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Z.Strugalski*

HADRON-NUCLEON INELASTIC COLLISION MEAN FREE PATH IN NUCLEAR MATTER

* On leave of absence from the Institute of Physics of the Warsaw Technical University, Warsaw, Poland.

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1. INTRODUCTION

In recent years a large amount of experimental data has accumulated, which gives information with regard to the interaction of high energy hadrons with nuclear matter. In presenting the data an important role plays the "average thickness", $\bar{\nu}$, of a nucleus seen by an incident hadron, which is conventionally measured in units of the mean free path for absorption of hadron h in the nucleus, i.e., $\bar{\nu}$ is considered as the average number of inelastic collisions h would make with nucleons in the nucleus if, following each collision, it remained as a single hadron h /1-6/. From the definition of $\bar{\nu}$ it follows that $\bar{\nu} = A\sigma_{hp\ in}/\sigma_{hA\ in}$, where A is the target nucleus mass number, $\sigma_{hp\,in}$ and $\sigma_{hA\,in}$ are the inelastic cross sections for h - proton and h- nucleus collisions, correspondingly /5/. For protons $\bar{\nu}_p = A\ 32.3/46\ A^{0.69} \doteq 0.7\,A^{0.31}$; for pions $\bar{\nu}_\pi = A\ 21.2/28.5\,A^{0.75} \doteq 0.75\,A^{0.25}$. Using the formula $r = r_0 A^{1/3} = 1.12A^{1/3}\ f$, it might be simply estimated the average mean free path $\bar{\lambda} \doteq 2r/\bar{\nu}$. For nuclei of average mass number, $\bar{A} \doteq 125$, $\bar{\nu}_p = 3.13$ and $\bar{\nu}_\pi = 2.47$; to these values correspond $\bar{\lambda}_p \doteq 3.5f$ for protons and $\bar{\lambda}_\pi \doteq 4.5f$ for pions.

In this paper we give the arguments that, in the light of the results received recently in investigating the hadron-nucleus collisions, the quantity $\bar{\nu}$ is inadequately defined parameter, and it should be applied in presenting data on hadron-nucleus interactions with great caution.

We call as "high" the energies of the projectile hadrons larger than the minimum energy below the pion production cannot take place, i.e., larger than the threshold value of the kinetic energy; often the term "high" is applied arbitrarily for the energies of the order of 10 GeV and more. The term "nuclear matter" we apply for the many nucleon medium, of spherical shape and definite radial nucleon density distribution and with given proton neutron ratio, existing in the nature in its natural form - as the atomic nuclei; usually the nuclear matter is considered, for convenience, as the unlimitedly large atomic nucleus of definite constant proton-neutron ratio it /7/.

In applying the parameter $\bar{\nu}$ in experimental data analysis it is not taken into account important experimental information that: a) Nuclei, from the point of view of the hadron-nucleus high energy collisions, consist of a rather loosely bound conglomerate of neutrons and protons which are spatially distributed in them in definite manner [8,9]. b) The hadron-nucleus collision process is localized along the projectile course in nuclear matter [10,11]; the experimental data received in investigations of the fast, 20÷400 MeV, proton emission in hadron-nuclei collisions provide a strong indication that hadrons interact only with the nucleons lying in the neighbourhood of their paths in nuclear matter - it is true for the proton emission process and for the particle creation acts as well [10]. c) Simple considerations performed by Faessler lead to similar conclusion - the energetic particles produced in the first collision will all hit the same "main" row of target nucleus and will not be spatially separated before they leave the target nucleus [11].

In considering the hadron-nucleus collision process, the target nucleus should be therefore treated as a simple spherical object consisting of loosely bound conglomerate of neutrons and protons. From many experiments we know that [9]: a)The proton distribution has a core of constant density surrounded by a surface region in which the density decreases outwards to zero. b) The evidence is clearest in the surface region and establishes with considerable accuracy the maximum density, the thickness of the surface region and the radial distance at which the density has fallen to half its maximum value. c) It is less clear in the interior, where the possibility of a slight decrease of the density towards the centre of the nucleus cannot be excluded [9,12]. d) There is inadequate direct evidence on the neutron distribution, and which exists is not conclusive. However, the indications are quite strong that the neutron distribution does not differ much from the proton distribution and, in particular, does not extend much beyond it [9,13,14]. e) If it is accepted that protons and neutrons have the same density distributions, then it should be concluded that the maximum nuclear density is quite remarcably constant as a function of the mass number A. f) Many aspects about the nucleon density distribution are now so firmly established [8,9] that it has been possible to use them in order to investigate other physical quantities [9]. Typical nucleon density distribution is shown in fig.1.

Taking into account both the two above-mentioned experimental facts: a) the nucleon density distribution varies with the distance from the centre of the target nucleus; b) the hadron-nucleus collision process goes only in the narrow vesselshape part of the nucleus along the projectile course, we must con-

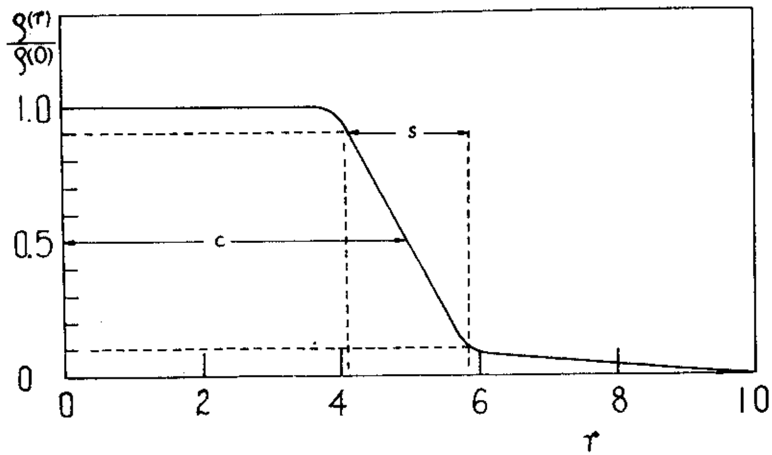

Fig.1. Typical radial nucleon density distribution in atomic nucleus.

clude that for various impact parameters d, i.e., for various minimum distances from the target nucleus center to the projectile course, there correspond various thicknesses of nuclear matter measured in number of nucleons per some surface unit.

It is found therefore to be necessary to characterize precisely, by adequate quantities, the atomic nucleus serving in experiments as some collection of nuclear matter "slabs" of various thicknesses, measured in nucleons per surface unit, on which projectile hadrons fall in the hadron-nucleus collision experiments. We would like to present how it is possible to do it; we shall present it in the next section.

2. BASIC DEFINITIONS

It is intended, in this section, to give adequate quantitative definitions characterizing the atomic nucleus as a slab of nuclear matter which has to be used in high energy hadron-nucleus collision experiments: a) the thickness of nuclear matter which is traversed by the hadron h in passing through an atomic nucleus at the impact parameter d; b) the average potential path length, or average nuclear matter thickness, for any target nucleus; c) the maximum thickness of nuclear matter for any target nucleus; d) the average mean free path for hadron interaction in nuclear matter. In defining these quantities, let us use the experimental results received in hadron-nucleus collision studies. Namely, we shall take into account that for definite path length of the projectile hadron traversing nuclear matter corresponds the number of emitted nucleons being equal to the number of nucleons met/15/:

$$n_{nucl} = \pi D_0^2 \bar{\rho} \bar{\lambda}, \tag{1}$$

where D_0 is the nucleon diameter, taken as the length unit; $\bar{\rho}$ is average nucleon density along the path length $\bar{\lambda}$, measured in nucl/D_0^3 ; $\bar{\lambda}$ is the "average" hadron path in nuclear matter, measured in nucleon diameter lengths D_0 . In particular - the number of emitted protons equals/15/:

$$n = \pi D_0^2 \bar{\rho} \bar{\lambda} \frac{Z}{A}, \tag{1'}$$

where Z/A is the ratio, between the proton number Z and the nucleon number A in target nucleus, which might be accepted to be radially independent in any nucleus. The term "average" is used for the path because for the definite number of emitted nucleons n_{nucl} not one value of λ but some sample of values $\bar{\lambda} \pm \Delta\lambda$ correspond - from the sample of values defined by the impact parameters $\bar{d} \pm \Delta d$ to which n_{nucl} corresponds/16/; we will note later simply λ instead of $\bar{\lambda}$ and d instead of $\bar{d}$, for convenience.

It follows from the relation (1) that the thickness of nuclear matter and the path length of a hadron in it will be convenient to express in the number of nucleons, or in the number of protons, per πD_0^2 - as [nucleons/πD_0^2]; similarly, the particle paths in various media in Cosmic Ray Physics are expressed usually in g/cm^2.

We will define now the quantities characterizing the target nucleus as a nuclear matter slab in hadron-nucleus collision processes; it will be mostly convenient to define them as follows:

1. The potential thickness λ which high energy hadron has to overcome in colliding with an atomic nucleus of the radius R at the impact parameter d we define

$$\lambda = 2\sqrt{R^2 - d^2}; \tag{2}$$

in particular - the average potential length $\lambda(i)$, on which incident hadron will met i protons in passing through the target nucleus at the average impact parameter $d(i)$, is

$$\lambda(i) = 2\sqrt{R^2 - d^2(i)}. \qquad (2')$$

In nuc/ πD_0^2 units the relation (2') expresses the column of nuclear matter of $\pi D_0^2 \lambda(i)$ volume situated along the projectile course, at distance d(i) from the target nucleus center.

2. The average potential path length, or the average nuclear matter thickness $\langle\lambda\rangle$, we define, taking into account the expression (1'), as:

$$\langle\lambda\rangle = \frac{\sum\limits_{i=0}^{i=n_D} \lambda_i(i) \cdot W_0(i)}{\sum\limits_{i=0}^{i=n_D} W_0(i)}\ , \qquad (3)$$

where $i = 0, 1, 2, \ldots, n_D$ is the number of emitted protons when the hadron traverses the target nucleus along the path length λ_i, according to the formula (1'); n_D is the maximum number of protons corresponding to the $\lambda = 2R = D$, where D is the target nucleus diameter; $W_0(i)$ is the probability for the projectile to collide with definite target nucleus at the impact parameter $d = \sqrt{4R^2 - \lambda^2}$, $W_0(i)$ is pure geometrical quantity /16/.

3. The maximum thickness of nuclear matter layer for any target nucleus we define as:

$$\lambda_{max} = 2R = D. \qquad (4)$$

4. The average mean free path $\langle\lambda_0\rangle$ for hadron interaction in nuclear matter we define as such average distance that a hadron covers in nuclear matter before to collide with one of nucleons in result of which the particle creation process starts.

To give the method of estimation of this quantity, let us consider the passage of a hadron beam through nuclear matter "slab". The collision process of many hadrons with identical target nuclei we can consider as the collision of a beam of hadrons with nuclear matter slabs of various thickness; in particular, we can consider the part of such collisions as the collision of a beam of hadrons with the slab of the thickness Δx protons/ πD_0^2 .

When a beam of intensity I_0 is incident on a slab of thickness Δx, the change ΔI in intensity of the beam, due to the interaction processes in the nuclear matter, as it passes thorugh the slab, is proportional to the thickness and to the incident intensity:

$$\Delta I = -\mu_0 \cdot I_0 \cdot \Delta x, \tag{5}$$

where the proportionality coefficient μ_0 is called the absorption coefficient. If the hadrons all are identical and have the same energy, μ_0 is independent of x, and the integration of equation (5) yields

$$I = I_0 e^{-\mu_0 x}, \tag{6}$$

where I is the intensity of the beam of hadrons not interacted when an incident beam of the intensity I_0 has traversed a thickness x of the nuclear matter slab.

The relation (6) might be expressed as

$$I = I_0 e^{-\frac{x}{\langle\lambda_0\rangle}} \tag{6'}$$

where $\langle\lambda_0\rangle = \frac{1}{\mu_0}$ is called the mean interaction length or the interaction mean free path of a hadron in nuclear matter.

The three above defined quantities: $\lambda(i)$, $\langle\lambda\rangle$, and λ_{max} are constant for a given target nucleus, but the fourth quantity $\langle\lambda_0\rangle$ might depend on the kinetic energy E_0 and on the sort of the projectile hadron h; therefore it must be written $\langle\lambda_0\rangle = F(h, E_0)$. It should be definite connection between the $\langle\lambda_0\rangle$ and the cross-section σ for the hadron-nucleon interaction; this cross-section is different for various hadrons h and for their various kinetic energies E_0, being $\sigma = F_1(h, E_0)$; we shall discuss this connection later on. The three first quantities are the subject of evaluations by calculations on the basis of the data on the target nuclei sizes and radial nucleon density distributions in them; the fourth quantity $\langle\lambda_0\rangle$, might be estimated both - by calculation and by measurement.

3. DETERMINATION OF THE $\lambda(i)$, $\langle\lambda\rangle$, λ_{max}, AND $\langle\lambda_0\rangle$

The three quantities: $\lambda(i)$, $\langle\lambda\rangle$ and λ_{max} are connected simply with the sizes of the atomic nuclei and the radial nucleon density distributions in them. We estimate them therefore using the data concerning the nuclear sizes and the distributions of the nucleon densities in the atomic nuclei.

Several different functions have been used successfully for a description of the nucleon radial density distribution in the nuclei [9,17-19], but all they give essentially the same type of distribution which consists of a spherical region of almost constant density surrounded by a surface region in which the density drops to zero (fig.1). Such a distribution is characterized by the so-called half-way radius c, which gives the distance from the centre at which the density has dropped to half its maximum value and a surface thickness s, which has been defined as the distance over which the density drops from 90% to 10% of its maximum value. We find to be mostly convenient to use the so-called Fermi distribution[9,17]

$$\rho(r) = \frac{\rho_F}{1 + e^{(r-c)/a}} \tag{7}$$

in calculations performed here; $a = s/4\ln 3 \approx 0.23s$, in all cases $c \gg a$. The usual normalization

$$4\pi \int_0^\infty \rho(r) r^2 dr = 1 \tag{8}$$

gives

$$\rho_F = \frac{3}{4\pi c^2} \left(1 + \frac{\pi^2 a^2}{c^2}\right)^{-1}. \tag{9}$$

On the assumption that the nuclear density distribution is given by $A \cdot \rho(r)$, the radius ℓ of the sphere occupied by a nucleon at the centre of the nucleus, i.e., in the part of the nuclear volume where the density is saturated, is:

$$\ell = \left(\frac{4\pi}{3} A \cdot \rho_F\right)^{-1/3}. \tag{10}$$

In terms of this length

$$c = \ell A^{1/3} - \frac{\pi^2 a^2}{3\ell} A^{-1/3} + O(A^{-5/3}) \tag{11}$$

$$R = \ell A^{1/3} + \frac{5\pi^2 a^2}{6\ell} A^{-1/3} - \frac{7\pi^4 a^4}{24\,\ell^3} A^{-1} + O(A^{-5/3}). \tag{12}$$

It is actually possible[9] to obtain a very good fit to the data for $A > 16$ with the two assumptions[9]: a) The thickness of the surface is constant at $s \approx 2.49$ f; b) The maximum density is constant at $A \cdot \rho_{max} = 0.168 f^{-3}$. This yields the value $\ell \approx 1.123$ f, for the radius of the sphere occupied by a nucleon in infinite nuclear matter; we use later $D_0 = 2\ell$ as the length unit expressed in f.

The path length $\lambda(i)$ (fig.2) of the projectile hadron passing through the target nucleus at the impact parameter d,

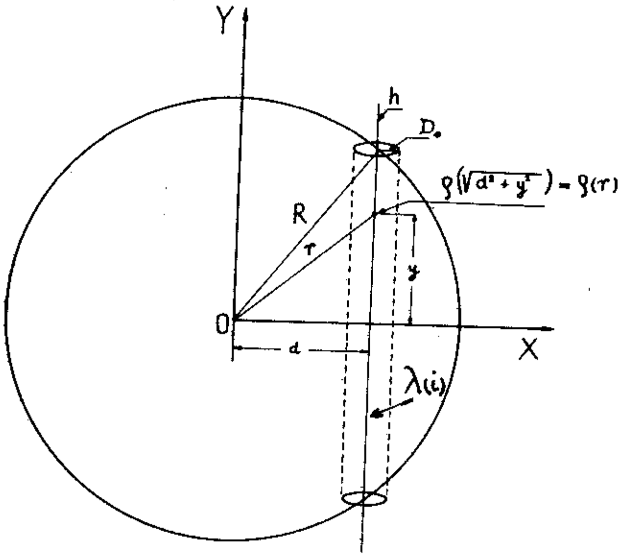

Fig.2. Scheme for geometrical explanation to the formula (13).

in D_0 units, we express as:

$$\lambda(i)=\pi D_0^2\, 2 \int_0^{\sqrt{R^2-d^2}} \rho(\sqrt{d^2+y^2})\,dy \qquad (13)$$

where ρ is expressed in protons/D_0^3 and $\sqrt{R^2-d^2}$ in D_0 units. For various $\lambda(i)=0,1,2,\ldots,2R$ there correspond various impact parameters d(i). Corresponding values of d(i) are presented in table 1 for Pb, Xe, Ag, Cu, Al, and C nuclei; in this table corresponding values of the $W_0(i)$ function /16/ are given as well. In calculations we have limited the values of the nuclear radii by the relation $\rho(r)/\rho(0) \leq 10^{-4}$.

The average potential path length $\langle\lambda\rangle$, or the average nuclear matter layer thickness, might be estimated using the formula (3) and the data from the table 1.

The maximum thickness λ_{max} of nuclear matter layer is estimated by the formula (4). The quantities $\langle\lambda\rangle$ and λ_{max} estimated are given for various nuclei in table 2.

Let us estimate now the average mean free path $\langle\lambda_0\rangle$ for hadron-inelastic collision in nuclear matter; let us start to do it firstly by the calculation. In such case the estima-

Table 1

Dependence of $\lambda(i)$ and $W_0(i)$ on the impact parameter $d(i)$

$\lambda(i)$	$^{207}_{82}Pb$		$^{131}_{54}Xe$		$^{108}_{47}Ag$		$^{64}_{29}Cu$		$^{27}_{13}Al$		$^{12}_{6}C$	
	d(i)	$W_o(i)$	d(i)	$W_o(i)$	d(i)	$W_o(i)$	d(i)	$W_o(i)$	d(i)	$W_o(i)$	d(i)	$W_o(i)$
0	4.22	0.132	3.69	0.159	3.50	0.161	3.00	0.192	2.31	0.281	1.82	0.341
1	3.91	0.123	3.37	0.144	3.18	0.142	2.67	0.171	1.97	0.239	1.44	0.269
2	3.60	0.099	3.05	0.117	2.86	0.124	2.34	0.131	1.63	0.186	1.06	0.200
3	3.36	0.079	2.80	0.092	2.61	0.094	2.08	0.102	1.33	0.152	0.69	0.133
4	3.13	0.077	2.56	0.091	2.37	0.086	1.82	0.104	0.99	0.102	0.32	0.057
5	2.88	0.076	2.28	0.101	2.10	0.094	1.49	0.118	0.33	0.039	-	-
6	2.57	0.091	1.91	0.119	1.74	0.116	1.00	0.094	-	-	-	-
7	2.16	0.109	1.37	0.100	1.20	0.123	0.51	0.086	-	-	-	-
8	1.55	0.091	0.83	0.077	0.66	0.054	-	-	-	-	-	-
9	0.94	0.121	-	-	-	-	-	-	-	-	-	-

The quantity $\lambda(i)$ is expressed in protons$/\pi D_0^2$; $d(i)$ is expressed in fermis. The values of $d(i)$ and $W_0(i)$ at $\lambda(i)$ corresponding to 0 emitted protons are calculated for the case when one neutron is ejected in passing of the hadron through the target nucleus.

Table 2

Values of the average and maximum nuclear matter layer thickness, $\langle\lambda\rangle$ and λ_{max}, for various target nuclei, expressed in protons/πD_0^2 units

Target nucleus	Pb	Xe	Ag	Cu	Al	C	Emulsion*
$\langle\lambda\rangle$	4.38	3.54	3.48	2.93	1.67	1.30	2.52
λ_{max}	8.92	7.90	7.77	6.69	5.12	2.41	-

* This value is given for average target nucleus in standard[5] emulsion; this average target nucleus is of $Z = 29.3$ and $A = 66.6$.

tion must be performed on the basis of some model of hadron-nucleus interaction process leading to the particle creation act. We use the simplest model: the projectile hadron interacts with one of nucleons met in its passing through the target nucleus; this interaction is the elementary two-body hadron-nucleon interaction, or, exactly, quasielementary one. Some indication that such assumption might correspond to the reality follows from our experiment as well[16].

Under such assumption the connection between the inelastic hadron-nucleon collision cross-section σ and the average mean free path $\langle\lambda_0\rangle$ can be expressed for nuclear matter as:

$$\langle\lambda_0\rangle = \frac{1}{k\cdot\rho\cdot\sigma}, \tag{14}$$

where ρ is the average number of nucleons per volume unit in nuclear matter along the hadron path; k is a coefficient accounting possible existence of groups of nucleons in nuclear matter, like molecules in materials. When such groups do not exist, $k = 1$; when nucleons are bounded in groups of m nucleons, in average, then $k = 1/m$. The quantity $\langle\lambda_0\rangle$ is expressed in fermis, if ρ is expressed in nucleons per f^3 and σ in f^2 per nucleon; it can be expressed in D_0 units, from the relation $\langle\lambda_0\rangle[D_0] = \langle\lambda_0\rangle[f]/D_0[f] = 0.445\langle\lambda_0\rangle[f]$. In this work it will be useful to use more convenient units for the $\langle\lambda_0\rangle$: Nucleons/πD_0^2 = nucleons / S = 15.85 nucleons/f^2 or proton/πD_0^2 = proton /S = 15.85 Z/A proton /f^2, where we denoted $S \equiv \pi D_0^2$.

In order to express $\langle\lambda_0\rangle$ in these units the relation (14) should be rewritten, taking into account the expression (1) and using $D_0 = 1$ as length unit, as:

$$\langle\lambda_0\rangle = \frac{1}{k\cdot\bar{\rho}\cdot\sigma}\cdot\pi\cdot D_0^2\cdot\bar{\rho} = \frac{\pi}{k\,\sigma}\left[\frac{\text{nucleons}}{S}\right] \tag{14'}$$

or, using the expression (1'), as:

$$\langle\lambda_0\rangle = \frac{1}{k\,\bar{\rho}\,\sigma}\cdot\pi D_0^2\,\bar{\rho}\,\frac{Z}{A} = \frac{A}{k\,A\,\sigma}\left[\frac{\text{protons}}{S}\right], \tag{14''}$$

where ρ is expressed in nucleons/ D_0^3 = 11.33 nucleons/f^3, and σ in D_0^2 /nucleon = $5.04\,f^2$/nucleon.

We note that: a) According to the expression (14') $\langle\lambda_0\rangle$ depends on σ only, if expressed in nucleon/S units; we have not taken into account the difference between the hadron-proton and hadron-neutron interaction cross-sections. b) The mean free path $\langle\lambda_0\rangle$ expressed in protons/S units depends on the mass number A, by the coefficient Z/A in expression (14''). c) The energy dependence of the value $\langle\lambda_0\rangle$ is via the σ energy dependence. d) The coefficient k should be evaluated from the experimental data, as it will be shown later.

Let us estimate now the $\langle\lambda_0\rangle$ by measurement. It is possible to do it; corresponding method follows from the formula (6'). Namely, this formula gives the possibility to apply the nuclear matter slab of definite thickness, $x = \lambda(i)$, corresponding to i emitted fast protons observed in experiments /21/; the relation between the nuclear matter thickness and the number i of emitted protons gives formula (1'). For the estimation the experimental data on pion-xenon nucleus collisions at 3.5 GeV/c momentum have been used /21/. It is known from this experiment the number N of hadron-nucleus collision events in which the particle creation does not take place, in collisions at the impact parameters d(i) corresponding to appropriate nuclear matter layer thickness $x = \lambda(i)$, and the total number N_0 of the hadron-nucleus collisions as well. The single one quantity, in the relation (6'), which has to be evaluated is the $\langle\lambda_0\rangle$. We can therefore estimate it simply, as:

$$\langle\lambda_0\rangle = -\frac{\lambda(i)}{\ln\frac{N}{N_0}}\left[\frac{\text{protons}}{S}\right]. \tag{15}$$

We use the quantity $\lambda(i)$ calculated for the xenon nucleus. Because of low statistical power of the experimental bubble chamber data for definite $\lambda(i)$, we found necessary to apply some average $\lambda(i) = \langle\lambda\rangle$ estimated for the values of the multiplicities of emitted protons $i = 6,7$ and 8. In this case $N_0 = 400 \pm 20$, $N \approx 96 \pm 10$, and $\langle\lambda\rangle = 6.86$ protons/S; the last quantity was evaluated in applying the formula (3) with $n \geq 6$. We note that in the class of events used here the numbers of events N and N_0 are mostly accurate evaluated in the experiment[21]. Therefore $\langle\lambda_0\rangle_{ex} = 4.81 \pm 0.38$ protons/S. This value differs from the calculated one, being $\langle\lambda_0\rangle_{calc} = 3.04$ protons/S. In fact the experimentally estimated value of $\langle\lambda_0\rangle = \langle\lambda_0\rangle_{ex}$ will differ much more from the calculated one, because in experiments only some part of all the events without multuparticle creation is taken into account; the experiments have been done not specially for the $\langle\lambda_0\rangle$ estimation, and, due to the scanning conditions[21], some number of events without multiparticle creation acts are lost; rough estimation gives that N should be of nearly 40% larger, and then $\langle\lambda_0\rangle_{ex} = 6.7$ protons/S. Therefore, we should postulate that nucleons in nuclei exist in some groups of nearly 2.2 nucleons, in average; then, the coefficient k in the formula (14) should be $k = (2.2)^{-1} = 0.45$. In future the value $\langle\lambda_0\rangle$ must be measured with greater accuracy. The correctness of the postulate proposed here might be supported in comparing the experimental characteristics of the hadron-nucleus collision process with corresponding characteristics predicted in which $\langle\lambda_0\rangle$ evaluated by means of formulas (14)-(14'') will be used.

The values of $\langle\lambda_0\rangle$ calculated for the incident pions and protons of various energies on the basis of the cross-sections for the elementary pion-proton and proton-proton collisions[20] are presented in table 3, in calculations $k = 0.45$ has been used.

4. CONCLUSIONS

In defining the quantities $\lambda(i)$, $\langle\lambda\rangle$, λ_{max} and $\langle\lambda_0\rangle$ it was attempted to work out a convenient and adequate formalism for a description of the passage of high energy hadrons through nuclear matter. These quantities seem to be fundamental for any model of the hadron-nucleus collision process, as defined on the basis of the target nuclei sizes and radial nucleon density distributions in nuclei, and on the basis of general properties of collision processes obserbed in experiments newly performed[15,16] and discovered in considerations presented lately[11].

It should be noted that all these quantities $\lambda(i)$, $\langle\lambda\rangle$, λ_{max} and $\langle\lambda_0\rangle$ might be determined, in principle, by measurement in experiments. We have shown here how it is possible

Table 3

Energy dependence of the average mean free path $\langle\lambda_0\rangle$ for pion-proton and proton-proton inelastic collisions in nuclear matter. P_{lab} - projectile momentum in GeV/c

P_{lab}	Pi - p inelastic		p - p inelastic	
	σ_{in} mbarn	$\langle\lambda_0\rangle \frac{\text{nucleons}}{\pi D_0^2}$	σ_{in} mbarn	$\langle\lambda_0\rangle \frac{\text{nucleons}}{\pi D_0^2}$
0.641	12.00	29.03	-	-
0.838	14.00	24.88	-	-
0.968	-	-	3.90	89.32
1.017	21.50	16.20	-	-
1.081	25.90	13.45	-	-
1.127	-	-	6.00	58.05
1.168	-	-	8.87	39.27
1.210	20.40	17.08	-	-
1.219	-	-	13.60	25.61
1.269	-	-	16.80	20.73
1.628	-	-	23.00	15.15
8.050	22.76	15.30	-	-
11.200	21.21	15.76	-	-
12.000	-	-	29.77	11.70
16.000	21.32	16.34	-	-
18.500	21.17	16.45	-	-
19.000	-	-	29.80	11.69
24.000	-	-	30.60	11.38
32.000	-	-	30.10	11.57
50.000	21.00	16.59	-	-
60.000	-	-	31.70	10.99
102.000	-	-	31.90	10.92
147.000	21.00	16.59	-	-
205.000	-	-	31.10	11.20
290.000	-	-	32.30	10.78
405.000	-	-	32.80	10.62
500.000	-	-	33.50	10.40
1070.000	-	-	35.08	9.93
1480.000	-	-	35.68	9.76

The average mean free paths were estimated by using the formula (14′) with the coefficient $k=1/2.2$; the values of σ_{in} are taken from the CERN-HERA tables /20/.

to measure the $\langle\lambda_0\rangle$. in next papers we will show that the quantity $\langle\lambda\rangle$ is given in experiments by the average proton multiplicity $\langle n_p\rangle$ being independent on the number n_s of all the particles created in collision process; the independence of $\langle n_p\rangle$ on the number of generated pions - positive charged, negative, and neutral - has been observed in our experiment as well /22/. In this experiment $\langle n_p\rangle \approx 3.5$ protons/S, for the pion-xenon nucleus collisions. The quantity $\langle\lambda\rangle$ estimated for the xenon nucleus by calculation, using formula (3), equals $\langle\lambda\rangle = 3.54$ protons/S; such coincidence of both these values might occur if the particle creation and nucleon emission go on according to the model proposed in our former works /10,16/.

In my opinion the above defined quantities should be used later on in discussing the experimental data on hadron-nuclei collisions, instead of the unobservable and unprecise quantity $\bar{\nu}$.

REFERENCES

1. Gurtu A. et al. Pramana, 1974, 3, p.311.
2. Gurtu A. et al. Phys.Lett., 1974, B50, p.391.
3. Anderson B., Otterlund I. Nucl.Phys., 1975, B88, p.349.
4. Busza W. et al. Phys.Rev.Lett., 1975, 34, p.836.
5. Busza W. In: High Energy Physics and Nuclear Structure, 1975, AIP Conference Proceedings No.26, p.211; Acta Physica Polonica, 1977, B8, p.333.
6. Babecki J. Report INP No. 887/PH, Krakow, 1975; Report INP No.911/PH, Krakow, 1975.
7. Bethe H.A. Theory of Nuclear Matter. In: Annual Rev. of Nuclear Sci., 1971, 21, p.93.
8. Hofstadter R. Revs.Mod.Phys., 1956, 28, p.4; Ann. Rev. of Nucl. Sci., 1957, 7, p.4.
9. Elton L.R.B. Nuclear Sizes, Oxford University Press, 1961.
10. Strugalski Z. et al. JINR, E1-11975, Dubna, 1978.
11. Faessler M.A. MPI H-1980-v.7 Report, Heidelberg, 1980.
12. Hahn B., Ravenhall D.G., Hofstadter R. Phys.Rev., 1956, 101, p.1131.
13. Strugalski Z. Nucl.Phys., 1966, 87, p.280.
14. Miller K. PhD Theses, Institute of Physics, Warsaw Technical University, Warsaw, 1979.
15. Strugalski Z. JINR, E1-11976, Dubna, 1978; JINR, E1-12088, Dubna, 1979.
16. Strugalski Z. JINR, E1-80-216, Dubna, 1980.
17. Elton L.R.B., Hiley B.J., Price R. Proc.Phys.Soc., 1958, 73, p.112.

18. Helm R.H. Phys.Rev., 1956, 104, p.1466.
19. Fregean J.H. Phys.Rev., 1956, 104, p.225.
20. Famino V. et al. CERN-HERA, 79-01; 79-02; 79-03, 1979.
21. Strugalski Z. et al. JINR, E1-80-39, Dubna, 1980.
22. Strugalski Z., Pluta J. Journ. of Nucl.Phys. (Russian), 1974, 27, p.504.

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