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Author
Russo, P.

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DEFORMATION EFFECTS AND SECONDARY FISSION IN THE DEEP INELASTIC REACTION Au + 979 MeV Xe*

P. Russo, B. Cauvin,** P. Glässel, R. C. Jared, R. P. Schmitt, G. J. Wozniak and L. G. Moretto†

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Abstract:

The reaction between Au and 979 MeV Xe projectiles has been studied with a ΔE - E counter telescope. Kinetic energy spectra, differential cross sections and angular distributions are presented for individual elements resolved up to and above Z = 60. The kinetic energy spectra show two distinct components. One of these is the binary deep inelastic product. The other is a contribution from secondary fission of the binary target-like product. The experimental evidence from the deep inelastic events indicates large fragment deformations.

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Heavy ion reactions have lead to the discovery of phenomena with characteristics intermediate to those of direct and compound nucleus processes.[1] The kinetic energy distributions of the fragments produced in these reactions show two components: a quasi-elastic component at near elastic energies, and a deep-inelastic or relaxed component at energies close to the Coulomb barrier expected for binary division. The continuous behavior of the energy damping seen in the evolution from quasi-elastic to relaxed is characteristic of a process in which the initial kinetic energy is converted into internal excitation of the fragments.

When relatively light projectiles like N, Ne and Ar are employed at energies well above the Coulomb barrier, the observed mass and charge distributions for the relaxed component are very broad. The shapes of these distributions reflect properties of the potential energy surface for an "intermediate complex" consisting of two touching fragments. Angular distributions for the relaxed component are forward peaked in excess of $1/\sin\theta$ for products near the projectile Z and tend to approach $1/\sin\theta$ with increasing mass transfer. These observations have been successfully interpreted in terms of a diffusion process along the mass asymmetry degree of freedom.[2]

In apparent contrast to the results obtained with lighter projectiles, early experiments with Kr projectiles and heavy targets revealed narrow mass distributions and gross angular distributions that were side-peaked.[3] A detailed study of this so-called quasi-fission in the reaction Au + Kr, where fragments were individually resolved in atomic number,[4,5] revealed a transition from side peaked angular distributions for Z's close to the projectile due to very short interaction times, to forward peaked distributions for Z's far removed from the projectile arising from the effective time delay associated with large mass transfers. These results suggest that no substantial difference exists between deep inelastic and quasi-fission processes.

Recent experiments with Xe[6,7] projectiles reveal strong side-peaking for the gross product angular distributions similar to those obtained with Kr. In order to study the relaxation along the mass asymmetry mode for these presumably very short time scales, we have applied an improved technique of Z-identification to the system Au + Xe.

Beams of 979 MeV ^{136}Xe were incident upon natural gold foils 0.630 mg/cm^2 thick. Singles events were detected with four telescopes[5] each consisting of a gas ionization ΔE counter and a solid state E counter. The process of Z-identification was accomplished by means of a computerized method for the automatic location and subsequent fitting of Z-ridges in the two-dimensional E vs ΔE map.[8] In order to systematically locate the Z ridges, a triangular function is convoluted with the data in a narrow cut in E across the ΔE coordinate. The value of the convolution integral oscillates through maxima and minima by the periodic superposition of the triangular function with ridges and valleys, respectively. Figure 1a is a plot of the convolution integral vs ΔE channel normalized so that the folding with a flat background yields a value of unity. From the maxima in the oscillations, a grid of ridge points is generated in the two-dimensional map. These are fit to define the Z-lines. By this procedure, individual elements have been identified up to and above Z = 60.

The laboratory kinetic energy spectra for individual elements produced in the Xe + Au experiments reveal two well-resolved peaks at forward angles particularly near Z = 40. Figure 1b shows examples of the bimodal spectra observed at 30° in the laboratory.

The energy difference between the two components decreases toward backward angles, and between 50° and 60° the two peaks merge.

Figure 2a shows the charge distributions at various laboratory angles for the component which corresponds to the higher energy peak resolved from the bimodal kinetic energy spectrum shown in Fig. 1b. The maximum at the projectile Z and the dominance of the cross section near the grazing angle (38°) indicates that this component is the binary product of the deep inelastic process.

The charge distributions for the low energy component shown in Fig. 1b are plotted in Fig. 2b. These are peaked near one half the target Z suggesting that this component originates from fission of target-like fragments. Evidence for such a fission process has been reported[9] in a radiochemical study of ^{238}U + 288 MeV Ar. The fission component for Xe + Au dominates the differential cross section near Z = 37. The mean laboratory kinetic energy for this component, averaged for three Z's (36, 37 and 38) and plotted in Fig. 1c vs laboratory angle, is peaked near 50°. The cross section for the relaxed gold-like products of binary break-up also peaks near 50° in the laboratory. This dependence of the kinetic energy on angle is strong evidence that secondary fission of target-like products is the origin of the second component. The peak near Z = 42 in the charge distributions for the fission component suggests that the fissioning nucleus is a product of the transfer of several nucleons to the gold target resulting in a higher fission yield from the less abundant but more fissionable nuclei several charge units above the projectile Z.

The mean center of mass kinetic energies (obtained by a transformation which assumes binary kinematics) for the deep inelastic products more than a few Z's removed from the projectile lie approximately 30% below the Coulomb energies for spherical fragments. Less than 10% of this discrepancy can be accounted for by particle evaporation. The average c.m. kinetic energies of the deep inelastic fragments from the Xe + Au experiments suggest large fragment deformations. Observations by Vandenbosch et al.[7] on data for Xe + Pb have prompted the same conclusion.

If the Xe + Au system is indeed highly deformed compared to Kr + Au, it is possible that the interaction times for the two systems are similar due to a reduction of the Coulomb repulsion for the more highly charged Xe + Au system. Evidence for this appears in the charge distribution widths for Xe + Au which are comparable to those for Kr + Au.[4] The width of the charge (or mass) distribution is an increasing function of time in a diffusive mass transfer process. Therefore, similarities in the observed charge distribution widths for both systems give evidence for the comparable lifetimes and hence enhanced deformation in the Xe + Au complex.

It can be argued that enhanced deformations for the Xe + Au system account for certain distinctions in the c.m. angular distributions as a function of fragment Z. The effect of extended shapes is to increase the rotation time so that even slower processes involving large mass transfer give side-peaked angular distributions. The center of mass angular distributions for individual Z's shown in Fig. 3 substantiate this hypothesis. A side peak of greatest intensity is observed for the projectile Z. The persistence of this side peak for the entire range of elements studied is unique among the very heavy ion reactions

The energy difference between the two components decreases toward backward angles, and between 50° and 60° the two peaks merge.

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FOOTNOTES AND REFERENCES

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**On leave from DPhN/MF-CEN, Seclay, France.

†Sloan Fellow 1974-76.

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FIGURE CAPTIONS

Fig. 1. (a) Normalized convolution integral vs ΔE for 979 MeV Xe + Au at 35° in the laboratory. Z resolution is shown up to and above Z = 60. (b) Sample kinetic energy distributions measured at 30° in the laboratory. (c) Mean laboratory kinetic energy for the fission component vs laboratory angle. The solid curve guides the eye.

Fig. 2. (a) Laboratory differential cross section vs Z for the deep inelastic component. (b) Same as (a) for the fission component.

Fig. 3. Center of mass angular distributions for individual Z's for the deep inelastic component.

0 0 0 0 4 5 0 4 6 7 1

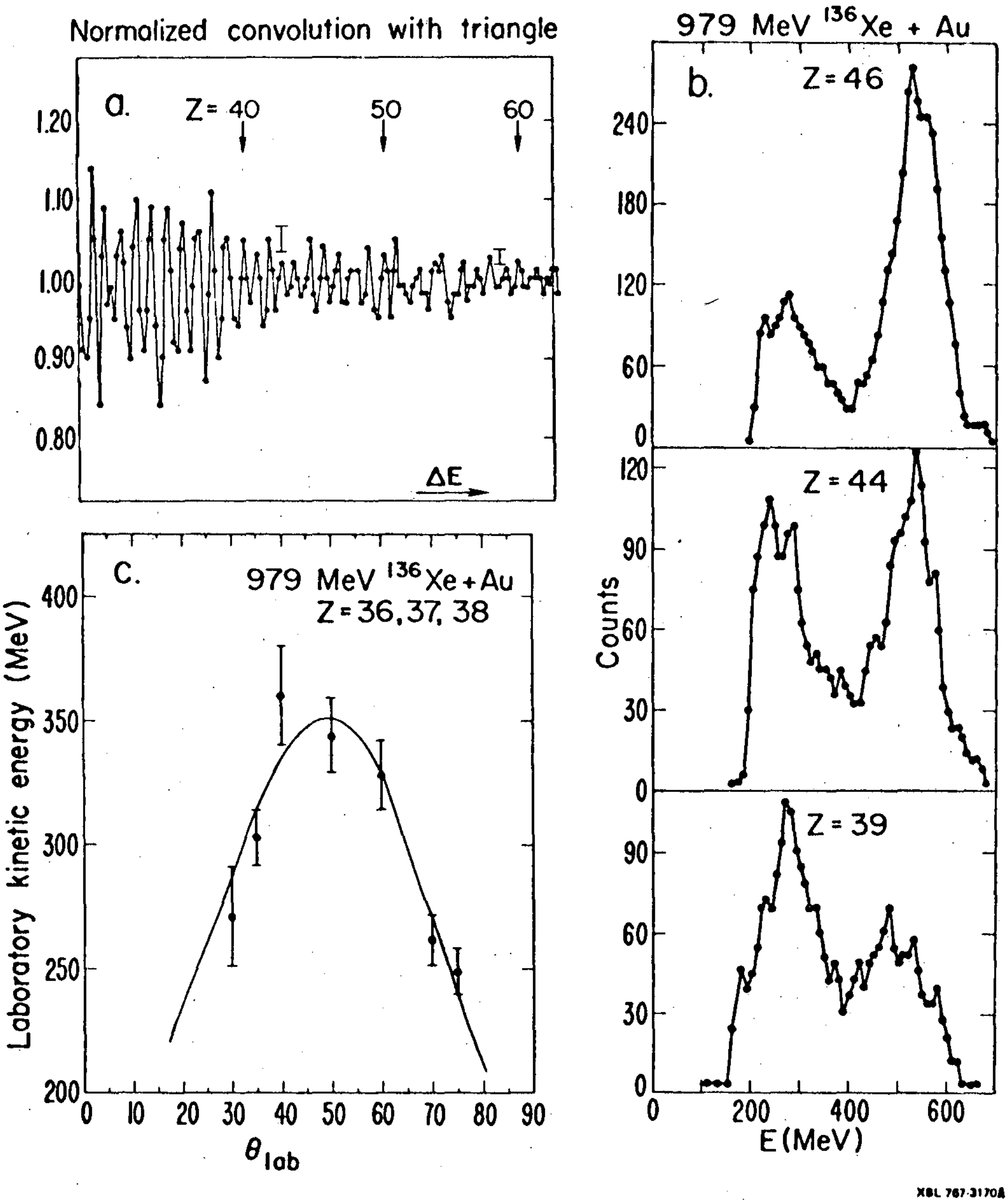

Fig. 1

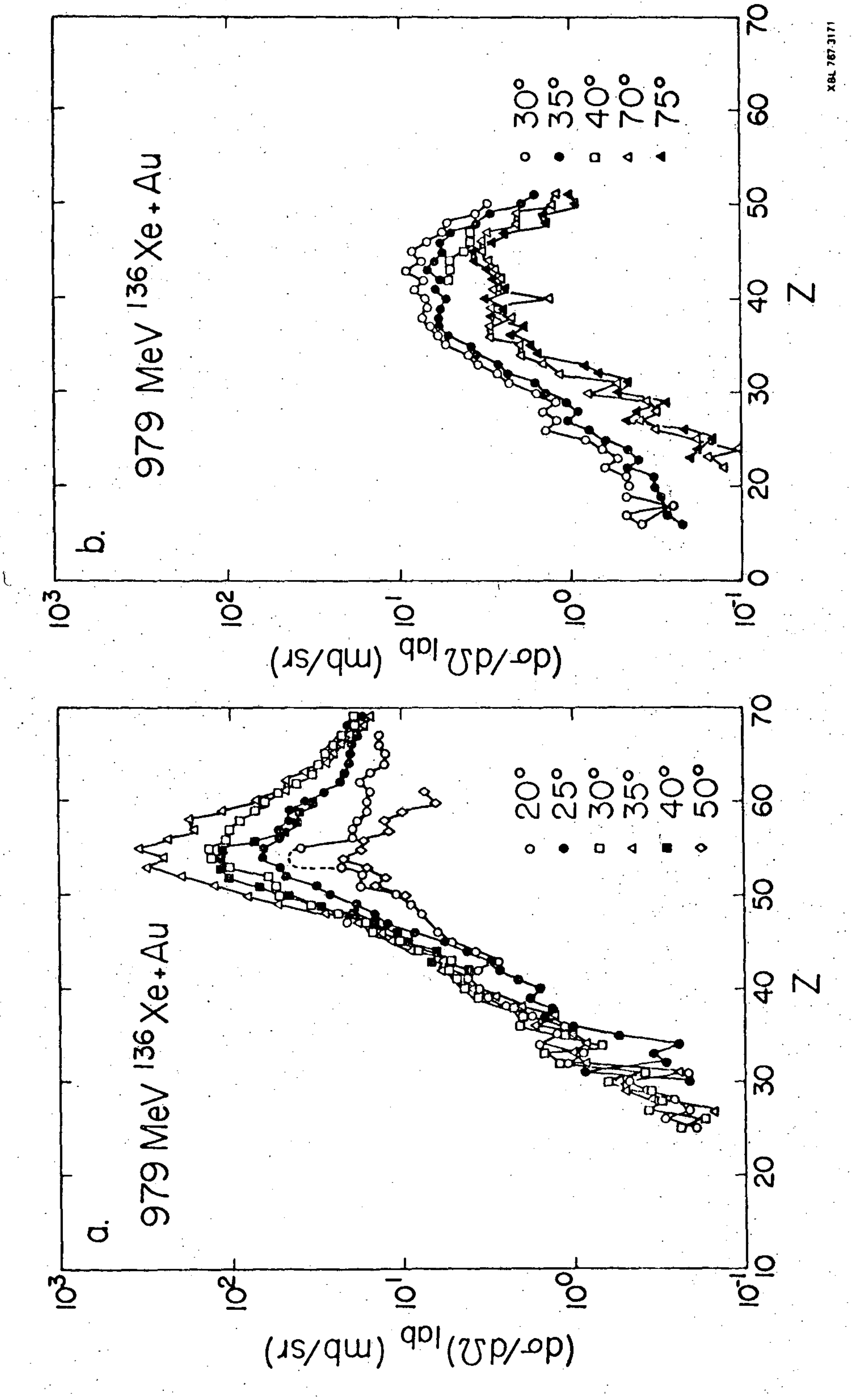
a.
979 MeV ¹³⁶Xe + Au
20°
25°
30°
35°
40°
50°
b.
979 MeV ¹³⁶Xe + Au
30°
35°
40°
70°
75°
(dσ/dΩ)lab (mb/sr)
Z
XBL 787-3171

Fig. 2

0 0 0 0 4 5 0 4 6 7 2

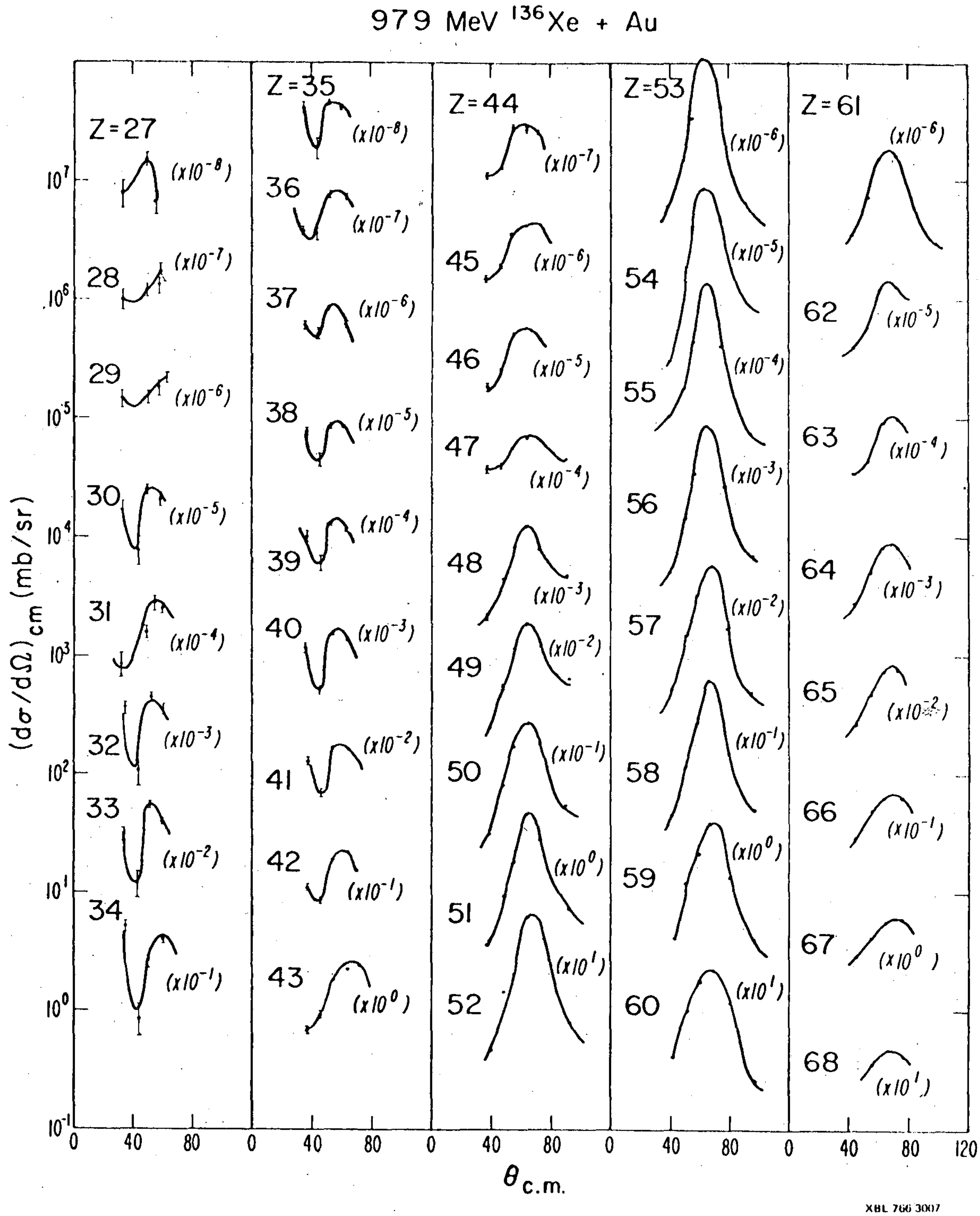

Fig. 3

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720