объединенный
институт
ядерных
исследований
дубна

E1-80-552

K.D.Tolstov

COMPLETE DESTRUCTION OF HEAVY NUCLEI BY HADRONS AND NUCLEI

Submitted to "Zeitschrift für Physik,A"

1980

The phenomenon of complete destruction of heavy nuclei, when the most part of nucleons is emitted, is of interest for studies of the behaviour of nuclear matter in extreme conditions [1-10]. This phenomenon occurs at central collisions of hadrons and high energy nuclei, and, considering it in the spacetime aspect, one can conclude that at some moment in the volume, which is close to that of the target nucleus, there are its nucleons, nucleons of the incident nucleus and particles produced. Thus, in the volume of the target nucleus or of its part there is concentrated an energy which is much higher than the binding energy of nucleons.

Probability of complete destruction. According to the data obtained in photoemulsion experiments, the complete destruction of Ag nuclei occurs when ≥ 28 charged particles are ejected, except those newly produced; as for Pb nuclei, their complete destruction takes place when ≥ 40 particles fly out. In papers [2,4,6] it has been shown that at such selection there is no residual nucleus with large mass, and the total charge of the fragments is close to that of the target nucleus. Figure 1 shows the probability of complete destruction of Ag and Pb nuclei by protons of energies of 10÷200 GeV and by ^{4}He and ^{12}C nuclei of 3.7 GeV/nucleon kinetic energy.

Number and energy of secondary particles. The Table presents the data on the number and energy of different secondary particles. Among them there are relativistic protons and pions, s ($\beta > 0.72$), protons, g, in an energy range of $30 \leq E \leq 400$ MeV, and slow fragments of the nucleus, b.

As it follows from the Table, and this is essential for collision mechanism, $\langle n_g \rangle$ and $\langle n_b \rangle$ are not related to the number of generated pions. A large difference between mean energies E_g and E_b is independent of the energy and mass of the projectile and of the target mass as well. At the same time the number of these particles is redistributed so that the ratio $\langle n_g \rangle / \langle n_b \rangle$ increases more than by a factor of four when P + Ag collisions are changed for ^{12}C + Ag ones. From this it follows that groups of these particles are due to various processes.

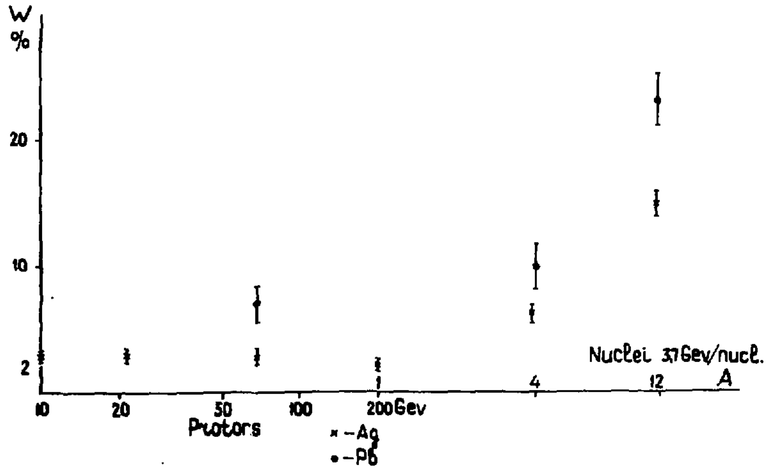

Fig.1. Probability of complete destruction of Ag and Pb nuclei as a function of the mass and energy of projectiles.

Table

mean	P+Ag 10 GeV	P+Ag 70 GeV	P+Pb 70 GeV	He^4+Pb 14 GeV	He^4+Ag 14 GeV	C^{12} + Ag 43 GeV
$\langle n_s \rangle$	4,0±0,5	17,1±0,8	20,7±1,0	12,5±1	9,4±0,4	18,6±0,7
$\langle n_g \rangle$	10,0±0,8	14,2±0,8	23,0±1,0	34,7±2,4	19,8±1,4	22,3±0,8
$\langle n_b \rangle$	22 ±1,2	15,8±1,0	19,2±0,4	12,7±1,3	10,9±1,0	11,1±0,5
$\langle E_g \rangle$	120±12 MeV	-	-	-	138 + 4	148±3 MeV
$\langle E_b \rangle$	19±2 MeV	19±2	18,5±2	22±2	18,2±2 MeV	-

Angular distribution of particles. In many papers [5,6,11] it has been noted that the angular distribution of g-particles is weakly dependent ("conservatism") on variation of the projectile mass and energy and the target mass. For example, the apex angles of cone, $\theta_{1/2}$, at which half the g-particles flies out, are equal to 70° and 68° in the collisions of 70 GeV protons with Ag and Pb nuclei and to 60° and 66° in the interactions of 16 GeV ^4He nuclei with Ag and He ones [6]. The angular distribution of b-particles has a small deviation from the isotropy along the primary beam axis and is also weakly dependent on the projectile mass and energy and on the target mass.

Data analysis. From figure 1 it follows that the probability of complete destruction of heavy nuclei of a given mass is independent of the number of pions generated in the collision. The data of the Table show that not pions are responsible for the multiplicity of g and b-particles. From these facts it follows that the process of complete destruction of nuclei is not due to the generation in collisions of new particles and their interactions in the nucleus, i.e., to the cascade process. The probability of complete destruction of nuclei and the number of g-particles increases strongly with increasing the mass of projectile and target. At the same time their mean energy and $\theta_{1/2}$ angles are practically unchangeable.

Further it is important to note that the characteristics of secondary particles when the complete destruction of nuclei takes place (central collisions) are similar to those at "average" collisions when the impact parameter is larger. Figure 2 taken from paper [12] illustrates this fact. It shows $\langle E \rangle$ for protons as a function of their emission angle in $^{12}C+Ag$ collisions at the complete destruction of target nuclei and in all other cases. In p+Pb collisions at 70 GeV [13,14] $\theta_{g,1/2} = 66° \pm 1°$ and $\langle E \rangle = 21 \pm 2$ MeV which is close to the data of the Table. From this it follows that there is no qualitative difference in interaction mechanism at central collision, which leads to the complete destruction of the target, and peripheral one, when the greater part of the target nucleus is conserved. At the same time the emission of slow b-particles is usually assumed to be the process of evaporation of the excited nucleus but it is not suited to describe the destruction as there is no residual nucleus. This contradiction can be overcome if the non-equilibrium (non-evaporating) process is accepted. However, the difference in energy and angular distributions of g- and b-particles is then indicative of a two-stage character of this non-equilibrium process. At the first stage, just as the projectile traverses the nucleon, there occurs the emission of g-particles. At the second stage b-particles fly out of the deformed (excited) part of the nucleus at the peripheral collision, and the residual nucleus receives a small portion

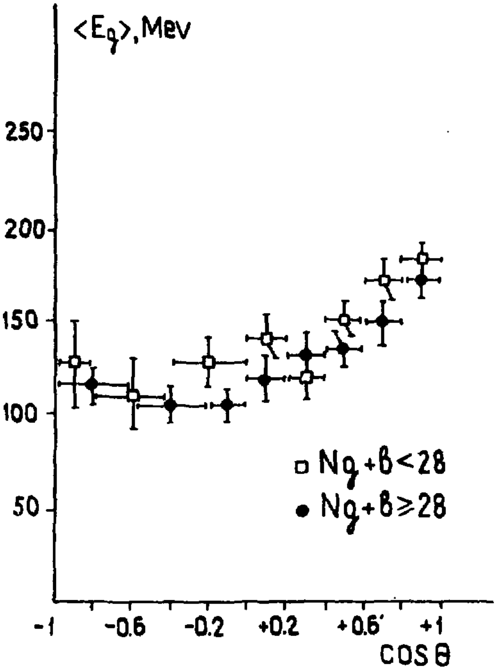

Fig.2. Average energy of g-protons in $^{12}C+Ag$ collisions as a function of emission angle in the laboratory system.

of energy. The second stage is also a fast non-equilibrium process and at the central collision the nucleus is completely destroyed, mainly, into individual nucleons; the non-equilibrium character of the process is responsible for the presence of a very soft part of the spectrum of 1 MeV particles found in works [2,6,14]. If we know the values of energies and, consequently, of velocities of g- and b-particles, we can estimate the time necessary for their emission from the nucleus. A velocity of ~0.2÷0.5 corresponds to 20÷50 MeV protons. Hence, for the time of flight of the projectile nucleus at the peripheral collision only the lesser part of its nucleons can fly out. At the central collision, excitation has no time to reach the peripheral nucleons for the time of flight of the projectile through the nucleus as the indicated velocity of recoil nucleons is small (and also as the sonic speed in the nucleus is estimated to be ~0.2÷0.3β).

Thus, at central collisions of nuclei the matter density in the zone of interaction is determined by the total number of nucleons plus pions generated. In the $^{12}C+Ag$ nuclei collisions, according to the table, when π^0 mesons are taken into account, one should expect nearly a 4-fold increases of the nuclear matter density in the interaction zone as compared to the usual one. To describe such a state, the author of paper "Central Impact of Relativistic Nuclei" [15] has proposed the model of nuclear fireball. While discussing a possible collective interaction which is due to a large density of matter and energy in the zone of collision, it has been said, "In this case nuclear matter behaves itself, as it were one gigantic fireball carrying a large baryon charge which next decays into baryons and pions". A similar model appeared later on in paper [16].

The mentioned properties of secondary particles when the complete destruction of heavy nuclei occurs indicate a collective character of interaction as noted in papers [6,10,12].

Among theoretical models the shock wave model has been developed most of all [17-22]. Comparing the energy spectrum of secondary particles and their emission angles with it, one should consider two components. The head shock wave captures the target nucleons which are enclosed in a tube with a section dependent on the projectile diameter. The wave normal to the Max cone captures the nucleons on this way. In the relativistic region, the velocities of projectiles are $v \simeq c$. Therefore the Max cone angles, $\arccos a/v$, are approximately independent of the projectile energy and mass if the velocity of nuclear sound, -a, changes weakly. However, the velocity of Fermi motion of nucleons in the nucleus is comparable to "a" and, consequently, one cannot expect a sharp maximum at particle emission. Further the velocity of the head shock wave is evidently smaller than that which corresponds to the equality of the projectile momentum to the sum of the nucleon momenta affected by the wave since a part of the momentum is transferred by pions. The velocity which corresponds to the maximum energy of g-protons 400 MeV, may be accepted as the head shock wave velocity; it corresponds to $\beta = 0.72$. In accordance with this, one can estimate the front delution of the head shock wave due to the Fermi momentum; for example, at $P_{\perp} = 150$ MeV/c $\beta = 0.15$ and $\phi = \mathrm{arctg}\, 0.15/0.72 = 12°$.

An indication that the shock wave does not contradict experiments has been noted already in the first works carried out by the group of E.Shopper. In model testing, the angular anisotropy of particles should be considered with regard to the contribution of the head shock wave and the influence of the Fermi momentum on particle emission.

Thus, the consideration of general properties of secondary particles, when the complete destruction of heavy nuclei occurs, provides an indication of the appearance of the collective interaction mechanism of the shock wave type in the nucleus with the ejection of fast particles out of the nucleus at the stage of flight of the projectile through the target, and the explosive decay of the residual nucleus into slow particles at the last stage.

REFERENCES

1. Tolstov K.D. JINR, P1-2016, Dubna, 1965.
2. Tolstov K.D., Khoshmukhamedov B.A. JINR, P1-6897, Dubna, 1973.
3. Gagarin Yu.F., Ivanova N.S. Izv.AS USSR, 1974, 38, p.988.
4. Tolstov K.D. JINR, P1-9286, Dubna, 1975.
5. Bannik B.P. et al. JINR, P1-1076, Dubna, 1977.
6. Akhrorov O. et al. JINR, P1-9963, Dubna, 1978.
7. Jakobson B., Kulberg R., Otterlund J. Z.Phys., 1974, 268, p.1.
8. Bannik B.P. et al. Z.Phys., 1978, A284, p.283.
9. Bogdanov V.G. et al. Preprint RI-92, 1978.
10. Solomov D.A. JINR, 1-11050, Dubna, 1977.
11. Antonenko V.G. IAE-3220, 1979.
12. Antonchik V.A. et al. JINR, P1-12111, Dubna, 1979.
13. Abdo K.M, et al. JINR, E1-8021, Dubna, 1974.
14. Dalkhazhav N. et al. Ya.F., 1976, 23, p.1210.
15. Tolstov K.D. JINR, P1-8662, Dubna, 1975.
16. Westfall G.D. et al. PRL, 1976, 37, p.1202.
17. Svheid W., Muller W., Greiner W. PRL, 1974, 32, p.241.
18. Kalinkin B.N., Shmonin V.L. JINR, P4-7479, Dubna, 1974.
19. Baumgordt H.G. Z.Phys., 1975, A273, p.359.
20. Amsden A.A. et al. PRL, 1975, 35, p.905.
21. Galitskii V.M., Mishustin I.N. Yad.Fiz., 1979, 29, p.363.
22. La Camera M., Wataghin A. Nuovo Cim., 1978, 47A, p.35.