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EXCLUSIVE FRAGMENTATION STUDIES OF 40 MeV/u ^{14}N

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Résumé - Les fragments de projectile provenant d'une réaction de 40 MeV/u ^{14}N sur l'or ont été étudiés à un angle de 12.5° dans le laboratoire, en coïncidence avec des ions légers aux angles avants. Différents mécanismes de réaction sont examinés au moyen des corrélations en angles et en énergies.

Abstract - Projectile fragments from 40 MeV/u ^{14}N on a gold target have been studied at 12.5° in coincidence with energetic light ions emitted in the forward direction. Reaction mechanisms are discussed in the light of the correlations in energy and angle.

INTRODUCTION

Inclusive studies of projectile fragmentation at beam energies near the nuclear Fermi energy have shown a rapid change from the narrow momentum widths observed in low-energy heavy-ion collisions to the greater widths associated with fast breakup at relativistic energies. Only recently have exclusive experiments with multi-element forward-angle arrays begun to address the dynamics of this transition /1,2/. In our experiment such an array allowed us to tag the heavy fragments by their coincident light ions so as to isolate the mechanisms contributing to the overall observed momentum widths.

EXPERIMENT

The experimental setup, shown in Fig. 1(a), was based on two heavy-ion silicon detector telescopes located at $\pm 12.5^\circ$ on opposite sides of the beam axis ; one telescope was surrounded by the Chalk River Forward Array /3/ consisting of 36 ΔE -E phoswich telescopes, from which four elements had been removed to accommodate the exiting beam. A beam of 40 MeV/u ^{14}N , supplied by the NSCL at Michigan State University, was incident on a 1-mg/cm² gold target. Coincidences of each heavy-ion telescope with any element of the light ion array were recorded ; singles data were also obtained.

Our first test was to see whether the singles data for projectile fragments were consistent with existing inclusive results. Indeed, the extracted momentum widths agree well with the compiled systematics /4/. We next compared the coincidence rates with the singles rates to find, in agreement with ref. 2, that only a few ($\sim 3\%$ for our geometry) of the heavy "fragmentation" products were in fact accompanied by

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beam-velocity light ions in the array, indicating that in most cases the light partners were either absorbed or violently deflected by the target.

Fig. 1 (a) Experimental setup showing array and silicon telescopes. (b-d) Angular correlations of light ions relative to heavy projectile fragment at $+12.5^\circ$ for three different exit channels.

ANGULAR CORRELATIONS

Analysis of the angular correlations between the light ions and the heavier projectile fragments was performed by using the symmetric placement of the heavy fragment detectors to effectively reflect the array across the beam axis; i.e. coincidences between the array and the $\theta = -12.5^\circ$ telescope were treated as if the telescope were at $\theta = +12.5^\circ$ and the array were on the opposite side of the beam. Fig. 1(b-d) shows bar graphs (normalized to maximum yield in each exit channel) for C-p, B-α and C-α coincidences, plotted as if all heavy projectile fragments were observed in Si telescope 1 and as if the array were on both sides of the beam. Each hexagonal array element subtends 5° ; the blank elements represent two modules that failed. The detector thresholds are 15 MeV/u for protons and alpha particles. Together with the forward orientation of the array, this serves to select largely ions emitted from projectile-velocity sources. In our analysis, all p, d and α coincidences with Be, B, C and N were examined. Note the strong angular correlations (e.g. protons peaked near the coincident carbon fragment but alpha particles peaked on the opposite side of the beam from the carbons).

Of the light ions accompanying heavier projectile fragments, some may come from in-flight decay of a primary fragment produced in a peripheral collision with the target. However, it was not intuitively obvious whether the strong angular correlations displayed in Fig. 1 could result from this type of "sequential decay", remote from the target. To answer this question, decay from an equilibrated primary fragment of specified excitation was simulated using a Maxwell-Boltzmann distribution moving at 88% of projectile velocity, which corresponds to the approximate average observed

fragment energy of 31 MeV/u. The angular distributions of primary fragments are strongly forward-peaked, favoring the observation at 12.5° of fragments which had been kicked out from a smaller angle by the recoil of the light ion decay. For this reason, it was necessary to obtain the fragment angular distribution from the phoswich array and fold it into the simulation. Data from the three rows of detectors nearest the reaction plane were summed and are compared with the simulation in Fig. 2. Only the primary fragment excitation energy and an overall normalization factor were varied to give the agreement shown. For the C-p and B- α channels, these excitation energies are consistent with the emission of only one charge particle; for the C- α case this is not clear. For the C+ α channel it was also necessary to change the slope of the carbon fragment angular distribution from that observed in the dominant carbon channels. Note that data and simulation agree well.

Fig. 2 In-plane angular correlation for three exit channels. Arrow denotes heavy projectile fragment angle. Solid curve is simulation.

It was next suggested that the azimuthal correlations might demonstrate deviations from isotropic in-flight decay. Accordingly, the yield obtained by summing detectors centered at $\phi \sim 15^\circ$ and $\phi = 71, 109, 251$ and 289° was compared with that from $\phi = 18, 162, 198$ and 342° , where ϕ is the azimuthal angle about the beam axis, relative to the horizontal plane. The azimuthal correlation ratios for several reaction channels, $Y(\text{out of plane})/Y(\text{in plane})$, are summarized below and compared with values from the simulation.

Channel	Azimuthal Ratio		Simulation
C-p	0.83	0.07	1.39
C- α	0.65	0.11	0.65
B-p	1.33	0.12	1.30
B- α	0.98	0.12	0.97

With the exception of the C-p channel, which appears to be more localized in plane than its simulation, no significant deviations from the calculations for isotropic decay were observed in the azimuthal correlations.

ENERGY CORRELATIONS

The energy spectra of the heavier projectile fragments measured in coincidence with various light ions in the array show significant deviations from the inclusive spectra. For example, Fig. 3 shows the inclusive ^{13}C spectrum in Si telescope 2 as a dashed line. Most of that peak, which has the momentum width and centroid commonly used in "fast fragmentation" analyses, comes from events in which the light ions are transferred to or sharply deflected by the target. In contrast, energy spectra of the ^{13}C fragments accompanied by protons and alpha particles (light and heavy solid lines in Fig. 3) look quite different: those for proton coincidences are narrower than the inclusive spectra but still have a less steep high-energy edge; those for alpha particles contribute mostly to the tail of the inclusive spectra. While these differences are in part due to the constraints of our setup, such as our detector thresholds and relative angles, it remains clear that the energy spectra for coincidence exit channels are narrower than, and contribute to different portions of, the inclusive spectra.

CONCLUSIONS

It is evident that many mechanisms contribute to the quasielastic fragment peaks in the Fermi energy domain. Our exclusive experiment has shown that fragments with roughly 90% of the beam velocity mainly result from absorption or deflection of projectile nucleons by the target, and to a lesser degree from excitation of the projectile followed by in-flight decay, or from pickup of target nucleons by the projectile which is also followed by in-flight decay. Of these mechanisms, the last corresponds to the highest excitation of the emitting system; nevertheless, the azimuthal angular correlation showed no evidence of the anisotropic emission expected from a localized excitation or "hot spot" on the projectile surface. A comparison of inclusive and exclusive energy spectra for projectile fragments has illustrated that many reaction channels contribute to the inclusive spectra and has shown that conclusions regarding fragmentation mechanisms should not be based on the singles spectra.

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Fig. 3 Energy spectra of ^{13}C in telescope 2 for various correlations. The inclusive data is normalized separately. See text.