HIGH-ENERGY γ-QUANTA EMISSION IN HEAVY-ION REACTION ^{18}O + ^{27}Al at 8.3 MeV/u*

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The ^{18}O + ^{27}Al reaction at 8.3 MeV/u is discussed in comparison with the same reaction performed for lower projectile energies between 2.5 and 6 MeV/u. In this report an influence of additional reaction mechanism — an incomplete fusion — has been analyzed.

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1. Introduction

The intention of this work was to study the importance of the incomplete fusion mechanism which may take place in the ^{18}O + ^{27}Al reaction at 8.3 MeV/u projectile energy and to compare the results with those for the same reaction analyzed earlier for lower energies of 2.5–6 MeV/u [1,2]. High-energy γ-ray emission studies performed for several heavy-ion collisions at projectile energies of 6–11 MeV/u [3] allow us to expect that contributions of bremsstrahlung emission and incomplete fusion in the ^{18}O + ^{27}Al reaction up to 6 MeV/u were absent or almost negligible, as it was assumed in the analysis in [1,2]. The γ-ray spectra at higher projectile energies are obviously influenced by these processes which may be, however, difficult to observe in this nearly mass-symmetric reaction. The available data at 8.3 MeV/u [4] were earlier analyzed taking into account the complete fusion and bremsstrahlung emission [5]. We decided to continue the analysis reported in [5] in order to estimate the contribution of incomplete fusion.

In the analysis performed here for the reaction studied the CASIBRFIT code [6] has been used and both complete and incomplete fusion and the bremsstrahlung process have been included. The statistical emission from

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the average compound nucleus produced in fusion reactions and the nonstatistical emission during the initial stages of the collision process [5] has been taken into account.

2. Incomplete fusion mechanism and assumptions

In the case of an incomplete fusion of two colliding nuclei only a part of a projectile undergoes the fusion with the target creating a new compound nucleus of mass number $\widetilde{A}_{\rm CN}$ and atomic number $\widetilde{Z}_{\rm CN}$. The other part of the projectile — the Preequilibrium Particle (PreeqP) — is emitted before equilibration of a compound nucleus. The preequilibrium particles here could be protons, neutrons, α-particles and ^{8}Be nuclei decaying into two α-particles. Each PreeqP carries away a part of available mass (ΔA_i), energy (ΔE_i), charge (ΔZ_i) and spin (ΔI_i). Thus, the initial excitation energy $\widetilde{E}^*_{\rm CN}$, mass $\widetilde{A}_{\rm CN}$, charge $\widetilde{Z}_{\rm CN}$ and spin $\widetilde{I}_{\rm CN}$ of the created compound nucleus are correspondingly lower:

$$\widetilde{A}_{\rm CN} = A_{^{45}{\rm Sc}} - \Delta A\,, \quad \widetilde{Z}_{\rm CN} = Z_{^{45}{\rm Sc}} - \Delta Z\,, \quad \widetilde{E}^*_{\rm CN} = E^*_{^{45}{\rm Sc}} - \Delta E^*, \tag{1}$$

$$\Delta E^* = \sum (T_i + B_i)\nu_i\,, \quad \Delta A = \sum \Delta A_i \nu_i\,, \quad \Delta Z = \sum \Delta Z_i \nu_i\,. \tag{2}$$

Here B_i and T_i (Table I) are the binding PreeqP energy calculated with CASCADE code and the average kinetic PreeqP energy evaluated in the Fermi Jet model [7], since in the ^{18}O+^{27}Al experiment only γ-rays were measured. The emission multiplicity ν_i of possible PreeqP's was estimated by using the literature data. The multiplicities of α-particles were evaluated from the ratio of cross-sections for complete and incomplete fusion (with α-particles emission) and its dependence on the projectile velocity ($\beta_{\rm lab}$) measured for the ^{12}C+^{51}V reaction at projectile energies of 36–100 MeV [8]. Such ratio of the cross-sections depends nearly linearly on $\beta_{\rm lab}$ and only weakly on the kind of reaction [9]. The multiplicity of the protons was calculated as a half of the α's multiplicity, according to [10]. The multiplicity of the neutrons was estimated on the basis of the ^{12}C+Gd reactions data [11].

TABLE I

Characteristics of the PreeqP's in the ^{18}O+^{27}Al reaction at 8.3MeV/u.

PreeqP	T_i[MeV]	B_i[MeV]	$E_i = T_i + B_i$[MeV]	A_i	Z_i	ν_i
n	10	11.3	21.3	1	0	0.75
p	12	6.9	18.9	1	1	0.23
α,^{8}Be	22	7.9	29.9	4	2	0.46

All the values found are given in Table I. In order to take into account an average effect of the complete and incomplete fusion, when analyzing the reaction, an average projectile $(\widetilde{A}_{\rm P}, \widetilde{Z}_{\rm P})$ has been assumed to interact with the target of ^{27}Al during the collision leading to fusion:

$$\widetilde{A}_{\rm P} = A_{^{18}{\rm O}} - \Delta A,\ \widetilde{Z}_{\rm P} = Z_{^{18}{\rm O}} - \Delta Z. \tag{3}$$

Considering the values given in Table I, the average projectile taking part in the fusion may be estimated to be ^{15}N. Thus the average compound nucleus is ^{42}Ca. The initial excitation energy of ^{42}Ca is $\widetilde{E}^{*}_{\rm CN} = 78.6$ MeV, which requires the ^{15}N projectile energy to be equal to 88.9 MeV in the laboratory frame.

3. CASIBRFIT calculations and conclusions

The CASIBRFIT code used in the presented calculations has included both the bremsstrahlung process in the ^{18}O+^{27}Al reaction at 8.3 MeV/u projectile energy and the statistical Giant Dipole Resonance (GDR) decay of the average compound nucleus ^{42}Ca at $\widetilde{E}^{*}_{\rm CN} = 78.6$ MeV/u created in the ^{15}N+^{27}Al reaction at 5.2 MeV/u. The γ-ray emission calculated for both statistical and nonstatistical processes has been fitted to the measured data [4]: γ-ray spectrum $\sigma_\gamma(E_\gamma)$ and angular distribution coefficient $a_1(E_\gamma)$. The GDR parameters for the two components of the GDR: S_1, E_1, Γ_1, S_2, E_2, Γ_2 and the bremsstrahlung parameters: σ_0, E_0^0 have been varied and extracted from the fit. They are listed in Table II.

TABLE II

GDR and bremsstrahlung parameters for the ^{18}O + ^{27}Al at 8.3 MeV/u.

$\bar{E}$	E_2/E_1	S_2/S_1	S_1+S_2	FWHM
19.9 ± 7.5	1.35 ± 0.18	0.9 ± 10.5	1.33 ± 0.92	18.2 ± 1.1
Γ_1	Γ_2	σ_0	E_0(30 MeV) [MeV]	
13.5 ± 19.2	17.0 ± 34.9	0.078 ± 0.115	7.3 ± 2.9	

Results of the fit are shown in the Fig. 1. The presence of the incomplete fusion contribution in the calculations resulted in lowering of the excitation energy of the compound nucleus formed. As a consequence the statistical γ-ray cross-section decreased at high E_γ. It forced the second GDR component and bremsstrahlung contribution to increase in order to fit the data. As a result the fitted value of $a_1(E_\gamma)$ coefficient became positive and slowly

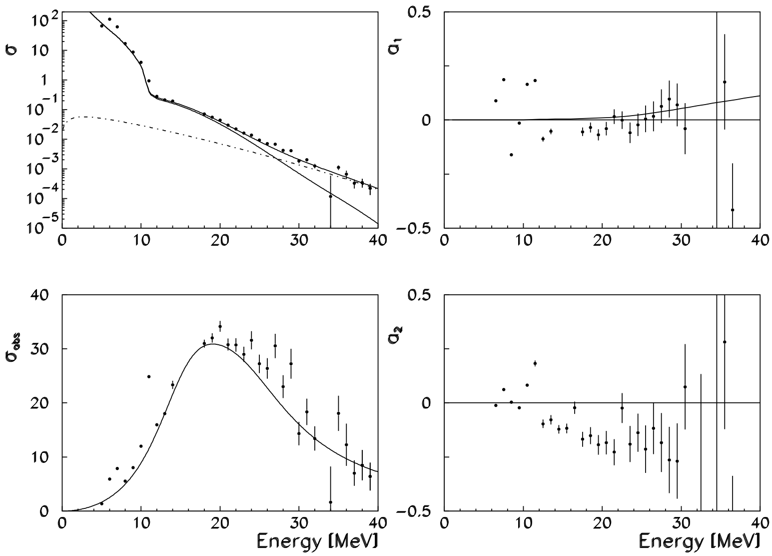

Fig. 1. CASIBRFIT calculations for ^{18}O + ^{27}Al at $E_{\rm proj}/A$=8.3 MeV/u: measured and fitted γ-ray spectrum $\sigma(E_\gamma)$ (upper solid line — total, lower solid line — statistical contribution, dashed — bremsstrahlung contribution), $a_1(E_\gamma)$ coefficient, absorption cross-section $\sigma_{abs}(E_\gamma)$ and $a_2(E_\gamma)$ coefficient.

increasing at high E_γ. The ratio of the S_2/S_1 became larger and the relative contribution of the second GDR component increased, improving the quality of the fit, when comparing with the results for only the complete fusion and bremsstrahlung included [5]. It suggests that even if the incomplete fusion and bremsstrahlung processes should be taken into account at projectile energy of 6 MeV/u for the reaction studied, they would cause an increase of the second GDR component in the calculated absorption cross-section which would support the conclusion of [1,2].

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