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Alpha-particle emission from the deep-inelastic reaction 1354 MeV ^{165}Ho + ^{181}Ta

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The in-plane correlation between projectilelike fragments and α particles has been studied over a broad range of angles for the system 1354 MeV ^{165}Ho + ^{181}Ta. These data unambiguously indicate that the dominant sources of α particles are the fully accelerated fragments.

[NUCLEAR REACTIONS ^{181}Ta(^{165}Ho,x), $E = 1354$ MeV, measured $\sigma(E_\alpha, \theta)$.]

The study of light particles emitted in low energy ($\leq$10 MeV/nucleon) heavy-ion reactions in coincidence with deep-inelastic or relaxed exit channels has been conducted in two steps. First, one has tried to identify the emission source of the light particles and then, after verification of the emitting sources, the emitted particles have been used as a probe of the temperature and spin of the emitter. So far, these studies have not yielded a consensus on the dominant source of light particles. For example, the reactions 96 MeV ^{16}O + ^{58}Ni,[1] 280 MeV ^{40}Ar + ^{58}Ni,[2] 400 MeV ^{40}Ar + ^{93}Nb,[3] and 664 MeV ^{84}Kr + ^{nat}Ag (Refs. 4 and 5) have indicated that the dominant sources of α particles are the fully accelerated fragments. On the other hand, studies of 222, 274, and 340 MeV ^{40}Ar + ^{116}Sn, ^{154}Sm, ^{164}Dy, ^{197}Au,[6,7] and 480 MeV ^{56}Fe + ^{nat}Ag (Ref. 8) have indicated that the bulk of the α-particle emission occurs prior to scission of the dinuclear system. In addition to evaporative components, some studies have observed a fast forward component not easily explained in terms of evaporation.[6] With this Communication we present evidence that the bulk of α-particle emission, from the 1354 MeV ^{165}Ho + ^{181}Ta system, occurs from the fully accelerated fragments.

A natural Ta target (1.4 mg/cm^2) was bombarded with 8.2 MeV/nucleon ^{165}Ho (~10 ena) from the Lawrence Berkeley Laboratory SuperHILAC. A solid state detector (300 μm) positioned at the grazing angle (29°) was used to detect the projectilelike fragment and to define the reaction plane. On the other side of the beam, five solid state ΔE-E telescopes (40 μm, 5 mm) were used to detect the α particles. While both in- and out-of-plane angular distributions were obtained, only the in-plane data will be presented in this Communication.

Laboratory α-particle energy spectra are shown in Fig. 1 for angles between 30° and 115°. These spectra were obtained by requiring a coincidence between an α particle at the laboratory angles indicated in Fig. 1 and a heavy ion detected at $-29°$ with an energy in the deep-inelastic region. A notable feature of these spectra is the occurrence of two separate peaks at the most forward angle, suggesting the presence of two emission sources. The data at larger angles show essentially a single component, which shifts towards lower energy as the in-plane angle increases.

In order to determine the emission sources, we have plotted in Fig. 2(a) the experimentally extracted root-mean-square velocity (v^{rms}) of the α particles. Also indicated on this figure are the velocity vectors for the detected projectilelike fragment (gated on the deep-inelastic events), the calculated velocity

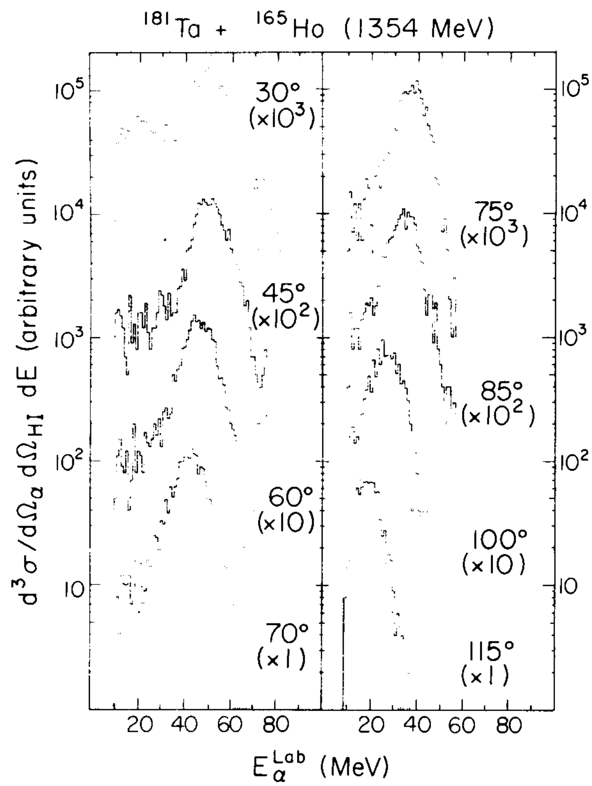

FIG. 1. Coincident laboratory α-particle energy spectra. Laboratory angles are indicated.

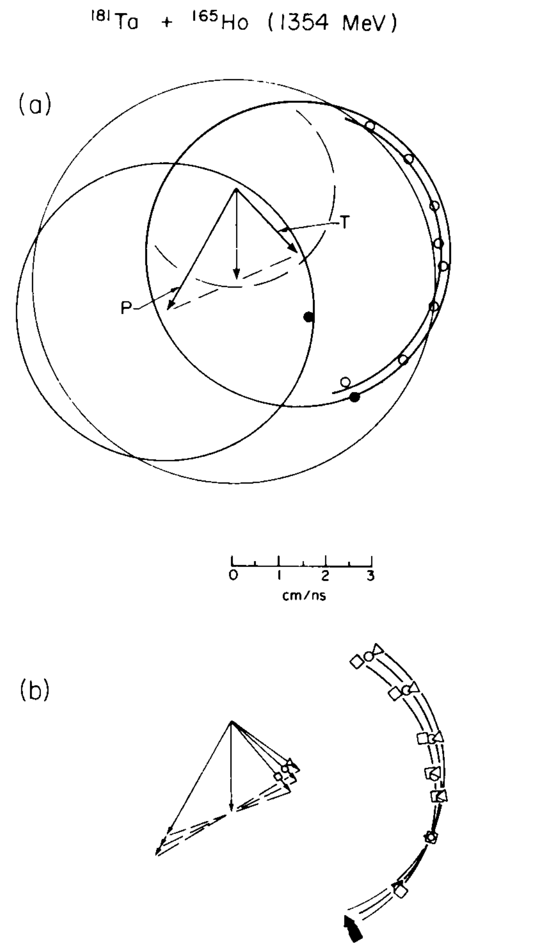

FIG. 2. (a) Velocity diagram for the $^{181}Ta + ^{165}Ho$ (1354 MeV) system. The open circles are the rms velocities extracted from the coincident laboratory α-particle energy spectra. The solid circles indicate the rms velocities of the two separate peaks that appear in the most forward data. The full large rings indicate the loci of expected α-particle velocities (Ref. 7) from the three different rest frames. For the targetlike fragment, the locus of velocities for a 10% reduction in the expected average emission energy is indicated by a partial ring. The detection threshold is shown as a dashed arc. The letters P and T stand for projectilelike and targetlike, respectively. (b) The velocity diagrams for three different Q bins (all in the deep-inelastic region). The rms α-particle velocities for each bin are indicated. The smallest energy loss bin is indicated by triangles and the largest energy loss data by squares. The three partial rings are drawn to guide the eye. They have the same radius and are centered on the three different recoil velocities.

of the undetected fragment, and the velocity of the system center of mass. As Fig. 2(a) shows, the α-particle velocities are centered around the end of the velocity vector of the targetlike fragment. This agrees with the assumption that the α particles are emitted from the fully accelerated targetlike fragment, rather than from a system moving with the center of mass velocity.

Further evidence for fragment emission can be obtained by determining the Q-value dependence of v_α^{rms}. In Fig. 2(b) we have plotted the average vector diagram for three different Q-value bins (all in the deep-inelastic region) and the corresponding v_α^{rms}. A systematic motion of the loci of v_α^{rms} values is seen that can only be explained by a source that has a Q-dependent velocity. This trend is explained by the change of the velocity of the targetlike fragment with Q value, as shown in the figure.

Finally, utilizing two body kinematics the events were reconstructed and transformed event by event into the rest frame of the target recoil. In this frame the α-particle spectral shape is found to be independent of angle with the exception of the most forward angle. In addition, this spectral shape is reproduced quite well by an evaporation formalism that accounts for exit channel shape polarization and fluctuations.[9] The importance of such deformation effects can be readily appreciated by comparing the effective Coulomb barrier (B_c) observed in the present data, calculated from $\langle \epsilon_\alpha \rangle = B_c + 2T$ with observed entrance channel Coulomb barriers in α-particle plus nucleus reactions.[10] The former effective barrier is approximately 25% lower than the latter value.

As has been seen in previous studies of α particles emitted in heavy-ion reactions,[5] a high energy contaminant to the major evaporative component was observed at the most forward angle. Unfortunately, insufficient data were obtained at forward angles to determine the source of these α particles.

In conclusion, by use of in-plane correlation techniques we have shown that for the system 1354 MeV $^{165}Ho + ^{181}Ta$, the dominant sources of α particles are the fully accelerated fragments.

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[1]H. Ho, R. Albrecht, H. Damjantschitsch, F. J. Demond, W. Kühn, J. Slemmer, J. P. Wurm, D. Disdier, V. Rauch, F. Scheibling, and T. Døssing, Z. Phys. A300, 205 (1981).

[2]R. Babinet, B. Cauvin, J. Girard, J. M. Alexander, T. H. Chiang, J. Galin, B. Gatty, D. Guerreau, and X. Tarrago, Z. Phys. A295, 153 (1980).

[3]W. Kühn, R. Albrecht, H. Damjantschitsch, H. Ho, R. M. Ronningen, J. Slemmer, J. P.Wurm, I. Rode, and F. Scheibling, Z. Phys. A298, 95 (1980).

[4]L. G. Sobotka, C. C. Hsu, G. J. Wozniak, G. U. Rattazzi,

R. J. McDonald, A. J. Pacheco, and L. G. Moretto, Phys. Rev. Lett. 46, 887 (1981).

[5]L. G. Sobotka, C. C. Hsu, G. J. Wozniak, D. J. Morrissey, and L. G. Moretto, Nucl. Phys. A 371, 510 (1981).

[6]D. Logan, H. Delagrange, M. F. Rivet, M. Rajogopalan, J. M. Alexander, M. Kaplan, M. S. Zisman, and E. Duek, Phys. Rev. C 22, 1080 (1980).

[7]M. F. Rivet, D. Logan, J. M. Alexander, E. Duek, M. S. Zisman, and M. Kaplan (unpublished).

[8]D. Guerreau, D. Logan, M. S. Zisman, J. M. Alexander, E. Duek, and M. Kaplan (unpublished).

[9]L. G. Moretto, Nucl. Phys. A247, 211 (1975).

[10]M. A. McMahan and J. M. Alexander, Phys. Rev. C 21, 1261 (1980).