Fragmentation in Peripheral Heavy-Ion Collisions: from Neck Emission to Spectator Decays

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Invariant cross sections of intermediate-mass fragments produced in peripheral collisions of ^{197}Au on ^{197}Au at incident energies between 40 and 150 MeV per nucleon have been measured using the 4π multi-detector INDRA [1] and the beams from the SIS synchrotron at the GSI Darmstadt. A sample of the measured spectra for selected fragments is presented in Fig. 1.

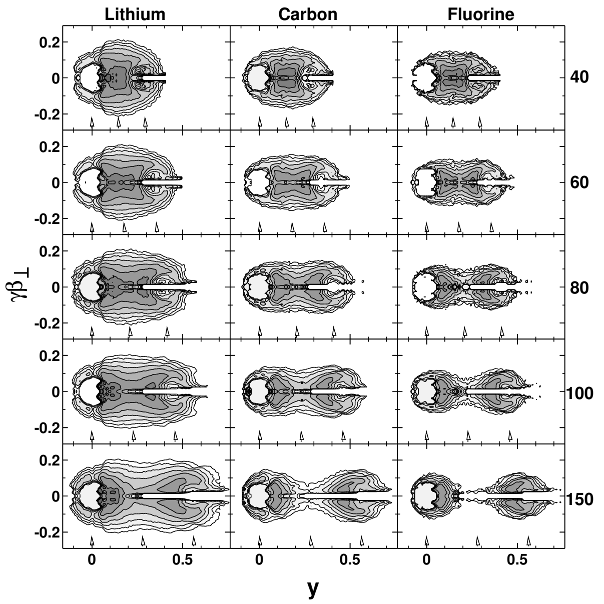

Figure 1: Experimental invariant cross sections of fragments with $Z = 3$, 6, 9 emitted in peripheral collisions as a function of transverse velocity $\gamma\beta_\perp$ and rapidity y for ^{197}Au + ^{197}Au collisions at $E/A = 40$, 60, 80, 100, and 150 MeV. The arrows correspond to the target, center-of-mass and projectile rapidities (from left to right).

A detailed inspection of the invariant cross section distributions leads to the following observations:

- The maximum of the fragment production is located near mid-rapidity at the lower energies and moves gradually towards the projectile and target rapidities as the energy is increased.
- In all cases the fragments are emitted preferentially towards mid-rapidity with a characteristic forward-backward asymmetry with respect to the source rapidity.
- The shapes of the transverse velocity (energy) spectra at mid-rapidity are virtually invariant with respect to the incident energy as well as with respect to the fragment Z (see also [2] and Fig. 2).
- The value of the mean transverse energy at mid-rapidity, $\langle E_\perp \rangle \approx$30 MeV, appears to be surprisingly high and rules out a simple thermal picture.

Some of the observed trends, especially the high value of the mean transverse energy are difficult to be explained satisfactorily by either the available statistical or dynamical models.

In order to identify the basic ingredients that govern the evolution of the fragment production mechanisms in the transition region between the Fermi energy and relativistic energies we have introduced an extended Goldhaber model[3, 4]. Within this simple scenario the initial fragment momenta are composed of the Fermi momenta of constituent nucleons of both the projectile and the target, and also of momenta of hard scattered nucleons. The results of the calculation show that inclusion of on average one scattered nucleon in a fragment is essential to reproduce the experimental transverse energy spectra of mid-rapidity fragments (Fig. 2).

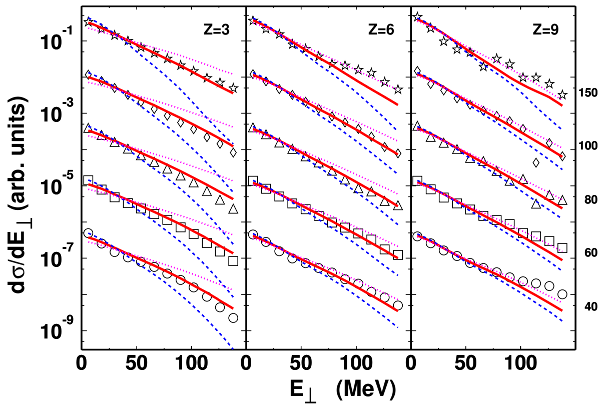

Figure 2: Experimental (symbols) and calculated (lines) transverse-energy spectra of ^{7}Li (left panel), ^{13}C (middle), and ^{19}F fragments (right) emitted at mid-rapidity in peripheral ^{197}Au + ^{197}Au collisions at five incident energies, as indicated. Solid, dashed and dotted lines correspond to the calculations with on average one, zero or two scattered nucleons in a fragment, respectively. In each panel, the experimental spectra are displaced vertically by consecutive factors of 30, and the calculated spectra are individually normalized relative to the corresponding measurement.

The results of the calculation demonstrate also that the observed cross-section distributions and their evolution result predominantly from the clustering (coalescence) requirement for the emerging fragments and from the Coulomb repulsion from the projectile and target residues. Besides the roles of Fermi motion and of hard scattered nucleons, the model emphasizes also those of Pauli blocking and nucleon mixing in the fragmentation process.

As an important result, we find that the same criteria are at work throughout the covered energy range.

References

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[3] A.S. Goldhaber, Phys. Lett. **53B**, 306 (1974).

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