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Effect of the phase space factor in the breakup of composite particles

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The need to include the phase space factor in the analysis of α breakup spectra according to Fermi's Golden Rule is indicated. The importance of the number of particles present in the final state is exemplified by a model calculation for proton, deuteron, and triton spectra produced by the breakup of 160 MeV alphas on zirconium.

[NUCLEAR REACTIONS phase space factor, model alpha breakup spectra for $Zr(\alpha,xp)$, $Zr(\alpha,xd)$, and $Zr(\alpha,xt)$ reactions at $E_\alpha = 160$ MeV.]

Recently there has been a renewed interest in the study of the breakup of composite particles in the field of nuclei.[1-3] Qualitatively the explanation of the form of the spectra has been given by Serber[4] but the detailed reproduction of the spectra is still a problem pondered by theorists.[5]

In the Serber approach the observed particle is treated as a spectator and is detected in a small cone around 0° with approximately the velocity it had in the projectile. The later experiments and theories have shown that the details of the interaction of the fragments of the projectile with the target cannot be ignored and that considerable inelastic interactions occur.[2,6]

So far the theoretical approaches to the breakup of the deutron and α particle in the field of the nucleus have supposed that in the final state one has three bodies.[2,5,7] The number of particles in the final state and correspondingly the phase space factor was not considered in Refs. 1, 3, and 4, leading to difficulties in the high energy part of the spectrum as pointed out by Serber.

It is our aim to show that the shape of the spectrum is critically dependent on the number of particles that are assumed in the final state. This dependence is introduced through the phase space factor.

The general form of the spectrum is given by the expression

$$\frac{d^2\sigma}{d\Omega dE} = \sum_i R_n |T_n|^2 ,$$

where T_n describes the matrix element for processes resulting in a given final state with n particles, R_n is the phase space factor for the specified n particles, and i denotes the number

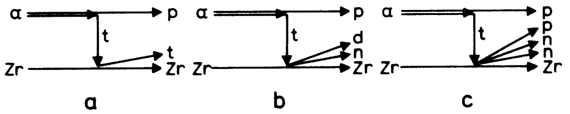

FIG. 1. Graphs of the processes in which the triton from the projectile interacts with the target nucleus: (a) without breaking, (b) with breaking into two particles, and (c) with breaking into three particles, respectively.

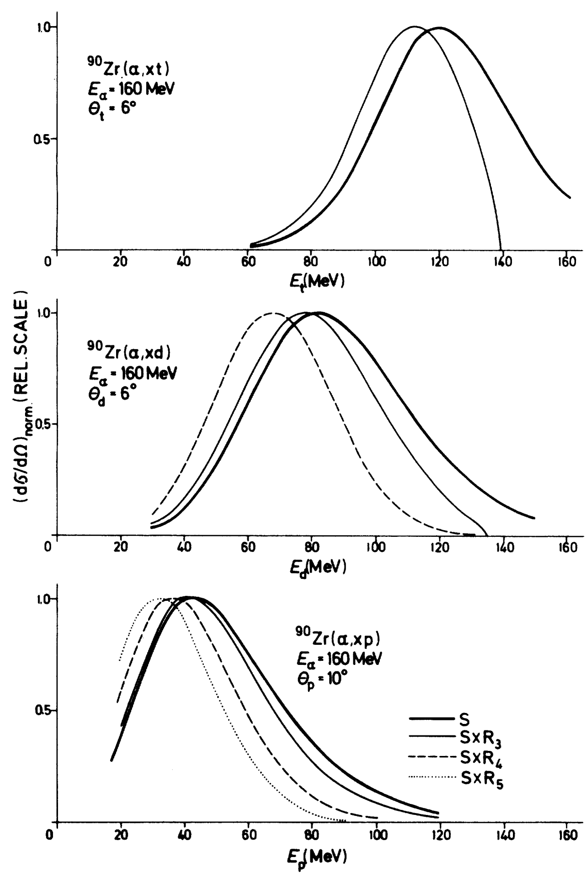

FIG. 2. Normalized theoretical spectra for $^{90}Zr(\alpha,xt)$, $^{90}Zr(\alpha,xd)$, and $^{90}Zr(\alpha,xp)$ at $E_\alpha = 160$ MeV. The heavy line shows the results of the calculation of the Serber type mechanisms (Ref. 1), denoted by S, not taking into account the phase space factor. The thin, dashed, and dotted lines show the result of the calculation when a three, four, and five body phase space (R_n) is included, respectively. The angles of emission of the detected particles are indicated in the figure.

of considered final state combinations.

We have considered the effect of the number of particles in the special case when the interacting part of the projectile is considered to breakup during the interaction with the target. The combinations considered in the case of proton spectra in the α breakup on Zr are given is Fig. 1.

To indicate the distinct influence of introducing a different number of particles in the final state we have calculated the shape of the spectrum separately for different final states. For simplicity, instead of computing the matrix element we have used a Serber type form modified with the phase space:

$$\frac{d^2\sigma}{d\Omega dE} \propto |\psi(p)|^2 R_n \,.$$

$\psi(p)$ is the Fourier transform of the p-t or d-d relative wave functions in the α particle, where p denotes the relative momentum of the fragments in the α particle and R_n is the phase space factor for 3, 4, and 5 particles, respectively.

The results obtained for the reactions ^{90}Zr(α, xp), ^{90}Zr(α, xd) and ^{90}Zr(α, xt) at $E_\alpha = 160$ MeV are shown in Fig. 2. It can be seen that the number of particles involved influences considerably the shape of the spectrum so that admixtures of breakup with higher multiplicity of particles in the final state should be considered when analyzing the breakup of composite particles.

The differences in spectral shape and in the energy position of the maxima clearly indicate that the proper inclusion of the phase space factor is essential for any successful analysis.

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