TRANSVERSE MOMENTUM DISTRIBUTIONS OF RELATIVISTIC CHARGED FRAGMENTS IN ^{12}C–EMULSION COLLISIONS

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The systematic study of the transverse momentum distributions of the multicharged fragments shows that the presence of high p_t tail distorts the distributions of fragments and the fragmentation model describes the features of these distributions only for $p_t \leq 500$ MeV/c. Values of Nuclear Fermi momentum obtained in the present experiment are in agreement with that of electron scattering experiment and the excitation energy observed is the order of binding energy per nucleon. Analysis of diffraction dissociation ($^{12}\mathrm{C} \rightarrow 3\,^4\mathrm{He}$) events shows that the percentage of such type of events is 2.0 of the total inelastic collisions and such type of reaction goes through an intermediate ^{8}Be state.

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1. Introduction

Recently much experimental and phenomenological effort has been devoted towards the investigation of relativistic heavy ion collisions. On account of the complex nature of these collisions, only multiplicity and single particle inclusive spectra have been commonly studied. It is well known that nuclear emulsion have by far the highest spatial resolution than any other particle detectors. It is a 4π detector and allows an exclusive type of analysis on an event by event basis. Much information about the dynamics of the fragmentation process can be obtained from the analysis of momentum distribution of fragments. A very important result found in the inclusive experiment [1] is that the momentum distributions of the fragments have approximately a Gaussian shape in the rest frame of fragmenting nucleus. The momentum distribution has also a parabolic dependence on the mass of the fragment. These regularities follow naturally from the statistical approach to the fragmentation process with minimal correlations between momenta of intranuclear nucleons.

Fragmentation of relativistic projectile nuclei would give the information about the internal structure of nuclei under condition of small transfer of momentum and energy. However, the partner nucleus in an inelastic collisions is not a simple spectator of the fragmentation process as it is assumed in participant and spectator model. The dynamics of inelastic collisions of high energy nuclei appreciably distorts the intranuclear characteristics of the nucleons and nucleon cluster as a consequence of transverse motion of the fragmenting residual nuclei, the angular momentum, effects of intranuclear rescattering and so forth [2, 3]. This makes it interesting to study those collisions channel of nuclei in which the effect of the partner-nucleus would be minimal. One should expect that we can assign reactions of this type, those which are extremely peripheral, *i.e.*, reaction of dissociation of incident nucleus in the field of the target.

In the present paper the transverse momentum distributions of ^{12}C--fragments have been discussed. Different parameters such as momentum width, Fermi momentum and temperature for excitation are calculated and compared with the other experimental results for different projectiles and energies. Finally, the diffraction dissociation of ^{12}C nuclei in nuclear emulsion have been also studied.

2. Experimental details

This experiment has been performed in a stack of BR-2 emulsion having 600 μm thickness exposed at Dubna Synchrophasotron to a beam of ^{12}C nuclei with momentum 4.5 A GeV/c. A total of 4587 inelastic collisions of carbon nuclei were picked up by following 63254.74 cm of primary track length, leading to the mean free path of ^{12}C nuclei in emulsion equal to (13.79 ± 0.25) cm. Out of these, 2550 inelastic collisions were selected, without any bias, for the final analysis. Details of classification of events, selection criteria, methods of measurements and identification of projectile fragments *etc.* are already given in our earlier publications [4, 5].

3. Experimental results

3.1. Transverse Momentum Distribution

In an emulsion experiment it is not possible to make direct measurement of momentum of high energy projectile fragments. However, the transverse momentum can indirectly be measured by using the fact that the fragments have nearly the same momentum per nucleon as that of the projectile. Thus the transverse momentum of a fragment of charge Z can be calculated by using the relation [6]

$$p_t = A_F p_0 \sin\theta\,, \tag{1}$$

where p_0 is the momentum of the projectile, A_F is the mass number of fragment and θ is the angle of emission of the fragment. For fragments with $Z \leq 2$ the above relation gives a reliable estimate of the transverse momentum. However, due to the excess of neutron rich isotopes, it gives a lower limit for the transverse momentum of fragments with $Z \geq 3$.

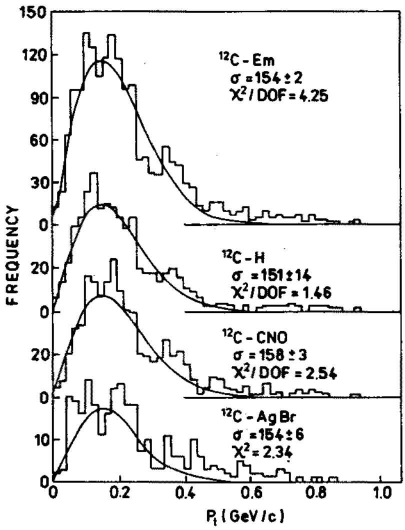

Fig. 1. Transverse momentum distributions of $Z = 2$ fragments in different target groups with Gaussian curves fitted to the data for $p_t \leq 500$ MeV/c.

TABLE I

Average transverse momenta of projectile fragments in different group of $^{12}C - Em$ collisions

Charge of fragments	$\langle p_t \rangle$ GeV/c			
	$^{12}C - H$	$^{12}C - CNO$	$^{12}C - AgBr$	$^{12}C - Em$
Z=2	0.21 ± 0.02	0.24 ± 0.02	0.29 ± 0.03	0.24 ± 0.01
Z=3	0.21 ± 0.06	0.33 ± 0.07	0.34 ± 0.01	0.29 ± 0.04
Z=4	0.21 ± 0.09	0.23 ± 0.08	0.32 ± 0.13	0.24 ± 0.05
Z=5	0.21 ± 0.12	0.27 ± 0.08	0.32 ± 0.11	0.28 ± 0.06
Z=6	0.22 ± 0.14	0.29 ± 0.08	0.30 ± 0.12	0.28 ± 0.06

Table I gives the average transverse momentum $\langle p_t \rangle$ of fragments with different charges in collisions of ^{12}C with different target groups. We notice that $\langle p_t \rangle$ increases with the mass of the target.

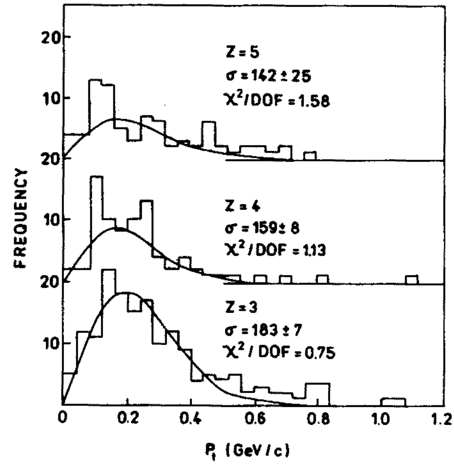

Fig. 2. Transverse momentum distributions of $Z = 3, 4$ and 5 fragments with Gaussian curves fitted to the data for $p_t \leq 500$ MeV/c.

Figs. 1 and 2 show the transverse momentum distributions of fragments with charge $Z \geq 2$. For $Z = 2$ fragments, these distributions are plotted for different target groups. The distributions are fitted with a curve of type

$$N(p_t) = A p_t \exp\left(-\frac{p_t^2}{2\sigma^2}\right), \tag{2}$$

for $p_t \leq 500$ MeV/c. The curve is expected if each component of transverse momentum, p_x and p_y follow a Gaussian distribution [11, 12]

$$N(p) = A \exp\left(-\frac{p^2}{2\sigma^2}\right). \tag{3}$$

It should be mentioned here that if we include fragments with $p_t > 500$ MeV/c, then the p_t distribution cannot be fitted with the curve given by relation (2) indicating presence of nonstatistical contribution [7–10].

The observed values of $\sigma(P)$ can be related to the nuclear Fermi momentum, p_f, assuming the sudden emission of α-clusters [11, 12]. The relation comes out to be

$$\sigma^2(P) = \frac{p_f^2 A_F(A_P - A_F)}{5(A_P - 1)} \tag{4}$$

and if it is assumed that the nucleus comes to thermal equilibrium, then $\sigma(P)$ can also be related to excitation energy, KT, through the relation

$$\sigma^2(P) = KT\frac{m(A_P - A_F)A_F}{A_P}, \tag{5}$$

where A_P and A_F are respectively the mass numbers of the projectile and the fragment and m is the proton mass.

TABLE II

Table showing the temperature (excitation energy of binding energy), Fermi momentum and $\sigma(P)$

Projectile (A GeV/c)	Fragments	$\sigma(P)$ (Experiment) MeV/c	$\sigma(P)$ (Theory) MeV/c	Fermi momentum (p_f) MeV/c	Temperature (KT) MeV	Reference
^{12}C	He	125 ± 3	143	176(221)*	6.2	
(1.0)	Li	122 ± 10	146	151	5.3	
	Be	131 ± 9	125	187	8.1	[1]
	B	135 ± 9	108	224	11.5	
^{12}C	He	129 ± 1	134	169(221)*	6.7	
(2.85)	Li	127 ± 7	146	157	5.7	[1]
	Be	133 ± 3	125	190	8.4	
	B	134 ± 3	108	222	11.5	
^{12}C	He	154 ± 2	134	202(221)*	9.5	present
(4.5)	Li	183 ± 7	146	226	11.9	Experiment
	Be	159 ± 8	125	227	12.0	
	B	142 ± 25	108	235	12.9	
^{14}N	He	141 ± 6	134	180(226)*	7.4	
(2.8)	Li	212 ± 15	153	247	13.9	[13]
	Be	237 ± 22	152	285	18.6	
	B	174 ± 20	131	221	11.3	

*Fermi momentum obtained in electron scattering experiment of Moniz *et al.* [14]

Table II presents values of $\sigma(P)$ for fragments of different charges observed in the present as well as in other experiments on the fragmentation of relativistic nuclei along with the values of p_f and KT calculated using relations (4) and (5). We notice that $\sigma(P)$ values observed in emulsion experiments are higher than those observed in 0° experiment [1]. This is due to the fact that in the 0° experiment projectile fragments with $\theta < 0.7°$ were detected using a spectrometer and therefore large transverse momentum transfers were not recorded in this experiment. The values of Fermi momentum obtained in the present experiment are quite comparable with those obtained in electron scattering experiment of Moniz *et al.* [14]. We further notice that values of the excitation energy, KT are also comparable to the binding energy per nucleon, indicating that very small energy transfer takes place between the target and a fragment during the fragmentation process.

3.2. Diffraction Dissociation of ^{12}C Nuclei

In the present Section we will discuss the diffraction dissociation of relativistic carbon nucleus into three ^{4}He fragments ($^{12}C \rightarrow 3\,^4He$). The percentage of such type events in our sample is 2.0, which is complete diffraction dissociation events.

We assume that the momentum of each ^{4}He fragment emitted in a dissociated events is equal to one third of the projectile nucleus momentum p_0 consequently, the transverse momentum of each fragment is given by

$$q_i = \tfrac{1}{3} p_0 \sin\theta_i \,, \tag{6}$$

where θ_i is the angle of emission of the fragment. The vector sum of q_i in each event is equal to the transverse momentum transferred to the ^{12}C nucleus in the diffraction dissociation process. Therefore, to the first approximation, the transverse momentum of each ^{4}He particle

$$\vec{q_i}^{\,*} = \vec{q_i} - \tfrac{1}{3}\sum_{i=1}^{3} \vec{q_i} \,. \tag{7}$$

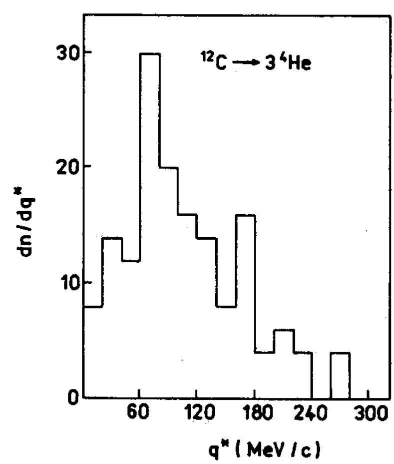

Fig. 3. Transverse momentum distribution of ^{4}He particles inside the carbon projectile nucleus as deduced from $^{12}C \rightarrow 3\,^4He$ dissociation events.

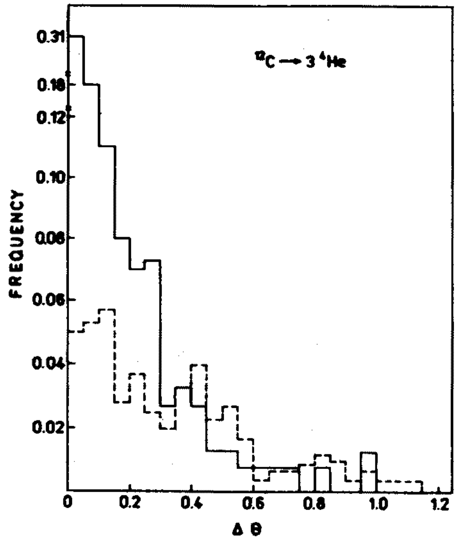

Fig. 4. Frequency distribution of the difference in the angle of emission of ^{4}He fragments for ^{12}C → 3 ^{4}He events (___ observed distribution, ... uncorrelated distribution).

Fig. 3 shows the transverse momentum distribution of ^{4}He particles inside the carbon projectile nucleus, q^*. In the case of diffraction dissociation events, it has been observed that in most of the events, two ^{4}He fragments are emitted within a very narrow angle along the beam direction, *i.e.*, having low transverse momentum. The third ^{4}He fragment is emitted at relatively large angle, *i.e.*, it has a relatively large transverse momentum, probably to compensate for the sum of transverse momenta of the other two ^{4}He particles. This indicates that the dissociation of ^{12}C to 3 ^{4}He goes through an intermediate ^{8}Be state. To confirm this, we plot in Fig. 4 the frequency distribution of the difference of the angle of emission of ^{4}He fragments, $\Delta\theta$. From the figure it is clear that about one third events lie in the low range of $\Delta\theta$. Also shown in Fig. 4 is the uncorrelated distribution which has been generated taking into account the transverse momentum conservation. The observed distribution deviates significantly from the uncorrelated distribution. Therefore we conclude that the dissociation of ^{12}C to ^{4}He occurs through an intermediate ^{8}Be state.

4. Conclusions

The following conclusions can be drawn from the present investigations:

(i) Presence of large p_t particles distorts the transverse momentum distributions. However, for $p_t \leq 500$ MeV/c, the distributions agree with the predictions of the fragmentation model.

(ii) The value of Fermi momentum calculated from the observed values of $\sigma(P)$ is in agreement with that obtained in electro scattering experiment.

(iii) The observed excitation energy is of the order of binding energy per nucleon, indicating that little energy transfer takes place during the fragmentation of ^{12}C nuclei.

(iv) The percentage of diffraction dissociation events are 2.0 of the total inelastic collisions. The study of such type of events indicates that this reaction goes through an intermediate ^8Be state.

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