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Z.Strugalski

NUCLEON EMISSION FROM TARGET NUCLEI WHICH OCCURS WHEN HADRONS TRAVERSE THEM

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1. INTRODUCTION

The collisions of hadrons with atomic nuclei give rise to a great variety of secondary effects. The emission of nucleons from the target nuclei is one of the mostly general and frequently observed among the phenomena occuring, when high energy hadrons - of kinetic energies higher than the pion production threshold - are employed as projectiles. Events have been observed as well in which the nucleon emission occurs intensively when particles are not produced in the collisions [1]; such events seem to be reasonable to interpret as the passages of the incident hadrons through target nuclei.

The emitted nucleons are "fast" - of kinetic energies from about 20 up to about 400 MeV; they are known as the g-track leaving particles, when fast protons are registered in nuclear emulsions [2]. Characteristics of the nucleon emission in the passages are practically the same as in the any-type hadron-nucleus collisions. The number n_N of nucleons emitted in a collision, or the so-called nucleon multiplicity n_N, can serve as a measure of the nucleon emission intensity.

Despite many experimental studies of hadron-nucleus collisions, results of the analysis of the data on the passages of hadrons through nuclear matter have never been described widely and clear enough; some preliminary experimental information about such kind of events is contained in our preprints and conference papers [3,4]. It could be obtained only in some total experiment, when all collision reaction products, including neutral pions, are registered totally. Here, I would like to put on record results of our investigations of the passage process, and of a physical meaning of the nucleon emission intensity accompanying it. The passages of hadrons through nuclear matter are in an analogy with the passages of fast charged particles through a material and, may be, the observed nucleon emission accompanying them is a secondary effect caused by some process in nuclear matter which corresponds, in its rough similarity, to the particle energy loss process in materials.

An understanding the hadron passage process through nuclear matter shall be of a great value for applications of the target nucleus as a fine detector of properties of the particle production process in its statu nascendi, when the production occurs in elementary hadron-nucleon collisions; it may throw a light on the results obtained in experimental studies of the so-called highly excited states of nuclear matter, which can be produced, as it is believed, in hadron-nucleus and nucleus-nucleus collisions, as well.

Many works on the nucleon emission have been performed /5-8/, but presently there is no model which in a convincing manner can account for all data on nucleon emission intensity in terms of our knowledge of hadron-nucleon interactions and of nucleus structure - its size and nucleon density distribution in it. Some qualitatively new information about the nucleon emission process and its interpretation are highly desired, therefore.

The aim of this work has been to gain insight in the physics of the hadron passage through nuclear matter and of the nucleon emission process accompanying it.

On this way, firstly we have searched for collision events in which the nucleon emission process might manifest itself in its purest form - when other processes do not occur in them, as in the passages, for exapmle; we have done it by using xenon bubble chambers in which Pi0 mesons are registered exceptionally effectively - the 26 litre chamber of the Joint Institute for Nuclear Reasearch, Dubna and the 180 litre chamber of the Moscow Institute of Theoretical and Experimental Physics. Secondly, we have analysed in detail the events found and singled out such of them in which the particle production in fact does not occur. Thirdly, we have obtained characteristics of the nucleon emission process in such events and compared them with corresponding characteristics of the nucleon emission process in collisions in which particles are produced, using the data obtained by means of the same chambers. Fourthly, we attempted to find some relations between the nucleon emission intensities and the target nucleus size and nucleon density distribution in it.

The present paper is arranged as follows: After the introduction, in section 1, in section 2 we describe shortly the method applied. Section 3 contains the presentation of appropriate experimental data, which are analysed later, in section 4. Section 5, in which we present our conclusions and remarks, closes the paper.

2. METHOD

The method bases on simple finding that the special class of hadron-nucleus collision events can be identified experimentally and singled out - in which incident hadron passes through the target nucleus accompanied by intensive nucleon emission without causing ejection of produced particles, of the pions in particular. Such events can be found in some "total" experi-

ment - when all the collision reaction products are registered and identified. The 180 litre xenon bubble chamber provides practically such conditions for the registration and identification of the products of the hadron-xenon nucleus collisions as desired. This chamber is of the dimensions 103x44x40 cm^3, and it was exposed to hadron beams along its length. Collisions of the beam hadrons with Xe nuclei are accepted for further analysis, if are recorded in the chamber central fiducial region of 40x10x10 cm^3, centered coaxially in it.

Particle tracks of the length larger than nearly 5 mm are visible well and detectable with the constant efficiency which is close to 100%. To this minimum length there corresponds the minimum energy of the registered protons of nearly 20 MeV and of the registered charged pions of 10 MeV. Shorter tracks are visible as well, but in this case the detection efficiency is not constant. The emitted protons with kinetic energies from nearly 20 up to nearly 200 MeV, the secondary pions: the negatively charged with kinetic energy from nearly 10 up to nearly 100 MeV, positively charged with the energy from 0 up to 100 MeV stopping within the chamber, and the neutral pions with any kinetic energy over 0 MeV, including 0 MeV, are recorded and identified with the efficiency near to 100% within the total solid angle 4Pi; the kinetic energy of the protons emitted forward and backward from the center of the chamber within the 60 degree cone and stopping inside the chamber is no more that nearly 350 MeV.

We are able, therefore, to select pion-xenon nucleus collisions in which incident pion passes through the target nucleus or it is absorbed in it without causing particle production, without ejection of the produced pions in particular. In fact, in such events only pions absorbed inside the target nucleus may be produced, if any. The "absorptions" are special cases of the "passages" - when incident hadrons stop inside the target nuclei; we will call such events "stoppings" later on, they can occur at projectile energies smaller than a few GeV only, as it was proved experimentally.

According to the scanning and selection criteria, the emitted fast protons stopped inside the chamber were recognized as particles leaving the characteristic straight tracks ended inside the chamber; any sharp change of a track - a sharp deflection or a branching at its end were accepted as indications that the track leaving particle might be not the proton. It was estimated that the number of fast protons emitted from points located near to the chamber center and having left the chamber or forming the deflected or branched tracks is no more than about 10% of the total number of the proton tracks registered. The rest of the tracks, qualified as the non-proton tracks are accepted as the tracks left by charged pions; the positively charged pions stopped inside the chamber are identifiable in it, because they decay into simply recognizable positons, even if their kinetic energy equals 0. Neutral pions, eta and omega mesons decaying via neutral channels are detectable by registration of the gammas from the neutral pions decays and from radiative decays with an efficiency near to 100%.

The events which could imitate the stoppings and passages are mainly those in which one neutral pion is produced and it is not recorded in the chamber; in the rest of cases, when more than one neutral pion or two, four, or six charged pions are produced the events cannot be wrongly qualified as that without pion production, because it is practically impossible to lose all of the gammas from decays more than one neutral pion, and among the charged pions at least the positively charged are always detectable. The estimation of the number of events qualified wrongly is performed using the data on neutral pion production in the total sample of the any-type collisions. Namely, in the total sample of the any-type pion-xenon nucleus collisions N = 239 events with one Pi0 are found; the number of the wrong events might be then $N\cdot(1-\epsilon^2) = 1.52$, where $\epsilon = 0.92$ is the detection efficiency of a gamma quantum from Pi0 decays. The percentage in question is then 0.03%, for pion-xenon collisions at 3.5 GeV/c momentum.

Additional source of events which may be recognized wrongly as those without particle production is the generation of the V-shaped track leaving particles, mainly the lambdas and the K^0 mesons, escaping the chamber. For estimation of the percentage of the false events, data on the V-particle production in the xenon bubble chambers were applied; estimation gives the value 0.16% of events which could contain V-particles and imitate the events without particle production.

Some number of the straight line tracks of the particles stopped within the chamber are recognized, according to the scanning and selection criteria, as the proton tracks can be in fact tracks left by "slow" Pi^- mesons of kinetic energies smaller than about 120 MeV. In our experiment, when as projectiles the negatively charged pions are employed, production of the Pi^- mesons should be accompanied by Pi^+ meson, which is detectable directly and simply when of kinetic energy higher than 0 MeV or equal to 0 MeV. In other words, the persentage of the wrong events without particle production is practically 0%.

The maximum percentage of the total number of "wrong" events without particle production is about 0.2%; it means that among the total number 6301 events of the any-type pion-xenon nucleus collisions used for the analysis only 12 events may be recognized wrongly as the stoppings or as the passages of the incident hadrons through the xenon target nucleus accompanied by nucleon emission but without causing the particle production.

The photographs of the chamber, exposed to negatively charged pion beam from the ITEPh accelerator, at 3.5 GeV/c momentum, were scanned and rescanned for pion-xenon nucleus collisions of the type

$$\pi^- + Xe \rightarrow n_p + f \qquad (1)$$

and

$$\pi^- + Xe \rightarrow n_p + \pi^- + f \qquad (2)$$

which occur within the fiducial central region; $n_p = 0, 1, 2, 3, \ldots$ denotes the number of the emitted fast protons and f denotes residual nuclear fragments.

Any sharp change on the straight-line track left by any beam pion was considered to be an indication that this pion suffers an interaction with the target nucleus; the end- or deflection-point of any beam pion track was accepted to be the point of impact. We were able to detect the collision events in which the incident pion track ends off or deflects at an angle of no less than 2 degrees, accompanied or not by any number of the proton tracks outgoing from the interaction place.

In any of the events the deflection angle θ_π of the incident pion track, the number n_p of the protons emitted, the emission angle θ_p and the azimuth angle ϕ_p, the kinetic energy E_{kp}, the longitudinal momentum P_{Lp}, and the transverse momentum P_{Tp} of each of the protons emitted were determined. The accuracy in measuring the pion deflection angle is about 1 degree; the accuracy in measuring the proton emission angle is about 3 degrees, on the average. Energies of the protons were measured, using the range-energy relation, with an accuracy of about 4%. The number n_p of the proton tracks, corresponding to the proton kinetic energy larger than about 20 MeV, was determined with a constant detection efficiency close 100%.

3. EXPERIMENTAL DATA

The data, set forth below, are obtained in the analysis of 972 events of the kind in question (1) and (2) singled out in the scanning of about 150 000 chamber stereophotographs. Systematical scanning of some part of the photographs for any-type pion-xenon nucleus collision events, with and without particle production, shows that a sample of 6301 such collisions at 3.5 GeV/c momentum contains 848 events without particle pro-

Table 1. Proton multiplicity n_p distribution $N(n_p)$ in collisions of negatively charged pions with xenon nuclei at 3.5 GeV/c momentum: a) in any-type collisions, when the number of secondary pions $n_\pi \geq 0$; b) in collisions without particle productions, when the number of secondary negatively charged pions is $n_\pi \leq 1$ or $n_\pi = 0$; c) in the passages, when the number of negatively charged secondary pions $n_\pi = 1$; d) in the stoppings, when the number of secondary pions $n_\pi = 0$.

n_p	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	$\Sigma N(n_p)$
a) $n_\pi \geq 0$	1309	1120	902	731	598	538	417	270	200	99	59	36	9	8	3	1	1	6301
b) $n_\pi \leq 1$	323	165	90	50	52	48	57	44	45	31	27	27	4	4	3	1	0	972
c) $n_\pi = 1$	320	161	87	42	48	43	46	32	29	27	16	18	3	3	0	1	0	876
d) $n_\pi = 0$	3	4	3	8	4	5	11	12	16	4	11	9	1	1	3	0	0	96

duction; 78 of them are such in which incident pion is absorbed in the target nucleus, in 588 events incident pion deflection is observed, and in 182 events incident pion charge exchange is registered. Thus, the pion passage through the target nucleus without causing particle production occurs in (10.6±0.5)% of all the pion-xenon nucleus collisions at 3.5 GeV/c momentum. This percentage is larger by much than the percentage of the events which may be accepted wrongly as the passage of the incident pion through nuclear matter without causing particle production, which is 0.2% as determined in section 2.

It can be concluded, therefore, that the passage of the incident hadrons through massive xenon target nuclei is observed evidently in its pure form; in passing through nuclear matter the hadron causes intensive emission of the observed fast protons, reasonable to think that fast neutrons are emitted intensively as well, but they are not registered effectively enough in the chamber. This could not be done in other experiments where all neutral mesons and other neutral particles produced were not observed effectively enough. In fig.1, one of such "passage events" registered in the 180 litre chamber is presented.

Table 1 contains the proton multiplicity n_p distributions, $N(n_p)$ in: a) the sample of any-type collisions - when the multiplicity of the secondary pions of any electric charge is $n_\pi \geq 0$; b) the sample of collisions without

Fig.1. The passage of incident pion through xenon target nucleus. The pion deflected firstly in collisin with a xenon nucleus traversed the next nucleus accompanied by nucleon emission and then interacted with the third nucleus, and left it; tracks of the emitted fast protons are visible well in the second and i the third interactions.

particle production - when incident pion traverses the target nucleus or it is absorbed in it in accompaniment by the nucleon emission; c) the sample of collisions without particle production - when incident pion traverses the target nucleus accompanied by nucleon emission; d) the sample of events in which the incident negatively charged pion suffered the absorption inside the target nucleus. Events of the kind as in c) and d) are in result of the reactions (2) and (1) correspondingly, and they are of special interest in this paper. The distributions c) and d) are taken directly from the scanning and some number of the events of the type c) could be classified wrongly as that of the type d) and vice versa. Additional analysis of the data allowed to introduce appropriate corrections and to obtain the proton multiplicity which can be treated as the true one. About the corrections applied we discuss shortly later, in the last section.

In fig.2, the corrected proton multiplicity distributions are shown, in the samples of events of the type (1) and (2). The distributions are different, and they differ from the distribution for any-type events shown in fig.3; the mean proton multiplicity in the any-type events is $\langle n_p \rangle = 3.20 \pm 0.01$.

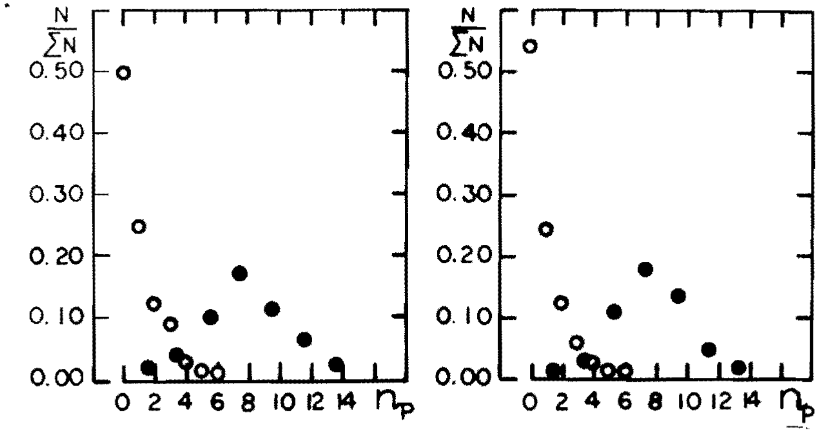


Fig.2. Proton multiplicity n_p *distributions in the pion-xenon nucleus collisions at 3.5 GeV/c momentum in which incident pion is absorbed inside the target nucleus (full circles) or traverses it (empty circles) without particle production; left side - experimental data, right side - predictions given by formulas presented in section 4.*

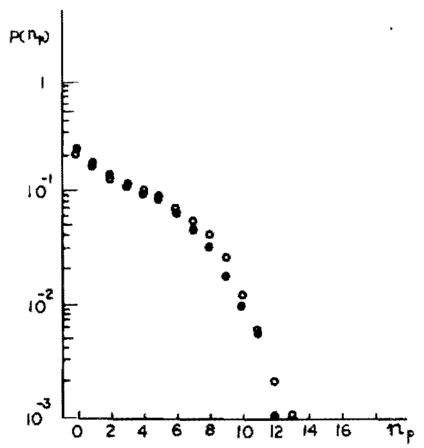


Fig.3. Proton multiplicity n_p *distribution* $P(n_p)$ *in the total sample of the pion-xenon nucleus collisions at 3.5 GeV/c momentum; full circles - experimental data, over 19000 protons are distributed from 6301 collision events any type; empty circles - prediction given by formula (5).*

The distribution for the stoppings is almost symmetrical relatively to the mean proton multiplicity $\langle n_p \rangle = 7.4 \pm 0.3$. It is reasonable to treat the events as such in which the projectiles fel on the target nucleus parallelly to its diameter at the impact parameter short enough, when the nuclear matter layer thickness is sufficiently large; at 3.5 GeV/c such events occur in about 2% of the any-type collisions. Then, the passages happen when collisions are at longer impact parameters - when the nuclear matter layer thicknesses are smaller.

The occurence of the stoppings depends on the incident pion energy. In scanning of photographs of the 26 litre xenon bubble chamber we obtained that at 2.34 GeV/c momentum of the incident pions stoppings are in about 12% of the any-type collision events at 5 and at 9 GeV/c the percentage is practically 0. It leads to the conclusion that some range-energy relation exists for hadrons in nuclear matter; at 3.5 GeV/c this range for the incident pions is as approximately large as the target xenon nucleus diameter is.

In both the cases under discussion intensive emission of fast protons is observed, the mean number of the emitted protons in the events without particle production at 3.5 GeV/c is $\langle n_p \rangle = 3.31 \pm 0.26$. Similar emission occurs in the any-type collision events, when particles are produced in more than about 90% of the events. The comparison of characteristics of the proton emission: of the momentum spectra and angular distributions in various samples of events presented in Table 1 as a), b), c), and d) samples should throw a light on the emission and, may be, on its relation to the nucleon density and electric charge distributions within the target nucleus.

In figs. 4 - 6, the transverse momentum spectra, the longitudinal momentum spectra, and the angular distributions of the emitted protons in various samples of events are shown. The

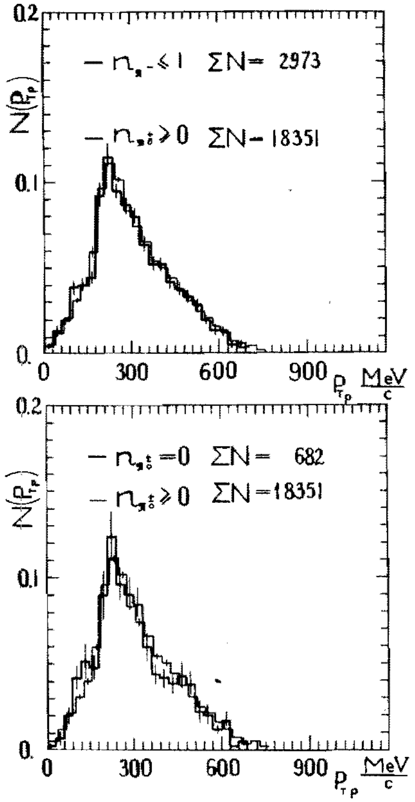


Fig.4. Transverse momentum P_{Tp} *distributions* $N(P_{Tp})$ *of protons emitted in various classes of the pion-xenon nucleus collisions at 3.5 GeV/c momentum:* $n_{\pi^-} \le 1$ *- events without particle production when the projectile traverses the target nucleus or it is absorbed in it;* $n_{\pi}^{\pm} = 0$ *- events without particle production when the projectile is absorbed inside the target nucleus;* $n_{\pi}^{\pm} \ge 0$ *- any-type collision events.* ΣN *- number of protons in a histogram.*

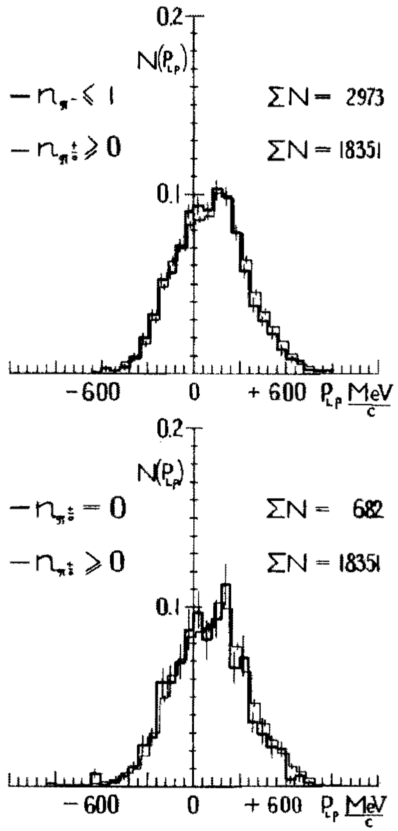
spectra are practically the same. It indicates that the proton emission proceeds in the same manner when the projectile traverses the target nucleus without particle production or when the particle production occurs. Reasonable to extrapolate this indication on the neutron emission as well, or on all the nucleons as a whole. In the classes of events without particle production the nucleon emission is observed in its purest sort.

Let us analyse, in the next section, the experimental facts presented here.

4. DATA ANALYSIS

Suppose to be true our conclusion, formulated in section 3, that stoppings in pion-xenon nucleus collisions at 3.5 GeV/c momentum correspond to the passage of incident pion through nuclear matter layer as thick as the maximum thickness λ_{max} of the target nucleus is. Let, for convenience, express this thickness in nucleons per some area S units (nucl/S). The thickness can be expressed in protons per S units as well, (prot/S), because in average the proton-nucleon ratio is almost as large [9,10] as Z/A, where Z and A are the charge and mass numbers of the target nucleus. The thickness can be de-

Fig.5. Longitudinal momentum P_{Lp} *distributions* $N(P_{Lp})$ *of the fast protons emitted in various samples of pion-xenon nucleus collisions at 3.5 GeV/c momentum. Denotations used as in fig.4.*



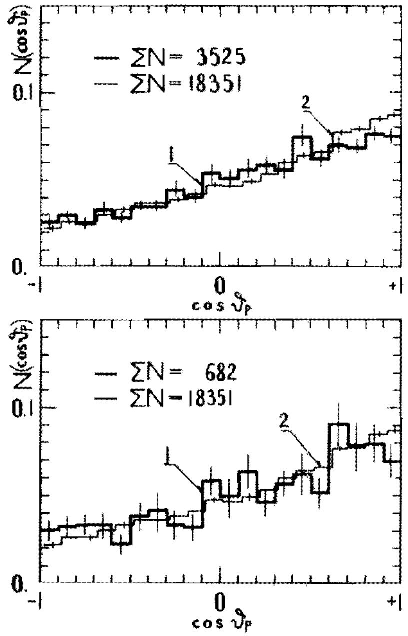


Fig.6. Proton emission angle ν_p *distributions in pion-xenon nucleus collisions at 3.5 GeV/c momentum: In the sample of collision events without particle production, when incident pion is absorbed inside the target nucleus or has traversed it - histogram 1, over; In the sample of events without particle production, when incident pion is absorbed inside the target nucleus, histogram 1 below; In the sample of any-type collisions - histograms 2.* ΣN *- number of protons in a class of events.*

termined for a nucleus using the known nucleon density distribution in nuclei, for example - the Fermi distribution [9]. Similarly, the mean thickness $\langle\lambda\rangle$ of the target nucleus, in (nucl/S) or in (prot/S), can be determined, and the distribution $W[\lambda(b)]$ of thicknesses $\lambda(b)$ in (nucl/S) corresponding to various distances b from the target nucleus center can be calculated this way. As the S value it is reasonably to apply $S = \pi D_0^2 = 10.3\ fm^2$, where D_0 is the nucleon diameter.

For the xenon target nucleus, the calculations give: $\lambda_{max} = 18.66$ (nucl/S) or $\lambda_{max} = 7.69$ (prot/S); $<\lambda> = 8.52$ (nucl/S) or $<\lambda> = 3.51$ (prot/S).

Comparisons of the values calculated with corresponding data obtained experimentally lead to the conclusion that: a) The mean multiplicity of the emitted protons $<n_p> = 7.4 \pm 0.3$ in the stoppings at 3.5 GeV/c momentum equals the calculated number of the protons $n_p = 7.7$ contained within the cylindrical volume $\lambda_{max} \cdot S = D \cdot S$ centered on the nucleus diameter $D = \lambda_{max}$. b) The mean multiplicity of the emitted protons $<n_p> = 3.31 \pm 0.26$, in the total sample of the events without particle production, is almost the same as the number of protons $<\lambda> \cdot S = 3.51$ contained within the volume $<\lambda> \cdot S$ centered on the mean path of the incident pions in nuclear matter; this mean path corresponds to the mean nuclear matter layer thickness $<\lambda>$ (prot/S) in the xenon target nucleus.

The finding presented above leads obviously to simple relation between the mean multiplicity $<n_p>$ of the emitted fast protons and the nuclear matter layer mean thickness $<\lambda>$(nucl/S) involved in the collisions:

$$<n_p> = \frac{Z}{A} <\lambda> \cdot S(1 - e^{-\frac{<\lambda>}{\lambda_t}}), \qquad (3)$$

where $\lambda_t = 1/\sigma_t$ is the hadron mean free path in (nucl/S), σ_t is the total hadron-nucleon cross-section in (S/nucl). For the events without particle production at 3.5 GeV/c momentum, the experimentally obtained value $<n_p> = 3.31 \pm 0.26$ and corresponding calculated value of the multiplicity is $<n_p> = 3.19$, as given by formula (3).

In searching for effects of the particle production process on the nucleon emission process [11,12], it has been found that the particle production does not effect on the nucleon emission at any energy of the incident hadrons; at energies higher than a few GeV it is seen simply - the mean multiplicities of the emitted fast protons are almost energy-independent, for example. It leads to the conclusion that formula (3) may be applicable for any-type collisions. Simple comparison of predictions of this formula with corresponding experimental data shows that it is the case, Table II.

In attempts to describe the proton multiplicity distribution $N(n_p)$ in the stoppings, fig.2, we found that the binomial distribution:

$$P(n_p) = C_{DS}^{n_p} \left(\frac{Z}{A}\right)^{n_p} \left(1 - \frac{Z}{A}\right)^{DS - n_p} \qquad (4)$$

Table 2.

Mean multiplicities of fast protons $<n_p>$ emitted in hadron-nucleus collisions at various energies: experimental data and predictions by formula (3)

Reaction	Energy GeV	$<n_p>$ experiment	& ref.	$<n_p>$ calc.
$Pi^- + Xe$	3.5	3.20 ± 0.01	/3/	3.19
$Pi^- + Em$	60	2.04 ± 0.12	/5/	2.99 *
				1.90 **
$Pi^- + Em$	200	2.17 ± 0.10	/5/	2.62 *
				1.87 **
$Pi^+ + Al$	250	1.2 ± 0.1	/6/	1.23
$Pi^+ + Au$	250	3.7 ± 0.3	/6/	3.71
$K^+ + Al$	250	1.2 ± 0.06	/6/	1.09
$K^+ + Au$	250	3.3 ± 0.2	/6/	3.54
p + Em	6.2	3.58 ± 0.11	/13/	3.01 *
p + Em	22.5	3.38 ± 0.14	/13/	2.99 *
p + Em	67	2.66 ± 0.12	/5/	2.99 *
p + Em	200	2.61 ± 0.18	/5/	2.99 *
				2.26 **
p + Em	300	2.60 ± 0.2	/8/	2.83 *
p + Em	400	2.90 ± 0.2	/8/	2.85 *
p + Em	2000	2.62 ± 0.50	/5/	3.03 *
				2.29 **
p + Em	3500	2.6 ± 0.5	/7/	3.03 *
				2.29 **

*In calculations, using formula (3), following quantities were used: $<\lambda>$ in prot/S from our work [14]; $\lambda_t = 10.3/\sigma_t$ where σ_t in fm^2 is from pp or Pip reactions given in Rev. of Particle Properties [15]; for emulsions the mean values for the charge and mass numbers are $<A> = 66.6$ and $<Z> = 2.93$. * - calculations for AgBr composition, ** - for the "average" emulsion.*

describes it quantitatively [3], where $D = \lambda_{max}$ is in (nucl/S), for the xenon nucleus D = 18.58 (nucl/S); $C_{DS}^{n_p} = [n_N!]/[n_p!(n_N - n_p)!]$ and $n_N = DS = \lambda_{max} S$. χ^2 - test shows that the distributions, the experimentally obtained $N(n_p)$ and the $P(n_p)$ given by formula (4), are practically the same [3]. Physically, it means that in traversing the target nucleus along its diameter D the hadron meets always $n_N = DS = const$

nucleons around its course and among the nucleons met the number n_p of the protons fluctuates; the maximum value of the probability $P(n_p)$ to meet n_p protons lies at the proton multiplicity n_p interval $n_N \frac{Z}{A} + \frac{Z}{A} - 1 \leq n_p \leq n_N \frac{Z}{A} + \frac{Z}{A}$.

Reasonably to suppose that such charge fluctuations occur around any path of a hadron in nuclear matter, and the distribution $W[\lambda(b)S] \equiv W(\lambda S)$ of the nuclear matter thicknesses $\lambda(b) \equiv \lambda$ (nucl/S) in a target nucleus corresponds to the distribution $N(n_N)$ of the nucleon multiplicities n_N in collisions of hadrons with this target nucleus. The distribution $W(\lambda S) = W(n_N)$ can be evaluated from the Fermi nucleon density distribution as well.

Then, formula for the proton multiplicity distribution in any-type hadron-nucleus collisions will be obviously:

$$N(n_p) = k \sum_{n_N=\lambda S=1}^{n_N=DS} W(n_N)(1 - e^{-\frac{n_N}{n_t}}) C_{n_N}^{n_p} (\frac{Z}{A})^{n_p} (1 - \frac{Z}{A})^{n_N - n_p} \qquad (5)$$

for $n_p = 0, 1, 2, 3, \ldots, DS$; $n_N \geq n_p$, $n_t = \lambda_t S$, where λ is expressed in (nucl/S), and $\lambda_t = 1/\sigma_t$, σ_t in (S/nucl). This formula contains the A-dependence of $N(n_p)$ because $W(n_N) = W(\lambda S)$ depends on A, it contians the energy- and hadron identity-dependence as well, because σ_t is dependent on the hadron energy and identity. The formula can be applied without any limitation at energies over a few GeV, at lower energies absorption of hadrons inside target nuclei should be taken into account in calculations of the distribution $W(n_N) = W(\lambda S)$. k - the normalization coefficient.

Comparisons of the distributions given by formula (5) with corresponding distributions obtained experimentally for pion- kaon-, and proton-nucleus collisions at energies from 3.5 GeV up to 400 GeV show that formula (5) describes experimental data well enough. As an example, comparison of the proton multiplicity distribution obtained experimentally for the pion-xenon nucleus collisions at 3.5 GeV/c momentum with the multiplicity distribution given by formula (5) is presented in fig.3.

What is remarcable in formulas (4) and (5) is that they do not contain any free parameters!

The results presented in this section indicate that in analysing the proton emission only, an information about the nucleon emission as a whole is obtained as well.

5. CONCLUSIONS AND REMARKS

A short conclusion review may be useful and give a summary of this work.

1) Hadrons can traverse nuclei without causing the particle production; the passage is accompanied by fast nucleon emission in a strictly definite manner.

2) The nucleon emission in the collisions without particle production proceeds in the same manner as the emission in any-type collisions.

3) Hadrons, in their passages through nuclear matter, see the nucleon density distribution as stable in which the proton-nucleon ratio fluctuates in definite manner, as it expresses formula (4).

4) Nucleon emission intensity is determined by the target nucleus geometry - by the target nucleus size and nucleon density distribution in it.

5) Hadrons lose their energy in passing through nuclear matter, the nucleon emission may be the observable phenomenon related to the energy loss.

The findings presented in this paper are of valuable methocal nature:

a) The nucleon emission process may be underlain as a physical basis for an application of the massive target nucleus as a fine detector of properties of the particle production process in statu nascendi.

b) The target nucleus can be applied in various experiments as a nuclear matter slab or foil, similarly as metallic foils were applied in Rutherford and Marsden experiments.

c) In experiments, when fast neutrons and protons are totally registered in hadron-nucleus collisions, the nuclear matter layer thickness λ (nucl/S) involved in a collision is always determined - the number n_N of nucleons observed corresponds to the λ thickness as $\lambda S = n_N$.

Conclusions on the size and shape of the regions in which reactions leading to the nucleon emission occur can be deduced from the data obtained as well. The reactions happen along the incident hadron course, and nucleons are emitted from the region of the volume λS fm^3 inside the target nucleus, centered on the hadron path λ fm in it.

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Испускание нуклонов при проникновении адронов через ядра-мишени

Изучается испускание нуклонов, в частности протонов, с ядер мишеней, которое происходит, когда адроны проникают через ядра. Наблюдаются проникновения адронов через ядра ксенона; адроны, проникая через ядерную материю приводят к появлению интенсивного испускания нуклонов, в частности - обычно наблюдаемых протонов. Испускание нуклонов протекает так же, как в событиях, где рождаются частицы, и в событиях без рождения частиц. Приведены энергетические спектры и угловые распределения протонов, испускаемых в разных классах событий.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Nucleon Emission from Target Nuclei which Occurs when Hadrons Traverse Them

Emission of fast nucleons, of fast protons in particular, from target nuclei which occurs when hadrons traverse them is studied. The passages of hadrons through massive xenon nuclei are observed; hadrons, in passing through nuclear matter, cause intensive emission of fast nucleons, in particular of fast protons observed usually. The nucleon emission in the passages proceeds in the same manner as in events in which particles are produced. Formulas proposed for description of the proton intensity distribution are tested experimentally. Energy spectra and angular distributions of the protons in various classes of pion-xenon nucleus collisions are compared.

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

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