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NEUTRON EMISSION FROM TARGET NUCLEI INDUCED BY HIGH ENERGY HADRONIC PROJECTILES

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1. INTRODUCTION

In hadron-nucleus collision reactions at high energies, above the pion production threshold, nucleons are emitted plentifully from the target nuclei; the kinetic energies of the nucleons are from a few up to about 500 MeV, as it can be concluded from the energy spectra of the emitted protons obtained experimentally [1] in the xenon bubble chambers and other track detectors.

The registration efficiency of the proton component in the 180 litre xenon bubble chamber [2] is almost 100%. The neutron component of the nucleons is registered in this chamber as well – neutrons can interact with the downstream atomic nuclei in the chamber and produce characteristic "stars" which may be observed around the hadron-nucleus collision center; we call these stars "neutral stars", because the hadrons initiating them (neutrons) are invisible. The registration efficiency of the neutrons by means of the neutral stars is much smaller than the registration efficinecy of the protons, it should be determined experimentally.

The subject matter in this paper is: 1. To determine experimentally the neutron registration efficiency in the 180 litre xenon bubble chamber [2] exposed to 3.5 GeV/c momentum pion beams from the Moscow accelerator at the Institute of Theoretical and Experimental Physics. The volume of this chamber is 103x44x40 cm^3, the beam is directed to the chamber along its length. 2. To obtain some direct experimental information about emission intensity of the neutrons in hadron-nucleus collisions.

The hadron-nucleus collisions under study occur within definite small fiducial volume around the center of the chamber.

2. DETERMINATION OF THE NEUTRON REGISTRATION EFFICIENCY

Let us start the determination of the neutron registration efficiency with some simple calculation.

2.1. Calculation of the Efficiency Coefficient

The registration efficiency for the neutrons is determined by the registration efficiency for the neutral stars.

The numbers n_p of the protons emitted from the target nuclei in pion-xenon nucleus collisions at 3.5 GeV/c momentum are $0 \leq n_p \leq 16$. The total sample of N collisions contains the total number N_p of the emitted protons:

$$N_p = \sum_{i=1}^{n} n_{p_i} \cdot N_{p_i} , \qquad (1)$$

where N_{p_i} is the number of the hadron-nucleus collisions in which n_{p_i} protons are emitted, among the total number N of the collisions; i = 1, 2, ..., 16. Together with the protons, corresponding number N_n of the neutrons should be emitted[3]:

$$N_n = N_p \frac{A-Z}{Z}, \qquad (2)$$

A = 131, Z = 54.

Some part of the neutrons produce the neutral stars observed in the chamber around the hadron-nucleus collision centers. The number of the neutral stars registered in the chamber we denote by N_n'.

The neutron registration efficiency we define as:

$$\eta = \frac{N_n'}{N_n} = \frac{N_n'}{\frac{A-Z}{Z} N_p} = \frac{Z}{A-Z} \cdot \frac{N_n'}{N_p}. \qquad (3)$$

But, the efficiency η expressed by formula (3) is overestimated, because the neutral stars are produced not only by the neutrons from the hadron-nucleus collisions under study but by the background neutrons as well. The background neutrons should be taken into account therefore.

2.2. Neutral Stars Background

The neutron background manifests itself, in its pure form, by the neutral stars on the photographs without interactions of the beam hadrons with nuclei inside the chamber. In order to determine this background, neutral stars were looked for on the photographs when the beam of hadrons passed without interactions inside the chamber. On z_0 = 2337± 94 such photographs z_1 = 379 ±20 neutral stars were found. These stars are the background neutral stars. The background per one photograph is then

$$k = \frac{z_1}{z_0}, \qquad (4)$$

its value depends on the neutron background sources. In our experimental conditions k = 0.169 ±0.016.

2.3. The Efficiency Coefficient

The mean number of the neutral stars registered on pohotographs on which the beam interactions with nuclei occur in the chamber is always larger than the mean number of the background neutral stars. The number N_n of the neutrons emitted from the nuclear targets in hadron-nucleus collisions, determined by formula (2), will be represented by new formula:

$$N_n^* = N_n' - N_{n\,b}, \qquad (4')$$

where N_n' is the number of neutral stars registered on the pictures with interactions of beam hadrons with nuclei inside the chamber; and $N_{n\,b}$, the number of stars registered on photographs but caused by the background neutrons.

And so, using the corrected data on N_n' and $N_{n\,b}$, we obtain from formula (3) the efficiency coefficient:

$$\eta = \frac{N_n' - N_{n\,b}}{N_n} = \frac{Z}{A-Z} \cdot \frac{N_n' - N_{n\,b}}{N_p}. \qquad (5)$$

Using experimental data, we obtain:

$$\eta = (27.6 \pm 5.8)\ \%. \qquad (6)$$

3. THE NEUTRON EMISSION INTENSITY

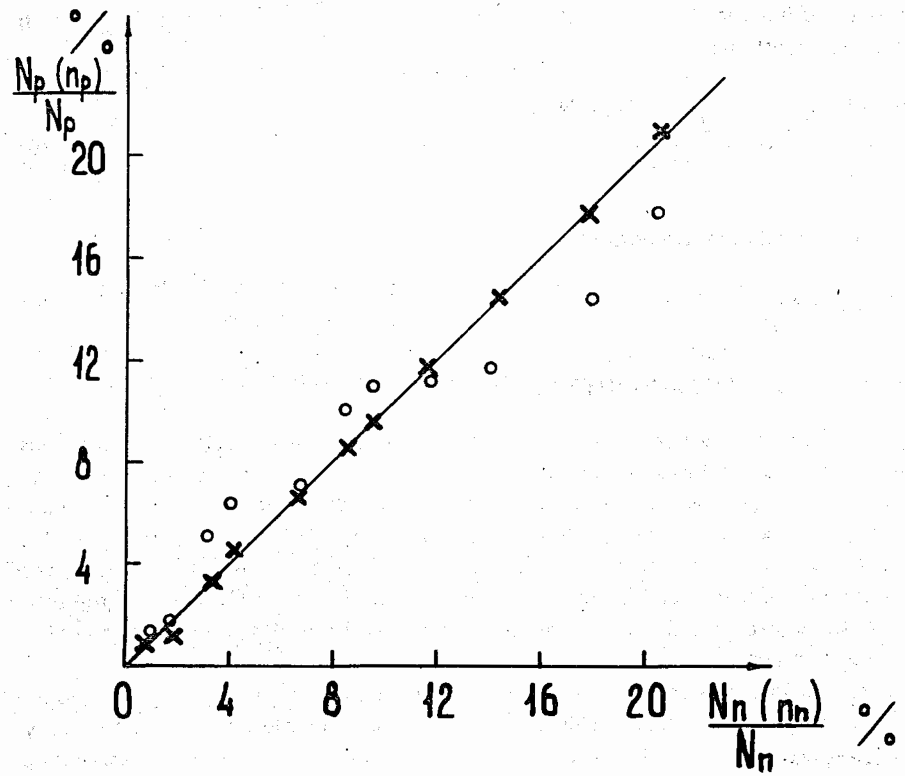
The intensity of the nucleons emitted in high energy hadron-nucleus collisions was studied at first on the basis of the experimental data on the proton component only; the mostly accurate analysis was performed for the data from the 180 litre xenon bubble chamber exposed to negatively charged pion beam at 3.5 GeV/c momentum[1].

The efficiency of the proton registration in various track detectors, and in the xenon bubble chamber used in our experiments as well, is about 100%, but the efficiency of the neutron registration is much smaller; it is about 28% in our xenon bubble chamber experiments[1].

It is convenient, therefore, to obtain some information about the neutron emission intensity from the neutral stars registered in the xenon bubble chamber not directly but by comparison of the data on the proton emission intesity with corresponding data on the neutron emission intensity obtained at identical conditions. As the measure of the intensity of the nucleon emission — of the proton and neutron emission — we use the number n_N of the nucleons emitted in a hadron-nucleus collision; for the protons it will be the number n_p of protons, for the neutrons — the number n_n of neutrons; the numbers n_N, n_p, and n_n are known as well as the multiplicities of the emitted nucleons, protons, and neutrons correspondingly.

Table. Experimental testing of the relation (8). $N_p(n_p)$ – the multiplicity n_p distribution of the emitted protons, $N_n(n_n)$ – the multiplicity n_n distribution of the emitted neutrons, in pion-xenon nucleus collisions at 3.5 GeV/c momentum in which definite number n_p = 0, 1, 2, ... protons is emitted; N_p and N_n values are in % of the total number of the pion-xenon nucleus collision events. The data on N_p are from previous work /1/

n_p	0	1	2	3	4	5	6	7	8	9	10
n_p %	20.8	17.8	14.3	11.6	9.5	8.5	6.6	4.3	3.2	1.6	0.9
n_n %	17.8	14.3	11.8	11.4	11.1	10.2	7.0	6.6	5.3	1.8	1.6



Experimental testing of the formula (8). $N_p(n_p)$ and $N_n(n_n)$ - the numbers of the pion-xenon nucleus collision events at 3.5 GeV/c momentum in which n_p protons are emitted; to this value of n_p n_n neutrons are emitted; n_p can be equal to 0, 1, 2, ..., 16. N_p and N_n - the total number of collisions at all the values of n_p – from n_p = 0 up to n_p = 16. X – experimental data obtained in this work, ● – experimental data from previous work /1/.

One question arose here of main importance in investigations of the nucleon emission: Whether various corresponding dependences on n_p and n_n are identical for a sample of the collision events or not? In particular, whether the $N_p(n_p)$ and $N_n(n_n)$ distributions of the multiplicities n_p of the emitted protons and of the multiplicities n_n of the emitted neutrons are identical for a sample of the collision events or not? The answer should be found in experiments; the correlations between $N_p(n_p)$ and $N_n(n_n)$ distributions should be found experimentally.

In the case when both the distributions $N_p(n_p)$ and $N_n(n_n)$ are identical – all the experimental values of the distributions at definite values of n_p – of the proton multiplicities in the hadron-nucleus collisions – lie on the line

$$N_p(n_p) = a \cdot N_n(n_n) + b \tag{7}$$

for the same proton multiplicities n_p = 0, 1, 2, ..., 16 in the sample of collisions under analysis. When a collision does not occur, $N_p(n_p) = 0$ and $N_n(n_n) = 0$, and b = 0. For collisions with given multiplicity n_p of the emitted protons it should be $N_p(n_p)$ = k% and $N_n(n_n)$ = k% of the collision events, and then

$$N_p(n_p) = N_n(n_n) \tag{8}$$

and a = 1, N are in percents of all the collision events under study, at some definite values n_p held unchanging.

Results of the experimental testing are presented in the table and in the figure.

4. CONCLUSIONS AND REMARKS

On the basis of the experimental results presented above, it may be concluded that:

1. Neutrons can be registered in the xenon bubble chamber by means of the "neutral stars"; in the 180 litre chamber the registration efficiency is about 28%.
2. The proton multiplicity n_p distribution $N_p(n_p)$ and the neutron multiplicity n_n distribution $N_n(n_n)$ in high energy hadron-nucleus collisions are practically the same; to any definite number n_p of the emitted protons the multiplicity $n_n \approx$ $\approx (A - Z)/Z \cdot n_p$ of the emitted neutrons corresponds.
3. From the known neutron registration efficiency, for a given detector, it is possible to determine the intensity of the neutron emission from the target nucleus by means of the neutral stars which the collisions under study are accompanied by.

The experimental information about the intensity of all the nucleons – neutrons and protons – allows to test the relation between the number of the emitted nucleons and the intranuclear matter layer thickness involved in a hadron-nucleus collision.

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