Observation of a minimum in the energy dependence of the parameter τ of a charge fragment yield in the interaction of relativistic ^{4}He nuclei with gold nuclei

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The charge yield of fragments ($5 \leqslant Z \leqslant 12$) in the reaction ^{4}He + Au has been measured in the kinetic energy range $E_{^4\mathrm{He}} = 1.3$–13.5 GeV at angles 35–135°. The cross sections of the yield were parametrized in terms of the dependence $\sigma(Z) \sim Z^{-\tau}$. The nature of the detected minimum of the parameter $\tau(E_{^4\mathrm{He}})$ at $E_{^4\mathrm{He}} \cong 6$ GeV is discussed.

Study of the dependence of the formation of intermediate-mass fragments on the energy of incident particles is of great importance in determining a possible manifestation of instabilities and critical phenomena in nuclear matter.[1] The parameter τ, the key parameter in this case, can be determined from the charge yield of fragments $\sigma(Z)$ by using the equation

$$\sigma(Z) \sim Z^{-\tau}. \tag{1}$$

The intermediate-mass fragment-formation model which suggests that there is a "liquid-gas" phase transition,[2] the statistical multifragmentation theory,[3] the nuclear-lattice model,[4] and other models which have recently been developed predict a certain behavior of the charge yield, depending on the excitation energy of the system or on other parameters which are characteristic of the given model. The theory of the liquid-gas phase transition, for example, predicts that the parameter τ will reach a minimum value at the critical pressure and density of matter in the system. In experimental studies of the dependence of τ on the energy of incident particles the minimum has so far not been detected, although an analysis of the available data[5] shows that it does exist.

In the preceding study[5] we analyzed the dependence of τ on the energy of protons in the reaction ^{1}H + Au. We found that τ becomes saturated with increasing beam energy. In this letter we present the results of a study of the inclusive differential cross sections for the production of intermediate-mass fragments in the reaction ^{4}He + Au in the energy range of ^{4}H 1.3–13.5 GeV. We detected the fragments with the charges $Z = 5$–12 in the kinetic energy range 1–11 MeV/nucleon at angles 35–135°. The measured cross sections were reported elsewhere.[6] The experimental procedure was described in Ref. 7.

The fragment spectra were analyzed by means of the diagrams

$(1/p)(d^2\sigma/dE_f d\Omega) = f(v_{\parallel}, v_{\perp})$, where $v_{\parallel}$ and $v_{\perp}$ are the longitudinal and transverse components of the velocity of the given fragment. At least two sources which determine the shape of the energy spectrum of the fragments have been detected. The source with the longitudinal velocity $\beta_1 = 0.008 \cdot s$ is the dominant component at low kinetic energies E_f of the fragment and the source with the longitudinal velocity $\beta_2 = 0.02 \cdot s$ is the dominant component at high energies, where c is the velocity of light. These values of β_1 and β_2 are characteristic of all Z fragments and beam energies. The experimental data[8] and theoretical models[9,10] suggest that the two-body decay of highly excited nuclei contribute significantly to the cross section for the production of intermediate-mass fragments. The differential cross section for the production of a fragment at a given angle can therefore be parametrized in the form

$$d\sigma(Z,T) = d\sigma_1(Z)\, f_1(\beta_1, T_1, E_f) + d\sigma_2(Z)\, f_2(\beta_2, T_2, E_f), \quad (2)$$

where f_1 describes a statistical two-body decay in accordance with the equations of the theory of asymmetric fission of a highly excited nuclear system[10] with a velocity β_1 and temperature T_1, f_2 is the contribution of the source with a velocity β_2 and tem-

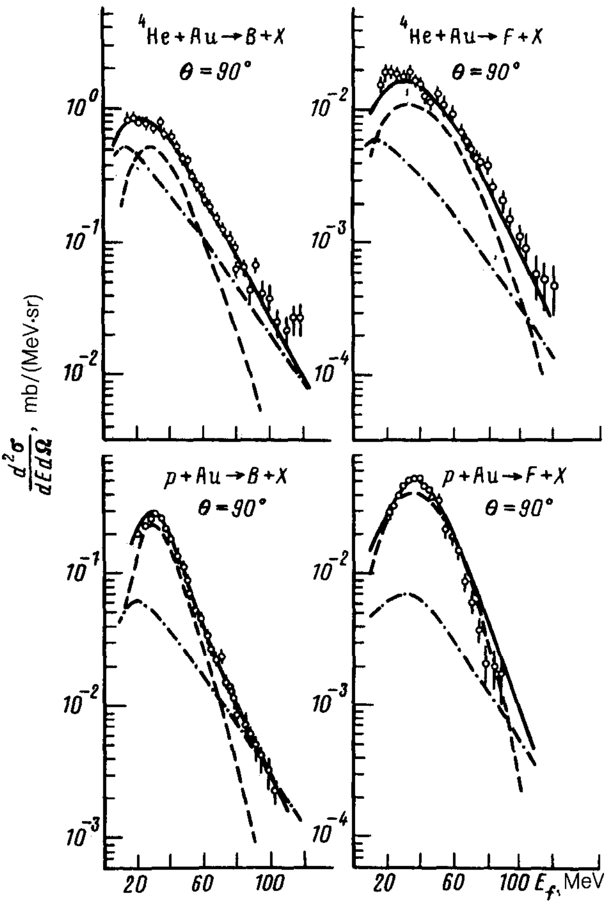

FIG. 1. The energy spectra of the fragments B and F emitted at a c.m. angle of 90° in the reaction p + Au at an incident proton energy of 2.55 GeV and in the reaction ^{4}He + Au at an ^{4}He energy of 13.48 GeV. The solid lines were obtained from Eq. (2). The dashed and dot-dashed lines represent the components f_1 and f_2.

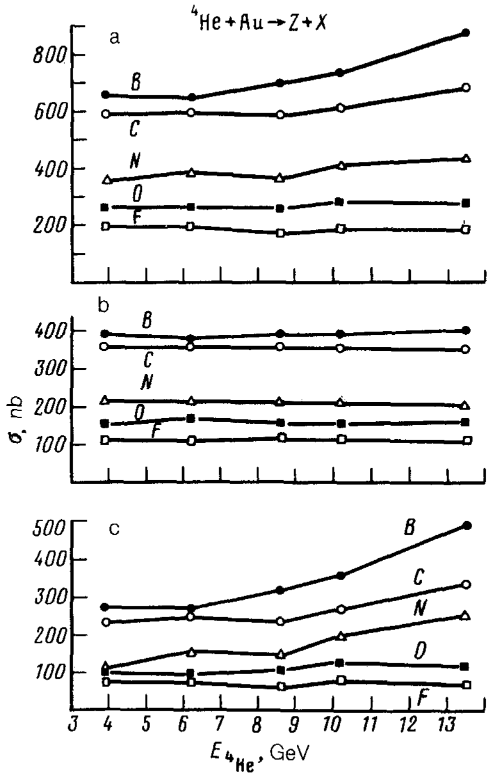

FIG. 2. Yield of the fragments with $Z = 5$–9 in the reactions ^{4}He + Au, integrated over the viewing angle. a—Total yield (2); b—yield of the component f_1; c—yield of the component f_2.

perature T_2, and $d\sigma_1$ and $d\sigma_2$ are the weights of these sources. The component f_2 was parametrized as a modified Maxwell-Boltzmann distribution[5,11] with a Coulomb barrier of nearly zero. The description of the experimental data on the basis of relation (2) yields $T_1 = 9.6$ MeV and $T_2 = 20$ MeV. Figure 1 describes the differential spectra of the fragments with $Z = 5$ and 9 in the reactions ^{1}H + Au and ^{4}He + Au in the form in (2). The components f_1 and f_2 are also shown in Fig. 1.

Parametrization (2), which describes well the data obtained at various viewing angles, is used to reconstruct the unobservable low-energy part of the spectra (we estimate its contribution to be ~8%) and to determine the total fragment charge yield. Figure 2 is a plot of the total charge yields , σ, σ_1, and σ_2 as a function of the energy of an ^{4}He beam. We see that the cross section $\sigma(Z = 5$–$7)$ increases, while the cross section $\sigma(Z = 8$–$9)$ remains constant. The increase in the total cross section of the fragment yield in this case is determined by the component σ_2.

Analysis of the charge yield based on Eq. (1) (Fig. 3) leads to the following results. The parameter $\tau(E_{^4\mathrm{He}})$ has a minimum at $E_{^4\mathrm{He}} \sim 6$ GeV. The subsequent increase of τ in this case is stipulated by the fast component σ_2.

The result which we have obtained cannot be uniquely connected with the liquid-gas phase transition in nuclear matter because of the absence of data on the fragment

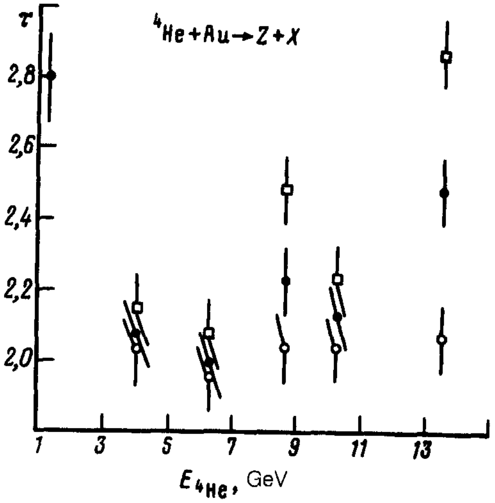

FIG. 3. Dependence of τ on the energy of the ^{4}He beam for the reaction ^{4}He + Au. (●)—The parameter τ determined from the total yield (2); (O)—the parameter τ determined from the yield of the component f_1; (□)—the parameter τ determined from the yield of the component f_2.

production multiplicity. Also not fully understood is the physical nature of the fast component of the cross section. The characteristics of this component can, however, be regarded as a manifestation of the multifragmentation mechanism[3] (the interaction barrier is nearly zero and the temperature $T \sim 20$ MeV possibly reflects the momentum distribution of the nucleons in the nucleus).

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