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ANGULAR MOMENTUM DEPENDENCE OF CLUSTER EMISSION FROM HIGHLY EXCITED NUCLEI*

Sh.A. Kalandarov[a,b], G.G. Adamian[a,b], N.V. Antonenko[a]
W. Scheid[c], J.P. Wieleczko[d]

[a]Joint Institute for Nuclear Research, 141980 Dubna, Russia
[b]Institute of Nuclear Physics,702132 Tashkent, Uzbekistan
[c]Institut für Theoretische Physik der Justus-Liebig-Universität
Giessen, Germany
[d]GANIL, CEA et IN2P3-CNRS, B.P. 55027, 14076, Caen Cedex, France

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Angular momentum dependence of cluster emission from highly excited intermediate nuclear system formed in ^{93}Nb + ^{9}Be and ^{45}Sc + ^{65}Cu reactions is studied within the dinuclear system model. The charge distributions of decay products and partial production cross-sections for C, O, Ne clusters are given.

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1. Introduction

Heavy ion collisions involve the large range of angular momenta. It is very important to have information about the role of rotational degree of freedom in the time evolution of the colliding system from the initial stage of the reaction until the final stage. The experimental evidence of the strong effect of angular momentum on final fragments Z-distribution was shown in Ref. [1]. It was shown there, that by measuring the final fragment spin distributions, one can extract a piece of information on the primary L-wave distributions, which contribute to the certain exit channels. Such a knowledge on cluster emission channels is very important because of the increasing interest on the possibility of production of exotic nuclei via cluster emission channels [2, 3]. Here, we investigate the formation of long-lived intermediate system and its decay in the reactions ^{93}Nb + ^{9}Be, ^{45}Sc+^{65}Cu within the dinuclear system (DNS) model [4]. Cluster emission is treated under

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the assumption that light clusters are produced by collective motion of the nuclear system in the charge and mass asymmetry coordinate, with further thermal escape over the Coulomb barrier. Potential energy surface of DNS is calculated as in Refs. [5, 6]. Both evaporation and binary decay are treated in the same way. Important role of the angular momentum of the system in the binary decay process is demonstrated. For excitations treated, the temperature effect on emission barriers is not taken into consideration for the reactions of interest.

2. Formation of dinuclear system and its time evolution

An essential condition for the capture of projectile by target is existence of the potential pocket in nucleus–nucleus interaction potential. The angular momentum window $J = J_{\min} - J_{\rm cr}$ for such process depend on dissipation of kinetic energy, which determine $J_{\min}$ and from the existence of potential pocket in the nucleus–nucleus interaction potential for the entrance channel, which determines the critical angular momentum $J_{\rm cr}$. Radial friction coefficient depends on relative distance coordinate R and one can assume a strong dissipation when $R < R_{\rm b}$, where $R_{\rm b}$ is the distance, where entrance Coulomb barrier is located. Critical angular momentum depends on mass and charge asymmetry of projectile-target combination and from total mass and charge numbers of the system. For asymmetric reactions $J_{\rm cr}$ is smaller than for more symmetric reactions. The capture cross-section is given as

$$\sigma_c(E_{\rm c.m.}) = \pi \lambda\!\!\!^{-}{}^2 \sum_{J=0}^{J_{\rm cr}} (2J+1) P_{\rm cap}(E_{\rm c.m.}, J)\,, \qquad (1)$$

where $\lambda\!\!\!^{-}{}^2 = \hbar^2/(2\mu E_{\rm c.m.})$ is the reduced de Broglie wavelength and μ the reduced mass. The transition probability is calculated with the Hill–Wheeler formula $P_{\rm cap}(E_{\rm c.m.}, J) = (1 + \exp[2\pi(V(R_{\rm b}, J) - E_{\rm c.m.})/\hbar\omega(J)])^{-1}$, where the effective nucleus–nucleus potential V is approximated near the Coulomb barrier at $R = R_{\rm b}$ by the inverted harmonic-oscillator potential with the barrier height $V(R_{\rm b}, J)$ and the frequency $\omega(J)$ [6].

The time evolution of the DNS depends on the potential energy surface, which is the function of relative distance, mass and charge asymmetry, shape degrees of freedom and rotational degrees of freedom. The motion in mass and charge asymmetry coordinate is responsible for the fusion process and for the distribution of initial system among all possible dinuclear configurations, while the motion in relative distance coordinate is responsible for the decay of the system into two fragments. The evolution of DNS in charge and mass asymmetry coordinate is described in the framework of the transport model. In this approach the time dependence of the probability $P_{Z,A}(t)$ of finding a system at the moment t in a state with charge Z and mass A of one of the nuclei in DNS is calculated by the master equation [7]. The lifetime of an excited CN (DNS) is predetermined by the time of neutron emission (the time of quasifission), which is sufficiently long to reach the mass and charge equilibrium limit in master equation. So, in the treatment of the formation of complex fragments, the equilibrium limit of the master equation can be imposed. The emission probability $W_{Z,A}(E^*_{\rm CN}, J)$ of a certain cluster from the excited intermediate system is the product of the DNS formation probability and the DNS decay probability, which is given in [6]. The cross-section of the cluster emission from the excited intermediate system is calculated as follows

$$\sigma_{Z,A}(E_{\rm c.m.}) = \sum_{J=0}^{J_{\rm max}} \sigma_c(E_{\rm c.m.}, J) W_{Z,A}(E^*_{\rm CN}, J)\,. \tag{2}$$

The detailed formulation of the model and its ingredients are given in our recent work [6].

To treat the angular momentum dependence of charge distributions of decay products, we calculate the cross-sections for the reactions ^{93}Nb+^{9}Be at $E_{\rm lab} = 782$ MeV and ^{45}Sc + ^{65}Cu at $E_{\rm lab} = 200$ MeV. For the first reaction, $J_{\rm max} = J_{\rm cr} = 38$ and for the second one, $J_{\rm max} = J_{\rm cr} = 73$. We assume strong dissipation of the kinetic energy and take $J_{\rm min} = 0$ for both reactions. By calculating the driving potentials for these reactions, one can guess about the shape of final fragments Z distributions prior to the calculations of whole cascade of decay channels [6]. The calculated Z distributions of the final decay products are given in Fig. 1, and in good agreement with experimental

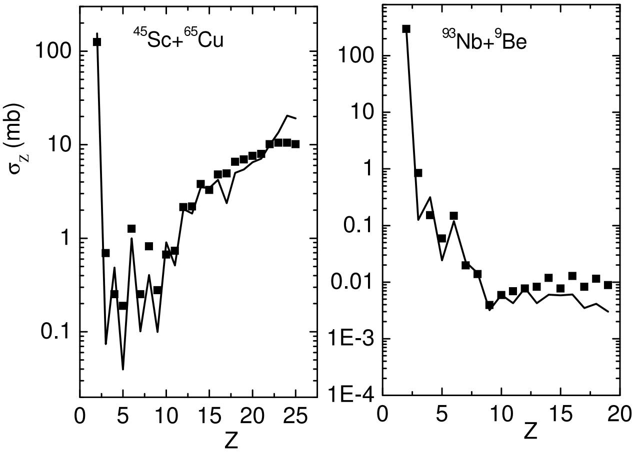

Fig. 1. Calculated Z distributions of the final fragments in comparison with experimental data.

data given in [1] for these two reactions. High cross-sections for fission-like fragments in ^{45}Sc + ^{65}Cu reaction reflects the effect of high angular momentum(s) involved in the reaction. The partial production cross-sections for the clusters C, O, Ne integrated over all isotopes are presented for both reactions in Fig. 2. The particular interest has the angular momentum dependence of production cross-section for carbon, since as mentioned in the Ref. [3], one can search the possibility of producing exotic residual nuclei via carbon emission. From Fig. 2, one can see that the partial production cross-section for carbon in the reaction 200 MeV ^{45}Sc + ^{65}Cu has the maximum around $J = 50$. The optimal conditions for the production of exotic nuclei via carbon emission can be determined in such a way, that the maximal kinematical angular momentum of the reaction have to be around $J = 50$ for similar systems considered here. From Fig. 2, one can also conclude that the very asymmetric reactions, where $J_{\rm cr}$ is not enough large, are not suitable for the studies dealing with the production of exotic nuclei via cluster emission channels, since the cross-sections are small due to the small angular momentum(s) involved in the reaction.

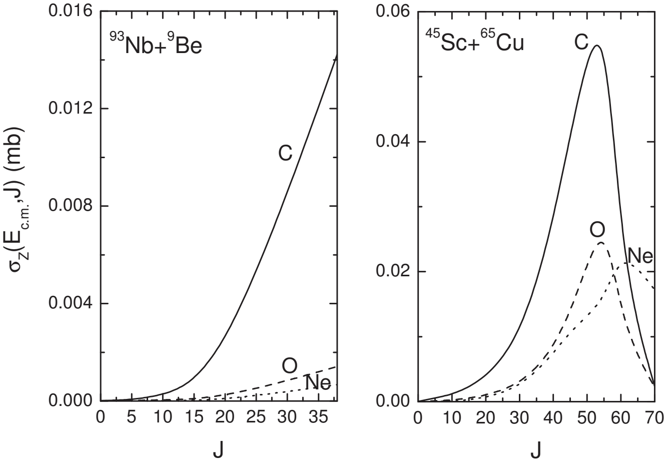

Fig. 2. The partial production cross-sections for the clusters C, O, Ne in the reactions ^{93}Nb + ^{9}Be at $E_{\rm lab} = 782$ MeV and ^{45}Sc + ^{65}Cu at $E_{\rm lab} = 200$ MeV.

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REFERENCES

[1] L.G. Sobotka *et al.*, *Phys. Rev.* **C36**, 2713 (1987).

[2] J. Gomez del Campo *et al.*, *Phys. Rev.* **C57**, 2 (1998).

[3] M. La Commara *et al.*, *Nucl. Phys.* **A669**, 43 (2000).

[4] V.V. Volkov, *Izv. Akad. Nauk SSR Ser. Fiz.* **50**, 1879 (1986).

[5] G.G. Adamian *et al.*, *Int. J. Mod. Phys.* **E5**, 191 (1996).

[6] Sh. Kalandarov *et al.*, *Phys. Rev.* **C82**, 044603 (2010).

[7] G.G. Adamian, A.K. Nasirov, N.V. Antonenko, R.V. Jolos, *Phys. Part. Nucl.* **25**, 583 (1994).