Investigation of the emission of correlated charged particles due to absorption of stopped π^0 mesons in silicon

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The spectra of correlated (at an angle of 180°) pairs of charged particles emitted by silicon nuclei due to absorption of stopped π^- mesons are measured. The results permit observing compound particles of cluster (direct) origin and particles produced as a result of secondary intranuclear interactions.

Pion absorption reactions are currently being studied in detail both theoretically and experimentally. The dominating, two-nucleon absorption mechanism seems to have been reliably determined. The contribution of cluster mechanisms, including the α-particle mechanism, is less well understood. In particular, their role in reactions involving emission of compound particles is not clear. In recent papers,[1,2] in order to describe the inclusive spectra of compound particles (deuterons, tritons, and ^{3}He), the authors make use of a model in which these particles are formed as a result of two-nucleon absorption followed by intranuclear capture. Comparison of the computed and experimental spectra indicates that the deuteron and ^{3}He spectra are satisfactorily described by such a model, while the $\simeq 10\%$ contribution of α-particle absorption must be taken into account in order to describe the tritium spectra. Information presented in this paper on the dynamics of absorption reactions accompanied by the emission of pairs of correlated charged particles can serve as a test for checking the hypothesis of formation of compound particles. For example, when deuterons are formed as a result of the capture reactions, the momentum of the deuteron in correlated *pd* pairs must exceed the momentum of the proton. This situation is clearly seen at low excitations of the residual nuclei, when the proton and deuteron energies are approximately equal. At the same time, the hypothesis that such pairs form as a result of the capture of a π^- meson by three-proton association requires that the momenta, rather than the energies, be equal. Analogous criteria can also be applied to events with tritons, for example, for *pt* and *dt* pairs, in order to determine the role of α-particle absorption.

The experiment was performed with the help of a dual-beam semiconducting spectrometer[3] using a low-energy pion beam from the synchrocyclotron of the Leningrad Institute of Nuclear Physics, USSR Academy of Sciences.[4] Pairs of charged particles, correlated at an angle of 180° and emitted by silicon nuclei with absorption in a "live" target Si(Au) semiconductor detector, were recorded. The energy resolution of the spectrometer for total energy of the pairs is ~ 1 MeV. The use of a detector as a

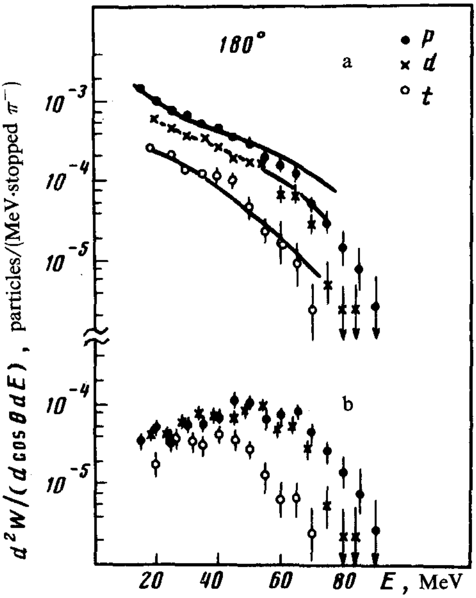

FIG. 1. Spectra of particles from recorded pairs, $E_p \geqslant 12.1$ MeV; $E_d \geqslant 16.2$ MeV; $E_t \geqslant 19.3$ MeV. (a) Unrestricted. The smooth curves show the inclusive spectra of particles from Ref. 5, normalized in the interval 25–55 MeV, (b) excitation energy of residual nuclei $-E^* \leqslant 25$ MeV, the energy released in the target $E_M \leqslant 5$ MeV.

target made it possible to single out the reaction channels in which only two charged particles are emitted. This could be done by measuring the energy evolution of the target.

Figure 1a shows the spectra of protons, deuterons, and tritons from the detected pairs. The smooth curves show the inclusive spectra of the same particles from the previously published work.[5] It is evident that there is no significant difference between the inclusive spectra and the spectra of particles recorded in coincidence; i.e., simply put, the spectra of charged particles correlated at 180° do not give new information on the mechanism of formation of such pairs, including those with deuterons and tritons.

This absence of distinguishing features in the recorded spectra is apparently due to the increase in the role of secondary interactions and, as a result, an increase in the multiplicity of particles in the reactions induced by the central nucleus. Figure 2 shows the spectra of excitations of residual nuclei for the recorded pairs. From these spectra it is evident that primarily pairs of particles are recorded from reactions with large multiplicity, since the regions of small excitations, corresponding to the possible nuclear states with stable nucleons, comprise a small fraction of the total spectra. This fact is also confirmed by spectra from a "live" target, where the events involving the emission of additional charged particles are recorded from the large release of energy.

To identify the pairs of particles with characteristics which are sensitive to the formation mechanism we must select the reactions with a low multiplicity. There are two ways in which this can be done: the first way is to use the readings of the "live"

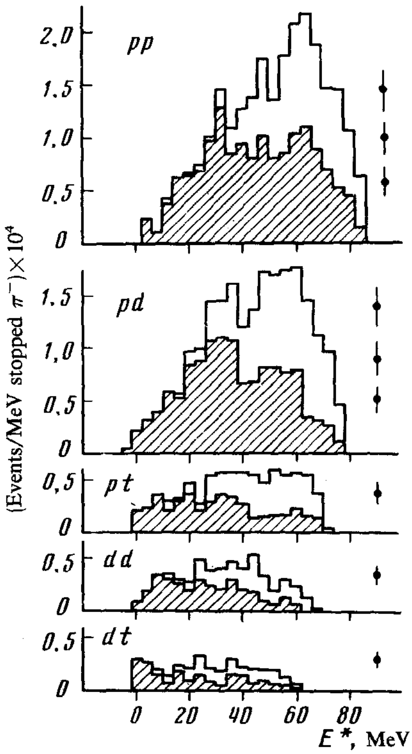

FIG. 2. Excitation spectra of residual nuclei. $E^* = MM - M_k$, where MM is the missing mass in the recorded reactions, M_k is the mass of the nucleus $(A-N, Z-3)$, where N is the total number of nucleons in the recorded particles. The hatched area shows the events with $E_M \leqslant 5$ MeV.

target in order to eliminate the reactions involving the emission of additional charged particles, and the second one is to introduce restrictions on the energy of excitation of the residual nuclei.

The spectra for events with restricted energy release in the "live" target $\leqslant 5$ MeV, which correspond to reactions in which only two charged particles are emitted (the maximum energy of a pion stopped in the target is ≈ 4 MeV and the energy of recoil nuclei is $\leqslant 1$ MeV), are represented by the hatched area in Fig. 2. It is evident that in the excitation spectra the restriction imposed on the target led to the suppression of high values. However, the relative proportion of events with high excitations, corresponding to reactions with emission of neutrons, is quite high. From the point of view of the separation of pairs of particles with characteristics which are sensitive to the mechanism of formation, the admixture of reactions involving the emission of neutrons is a background effect. For this reason, it is expedient to analyze the dependence of the parameters of the particle spectra on the excitation energy.

Figure 3 shows the dependence of the average energies of particles in the *pd*, *pt*, and *dt* pairs on the excitation energy.

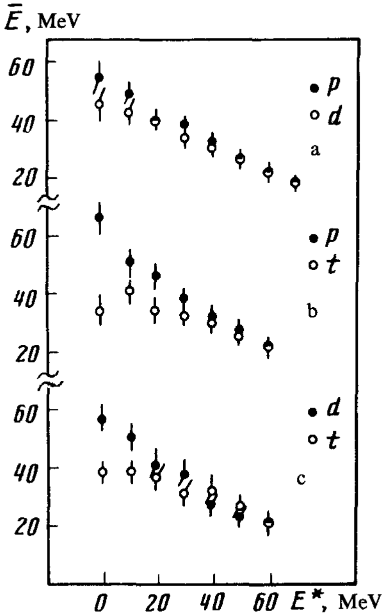

FIG. 3. The average energies of particles in *pd*, *pt*, and *dt* pairs versus the excitation energy for events with $E_M \leqslant 5$ MeV.

In the region of low excitations the smallest difference in the particle energies, ~ 10 MeV, is observed for *pd* pairs (Fig. 3a), in agreement with the expected value of 12 MeV for the mechanism of formation of deuterons as a result of capture reactions. It should also be noted that the dependence obtained for *pd* pairs corresponds to an increase in the difference between the momenta $(P_p - P_d)$ with a decrease in the excitation energy, which, as indicated above, distinguishes the capture mechanism from the cluster origin of deuterons.

For *pt* and *dt* pairs (Figs. 3b and 3c) the average energy of tritons in the region of low excitations is much lower than the energy of lighter particles. The observed ratios of the energies clearly do not agree with the hypothesis of formation of tritons as a result of secondary (N,t) reactions and apparently indicate the significant contribution of α-particle absorption.

An analysis of the energies of particles in the *pt* and *dt* pairs suggests that there is a contribution of direct-origin tritons. For example, from the dependences obtained it is evident that in the interval of excitations 0–25 MeV the average energy of tritons for these pairs is identical and remains essentially unchanged, while the entire change in excitation energy is due to the change in the energy of the lighter particle; i.e., the observed dependences do not contradict the mechanism of formation of such pairs via absorption of π^- meson by an α-cluster when the triton is a direct particle, while the other charged particles are secondary products of intranuclear interaction.

Such a situation is not contradictory when the dynamics of *pd* pairs shows no evidence of absorption by clusters, while for *pt* and *dt* pairs there is evidence for such an occurrence. The reason for this is that the cross section of (N,d) reactions is approximately an order of magnitude greater than the cross section of (N,t) reactions,[6] so that the absence of a large contribution of high-energy tritons is understandable. At the same time, deuterons obtained from absorption by α-particles, in contrast to tritons, cannot be identified by observing the pairs of correlated particles.

The spectra of particles for low-excitation energy of residual nuclei, shown in Fig. 1b, do not contradict these conclusions.

Thus the analysis of correlated pairs shows that both secondary interactions and absorption by heavy clusters contribute significantly to the formation of compound particles emitted by nuclei upon absorption of pions. The model calculations must be developed further with the aim of making comparisons with experiment in order to draw quantitative conclusions.

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