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COMPLEX PARTICLE EMISSION IN THE EXCITON MODEL OF NUCLEAR REACTIONS[1]

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Much attention within the pre-equilibrium model of nuclear reactions has been given especially lately to the complex particle emission. It is possible to divide the approaches used today into two groups. The first of them uses the method developed by Blann and Lanzafame [1], highly improved by Cline and Ribanský and Obložinský [2]. This approach is based on the assumption that a complex particle takes away a number of excitons equal to its mass number. The second approach, so far applied only to the α-particles, assumes that the α-particles are preformed in the nucleus [3] and that their emission shows itself by the decrease of one exciton [3, 4].

In this paper the spectra of particles from different reactions are studied. The exciton model of nuclear reactions reflects, as the other statistical models in the investigated energy region do, only the gross structure of the spectra and it is not useful for the study of their fine structure (resonances etc.). The method of the papers [2] is used here due to the fact that the spectra of different complex particles are studied. The comparison with the experiment enables to determine the transition matrix element and the forming probabilities of the complex particles.

The probability of an emission of the complex particle β with the mass number p_β, the spin s and the energy ε from a state with p excited particles and h holes is according to [2].

$$W_\beta(p, h, \varepsilon)\,\mathrm{d}\varepsilon = \gamma_\beta \frac{2s+1}{\pi^2\hbar^3}\,\mu_\beta\varepsilon\sigma_{INV}(\varepsilon)\,\frac{\omega(p_\beta, 0, E-U)}{g}\,\frac{\omega(p-p_\beta, h, U)}{\omega(p, h, E)} \times \\ \times R_\beta(p)\,\mathrm{d}\varepsilon. \tag{1}$$

In Eq. (1) the γ_β is the probability of formation of the complex particle β in the nucleus and $R_\beta(p)$ is the combinatorial factor which expresses the numbers of the proton and the neutron excitons [2].

The total particle emission probability from a state with $n = p + h$ excitons is thus

$$L(n, E) = \sum_\beta \int_0^{E-B} W_\beta(p, h, \varepsilon)\,\mathrm{d}\varepsilon \tag{2}$$

and the set of master equations of the pre-equilibrium decay of a nucleus has the usual form [2, 5]. The transition rates to states with $n \pm 2$ excitons are proportional to the average square of the transition matrix element $|M|^2$. It is often taken from the fit to

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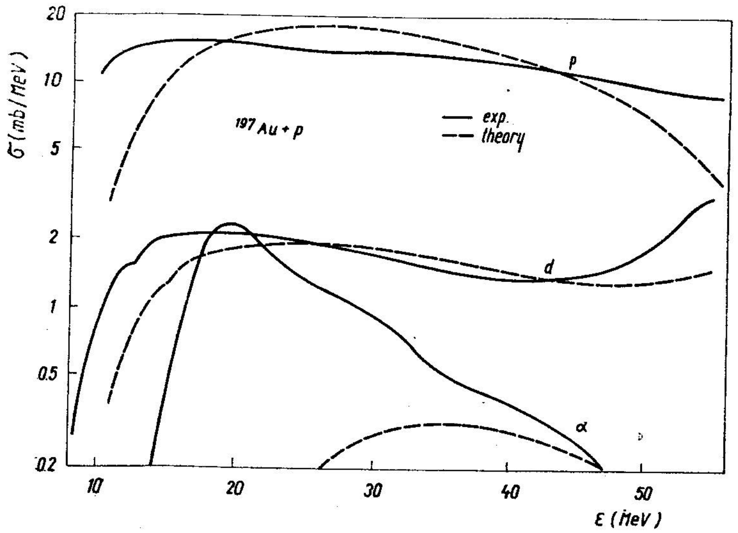

Fig. 1a. Proton-, deuteron-, and α-spectra from the system $^{197}\mathrm{Au}^{+}p$. The excitation energy is $E = 68.2$ MeV. The experiment is drawn in a full line, the theory in a dashed one. The parameters of calculations are summarized in Table 1.

the experiment; its empirical dependence on the nucleus mass and the excitation energy can be for most cases expressed as $|M|^2 = KA^{-3}E^{-1}$, where K is the reaction type dependent constant [6]. For the reactions investigated here and after its correction by the factor of 2 due to the indistinguishability of excitons [5] is $K = 190\ \mathrm{MeV}^3$ [6].

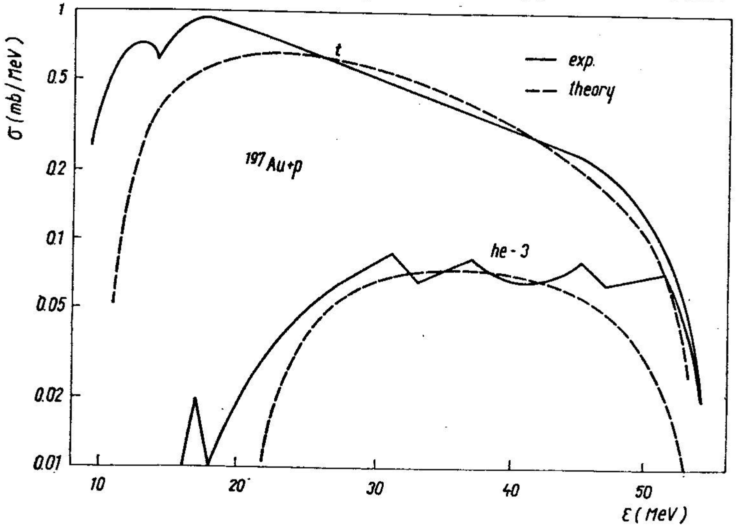

Fig. 1b. Triton and helion spectra from the decay of the same system as in Fig. 1a. The lines have the same meaning as in Fig. 1a.

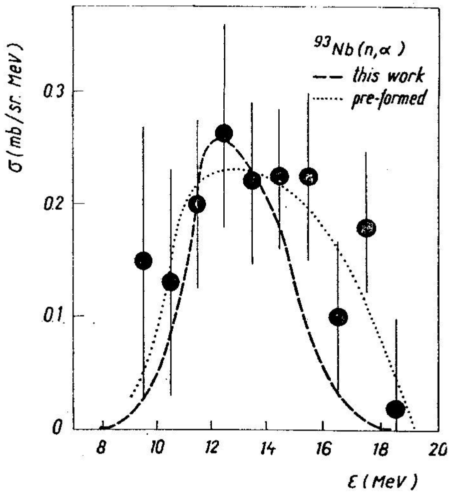

Fig. 2. Theoretical and experimental α-particle spectra from the reaction $^{93}\mathrm{Nb}$ (n, α). The theoretical spectrum with pre-formed α-particles is drawn in a dotted line, the spectrum calculated in this work in a dashed line. The experiment and the calculated spectrum of the pre-formed α-particle emission are from Ref. [3].

The set of master equations with the emission probabilities (2) was solved by the *PREEQ* program [7]. This program enables to calculate the competition of the emission of nucleons and that of complex particles up to the α-particle and it also includes the effect of the finite depth of the nuclear potential well [8].

The decays of the composite nuclei $^{120}\mathrm{Sn}^{+}p$ and $^{197}\mathrm{Au}^{+}p$ [9] have been analysed by use of the study of more output channels. Also the reactions (n, α) taken from Ref. [3] have been investigated. In the case of the first group of the reactions the value of the transition matrix element was determined from the fit of the proton channel and only the forming probabilities of the other outgoing particles were changed at fixed $|M|^2$. For the reactions (n, α), the transition matrix element according to [6] was taken due to the lacking experimental data.

While studying the first group of reactions we took into account that also the decays of daughter nuclei contribute to lower energies of particles (i. e. reactions of type (p, np), $(p, 2p)$, $(p, p\alpha)$ etc.). That is why we concentrated mainly on higher energies of the outgoing particles. The total fit of the theory to the experiment is very good for deuterons, where the theory reproduces even the cross-section increase at the high-energy edge of the spectrum. The worst agreement is for the α-particles. Fig. 1, which brings the charged particle spectra from a nucleus $^{197}\mathrm{Au}^{+}p$, is an intuitive example of a comparison of the theoretical and experimental spectra.

In the reactions (n, α) the fit of the theory to the experiment is again not too good. As an example the spectrum from the reaction $^{93}\mathrm{Nb}$ (n, α), already successfully analysed in Ref. [3], is presented in Fig. 2.

A not too good agreement of theoretical and experimental α-spectra is obviously caused by the fact that the nucleons are strongly bound in the α-particle, so that the α-particle manifests itself as a single whole. Such an explanation would lead at least with some probability to the pre-formed α-particle emission [3].

It was possible to obtain in most cases the data about the forming probability of complex particles and about the transition matrix element from the comparison of the theory and the experiment. These results are summarized in Tab. 1. The forming proba-

Table 1

System	Excitation energv (MeV)	Incident energy (MeV)	Outgoing particle	$K = |M|^2 A^3 E$ (MeV^3)	Forming probab.
^{120}Sn$+p$	67.2	61.5	p	100	
			d		0.024
			t		0.009
			he-3		~0.0016
			$alpha$		~0.005
^{197}Au$+p$	35.7	28.8	p	300	
			d		0.024
			t		~0.01
			he-3		xxx
			$alpha$		~0.003
^{197}Au$+p$	68.2	61.5	p	250	
			d		0.016
			t		0.008
			he-3		0.004
			$alpha$		~0.008
^{93}Nb$+n$	19.6	14.2	$alpha$	*	~0.0055
^{163}Dy$+n$	22.0	14.5	$alpha$	*	xxx
^{197}Au$+n$	20.7	14.5	$alpha$	*	~0.0025

Comments: * Due to the lacking experimental data this constant was taken according to [6], $K = 190$ MeV^3.

~ The insufficient fit to the experiment enables only an estimate of this quantity.

xxx It is not possible to determine the forming probability from the fit to the experiment.

bilities of complex particles in these reactions range up to 0.024. The transition matrix elements are close to the values suggested by Kalbach, with the exception of the ^{120}Sn$+p$ system decay, where our value of $|M|^2$ is somewhat lower.

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