объединенный
институт
ядерных
исследований
дубна

E1-84-417

EMISSION OF LIGHT FRAGMENTS ^{3}H, ^{3}He, AND ^{4}He IN ^{4}He-NUCLEUS COLLISIONS AT 3.33 GeV/N KINETIC ENERGY

Submitted to "Nuclear Physics A"

1984

L.I.Abashidze, G.G.Beznogikh, V.A.Budilov, N.L.Gorshkova, T.F.Grabovskaya, A.P.Laricheva, St.Mrówczyński, V.A.Nikitin, P.V.Nomokonov, N.K.Zhidkov
Joint Institute of Nuclear Research, Dubna, USSR

V.V.Avdeichikov, V.I.Bogatin, Yu.A.Murin, V.S.Oplavin
V.G.Khlopin Radium Institute, Leningrad, USSR

V.D.Maisyukov
Union Scientific Research Institute of Industry, Moskow, USSR.

A.Nawrot, I.P.Zielińsky
Institute for Nuclear Studies, Warsaw, Poland

J.Złomańczuk
Institute of Experimental Physics, Warsaw University, Warsaw, Poland

I. INTRODUCTION

In this paper we report on results of measurements of the emission of ^{3}H, ^{3}He, and ^{4}He in ^{4}He collisions with various nuclear targets: ^{9}Be, ^{12}C, ^{27}Al, ^{64}Cu, ^{108}Ag, and ^{197}Au at a beam kinetic energy of 3.33 GeV per nucleon. The inclusive cross sections have been measured at three angles $\theta = 45°, 90°$ and $135°$. The emitted fragments have been detected for energies of 20-180 MeV for Z = 2 fragments and 10-70 MeV for tritium.

The emission of fragments in high energy collisions has been studied over a long period of time, see Refs. 1-3 and references therein. The majority of experiments have been performed with hadron beams [1-5], but in the last decade it became possible to accelerate ions to an energy of a few GeV per nucleon and to study fragment production in nucleus-nucleus interactions [6-10]. For review of nucleus-nucleus collisions at high energy and an extensive list of references see [11].

Although the experimental situation seems to be quite good, our knowledge of fragmentation processes is not satisfactory. There is a common consensus that the emission of the slowest fragments, those with an energy of a few MeV, is dominated by the evaporation mechanism [12,13] proposed by V. Weisskopf. In this model the excited nucleus resembles a hot drop of liquid which evaporates to decrease its energy. The temperature of such an excited nucleus is a few MeV, and it cannot significantly exceed the binding energy per nucleon since the excited nucleus is assumed to be metastable.

On the other hand, a variety of models has been proposed to describe the emission of fast fragments with energy per nucleon greater than 30 MeV. The cross sections for proton emission can be reproduced in a wide class of cascade models [14-17] where a nucleus-nucleus interaction is a superposition of hadron-hadron collisions. Light nuclei are produced due to a coalescence mechanism [18-22]: final state interactions of nucleons with almost equal momenta. The defect of the coalescence model is that relative yields of fragments are unpredictable since coalescence radius is a free parameter of the model. A simultaneous description of the emission of nucleons and composite fragments is offered by statistical, hydrodynamical [23-25] and thermodynamical [26-30] models. In these models the assumption of chemical equilibrium makes it possible to predict relative yields of all produced, elementary and composite, particles.

The aim of this paper is to consider fragmentation processes in the intermediate energy region of secondaries. We have chosen three fragments: ^{3}H, ^{3}He and ^{4}He. An internal structure of two of them (^{3}H and ^{3}He) is very similar while the structure of ^{4}He is significantly different from the others. Thus, comparison of spectra of these ions can be helpful to differentiate mechanisms responsible for the emission of light fragments.

II. EXPERIMENT

The experiment has been performed at an internal beam of the Dubna synchrophasotron. The target has been placed inside a vacuum chamber of the accelerator. Secondaries have been registered by a telescope of six semicoductor detectors. The absolute monitoring of the beam has been reached by detecting deuterons knocked out of a deuterized polyethylene (CD_2) foil due to elastic interactions with incident nuclei. A good knowledge of elastic cross sections made it possible to determine absolute values of the fragmentation cross sections under study with an error of less than 20%. A detailed description of the experimental set-up and technical problems can be found in Ref.31.

III. QUALITATIVE FEATURES OF SPECTRA

In figs. 1, 2, 3, 4, 5,and 6 are shown the spectra measured in this experiment*. They have the following features:

- The form of the inclusive cross sections is not exponential. So, the spectra cannot be described by a single Weisskopf /12/ or Maxwell-Boltzamann distribution.
- The anisotropy of the spectra increases with fragment energy.
- The absolute values of the cross sections significantly increase with the atomic number of the target.
- For heavy targets the cross sections for ^{4}He emission with an energy less than 100 MeV exceed those for ^{3}He emission.

IV. VELOCITIES AND TEMPERATURES OF SOURCES OF THE FRAGMENTS

Assuming the existence of a source, which emits fragments, the anisotropy of fragment spectra can be treated as a measure of a longitudinal velocity of the source. This velocity can be

*The tables containing the numerical values of cross sections can be found in Ref.32.

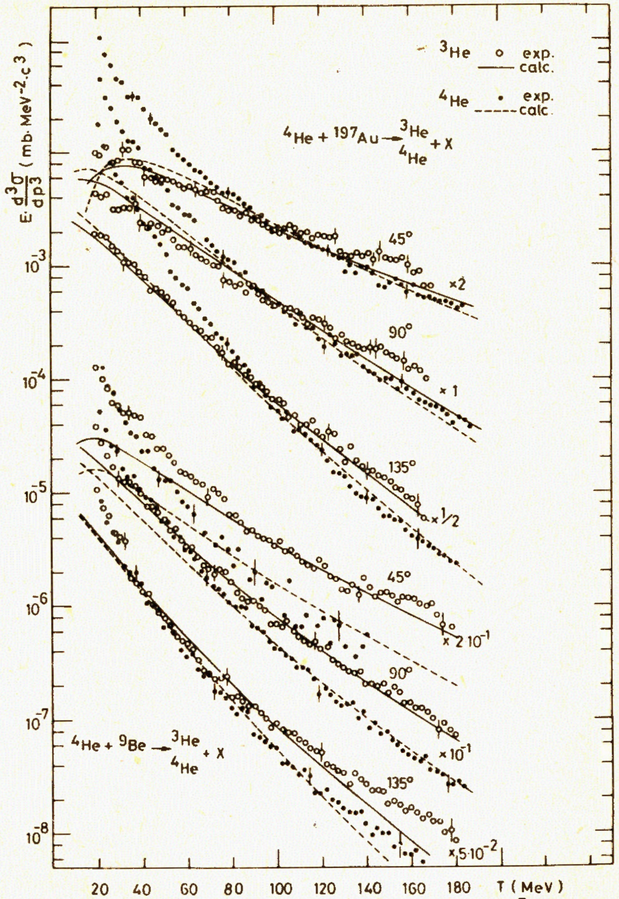


Fig.1. The invariant cross sections of ^{3}He *and* ^{4}He *emission in* ^{4}He-^{197}Au *and* ^{4}He-^{9}Be *collisions at θ =45°, 90° and 135° versus fragment kinetic energy. The errors of individual points (statistical and systematical) are indicated in the figure. The absolute normalization error is 20%. The firestreak model predictions (solid and dashed lines) are normalized at T = = 100 MeV.*

estimated applying the following procedure. We determine the energies for which the values of Lorentz invariant cross sections are equal at different angles. Assuming that these energies, different in the LAB system, correspond to the same energy in the CM of the source, we can find the velocity β of the source for each pair of spectra measured at different angles. For this analysis we have used no experimental points but the

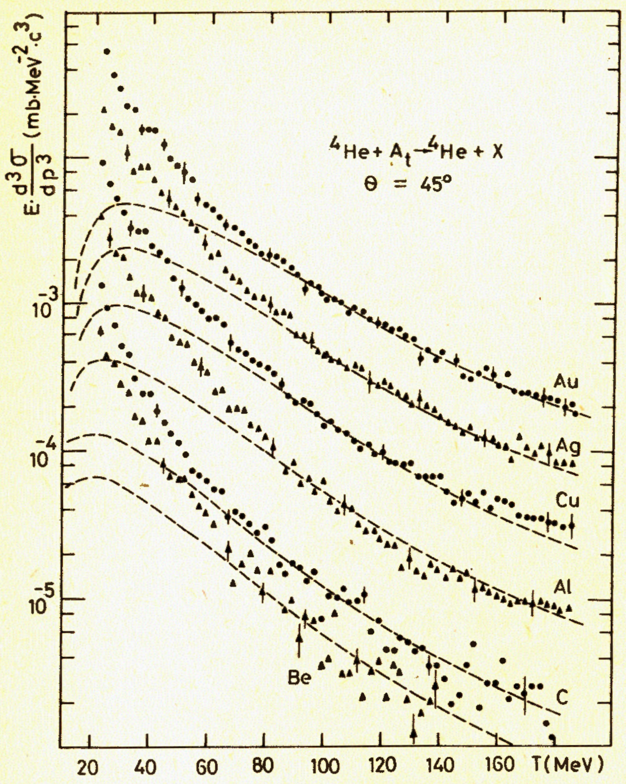


Fig.2. The invariant cross sections of ^{4}He emission at θ = = 45° in ^{4}He collisions with ^{9}Be, ^{12}C, ^{27}Al, ^{64}Cu, ^{108}Ag and ^{197}Au versus fragment energy. The errors of individual points (statistical and systematical) are indicated in the figure. The absolute normalization error is 20%. The firestreak model predictions (dashed lines) are normalized at T = = 100 MeV.

curves fitted to the experimental spectra. In Fig.7 are shown the values of β for different LAB energy of the fragment emitted at θ = 90°. Because there are spectra at three angles in our experiment, we have determined β three times for each pair of angles. The lines presented in the figure correspond to the average values, and the "errors" are differences between the average and maximal (minimal) values. It is seen that the fragments with higher energies are emitted by the source with, on the average, higher velocities. Let us observe a very striking feature of the sources. Their velocity does not depend on the target. When the target mass is changed by a factor of 22 (from ^{9}Be to ^{197}Au), the velocity as a function of fragment energy is practically the same.

To estimate the temperatures, T_0 of the sources, we have fitted the spectra at 90° with the formula

$$E\frac{d^3\sigma}{d^3p} = C E^* \exp\left(\frac{V - T^*}{T_0(T^*)}\right),$$

where T* is fragment kinetic energy in the CM of the source. E and E* denote total fragment energy in LAB and CM, respecti-

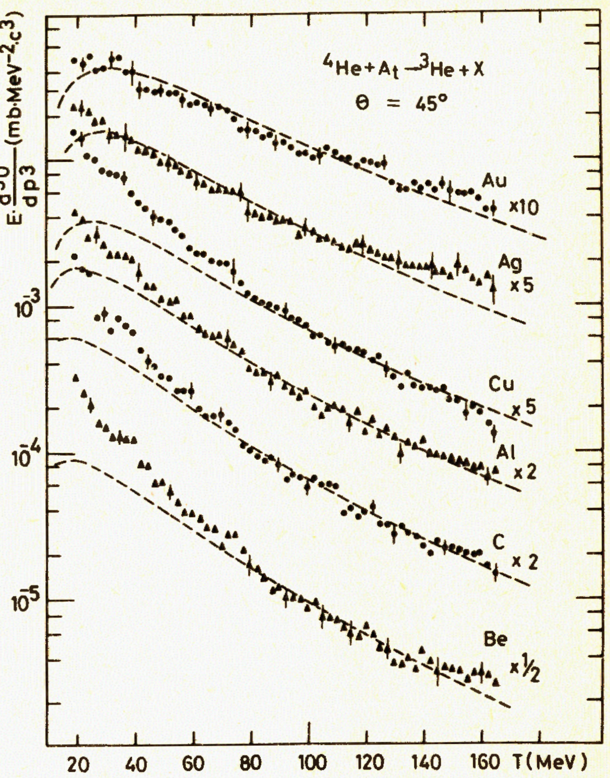


Fig.3. The invariant cross sections of ^{3}He emission at θ = 45° in ^{4}He collisions with ^{9}Be, ^{12}C, ^{27}Al, ^{64}Cu, ^{108}Ag, and ^{197}Au versus fragment energy. The errors of individual points (statistical and systematical) are indicated in the figure. The absolute normalization error is 20%. The firestreak model predictions (dashes lines) are normalized at T = = 100 MeV.

vely. Because the spectra cannot be described with a single exponential function, we have assumed the linear dependence T_0 on T*. For emission angle θ = 90°, $T^* = T + m\beta^2/2$. We have used linear parametrization for β(T), namely,

$$\beta = 0.0005\cdot T + 0.02 \quad \text{for } ^3\text{He} \qquad \beta = 0.0004\cdot T + 0.01 \quad \text{for } ^3\text{H} \tag{1}$$

$$\beta = 0.0003\cdot T + 0.01 \quad \text{for } ^4\text{He}.$$

Coulomb barrier, V, has been found according to the formula

$$V = \frac{Z_f(Z_t - Z_f)e^2}{r((A_t - A_f)^{1/3} + A_f^{1/3})},$$

where r = 1.4 fm and "f" denotes fragment parameters. In Fig.8 we show T_0 as a function of T. It is seen that the temperature increases with the energy of emitted fragment. For ^{4}He emission T_0(T) is similar for all targets, while for ^{3}H and ^{3}He we observe a systematic increase of the temperature with the target mass.

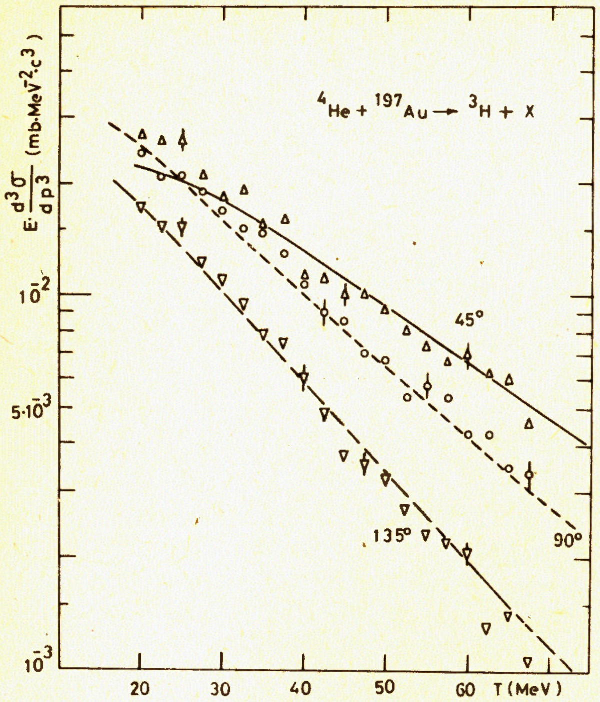


Fig.4. The invariant cross sections of ^{3}H *emission in* ^{4}He–^{197}Au *collisions at* $\theta = 45°$, *90° and 135° versus fragment energy. The errors of individual points (statistical and systematical) are indicated in the figure. The absolute normalization error is 20%. The firestreak model predictions (solid and dashed lines) are normalized at T = 50 MeV.*

V . A ROLE OF EVAPORATION

In the previous section we have found that the temperatures of some sources exceed a value of 10 MeV. This means that evaporation can contribute only to a soft part of the spectra. In our opinion, higher temperatures are not realistic from the point of view of the evaporation model to the assumption of metastability of an excited nucleus. Let us discuss a role of evaporation more carefully.

In the framework of the evaporation model[12, 13] the probability, P(T*), of emission of a fragment with energy T* can be approximated in the rest frame of emitting nucleus by the formula

$$P(T^*) = C\left(1 - \frac{V}{T^*}\right)\theta(T^* - V)\exp\left(-\frac{T^*}{T_0}\right), \qquad (2)$$

$(1 - V/T^*)\,\theta(T^* - V)$ is a classical penetrating factor and C is a constant. Using the formulae (1), we have transformed (2) from CM to LAB. In figs.5 and 6 we present the spectra of ^{3}He and ^{4}He emitted in collisions with ^{12}C and ^{108}Ag. For the ^{12}C case we have taken the experimental value of the evaporation temperature[34], while for ^{108}Ag we have got the maximal, in our

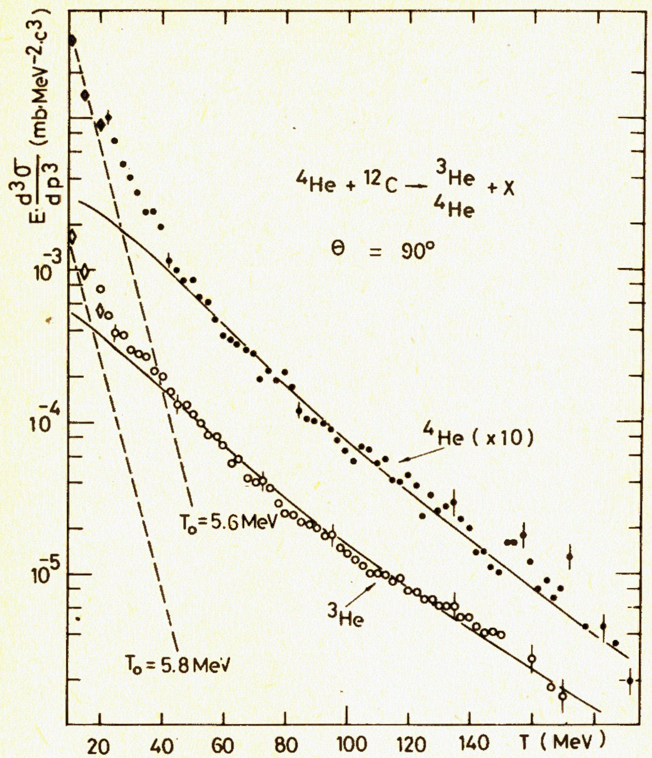


Fig.5. The invariant cross sections of ^{3}He *and* ^{4}He *emission in* ^{4}He–^{12}C *collisions at* $\theta = 90°$ *versus fragment energy. The experimental points , are taken from Ref. 33. Because* ^{2}H–^{12}C *collisions have been studied in*[33], *the points are renormalized according to the experimental dependence, namely* $A_p^{2/3}$. *The evaporation curves (dashed lines) are normalized at T = 10 MeV. The firestreak model predictions are normalized at T = = 100 MeV.*

opinion, value T_0 = 10 MeV. Normalization of the evaporation model predictions is arbitrary. It is seen that the contribution of evaporation is more important for light targets. In the case of ^{3}He emission from heavy targets the evaporation seems to be negligible in the fragment energy under consideration. For all targets the contribution of evaporation is bigger for ^{4}He than for ^{3}He. The above observations agree with the systematics of fragmentation cross sections performed for low energy nuclear collisions[35]. It has been shown[35] that, in agreement with the evaporation model, a fragment emission cross section crucially depends on reaction energy which, in particular, makes favourable emission of strongly bound system like ^{4}He.

VI .RATIO OF YIELDS OF ^{3}H AND ^{3}He

In Fig.9 we present the ratio, R, of the yields of ^{3}H and ^{3}He as a function of fragment energy in an interval of 20–70 MeV. There are three emission angles 45°, 90°, and 135° and three targets ^{12}C, ^{108}Ag, and ^{197}Au. It is seen that the ratio decrea-

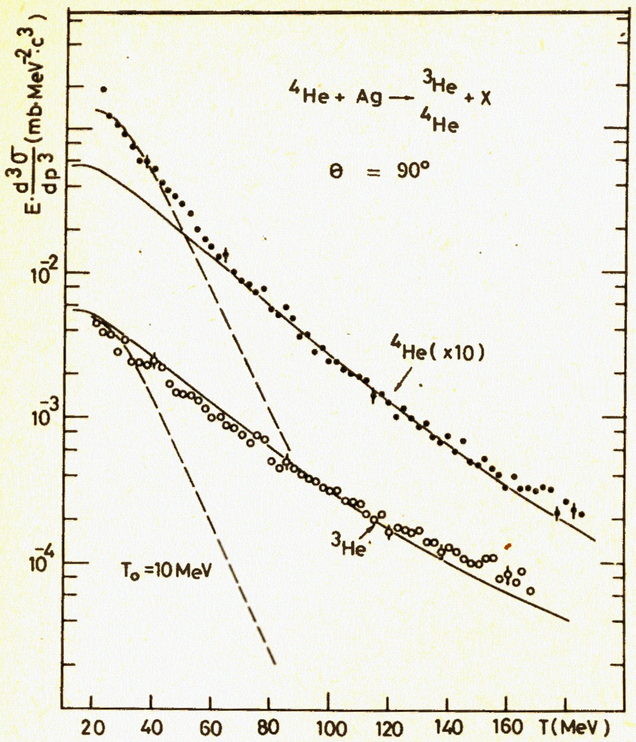


Fig.6. The invariant cross sections of ^{3}He *and* ^{4}He *emission in* ^{4}He–^{108}Ag *collisions at θ = 90° versus fragment energy. The errors of individual points (statistical and systematical) are indicated in the figure. The absolute normalization error is 20%. The evaporation curves (dashed lines) are normalized at T = 20 MeV. The firestreak model predictions (solid lines) are normalized at T = 100 MeV.*

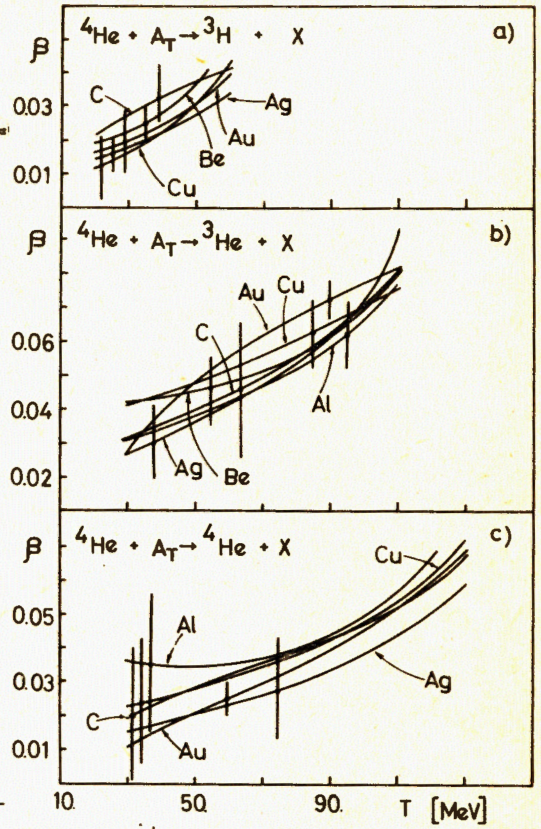
ses with fragment energy for the heavy targets, and it is fairly constant for ^{12}C. Let us notice that the ratio does not depend (within the experimental errors) on angle, while the spectra, in the energy interval under consideration, are far from isotropy.

The energy distribution of fragments, P(T*), emitted from the nucleus, being the source of the electrostatic Coulomb field, can be factorized in its rest frame in the following way: P(T*) = g(T*) f(T*), where g(T*) is the penetrating factor describing the influence of the Coulomb barrier and f(T*) is the energy distribution of fragments in the absence of electric field. In analysing the ratio R, we have not used the classical penetrating factor quoted previously but a more realistic semiempirical function found in studies of the reverse processes of compound nuclei formation/36/:

$$g(T^*) = (\omega/T^*)\ln(1 + \exp(2\pi(T^* - V)/\omega)),$$

where V and ω are the height and curvature of the parabolic potential barrier for s-wave. Deformation effects of nuclei are taken into account by considering the barrier V to have a uniform distribution of values between V − Δ and V + Δ. We have taken the values of parameters from Ref.36.

Fig.7. The velocities of ^{3}H, ^{3}He, *and* ^{4}He *sources for different targets versus laboratory energy of the fragment emitted at θ = 90°. The sense of the "errors" is described in the text.*



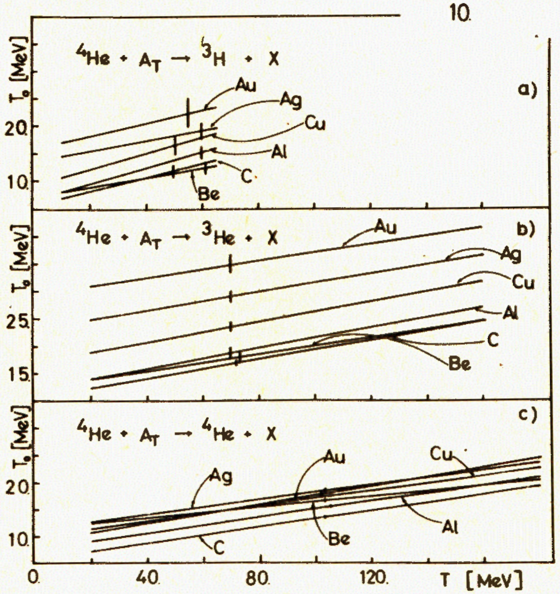


Fig.8. The temperatures of ^{3}H, ^{3}He, *and* ^{4}He *sources for different targets versus laboratory energy of the fragment emitted at θ = 90°. The indicated errors come from the errors of the fit parameters.*

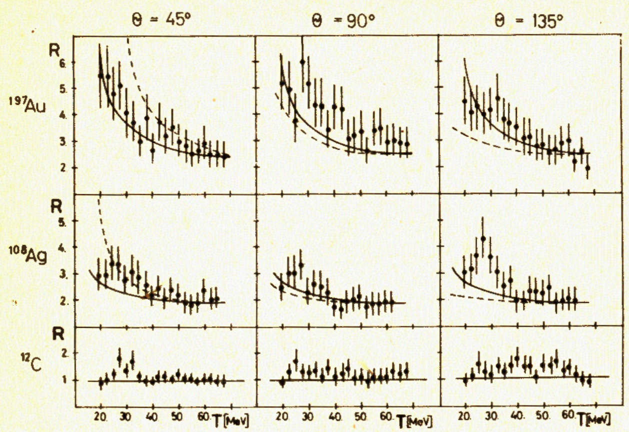


Fig.9. The ratio of the yields of ^3H and ^3He versus fragment energy for three targets ^{12}C, ^{108}Ag, and ^{197}Au and three emission angles of 45°, 90° and 135°. The solid lines are found assuming that the source of Coulomb field is at rest in LAB. The dashed lines are related to the moving source with a constant velocity of 0.05 c. The normalization of both curves is arbitrary but the same for all angles. The indicated errors contain uncertainties of absolute normalization.

It is reasonable to assume in the small interval of T* the functions f(T*) for ^3H and ^3He are the same up to the constant factor c related to a surplus of neutrons in heavy nuclei. Thus, in the rest frame of the Coulomb field (T* = T) the ratio R is expressed as follows:

$$R = c\, g_1(T)/g_2(T), \qquad (3)$$

where g_1 and g_2 are the penetrating factors of ^3H and ^3He, respectively. As is shown in the paper [8] and what is confirmed by our data, c is about 2 ÷ 3 for a heavy target like ^{197}Au, while simple combinatorical arguments give no more than 1.5 [8]. The explanation seems to look as follows [37,8]. The number of neutrons and protons for ^3H and ^3He formation are reduced by those nucleons which fall in other fragments, mainly ^2H and ^4He. Because the numbers of n and p are equal in these ions, the ratio of neutrons to protons deposited for ^3H and ^3He formation is greater than in the emitting nucleus. Unfortunately, it is not easy to convert this comprehensible argumentation into model-independent result. So, in our later considerations the constant coefficient c is arbitrary. If the ratio R were considered in a wide interval of fragment energy, it would be incorrect to assume that c does not depend on fragment energy. The problem is that the above mechanism depends on the temperature of the emitting source. When the temperature increases, the formation of composite fragments is suppressed and an amplification of the effective neutron to proton ratio is weaker. For fast fragments

it is experimentally shown that the ratio is compatible with the neutron to proton ratio in an initial colliding system [5].

The solid lines in Fig.9 are found according to the formula (3) assuming that the source of the Coulomb field, the target nucleus as a whole, is at rest in LAB. In addition, we have assumed that the numbers A and Z of the emitting nucleus coincide with those of the target. The dashed lines are found taking the velocity of the Coulomb field equal to 0.05c. It is a typical value of the velocity of fragment source being considered in chapter IV.

The fact that an agreement with the data is better, when the source of Coulomb field is assumed to be at rest in LAB, can be interpreted as follows. ^3H and ^3He are not emitted by the nucleus as a whole (evaporation mechanism), but the fragments are emitted by a small object which moves inside the nucleus. Thus, the velocity of a nucleus as a whole is much smaller than the velocity of a fragment source.

VII. A_t DEPENDENCE

In Figs.10, 11 and 12 we present the dependence of invariant cross sections measured at θ = 90° on the target mass for different values of fragment energy. It is used to parametrize the A_t-dependence on the form:

$$E\frac{d^3\sigma}{d^3p} = c A_t^{\alpha} \qquad (4)$$

with α independent of A_t. For ^3H and ^4He the above parametrization can be applied while for ^3He α changes with A_t. As is seen, in this case the experimental points do not lie on a straight line in the logarithmic scale. For ^3He emission we have applied (4) for middle mass targets (Al, Cu, Ag). The values of α are given in the figures. For the emission of all fragments α significantly increases with fragment energy.

VIII. COMPARISON WITH THE THERMODYNAMICAL MODEL

According to the previous sections, it is very natural to apply the thermodynamical model for description of fragment emission, for soft fragments (energy lower than 50 MeV) the old evaporation model and for more energetical fragments the nuclear fireball type models. In comparison with experiment many variations of the original fireball idea [26] have been used. A thermodynamical content in each of these models is the same, only geometrical parts differ. All these models exploit the so-called "participant-spectator" picture of nucleus-nucleus

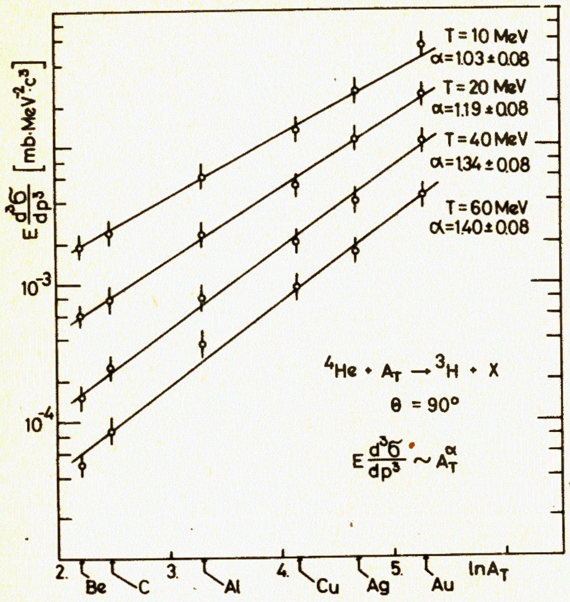


Fig.10. The invariant cross sections of ^{3}H emission for four values of fragment energy versus target mass number. The indicated errors contain uncertainties of absolute normalization. The solid lines are A_t^a fits.

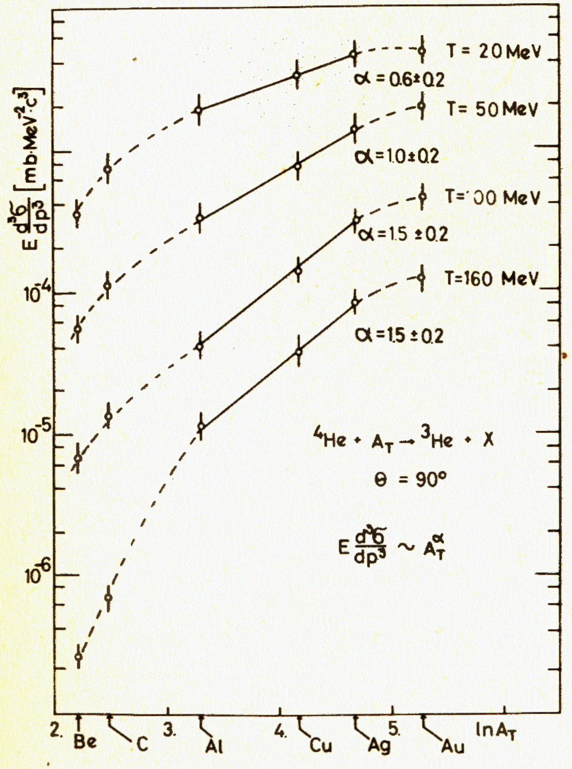


Fig.11. The invariant cross sections of ^{3}He emission for four values of fragment energy versus target mass number. The indicated errors contain uncertainties of absolute normalization. The solid lines are A_t^a fits.

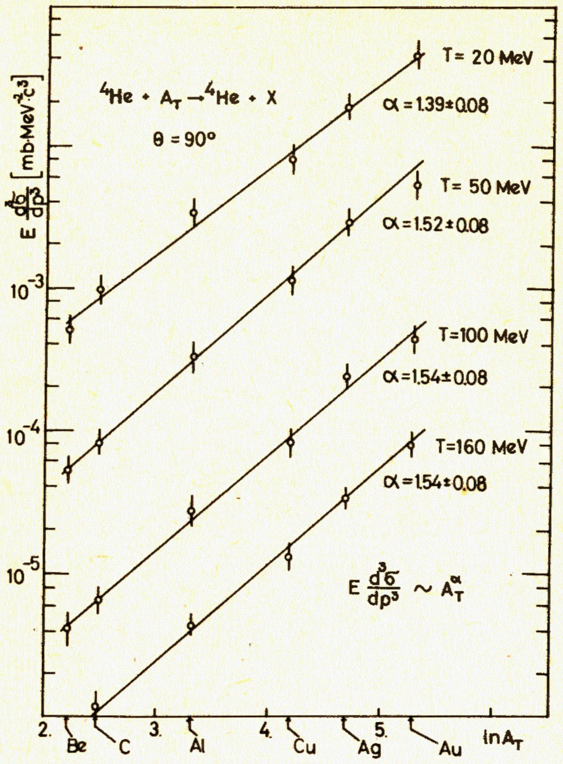


Fig.12. The invariant cross sections of ^{4}He emission for four values of fragment energy versus target mass number. The indicated errors contain uncertainties of absolute normalization. The solid lines are A_t^a fits.

interactions. In this picture the only nucleons (participants) which interact are those from the overlapping region of colliding nuclei. The rest of nucleons (spectators) fly off after collision with essentially unchanged velocity. The firestreak model/27/ is one of the most popular and quite successful in describing experimental data/28–30/. In this model the interaction region is broken up into infinitesimal collinear streaks. Collisions between the streaks occur independently. The interacting objects form highly excited nuclear matter which reaches thermal and chemical equilibrium. The fireobject expands to some critical density and decays as an ideal gas. Our firestreak calculations concerning secondary protons are described in Ref.30. To find the spectra of composite fragments, we have used the coalescence formula/18–22/:

$$E\frac{d^3\sigma^{A_f}}{d^3p} = C\left[E\frac{d^3\sigma^{p}}{d^3p}\right]^{Z_f}\cdot\left[E\frac{d^3\sigma^{n}}{d^3p}\right]^{A_f-Z_f}, \qquad (5)$$

where the cross sections of fragment A_f and nucleons n and p are taken at the same momentum per nucleon. C is a constant as a function of fragment momentum. The idea of coalescence can be treated dually: as a physical concept describing the formation of composite particles or as a well verified/38,39/ experimental law apart from the interpretation of final state interactions leading to fragment formation. It should be remembered that the assumption of chemical equilibrium also leads to the approximate power law formula (5)/29/. To improve an agreement with the data, the spectra of protons and neutrons are assumed to be different due to Coulomb barrier effects. Namely, it has been assumed that the minimal temperature of a fireobject, which is sufficient for emission of neutron is 9 MeV/14/, while the minimal temperature for proton emission is 9 MeV plus $\frac{2}{3}V_c$, where V_c is the value of Coulomb barrier for proton emission from target nucleus. (The fragments in our experiment came, of course, from the target fragmentation region). Because the coalescence radii (hidden in constant C in the formula (5)) are not precisely known and the results strongly depend on their values, the absolute normalization of the model predictions is arbitrary in our considerations. In Figs. 1, 2, 3, 4, 5,and 6 we show the firestreak model predictions. It is seen that for fragments with energy greater than 50 MeV the model reasonably agrees with our data. To describe slower fragments, the evaporation should be added.

IX. SUMMARY AND DISCUSSION

Let us summarize our results.

If one assumes the existence of an intermediate object which is responsible for fragment emission in high energy nucleus-nucleus collisions, the velocities and temperatures of the objects increase with an energy of emitted fragment. More precisely, on the average, more energetical fragments are emitted by the sources the velocities and temperatures of which are greater. The velocities of emitting objects seem to be independent of target, while temperatures increase with target mass. We have found that the temperatures and velocities of the sources emitting different kinds of fragments with, on average, equal energies are not the same. For example, the velocities and temperatures of the sources emitting ^4He are smaller than those of the ^3He sources. At first sight this fact could be treated as an argument against the hypothesis of thermal and chemical equilibrium. However, it is not the case because we choose different types of collisions detecting ^4He or ^3He. The detection of ^4He is likely to be the way for triggering small excitation events. Thus, inclusive experiments cannot give the answer to such questions as that of chemical equilibrium.

We have shown that the evaporation mechanism can be important for the emission of fragments with energy less than 50 MeV.

Considering the ratio of the yields of ^3H and ^3He, we have found that the existence of nonreduced Coulomb barrier seems to be compatible with our data. This result is in disagreement with those reported in Refs.2-4 and 6 where it has been argued an important reduction (about 50%) of the Coulomb barrier in high energy interactions. It should be underlined that our analysis is model-independent while in the quoted papers it has been assumed that experimental spectra can be described by the single (by two in Ref.6) Weisskopf of Maxwell-Boltzmann distribution. In chapter IV we have shown that the experimental spectrum is a superposition of many distributions with different velocities and temperatures. If one tries to fit such superposition with the single distribution, the value of temperature found by fitting is determined by the hottest sources what leads to an underestimation of the Coulomb barrier.

We have discussed the A_t dependence of fragment production. As in other experiments we have found that the A_t dependence is stronger for fast than for slow fragments.

At the end of our paper we have compared our data with the predictions of the slightly modified firestreak model. A reasonable agreement has been found for fragments with energy greater than 50 MeV. The yield of slower fragments, particularly ^4He, is, as one can expect, underestimated because a main contribution to such fragments comes from the evaporation.

REFERENCES

1. Piroue P.A., Smith A.J.S. Phys.Rev., 1966, 148, p.1315.
2. Poskanzer A.M., Butler G.W., Hyde E.K. Phys.Rev., 1971, C3, p.882.
3. Hyde E.K., Bulter G.W., Poskanzer A.M. Phys.Rev., 1971, C4, p.1759.
4. Westfall G.D. et al. Phys.Rev., 1978, C17, p.1364.
5. Bayukov Y.D. et al. Phys.Rev., 1979, C20, p.764.
6. Zebelman A.M. et al. Phys.Rev., 1975, C11, p.1280.
7. Sandoval A. et al. Phys.Rev., 1980, C21, p.1321.
8. Nagamiya S. et al. Phys.Rev., 1981, C24, p.971.
9. Anderson L. et al. Phys.Rev., 1983, C28, 1224.
10. Olson D.L. et al. Phys.Rev., 1983, C28, p.1602.
11. Nagamiya S., Gyulassy M. Preprint LBL-14035, Berkeley, 1982 and Adv.Nucl.Phys., 1984, 13, p.201.
12. Weisskopf V. Phys.Rev., 1937, 52, p.295.
13. Friedman W.A., Lynch W.G. Phys.Rev., 1983, C28, p.16.
14. Barashenkov V.C., Toneev V.D. "Interactions of High Energy Particles and Atomic Nuclei with Nuclei" (in Russian), Atomizdat, M., 1972.
15. Cugnon J. Phys.Rev., 1980, C22, p.1885.

16. Hakbert E.C. Phys.Rev., 1981, C23, p.295.
17. Toneev V.D., Gudima K.K. Nucl.Phys., 1983, A400, p.173.
18. Batler S.F., Pearson C.A. Phys.Rev., 1963, 129, p.836.
19. Schwarzschild A., Zupancic C. Phys.Rev., 1963, 129, p.854.
20. Kapusta J.I. Phys.Rev., 1980, C21, p.1301.
21. Sato H., Yasaki K. Phys.Lett., 1981, B98, p.153.
22. Boal D.H. Phys.Rev., 1982, C25, p.3068.
23. Amsden A.A., Harlow F.H., Nix J.R. Phys.Rev., 1977, C15, p.2059.
24. Amsden A.A. et al. Phys.Rev., 1978, C17, p.2080.
25. Tang H.H., Wong C. Phys.Rev., 1980, C21, p.1846.
26. Westfall G.D. et al. Phys.Rev.Lett., 1976, 37, p.1202.
27. Myers W.D. Nucl.Phys., 1978, A296, p.177.
28. Gosset J., Kapusta J.I. Westfall G.D. Phys.Rev., 1978, C18, p. 844.
29. DasGupta S., Mekjian A.Z. Phys.Rep., 1981, 72. p.131.
30. Avdeichikov V.V., Mrówczyński St. Phys.Lett., 1984, B134, p.293.
31. Abashidze L.I. et al. JINR, 1-83-185, Dubna, 1983 (in Russian).
32. Abashidze L.I. et al. Radium Institute report RI-190, L., 1984, (in Russian).
33. Beznogikh G.G. et al. Yad.Fiz., 1978, 27, p.246.
34. Greiner D.E. et al. Phys.Rev.Lett., 1975, 35, p.152.
35. Avdeichikov V.V. Phys.Lett., 1980, B92, p.72.
36. Vaz L.G., Alexander J.M. Phys.Rev., 1974, C10, p.464, 1978, C18, p. 2152.
37. Randrup J., Koonin S.E. Nucl.Phys., 1981, A356, p.223.
38. Gutbrod H.H. et al. Phys.Rev.Lett., 1976, 37, p.667.
39. Lemaire M.C. et al. Phys.Lett., 1979, B85, p.38.

Received by Publishing Department
on June 18, 1984.

Абашидзе Л.И. и др. E1-84-417

Испускание фрагментов ^3H, ^3He и ^4He при взаимодействии ядер ^4He с кинетической энергией 3,33 ГэВ на нуклон с ядрами

Представлены инклюзивные спектры выхода ^3H, ^3He и ^4He под углами 45°, 90° и 135° при столкновении частиц с кинетической энергией 3,33 ГэВ на нуклон с ядрами ^9Be, ^{12}C, ^{27}Al, ^{64}Cu, ^{108}Ag и ^{197}Au, использованными в качестве мишеней. В предположении о существовании движущегося источника, испускающего фрагменты, находится его скорость и температура для разных энергий фрагмента. Показано, что скорость и температура непрерывно возрастают при переходе к большим энергиям фрагмента. Обсуждается механизм испарения и утверждается, что испарение дает существенный вклад при энергиях фрагмента меньше чем 50 МэВ. При рассмотрении отношения выхода ^3H к выходу ^3He обнаружено, что оно больше, чем отношение количества нейтронов к количеству протонов в испускающей фрагменты системе. Из анализа спектров делается вывод, что кулоновский барьер играет важную роль. Изучается A_t зависимость выхода фрагментов. Экспериментальные спектры сравниваются с предсказаниями термодинамической модели. Модель файрстрик успешно описывает испускание фрагментов с энергией больше, чем 50 МэВ.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1984

Abashidze L.I. et al. E1-84-417

Emission of Light Fragments ^3H, ^3He, and ^4He in ^4He-Nucleus Collisions at 3.33 GeV/N Kinetic Energy

Inclusive cross sections for the emission of ^3H, ^3He, and ^4He at laboratory angles of 45°, 90° and 135° in collisions of ^4He with targets ^9Be, ^{12}C, ^{27}Al, ^{64}Cu, ^{108}Ag, and ^{197}Au at a beam kinetic energy of 3.33 GeV/nucleon are presented. Assuming the existence of an intermediate object emitting fragments, we have found its velocity and temperature for different fragment energy. It is shown that the velocity and temperature continuously increase with the fragment energy under consideration. The evaporation mechanism is discussed, and it is argued that the evaporation significantly contributes to the yield of fragments with energy less than 50 MeV. The considered ^3H to ^3He ratio is found to be larger than the neutron to proton ratio in the emitting system. Comparing ^3H and ^3He spectra, an important role of the Coulomb barrier is shown. The A_t-dependence of the yield of the fragments is studied. The experimental spectra are compared with thermodynamic firestreak model predictions. The model is successful in describing the emission of fragments with energy greater than 50 MeV.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1984