General Features of $^{48}Ca+^{124}Sn$ Heavy-Ion Reactions at 45 AMeV

M.J. Quinlan, I. Pawełczak, H. Singh, J. Tõke, and W.U. Schröder for the CHIMERA Collaboration

Departments of Chemistry and Physics, University of Rochester

Abstract

Charged products produced in the $^{48}Ca + ^{124}Sn$ heavy-ion reaction at 45 AMeV were measured by the CHIMERA multi-detector. The kinematics of the products were examined and in some aspects the inclusive data are consistent with a binary dissipative collision. Theoretical models reproduce the data to varying degrees. The angular distribution of events in which the PLF splits into two relatively large pieces, is asymmetric suggesting that the break-up occurs before the PLF reaches equilibrium.

Motivation & Theoretical Models

The data are compared to two reaction models of varying applicability to collisions of heavy ions at 45 AMeV. Peripheral reactions at this energy are generally thought to produce two excited nuclei with characteristics (e.g. size, N/Z content) similar to the projectile and target. These nuclei then decay leaving their residues, light-charged particles, and asymmetric fission fragments (IMFs). However, a number of the studies are incomplete and a consensus has not been reached regarding the relative importance and validity of a number of reaction scenarios and decay models[1]. A brief description of the models tested in this work is given below.

The classical transport (CLAT) model was originally developed for low energy heavy-ion reactions[2]. It assumes that the projectile dissipates kinetic energy through nucleon exchange and that the first step of the reaction produces two excited compound nuclei. These nuclei are termed the projectile-like and target-like primary reaction products. The model is applicable only to "binary" (two primary product) reactions and relatively peripheral collisions (b > 7 fm).

The quantum molecular dynamics (QMD) model calculates the trajectory of the projectile and target constituent nucleons as the two nuclei collide using phenomenological nucleon-nucleon forces[3]. The parameterization of these forces for the results presented here are consistent with a symmetric nuclear matter compressibility K=200 MeV. The equation of state also includes an 'ASY-SOFT' density dependent symmetry term[4], an 320 MeV fm^5 isoscalar and an 158 MeV fm^5 isovector term[5]. The latter two terms depend on the square of the density gradient. An algorithm associates the final spatial position of the nucleons with a number of (possibly complex) primary reaction products and predicts their internal spin and excitation. This model does not assume that the reaction is "binary" and can be used to model both peripheral and central collisions.

The decay of the excited primary reaction products predicted by these models was simulated using the GEMINI code[6]. In addition, a software replica of the CHIMERA multi-detector (CSR) which accounts for the triggering logic, electronic thresholds and active area of the array was developed. This program allows comparison of the model predictions to experimental data.

References:

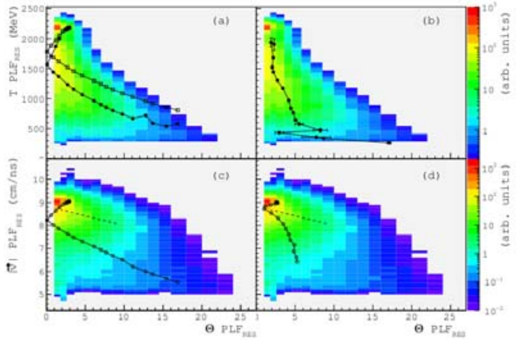
1. H. Fuchs and K. Möhring, Rep. Prog. Phys. 57, 231 (1994)
2. W.U. Schröder, *et. al.*, Nucl. Sci. Res. Conf. Ser. 11, 255 (1987) and references therein
3. J. Łukasik, Ph.D. Thesis, Jagellonian University (1993); J. Aichelin, *et. al.*, Phys. Rev. C, 37, 2451 (1988)
4. M. Colonna, *et. al.*, Phys. Rev. C 57, 1410 (1998)
5. V. Baran, *et. al.*, Nucl. Phys. A632, 287 (1998)
6. R. Charity, URL: www.chemistry.wustl.edu/~rc

Experimental Setup

Fig. 1 The CHIMERA multi-detector at the Laboratori Nazionali del Sud (LNS)

Results

Fig. 2 Logarithmic contours in (a) and (b) represent the measured double-differential cross section of PLF residues (Z≥10) plotted versus their laboratory kinetic energy and scattering angle. Open symbols in (a) represent the mean CLAT model predictions of PLF properties. Closed symbols in (a) represent the mean properties of the PLF residue (CLAT+GEMINI+CSR). Open and closed symbols in (b) represent the mean QMD model predictions for the PLF and PLF residue properties respectively. Logarithmic contours in (c) and (d) represent the measured double-differential cross section of PLF residues plotted versus their laboratory velocity and scattering angle. Open symbols in (c) and (d) represent the mean CLAT and QMD predictions for the PLF properties respectively. It is assumed that the average velocity and scattering angle are unaffected by sequential statistical decay. The lines are drawn to guide the eye.



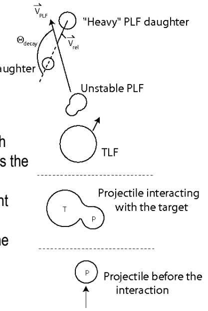
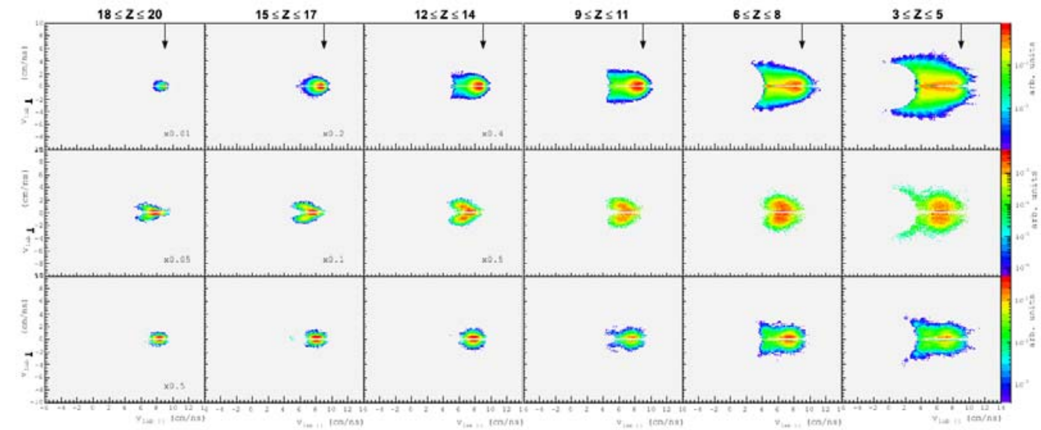


Fig. 3 Logarithmic contours of the invariant cross section plotted in the laboratory frame for a series of fragments with atomic number within the range indicated atop each column. The top row presents the data. The middle row presents the results of the CLAT+GEMINI+CSR model. The bottom row presents the results of the QMD+GEMINI+CSR model. Arrows mark the parallel velocity component of the projectile. In some panels the yields have been adjusted as indicated to allow the rows to share a common scale.



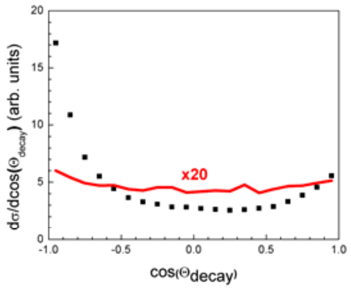


Fig. 4 Solid symbols represent the measured angular distribution of PLF splits. The solid line represents the predictions of the CLAT+GEMINI+CSR model. The illustration above depicts a possible reaction scenario leading to dynamic PLF fission and the definition of the Θ_{decay} angle.

Conclusions:

- The data are generally consistent with a heavy-ion reaction in which some dissipation of the projectile's kinetic energy occurs. Neither the CLAT nor the QMD models reproduce the data well. The former over-estimates the amount of damping, and the latter only reproduces the energy - and velocity - vs. angle correlations in peripheral collisions.
- Depending on the timescales involved, the observed non-equilibrium split of the PLF may not be consistent with a binary reaction scenario and requires further characterization.

Acknowledgements

This work was supported by the U.S. Department of Energy Grant No. DE-FG02-88ER40414