Neutron decay of states excited in α inelastic scattering

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Neutron spectra from the decay of highly excited states of ^{92}Zr and ^{119}Sn, populated in inelastic α scattering processes at 109 MeV, are analyzed with a model, recently proposed, in which one hypothesizes that the continuum spectrum of inelastically scattered α particles results from a cascade of α-nucleon interactions. The satisfactory reproduction of the data further corroborates this hypothesis.

Recently, a comprehensive model for the calculation of the cross sections of the reactions originated by high energy α particles on nuclei has been presented.[1-3] This model proved very successful when applied to the study of reactions induced on $A \sim 90$ and $A \sim 60$ nuclei by α's with energy up to 170 MeV.[2,3]

The main conclusion drawn from such a study was that the predominant process taking place at α energies of some tens of MeV is a cascade of α-nucleon interactions. The energy distribution of the α particle after the interaction with a nucleon and the probability of α breakup may be estimated by assuming that the dynamics of α-nucleon scattering, in nuclear matter, is essentially the same of the free interaction.

In order to simplify the calculation in the evaluation of the cross sections of the various processes taking place, the approximation that the excited residual nucleus might only decay by evaporation after the emission of a fast α particle, was introduced. This seemed to be a fair approximation since if the α particle carries away a high energy, the residual nucleus, which is left in a simple configuration, has a low excitation energy; if the α particle energy decreases, the residual nucleus excitation energy is shared among a much greater number of excitons.

Recently however, Ejiri and collaborators have measured the decay by neutron emission of continuum states excited in (α,α') inelastic scattering and have shown that a measurable amount of neutrons are emitted with a much greater energy than that expected on the basis of an evaporation decay.[4,5]

These authors were able to identify three different contributions to the spectrum of fast neutrons, which may be separated by looking at their energy and angular distributions.

The energy distribution of *knockout neutrons* displays a structure which reflects the favored excitation of a few hole states at a quite low excitation energy. Their angular distribution is strongly peaked at the recoil angle θ_R, the direction of the momentum transferred to the nucleus in an inelastic α scattering.

The neutrons from the decay of the *isoscalar giant quadrupole resonance* (IGQR) which consists of the coherent superposition of particular one-particle–one-hole states, also display a structured energy distribution and their angular distribution is symmetric with respect to $\theta_R + \pi/2$. Then they give the predominant contribution to the measured spectrum at the antirecoil angle $\theta_{AR} = \theta_R + \pi$.

Preequilibrium neutrons have a structureless energy distribution extending up to the maximum available energy and their angular distribution is enhanced in the beam direction.

Ejiri[4] and Shibata *et al.*[5] measured, in particular, the angle integrated spectra of preequilibrium neutrons corresponding to the deexcitation of 39 MeV ^{92}Zr and 24 MeV ^{119}Sn residual nuclei, when the inelastically scattered α, of 109 MeV incident energy, is emitted at an angle between 13° and 23° with respect to beam direction. They analyzed these spectra assuming for the excited Zr and Sn states a one-particle–one-hole (1p-1h) configuration.

No theoretical quantitative justification for this *ad hoc* assumption was offered and, indeed, the comparison between experimental and calculated spectra for Zr shows that the measured spectrum decreases more steeply with the energy than the calculated one, a clear indication that more complex configurations are important.

In the model discussed in Refs. 1–3, the approximation of considering only evaporative decays after an inelastic α scattering may be easily released. In this Brief Report we wish to show that, indeed, this model predicts the emission of a measurable amount of preequilibrium particles during the decay of the residual nucleus after an inelastic α scattering even if the excitation energy is not very high and that the predicted yield and energy distributions reproduce, satisfactorily, the ones experimentally measured.

This emission may be evaluated by assuming that the excitation energy of the nucleus, after the α particle scattering, is statistically distributed among the excited particles and holes.

The weight of the *i*-particle–*i*-hole configurations for a given energy is the same that have in the spectrum the

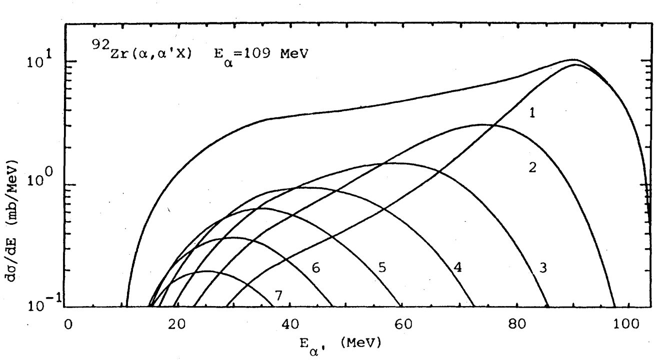

FIG. 1. Predicted angle integrated spectrum of inelastically scattered α particles in α bombardment of ^{92}Zr at 109 MeV. The contribution of α emissions after 1 to 7 α-nucleon scatterings is indicated.

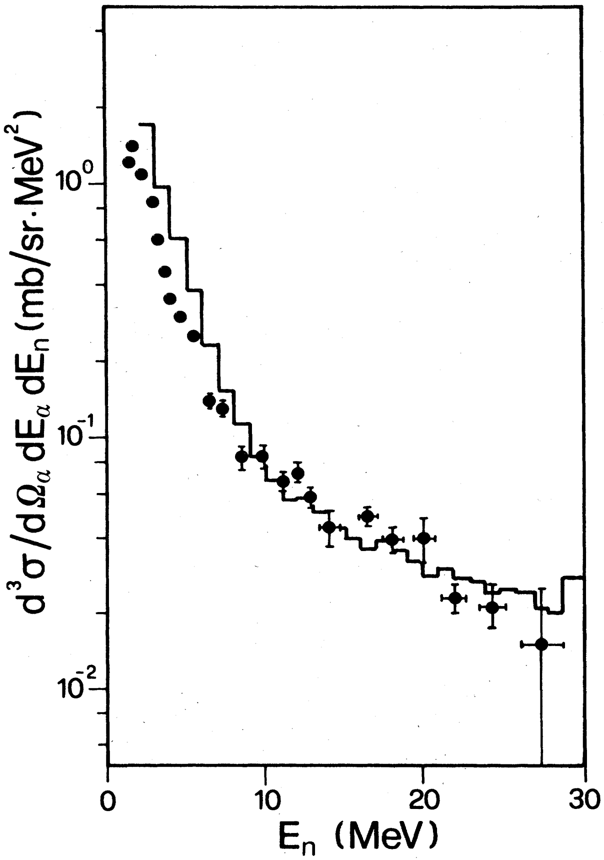

FIG. 2. Comparison of experimental (black circles) and calculated (histogram) spectrum of neutrons from the decay of 39 MeV ^{92}Zr nuclei, after inelastic α scattering.

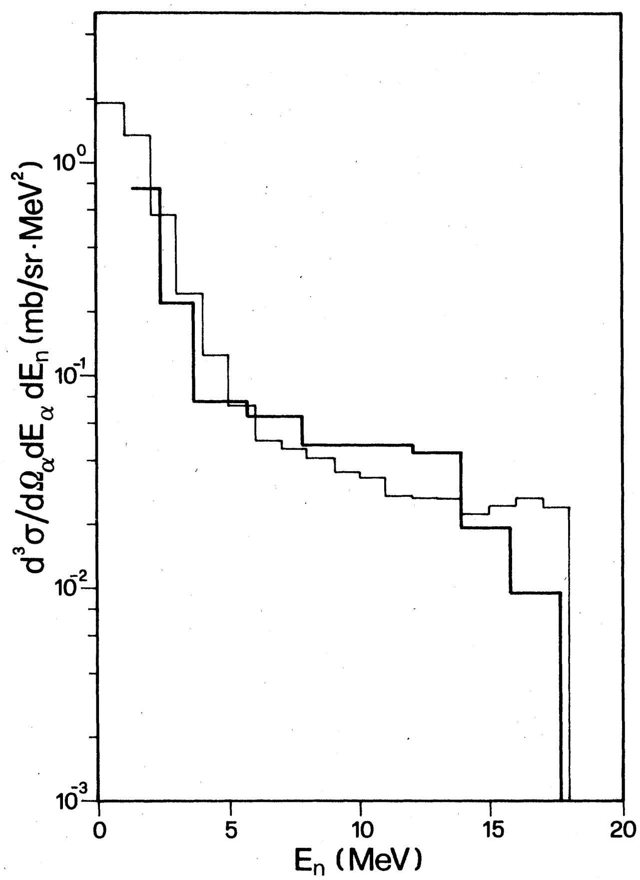

FIG. 3. Comparison of experimental (heavy histogram) and calculated (thin histogram) spectrum of neutrons from the decay of 24 MeV ^{119}Sn nuclei, after α inelastic scattering.

yields of α particles emitted after i scattering events.

In Fig. 1 the predicted angle integrated spectrum of α particles inelastically scattered in the reaction ^{92}Zr(α,α') at $E=109$ MeV is shown together with the contributions of α emissions after 1 to 7 scattering events.

The spectrum of α particles scattered at angles around 20° may be evaluated in the usual approximation of the *fast* or *leading particle*[6] by assuming classical rectilinear trajectories for the α, between two α-nucleon interactions, and classically evaluating the refractions of the incident and outgoing α waves.[7] However, the experimental results show that at the considered incident α energy the shape of the α spectra at $\sim 20°$ is very similar to the one of the angle integrated spectrum, thus indicating that, at not too high excitation energies, the weight of the different particle-hole configurations should be very nearly the same in the two cases.

In Figs. 2 and 3 the predicted spectra of neutrons emitted, respectively, in the decay of 39 MeV excited residual ^{92}Zr nuclei and 24 MeV ^{119}Sn nuclei, after inelastic α scattering, are compared to the ones measured by Ejiri[4] and Shibata *et al.*[5]

The theoretical calculations were made using the parameters reported in Ref. 2 and imaginary optical model potential depths for the α (to predict the α-nucleon collision probability per unit time) were taken from Perey and Perey compilation.[8] Finally, the total cross section σ_α, for processes initiated by an α-nucleon interaction at $E_\alpha=109$ MeV, was calculated as thoroughly discussed in Refs. 2 and 3 and resulted equal to 1520 and 1716 mb for, respectively, ^{92}Zr and ^{119}Sn.

The satisfactory agreement between the experimental and calculated spectra further confirms that our calculations afford a realistic description of the α-nucleus interaction mechanism.

It must be stressed that in both cases configurations involving more than one excited particle and hole were considered. In the case of ^{92}Zr, when the energy of excited states was 39 MeV, the percentage probability of occurrence of the i-particle–i-hole configurations $(i=1,2,3)$ was, respectively, equal to 23%, 47%, 25%; and also 4p-4h configurations played some role.

Even in the case of ^{119}Sn, in the decay of 24 MeV excited states, configurations up to 3p-3h had to be considered. The percentage probability of i-particle–i-hole configurations for $i=1,2,3$ was equal, respectively, to 60%, 35%, and 5%.

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