Brief Reports

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Fission of relativistic intermediate-mass nuclei

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We have studied the fission of nuclei with $36 \leq Z \leq 79$ produced in interactions of $1A$ GeV Au nuclei in CR-39 plastic track detectors. The energy released is typical of fission at lower energies, and the transverse momentum transferred to fissioning species is consistent with a peripheral interaction. The distributions of heavy-to-light fragment mass ratios are very broad, as in fission of nuclei with $28 \leq Z \leq 83$ by 600 MeV and 1 GeV protons.

In the first observation of fission of relativistic Au nuclei, Freier and Waddington[1] reported that a large fraction ($\sim \frac{1}{3}$) of the 18 fissions exhibited very asymmetric ratios of heavy (Z_H) to light (Z_L) charges. Using CR-39 plastic track detectors (composition $H_{18}C_{12}O_7$) exposed to relativistic Au nuclei, we have observed 64 fission events. The improved statistics allows us to compare the mass asymmetry in fission of intermediate-mass products of $1A$ GeV Au interactions with the mass asymmetry in fission of target nuclei in the same mass region by 600 and 1000 MeV protons.

We exposed a stack of 80 $15 \times 15 \times 0.072$ cm^3 sheets of CR-39, doped with 1% dioctyl phthalate,[2] at normal incidence to a $1A$ GeV beam of Au nuclei at the Lawrence Berkeley Laboratory Bevalac. We etched the sheets 362 h at 40 °C in 6.25 normal NaOH solution and selected 50 tracks of uninteracted Au nuclei at the left and right edges of the irradiated region to serve as reference events in tracing tracks from sheet to sheet. Using a PDP 11/40 minicomputer to store track diameters (measured with a Compumetric AMS-100 measuring system) and locations relative to the reference tracks, we were able to follow events through the stack, determine accurately the charges, emission angles, and transverse momenta of fission fragments as well as the transverse momentum imparted to each nucleus that fissioned following a peripheral interaction of the parent Au nucleus. Because of the smallness of the angles of deflection of the fissioning nuclei and laboratory angles of the fission fragments, it was essential to know accurately the initial angle of each Au nucleus to the sheet normal. Our measurement of a beam divergence of 1.62 mrad/cm, with respect to the center of the irradiated region, is an indication of the precision with which we were able to measure track angles. We determined the relation between track diameter and fragment charge by irradiating another CR-39 stack with relativistic ^{139}La ions that had passed through a polyethylene slab and fragmented into charges from $Z = 56$

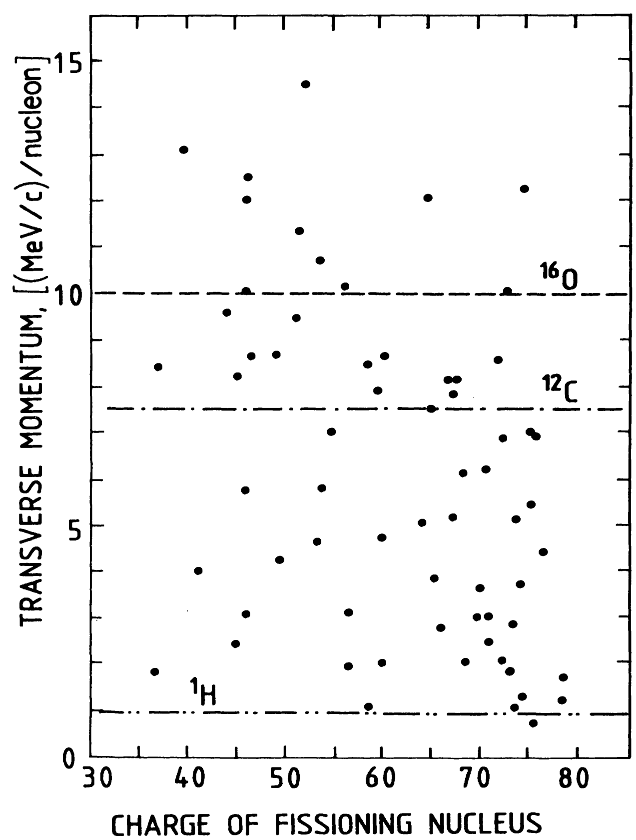

FIG. 1. Transverse momentum per nucleon as a function of charge of the fissioning projectile residue. The dashed lines are calculated values of transverse momenta from collisions of Au projectiles with ^{16}O, ^{12}C, and ^{1}H, assuming an impact parameter equal to the radius of the Au nucleus.

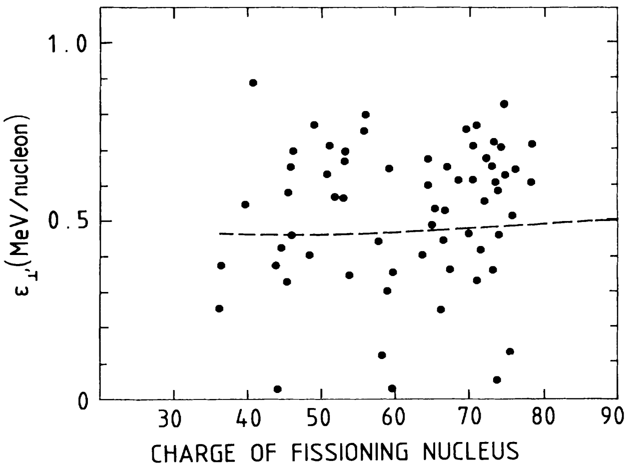

FIG. 2. Transverse kinetic energy per nucleon released in fission as a function of charge of fissioning projectile residue, computed from transverse momenta of the two fragments. The dashed line is the trend of transverse kinetic energies observed in previous fission studies (Ref. 4).

downward.[3] Our charge resolution was better than $0.5e/n^{1/2}$ over the entire charge regime studied, $12 \leq Z \leq 50$, where n is the number of successive etched track diameters used in charge determination.

Figure 1 shows the distribution of measured transverse momentum transfer as a function of charge of excited residual nuclei that subsequently fissioned. The dashed lines are the calculated values of transverse momenta of projectile residues in collisions of Au projectiles with ^{16}O, ^{12}C, and ^{1}H, assuming that the impact parameter is equal to the radius of the Au nucleus. The consistency of the calculated and measured values supports the assumption that interactions leading to fission are peripheral.

Figure 2 shows the portion of the kinetic energy per nucleon released in fission that could be inferred from the transverse momenta of the fission fragments. The dashed curve is the empirical dependence of the transverse portion of kinetic energy of fission as a function of charge, taken from Viola's compilation of previous data.[4]

Figure 3 shows the distribution of charges of the fissioning nuclei and their division into light and heavy fragments. The open circles are data of Freier and Waddington.[1]

Figure 4 shows the charge asymmetry—the ratio Z_H/Z_L—for three charge groupings in Fig. 3 and for all fissioning nuclei. In the approximation that $Z_H/Z_L = A_H/A_L$, the solid curves in Fig. 4 show the charge asymmetry for fission of Yb ($Z=70$), Ce ($Z=58$), La ($Z=57$), and Ag ($Z=47$) by 600 MeV protons[5,6] and the dashed curve is for fission of Bi ($Z=83$) by low-energy (36 MeV) protons.[7]

Our histograms for fission of nuclei with $67 \leq Z \leq 79$, with $54 \leq Z \leq 66$, and with $36 \leq A \leq 53$ appear quite consistent with the curves for 600 MeV proton fission of Yb, of

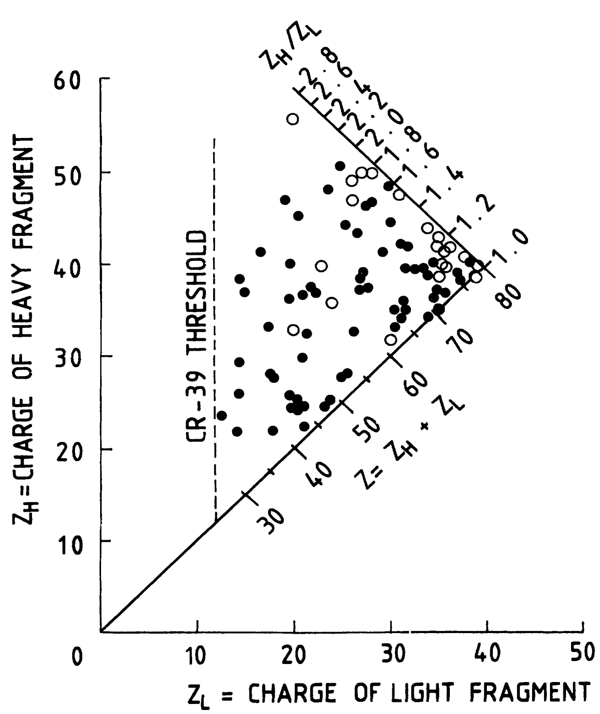

FIG. 3. Charges of heavy and light fission fragments observed by us (solid points) and from Ref. 1 (open circles). Charges below 12 were not detected in CR-39.

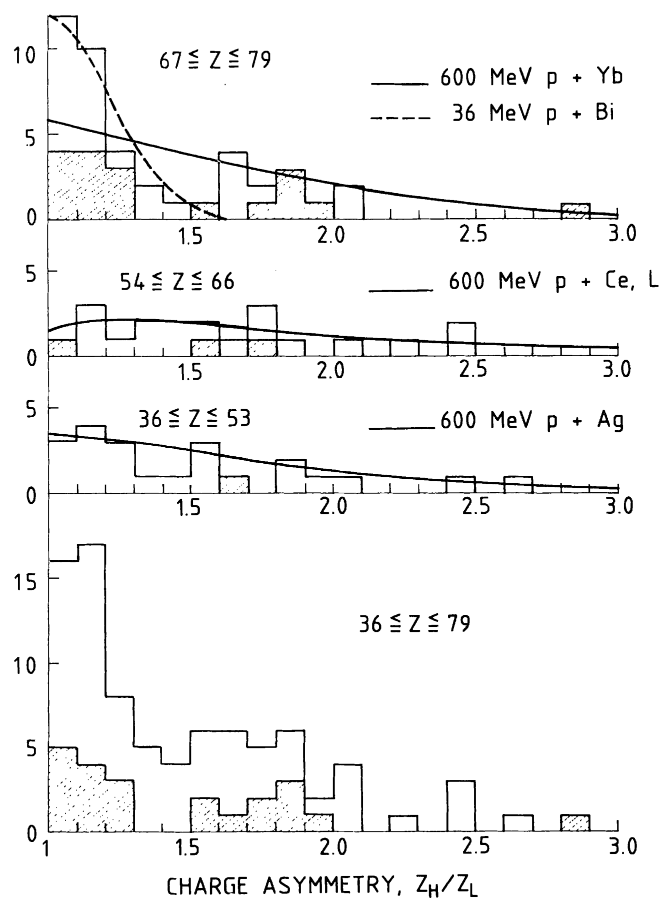

FIG. 4. Distribution of charge asymmetry, Z_H/Z_L, for all data and for three charge groupings. The shaded histogram is for data from Ref. 1. The solid curves are from Refs. 5 and 6; and the dashed curve is from Ref. 7.

Ce and La, and of Ag, respectively. Our results, when viewed in the rest frame of the Au projectiles, pertain to fission induced by 1*A* GeV carbon, oxygen, and hydrogen ions. When examined, together with old data[8] and recent data, for a large number of fissioning species,[5,6,9,10] they show that the mass distributions are much broader for fission induced by nuclei and nucleons above a few hundred MeV/nucleon than by low-energy projectiles.

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