons/S, two new subsamples can be distinct: subsample of collision events with a given n_p in which particle production occurs and subsample with the same n_p but in which particle production does not occur. The number of events in both the subsamples together, with definite multiplicity n_p of emitted protons, corresponds to the number I_0 of incident particles falling on a slab of nuclear matter of the thickness t, formula (2); the number of events without particle production in our subsample corresponds to the number I of projectiles coming out without causing particle production after passing the nuclear matter layer of the thickness t, formula (2).

To any definite proton multiplicity n_p in observed collision events corresponds a definite thickness t protons/S when a given target nucleus A is bombarded. Thus, for any target nucleus a definite average thickness <t> of nuclear matter layer can be ascribed. In the case under discussion, ^{131}Xe nuclei were used [17] for which <t> = 3.51 protons/S, as it has been determined [9].

We can determine, then, the average mean free path λ_i protons/S for the particle producing collision, using formula (2), where I = 848±29 is the number of events without particle production, when I_0 = 6301±79 pions fall on the nuclear matter layer of the mean thickness <t> protons per S.

We can determine as well λ_i protons/S using formula (1´) and the known value for the inelastic pion-nucleon collision cross section σ_i; the value for σ_i is taken from CERN-HERA tables [8] for pion-proton collisions and it is regarded it to be the same value for pion-neutron, too. From the tables we take σ_i = 21.60±1.10 mbarns = 0.21 S/nucleon. Results are given in table 1.

It can be concluded that the average value of the mean free path obtained from our experiment is almost the same as the mean free path obtained from our calculation. But, it is only for the average value of the mean free path. It is not the case, when we determine experimentally mean free path for pion-nucleon inelastic collision using subsamples of events when pions fall on the nuclear matter layer of a definite thickness $t = n_p$ protons/S.

In fact, we can determine experimentally the mean free path λ_i protons/S using subsamples of pion-xenon nucleus collision events at 3.5 GeV/c momentum with definite multiplicities n_p of emitted fast protons, using formula (2). Subsamples with n_p = 1,2,3...,8 protons are applied, when the relation $t = n_p$ is mostly accurate [18]. In any subsample we distinct the number I_0 of incident pions and the number I of events in which the incident pion did not cause the particle production. Results are listed in table 2. The values of the mean free path λ_i protons/S were obtained using formula (2), with I_0, I and t from our experiment. It is seen from table - that the measured values for the mean free path λ_i depend on the thickness t of the nuclear matter layer, which is meaningless.

The cause for this strange result can be: a) The numbers n_p of emitted fast protons do not correspond strictly the thicknesses t of nuclear matter layers; in other words formula (3´) is wrong, although it is little probable because this formula has been proved in our former experiments [19–24]. b) The beam pions collide in nuclear matter with constituents of nucleons, not with nucleons as a whole. c) Some of observed collision events, accounted for the events in which particle production occurs are in fact the events without particle production; for example, two-pion events in the final state are qualified as events with particle production but, in fact, they may be events in which incident pion collided inside nuclear matter with an object of the mass as large as the pion mass; experimental evidences are [25,26] that incident pions may collide in nuclear matter with objects of the rest mass as large as the pion rest mass.

In order to reject the assumption a), let us measure the mean free path λ_s for incident pion deflection through deflection angles [26] larger than about 30 degrees. It was shown [26,27], in studying the incident pion deflection process, in pion-xenon nucleus collision events without particle production at 3.5 GeV/c momentum, that two classes of pion-nucleus collisions can be sharply distinguished: the collisions leading to projectile deflection through small deflection angles $\theta_\pi \lesssim 30$ degrees, and the collisions leading to projectile deflection through large angles $180 \lesssim \theta_\pi \lesssim 30$ degrees. For experimental determination of the mean free path λ_s, we use the sample of pion-xenon nucleus collisions at 2.34 and 3.5 GeV/c momentum without particle production in which the incident pion is deflected only with an accompaniment by n_p = 0,1,2,...,8 emitted fast protons. In formula (2) we put as I_0 the total number of events under study and as I the number of events with the projectile deflection angles less than or equal to 30 degrees. Corresponding data are presented in table 3, where the values of the measured mean free paths λ_s are given at various proton multiplicities n_p.

The value of the mean free path λ_s determined experimentally does not fluctuate by much, it lies practically within the statistical errors; in average, it is λ_s = 5.28±0.62 protons/S. It is evident, therefore, that the assumption a) may be rejected; the proton multiplicities n_p reflect satisfactorily the thicknesses t of the nuclear matter layers, if expressed in nucleons/S, or protons/S, units.

Let us consider now the assumption b). The delailed analysis of the pion deflection angle θ_π distribution $N(\theta_\pi)$ in the subsample of events in which incident pion is deflected only through an angle θ_π, without causing the particle production, with an accompaniment by some number n_p = 0,1,2,... of fast nucleons emitted leads to the conclusion that [26]: 1) The observed deflection angle distribution is a result of two sorts of deflections - one is due to a multiple scattering from objects of the rest mass as large approximately as the pion rest mass, the second is due to a single scattering from massive objects in nuclear matter of the rest mass approximately as large as the nucleon rest mass. 2) The result of the multiple scattering $\langle\theta_\pi\rangle$ is described by simple formula $\langle\Theta_\pi\rangle = \langle\theta_\pi\rangle t^{1/2}$, where $\langle\theta_\pi\rangle$ is the value of the mean deflection angle per one nucleon and t nucleons/S is the path length of the pion in nuclear matter; the value of the $\langle\theta_\pi\rangle$ corresponds kinematically to the $\pi-\pi$ collision /25/.

From the information, about the pion deflection phemomenon, given above, it cannot be excluded that some 2π-pion-nucleus collision events cannot be the pion-production-events; they may appear in result of $\pi-\pi$ collisions. But the 2π-events are treated usually as events with particle production, and therefore the assumption c) is not meaningless. We try to show that in fact it is the case. As the starting point we take into account that the ejection directions of pairs of secondary pions being the result of the $\pi-\pi$ scattering should be coplanar with the direction of motion of the incident pion.

We would like firstly to estimate the rate of two-pion collisions which can be treated as the events without particle production in the subsample of all two-pion events with any number $n_p = 0,1,2,\ldots$ of observed fast emitted protons accompanying any of the rgistered collision events with two pions in the final state. Let us, therefore, to select the subsample of the pion-xenon nucleus collision events with the number $n_{\pi^\pm_0} = 2$ of secondary pions of any electric charge and with the number $n_p = 0,1,2,\ldots$ of emitted fast protons from the sample of 6301 of the any-type pion-xenon nucleus collisions. Using this subsample, let us construct the distribution of the azimuth angles ϕ_π of one of secondary pions relatively to the plane containing the directions of motion of the incident pion and the direction of ejection of the second secondary pion, fig.1. Similar azimuth distribution of emission directions of the emitted fast protons, relatively to the pion ejection plane is shown in fig.2. Taking into account the properties of the proton azimuth angle distributions /28/, we can treate the distribution presented in fig.2 as an indication that some of the pairs of the pions, in the subsample of the two-pion events, appeared inside the target nucleus, but some of them outside it; the passage of a pion inside nuclear matter influence the direction of the fast proton emission /28/. But, it is known /22-24/ that particles, the pions as well, are produced via intermediate objects decaying after having left the target nucleus.

From the distribution presented in fig.1, one can estimate that in about 46% of the two-pion events the two directions of the secondary pion ejection and the direction of motion of the incident pion are coplanar. Owing to the properties of the proton angular distributions, we can state as well that the distribution presented in fig.2 supports this conclusion. Therefore, it cannot be excluded that these "coplanar" two-pion events are not the pion production events but pion-pion collision events in nuclear matter.

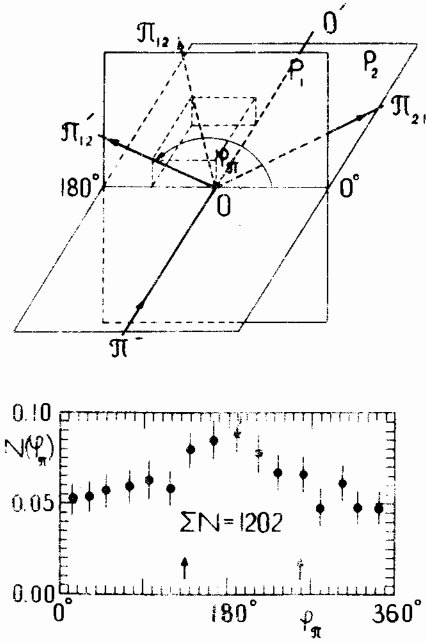

Fig.1. Azimuth ϕ_π distribution $N(\phi_\pi)$ for the emission direction of one of secondary pions π_{12} or π_{21}, in two-pion pion-xenon nucleus collisions at 3.5 GeV/c momentum with any number n_p of emitted fast protons, relatively to the emission plane of the second of secondary pions π_{21} or π_{12}. π^--o - incident pion direction of motion, π'_{12} - the projection of the direction of emission of the secondary pion π_{12} on the plane P_1 perpendicular to the incident pion direction of motion, P_2 - the emission plane of the secondary pion π_{21}. ΣN - number of events used in the distribution.

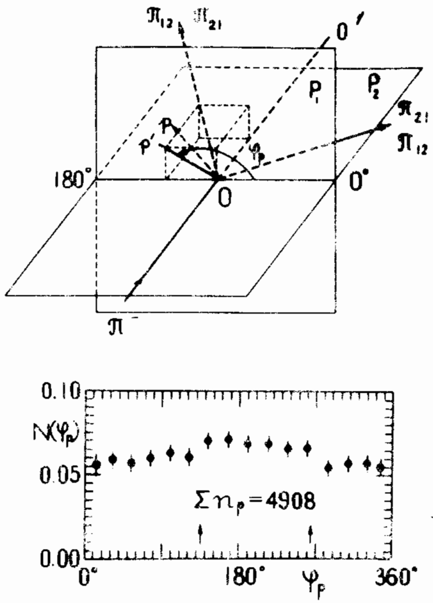

Fig.2. Azimuth ϕ_p distribution $N(\phi_p)$ for emission direction of an emitted fast proton p relatively to the emission plane of one of secondary pions π_{12} or π_{21}, in two-pion pion-xenon nucleus collision events at 3.5 GeV/c momentum. π^- - o′ - incident pion direction of motion, o - p emission direction of a proton, o - p′ - projection of the emission direction of a proton on the plane P_1 perpendicular to the incident pion direction of motion, P_2 - the emission plane of one of secondary pions π_{12} or π_{21}. Σn_p - number of protons used in the distribution.

Using the information about the number of pion-pion collision events, and regarding them as the events without particle production, one can determine the mean free path for one pion

Table 1

Results of the measurement and of the calculation of the mean free path λ_i for pion-nucleon collision in nuclear matter, at 3.5 GeV/c momentum

Mean free path protons/S	Calculated using formula (1´)	Measured using relation (2)
λ_i	1.96 ± 0.09	1.75 ± 0.05

Table 2

Results of the measurement of the mean free path λ_i for pion-nucleon inelastic collision in nuclear matter. Subsamples of events with various multiplicities $n_p = 1,2,3,\ldots,8$ of emitted fast protons are used, which corresponds to various thickness $t = 1,2,3,\ldots,8$ protons/S of the nuclear matter layers the incident pions fall on. I_0 - number of incident pions falling on the nuclear matter layer of a given thickness $t = n_p$ protons/S, I - number of events without particle production; I_0 and I are taken from experimental material used in our former works /17/.

$n_p = t$ protons/S	I_0	I	λ_i protons/S
1	1120 ± 33	137 ± 11	0.48 ± 0.02
2	902 ± 30	78 ± 9	0.82 ± 0.05
3	731 ± 27	53 ± 7	1.14 ± 0.08
4	598 ± 24	50 ± 7	1.61 ± 0.16
5	538 ± 23	47 ± 7	2.05 ± 0.17
6	417 ± 20	50 ± 7	2.83 ± 0.26
7	270 ± 16	46 ± 7	3.96 ± 0.50
8	200 ± 14	42 ± 6	5.13 ± 0.70

Table 3

Mean free path λ_s for the incident pion collision in nuclear matter leading to its deflection through the angle $\theta_\pi \geq 30$ degrees, determined using collision events of positively charged pions of $P_\pi = 2.34$ GeV/c momentum and negatively charged pions of $P_\pi = 3.5$ GeV/c momentum /27/ with $^{131}_{54}Xe$ nuclei, when particle production does not occur but the projectile undergoes the deflection only through any deflection angle with an accompaniment by any number $n_p = 0,1,2,\ldots,8$ of emitted fast protons. I_0 - number of events with a given proton multiplicity n_p; I - number of events with the proton multiplicity n_p in which projectile deflection angle $\theta_\pi < 30$ degrees; $t = n_p$ protons/S - the nuclear matter layer thickness; $S = \pi D_0^2 = 10.292\ fm^2$; D_0 - the diameter of the nucleon. Angular distribution of the deflected pions at 2.34 GeV/c momentum was obtained by K.Wosinska in Warsaw Technical University.

P_π GeV/c	$t = n_p$ protons/S	I_0	I	λ_s protons/S
2.34	1	128 ± 11	105 ± 10	5.05 ± 2.00
-"-	2	91 ± 9	62 ± 8	5.21 ± 2.10
-"-	3	49 ± 7	30 ± 6	6.11 ± 2.84
3.50	1	161 ± 13	133 ± 12	5.23 ± 2.00
-"-	2	87 ± 9	62 ± 8	5.90 ± 2.40
-"-	3	43 ± 7	25 ± 5	5.53 ± 2.53
-"-	4	48 ± 7	23 ± 5	5.44 ± 2.03
-"-	5	43 ± 7	14 ± 4	4.46 ± 1.60
-"-	6	46 ± 7	14 ± 4	5.04 ± 1.65
-"-	7	32 ± 6	9 ± 3	5.52 ± 2.09
-"-	8	29 ± 5	5 ± 2	4.55 ± 1.54

production in pion-nucleon collisions in nuclear matter. In fact, our subsample of the two-pion events contains $I_0 = 1202 \pm 27$ events and in them $I = 1202 \times 0.46 = 553 \pm 24$ pion-pion collision events; the remaining 649 events are the one-pion production events. Applying formula (2), where as the thickness t the value $\langle t \rangle$ = 3.51 protons/S is used [9], for the xenon nucleus one obtains: λ_π = 4.52±0.46 protons/S.

Let us estimate now the mean free path $\lambda_{s,\pi}$ for one pion production and large angle deflection process together, using the subsample of events with $n_\pi \le 2$. In this case I_0 = 2460±50, I = 1367±37 and $t = t$ = 3.51 protons/S. Formula (2) gives: $\lambda_{s,\pi}$ = 5.97±0.45 protons/S.

The most accurate determination of the λ_i, the mean free path for inelastic collisions leading to the particle production, is achieved when large enough thickness t of the nuclear matter layer is applied as an absorber. We use, therefore, the subsample of events with the number of emitted fast protons n_p = 8 and any number $n_{\pi^{\pm}}$ = 0,1,2,... of pions produced. The events from this subsample correspond to the pion-xenon nucleus collisions almost along the diameter of the target nucleus. From our experiment [17] we know that I_0 = 200±14 and I = 42±6, and t = 8 protons/S. In this case, formula (2) gives for the mean free path: λ_i = 5.13±0.70 protons/S.

The values for λ_s, λ_π, $\lambda_{s,\pi}$, λ_i, measured independently, are collected in table 4, for comparison.

One can see, from table 4, that at 3.5 GeV/c incident pion momentum the values of the λ_s, λ_π, $\lambda_{s,\pi}$ and λ_i are almost the same. In particular, the average value for the last three values, which can be treated as the mean free path for particle

Table 4

Values of the mean free paths for various pion collisions in nuclear matter, at 3.5 GeV/c momentum, expressed in units of protons/S. λ_s - mean free path for large angle deflection; λ_π - mean free path for pion collision in nuclear matter leading to one pion production; $\lambda_{s,\pi}$ - mean free path for pion collision leading to one pion production or large angle deflection; λ_i - mean free path for collision in nuclear matter leading to particle production.

Mean free path	Measured values, protons/S
λ_s	5.28±0.62
λ_π	4.52±0.46
$\lambda_{s,\pi}$	5.97±0.45
λ_i	5.13±0.70

production, is λ_i = 5.25±0.31 protons/S and the λ_s = 5.28±0.62 protons/S. These values can be expressed in units of nucleons per S: λ_s = 12.81±1.50 nucleons/S and λ_i = 12.74±0.75 nucleons/S. In units of nucleons per fm^2 these quantities are: λ_s = 1.24±0.15 nucleons/fm^2 and λ_i = 1.24±0.08 nucleons/fm^2.

The relation between the value of λ_i, determined by formula (1) using the data on cross section for inelastic collisions of pions with free nucleons [8] (table 1), and the value of λ_i determined experimentally is: k = 3.00±0.26. The formula for determination of λ_i from σ_i, taken from the tables [8], should be, instead of the formula (1):

$$\lambda_i = \frac{k}{\sigma_i}, \qquad (1'')$$

where k = 3.00±0.26, and λ_i and σ_i are in nucleons/fm^2 and fm^2/nucleon, correspondingly.

There are experimental indications [19-24,29] that this relation is valid for both - for the pion-nucleus and proton-nucleus collisions within wide projectile momentum value, from about 2 to about 1500 GeV/c; various quantities characterizing hadron-nucleus collision outcome, calculated using formulas in which the relation (1'') plays fundamental role, are in agreement with corresponding experimental data [19-24,29].

4. CONCLUSION

The mean free path λ_i for particle producing hadron collisions in nuclear matter, determined by means of formula (1), using the cross section for elementary hadron-nucleon collision, does not correspond to the mean free path determined experimentally. The correct relation between the cross section σ_i for elementary hadron-nucleon inelastic collision and corresponding mean free path λ_i in nuclear matter is given by formula (1''). Coefficient k in formula (1'') accounts for the display of the nucleon inner structure in hadron-nucleus collisions.

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Стругальский З. E1-83-563

Средние свободные пробеги для столкновений адронов высоких энергий в ядерной материи

Определены на опыте средние свободные пробеги пиона высокой энергии в ядерной материи до столкновения с использованием случаев взаимодействия пион-ксенон при 3,5 ГэВ/с. Выведена и широко обсуждается связь между свободным пробегом λ_i для неупругого столкновения адрона в ядерной материи и соответствующим эффективным сечением σ_i для неупругого столкновения этого адрона со свободным нуклоном. Эта связь следующая: $\lambda_i = k/\sigma_i$, где λ_i выражено в нуклонах на ферми^2 и σ_i - в ферми^2 на нуклон соответственно, $k = 3{,}00 \pm 0{,}26$ - коэффициент, учитывающий проявление структуры нуклона в столкновениях адрон-ядро.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1983

Strugalski Z. E1-83-563

The Mean Free Paths for High Energy Hadron Collisions in Nuclear Matter

The mean free paths for various collisions of high energy pion in nuclear matter are determined experimentally using pion-xenon nucleus collision events at 3.5 GeV/c momentum. The relation between the mean free path λ_i for hadron-nucleon particle producing collisions in nuclear matter and corresponding cross section σ_i for particle producing collisions of this hadron with free nucleon is derived and discussed. This relation is $\lambda_i = k/\sigma_i$, where λ_i is in nucleons per fm^2 and σ_i - in fm^2 per nucleon, correspondingly, $k = 3.00 \pm 0.26$ is a coefficient accounting for the display of the nucleon inner structure in hadron-nucleus collisions.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1983