Search for ^{5}He Emission from Hot Compound Nuclei

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In experimental studies of the Ni+Mo reaction [1,2] where compound nuclei were created with excitation energies of up to ~300 MeV, it was found that standard statistical models have serious difficulties in predicting the absolute magnitude and shape of the measured energy spectra for charged particles emitted in coincidence with evaporation residues.

For alpha particles, the experimental spectra show enhancements at low kinetic energies compared to the predictions of the statistical model. The average alpha particle energy, as well as the energy of the maximum in the spectra, were found to be smaller than predicted. This effect was observed to increase systematically with bombarding energy and excitation energy [1].

Such effects have been observed before [3,4,5,6,7,8,9] and have been attributed to a lowering of the average Coulomb barrier for alpha emission due to a large compound nucleus deformation or surface diffuseness. An alternative explanation was proposed in Ref. [1], attributing the effect to the sequential decay of particle-unstable clusters evaporated from the compound nucleus. For example, an alpha particle produced by the subsequent decay of the ^{5}He fragment retains, on average, only 80% of the ^{5}He kinetic energy. Therefore these alpha particles will, on average, have lower kinetic energies than the evaporated alpha particles. Statistical model calculations including the evaporation of ^{5}He fragments were found to produce quantitative agreement with experimental alpha particle energy spectra.

In an experiment to investigate this possibility, evaporated light charged particles and neutrons were detected in coincidence with evaporation residues formed in the 11 MeV/A ^{60}Ni+^{100}Mo reaction. Charged particles were detected in four large area, position sensitive, Si E-ΔE telescopes, behind which were placed 16 neutron counters. A large variety of evaporated clusters ($Z<6$), both stable and unstable, were found in coincidence with evaporation residues, but at low multiplicities.

Of the unstable clusters, the ^{5}He and the first excited state of ^{8}Be (3 MeV) contributed most to the alpha particle spectra. The lifetimes of these two clusters are extremely short, and they typically decay close to the compound nucleus, where its Coulomb field is still appreciable. This field modifies the final velocities of the sequential decay fragments giving rise to a dependence of their relative energy distribution on the orientation of their decay axis. This is clearly observed for the α-α relative energy distributions in Fig. 1, gated on the angle β between the initial (evaporation) and sequential decay axes. For $\beta<45°$ or $\beta>135°$ (solid points), the decaying ^{8}Be (3 MeV) fragments emits one alpha particle forward and one alpha particle backwards. The effect of the CN's Coulomb field can be understood in terms of tidal forces (because we have a repulsive Coulomb force, the tidal forces are in the opposite direction as those for gravity).

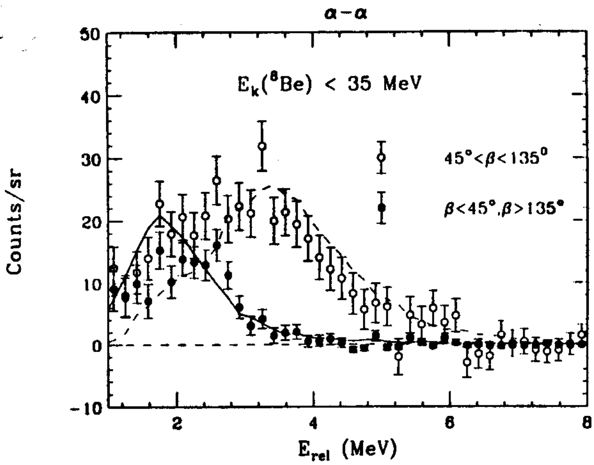

Figure 1. Effect of Coulomb field on ^{4}He fragments of ^{8}Be decay (see text).

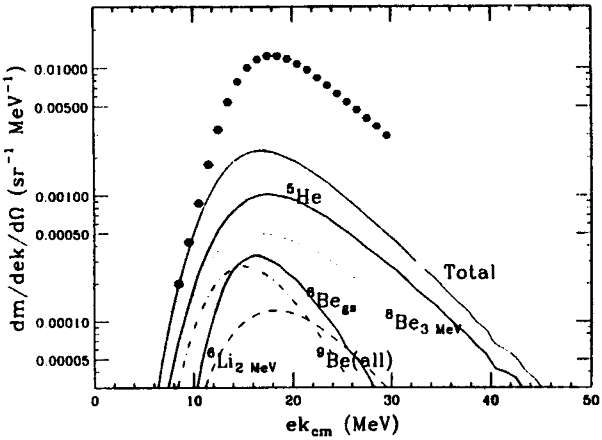

Figure 2. Experimental ^{4}He spectrum (solid points) and deduced contributions from sequential decay of unstable clusters.

For forward-backward emission, the tidal forces reduce the relative velocity. For sideways emission 45°<β< 135° (open points), the tidal force increase the relative velocity. These trends are clearly seen in Fig. 1 for relative energies above 1 MeV which are populated by ^{8}Be (3 MeV) fragments. The experimental data are well reproduced by simulations (the curves in Fig. 1) which follow the Coulomb trajectories of all the particles.

All together, alpha particles from the sequential decay of unstable clusters account for about 15% of the all alpha particles in coincidence with residues. At this level, the important features of the alpha particle energy spectrum like its peak energy and the slope at large energies are not greatly influenced by the contributions from sequential decay. However in the extreme "sub-barrier" region (12 MeV and less), alpha particles from sequential decays dominate the spectrum. This is illustrated in Fig. 2, where the experimental alpha particle energy spectrum is plotted together with the contributions from sequential decay of unstable clusters determined from fitting particle-particle correlations. In conclusion, although the emission of unstable cluster does give rise to an enhancement of low-energy alpha particles, this enhancement is too small to explain the difference between the experimental energy spectrum and the predictions of standard statistical model calculations. The cause of this discrepancy is presumably due to the Coulomb barriers (spherical) used in the calculations.

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