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исследований
дубна

E1-80-673

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AVERAGE NUMBER OF PROTONS KNOCKED OUT OF C, Ne, Al, Cu, Pb NUCLEI BY ^{4}He WITH A MOMENTUM OF 4.5 GeV/c PER NUCLEON

Submitted to ЯФ

1980

I. INTRODUCTION

Experimental data on positive particle production in ^{4}He+A interactions have been obtained using a 2m streamer chamber in a beam of ^{4}He nuclei with a momentum of 4.5 GeV/c per nucleon extracted from the Dubna synchrophasotron. A detailed description of the setup is presented in paper /1/ (see also /2/). Here we present briefly the information on the setup which is more significant to analyze the material obtained. The 60x100x200 cm^3 streamer chamber filled with pure neon at atmospheric pressure was placed in a magnetic field of ~0.8 T. The targets were mounted inside the fiducial volume of the chamber and had the following thicknesses: C- 0.40 g/cm^2, Al - 0.41 g/cm^2, Cu - 0.47 g/cm^2, Pb - 0.23 g/cm^2. The neon filling the chamber was used as a target as well. To select events, use was made of a system of scintillation counters and fast electronic logic /3/. The events were investigated of any interaction (except elastic scattering) of the projectile-nucleus in the target or in the chamber gas.

II. EXPERIMENTAL METHOD AND POSSIBLE SYSTEMATIC ERRORS

Experimental data on the total multiplicity of charged particles produced in ^{4}He+A interactions and characteristics of the multiple production of negative particles published previously /2/ have been obtained as a result of scanning the films twice. If there were discrepancies between results of the two scans, a third scan was made.

Let us consider the reasons which can lead to distortion of the multiple production characteristics.

1. Triggering system

In some cases when the ^{4}He nucleus is not broken up after inelastic interaction in the target and deflects through an angle of<10 mrad, it imitates the particle having passed through the target without interaction and, thus, such an event is not photographed. The cases, when ^{3}He nuclei enter a veto counter, lead to a similar distortion, although this probability turns out to be small due to the deflection of these particles by the magnetic field. These effects (as does a possible imitation of beam particles by singly charged ones) have been analyzed in detail and, as is shown, their influence on average multiplicity does not exceed $2 \div 3\%$ (see also[2]).

2. Multiple Interactions in the Target

Due to small thicknesses of the targets used in the experiment, the probability of multiple interactions is small and the corresponding error in determining the average multiplicity is no larger than $2 \div 3\%$.

To analyze data on the multiple production of positive particles, one should choose a bound of detected momenta of positive particles. As such bounds, one chooses $P_1 = 240$ MeV/c (kinetic energy $T_1 = 30$ MeV) and $P_2 = 290$ MeV/c ($T_2 = 45$ MeV). The first bound corresponds to the conventional one of the "b"-particle spectrum in emulsion terms. The estimates have shown that the loss of $T > 30$ MeV protons is insignificant due to absorption in the target.

Note that, when selecting b-particles, positive pions are sure to be not included in this group which differ markedly from protons in ionization over the momentum ranges considered.

III. RESULTS AND DISCUSSION

Later on the following designations will be used: n_{ch} is the observed number of charged particles; n_b is the observed number of protons with a kinetic energy of $T_1 < 30$ MeV ($T_2 < 45$ MeV); n_- is the number of negative particles; n_2 is the number of fast fragments with $Z=2$ (^{4}He and ^{3}He nuclei).

Table 1 presents experimental data on $\langle n_{ch} \rangle$, $\langle n_b \rangle$ and values of $\langle n_p \rangle = \langle n_{ch} \rangle - 2\langle n_- \rangle + \langle n_2 \rangle - 2$. The value of $\langle n_p \rangle$ is the average number of protons knocked out of the target-nucleus and having an energy of above 30 MeV (45 MeV). The term $2\langle n_- \rangle$ denotes the average number of π^+ and π^- mesons as $\langle n_{\pi^+} \rangle \simeq \langle n_{\pi^-} \rangle$ (for ^{4}He+C interactions it is performed accurately and for others approximately). The term $2 - \langle n_2 \rangle$ takes into account the number of charged particles which are the fragments of the projectile-nucleus. It is interesting to compare the experimental data obtained with those received using emulsion technique. To this end the value of $\langle n'_{ch} \rangle = \langle n_{ch} \rangle - \langle n_b \rangle - \langle n_2 \rangle$ has been found which corresponds to the sum $\langle n_g \rangle + \langle n_s \rangle$ of emulsion works[4,5]. Using the above experimental data, as well as those on ^{4}He+A interaction inelastic cross sections[6], it is not difficult to find the effective atomic

Table

Experimental data for the value of $\langle n_{ch}\rangle$, average observed number of charged particles, for $\langle n_b\rangle$, average observed number of protons with a kinetic energy of <30 MeV and < 45 MeV and for $\langle n_p\rangle$, average number of protons knocked out of the target-nucleus and having a kinetic energy of > 30(45) MeV in ^{4}He -nucleus interactions

	$\langle n_{ch}\rangle$	$\langle n_b\rangle$		$\langle n_p\rangle$	
		T_p<30 MeV	T_p<45 MeV	T_p > 30 MeV	T_p > 45 MeV
C	6.2±0.2	0.41±0.02	0.65±0.03	1.9±0.3	1.6±0.3
Ne	8.0±0.2	0.90±0.04	1.17±0.06	2.6±0.3	2.2±0.3
Al	8.0±0.2	0.75±0.03	1.10±0.05	2.7±0.3	2.4±0.3
Cu	10.5±0.4	1.44±0.07	2.08±0.1	4.6±0.5	4.0±0.5
Pb	17.2±0.9	2.42±0.13	3.51±0.2	8.8±1.0	7.7±1.0

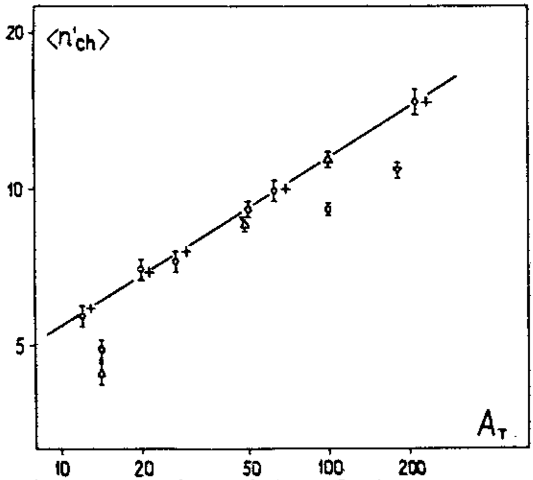

Fig.1. Atomic weight of the target-nucleus, A_T, versus the average multiplicity of singly charged particles, $\langle n'_{ch}\rangle$, (see the text) in the ^{4}He+A interactions. o – our data, Δ– emulsion data [4], ◇ – emulsion data [5], ∇ –He+Ta data[7], □ – calculation by the cascade model[10], + – calculation by the cascade model [8,9].

emulsion weight which turns out to be 50 for He+A interactions. Fig.1 shows that our data and those obtained in the emulsion experiments[4,5] are in good agreement.

The authors of paper[4], in addition to average multiplicity data for emulsion nuclei, present results on $\langle n_g\rangle$ and $\langle n_s\rangle$ for CNO and AgBr separately. As is seen from fig.1, if the value of $\langle n_g\rangle+\langle n_s\rangle$ for AgBr agrees well with our data, its difference for light nuclei is significant. The reason of this is likely to lie in the fact that the value of $\langle n_g\rangle+\langle n_s\rangle$ for light nuclei is rather sensitive to small changes of the corresponding value for heavy nuclei.

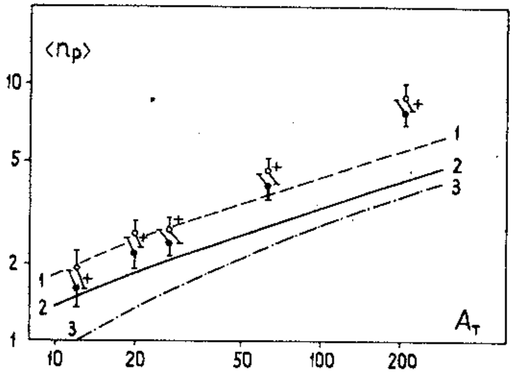

Fig.2. Atomic weight of the target-nucleus, A_T, vs the average number of protons knocked out of the target-nucleus by ^{4}He nuclei.

o – for protons with a kinetic energy of > 30 MeV.

● – for protons with a kinetic energy of > 45 MeV.

+ – calculation by the cascade model /8,9/. Curves:

1 – $\langle n_p\rangle = \frac{Z_T\sigma^{tot}_{NHe}}{\sigma_{HeA}}$;

2 –$\langle n_p\rangle = \frac{Z_T\sigma^{in}_{NHe}}{\sigma_{He}A}$;

3 – calculated by the fireball model /13/.

Figure 1 also presents the value of $\langle n_+\rangle + \langle n_-\rangle = \langle n'_{ch}\rangle$ for ^{4}He + Ta interactions (propane chamber data /7/). The value of $\langle n'_{ch}\rangle$ for ^{4}He + Ta is appreciably different both from our and from emulsion data. The results of calculation by the cascade model /8,9/ are in good agreement with the experimental data obtained (fig.1). The calculation by the cascade model presented in paper /10/ gives the worst agreement with experiment (fig.1). Figure 2 shows the average multiplicities, $\langle n_p\rangle$, of protons knocked out of the target-nucleus and having T > 30 MeV and T > 45 MeV. The dependence of $\langle n_p\rangle$ on the atomic weight of the target-nucleus, A_T, is well described by the formulae

$$\langle n_p\rangle = 0.5A_T^{0.55}$$

(T > 30 MeV),

$$\langle n_p\rangle = 0.4A_T^{0.55} \qquad (1)$$

(T > 45 MeV).

The formula /11,12/ for average number of nucleons of the nucleus B, which take part in interactions with the projectile A, is often used in the calculation related to hadron-nucleus and nucleus-nucleus interactions:

$$\nu = \frac{B\sigma_{NA}}{\sigma_{AB}} . \qquad (2)$$

Here σ_{NA} is the nucleon-nucleus interaction inelastic cross section and σ_{AB} is the A–B interaction inelastic cross section. The number of protons, $\langle n_p \rangle = \frac{Z_T \nu}{A_T}$, knocked out of the target-nucleus calculated by formula (2) is given in fig.2. One can see that the discrepancy of the calculated and experimental data is rather large, particularly for heavy targets. From our point of view, when the number of knocked out protons is calculated, one should substitute in the numerator of formula (2) not the inelastic cross section of nucleon-nucleus interaction (this is reasonable when the question is particle production) but some effective cross section σ_{eff} which includes interaction inelastic cross section and that part of elastic one when a nucleon gets a momentum sufficient for its knockout of the nucleus. Figure 2 shows the curve corresponding to formula (2) but with $\sigma_{NA} = \sigma_{NA}^{tot}$. It is seen that the discrepancy holds in this case. Note that formula (2) is valid in case of straightforward passage of the nucleons of the projectile-nucleus through the target-nucleus. Taking into account "disintegration" of the projectile-nucleus results in increasing the number of nucleons knocked out of the target.

The experimental data obtained can be compared to a fireball model developed in a series of papers/13-15/. The following mechanism of particle production is supposed in this model. A fireball and two nuclear fragments, which are in a weakly excited state, are produced in nuclear collisions. In the fragment system, protons fly out of it with an energy of no more than 30÷40 MeV/13/ Thus, the protons, which have an energy of above 30÷40 MeV in the laboratory system in this model, are produced as a result of decaying the fireball and the projectile-nucleus fragment. The number of nucleons in the fireball is determined by the sum of the numbers of nucleons "cut out" by the projectile-nucleus and the target-nucleus in one another ("clean out" hypothesis/13-15/). The value of $\langle n_p \rangle$ in our experiment comprises $>30(45)$ MeV protons and corresponds to the average number of protons of the target-nucleus which enters into the fireball. The result of the calculation made on the same assumptions as in papers/13-15/ is shown in fig.2 (curve 3). The model prediction differs from the experiment almost by a factor of 2 over the whole region of changing target atomic weights.

On the other hand, the calculation by the cascade model/8,9/ agrees well with the experimental data (see figs.1,2).

The authors express their gratitude to M. Gazdzicki, K.G.Gulamov and E. Skrzypczak for discussion of the questions considered in this paper.

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Received by Publishing Department
on October 20 1980.