Fragmentation of relativistic heavy ions

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The first experiments on the fragment yields in reactions with relativistic heavy ions are explained on the basis of a two-stage mechanism of the process. During the first stage the ion is excited by peripheral collision with the target nucleus, and during the second stage it decays statistically in flight and emits the fragment.

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After the first experiment on the fragmentation of relativistic oxygen ions by a beryllium target,[1] a number of models have been proposed for such a reaction.[2–6] It turned out that in addition to the subdivision of the fragments by momenta, the factor most critical to the choice of the mechanism is the analysis of the yields of the reaction products. However, no yield data whatever were given in[1], so that the question of the choice of the mechanism has remained so far open. Only recently[7] were the yields of the reaction measured experimentally. These yields of fast fragments with average velocity equal to that of the incident ion in collisions between relativistic ions ^{12}C($E = 2.1$ and 1.05 GeV/N) and ^{16}O($E = 2.1$ GeV/N), with various targets ranging from hydrogen to lead. It was possible to represent the results in the form

$$\sigma = \gamma_B^F \left(A_T^{1/3} + A_B^{1/3} - 1.6 \right), \tag{1}$$

where γ_B^F does not depend on the energy of the incident ion and on the atomic number A_T of the target or A_B of the incident ion, but characterizes only the dependence of the registered fragment on Z and A.

We shall attempt here to explain the observed fragment yields γ_B^F on the basis of the model proposed in[6]. The reaction proceeds in two stages. During the first stage the ion is excited to an energy E^* as a result of a peripheral collision with the target nucleus, and in the second stage the ion decays statistically in flight and emits a fragment of energy ϵ. Then the fragment distribution should obey the relation for the phase volumes in the final state

$$W(i)\,d\epsilon = \frac{\rho_f(E^* - \epsilon + Q_{gg})}{\rho_c(E^*)}\,\epsilon\,d\epsilon \sim c(\epsilon)\,e^{\frac{Q_{gg}(i)}{T}} \tag{2}$$

where ρ is the density of states before (c) and after (f) the statistical decay, and $Q_{gg} = M_{\rm ion} - M_{\rm fr} - M_r(i)$ is the reaction energy released in the disinteration chan-

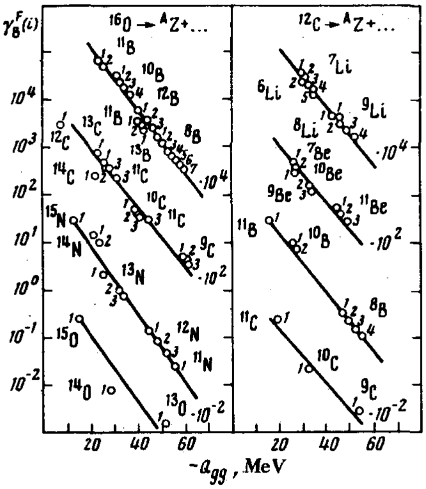

FIG. Relative yield of fragments on Q_{gg} of the reaction.

nel i, with emission of a fragment of mass M_{fr}, the mass of the remaining reaction being $M_r(i)$, and $T = \sqrt{2E^*/a}$ is the ion excitation temperature. (Formula (1) was obtained under the assumption that $\epsilon - Q_{gg}$ is small in comparison with the ion excitation energy E^*.) Since only one product of the reaction, a fragment of mass M_{fr}, is registered in the reaction, and the remaining products of the reaction with $M_r(i)$ are not registered, the summary yield $\gamma_B^F = \Sigma_i \gamma_B^F(i)$ is observed, where $\gamma_B^F(i)$ is the yield in channel i. The data can then be conveniently represented in the form

$$\gamma_B^F(i) = \gamma_B^F \Gamma(i) \tag{3}$$

where

$$\Gamma(i) = W(i) / \sum_i W(i) \tag{4}$$

characterizes the width of the channel. The figure shows the results of the calculation of $\gamma_B^F(i)$ with the aid of formulas (2) and (4). The circles represent the values of (2), and the numbers are those of the corresponding channels whose product masses are chosen from the condition that the reaction have a minimum Q.

We see the following:

1) The yields actually have an exponential dependence on Q_{gg} of the reaction, and this in turn confirms the mechanism of the statistical decay of the ion in its proper coordinate frame. (If the process is not in equilibrium, then T has the meaning of the effective temperature; see[6,8].) From the slopes of the lines we determine the temperatures $T \approx 7.5$ MeV for the ^{12}C ion and $T \approx 7.0$ MeV for ^{16}O. The small decrease of T for the heavier nucleus is natural.

2) An additional confirmation of this mechanism could be coincidence experiments with registration of the heavy fragment and the light products at momenta per nucleon close to the corresponding momenta of the incident ions.

3) This model does not answer the question of the first stage of the reaction, how is the large excitation energy $E^* \geq 50$ MeV transferred to the ion and why do the observed momentum distributions of all the fragment have approximately the same width? Thus, if the first stage proceeds in accord with the mechanism of the direct reaction, then one should expect a variation of the width with changing energy of fragment detachment in the incident ion, in proportion to $\sqrt{2A_{fr}(A_B - A_{fr})E_{fr}}$.

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