Isospin Dynamics in Fragmentation in Heavy Ion Collisions

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The isospin degree of freedom in nuclear physics is of large present interest in radioactive beam physics with spectroscopic experiments and also in heavy ion collisions. In heavy ion collisions one has access also to the density dependence of the isospin dependence of the equation-of-state (ISO-EOS) of nuclear matter. While the value at saturation density is well known from the mass formula the behavior at higher and lower densities is very differently predicted by different nuclear structure theories. One way to study it is in the compression and expansion phases of heavy ion collisions. The ISO-EOS is also of considereable importance in astrophysics, where it determines the proton fraction and cooling of neutron stars or the dynamics of supernovae.

Here we investigate in particular the expansion phase of heavy ion collisions which test the low density behaviour of the EOS. Because of the van-der-Waals character of the nuclear forces on expects a phase transition of first order of the liquid-gas type. Nuclear fragmentation is seen as an indication of these phase transitions. However, nuclei are binary systems of protons and neutrons which exhibit a more complicated phase diagram [1]. In particular one has to distinguish between mechanical and chemical instabilities of the binary system [2]. The result of these considerations is that one expects in fragmentation reactions of neutron rich nuclei more symmetric heavier fragments ("liquid") and more asymmetric, neutron rich light clusters and neutrons ("gas") [2].

We studied how these behaviors manifest themselves in heavy ion collision at energies in the Fermi energy domain. Since we are investigating fragment formation the physical amount of fluctuations is important in the transport calculation. In this work we are using a stochastic transport approach which inserts statistical density fluctuations into the evolution [3].

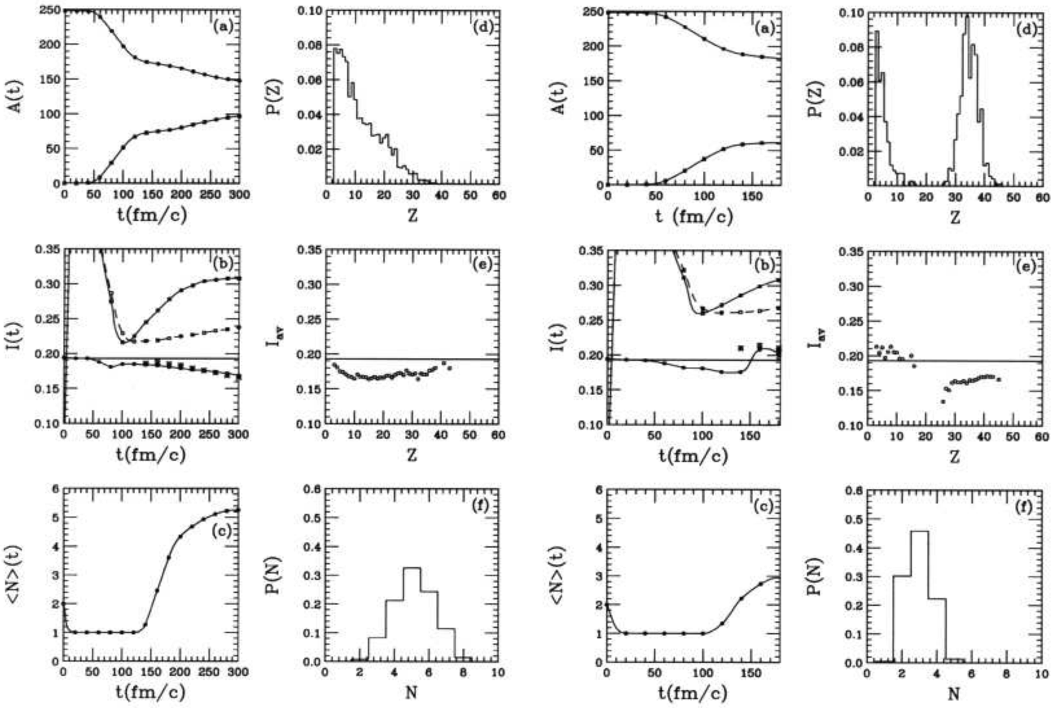
We have performed systematic calculations of symmetric $Sn+Sn$ collisions of neutron-rich (^{124}Sn) and neutron-poor (^{112}Sn) species. We have studied these for central and peripheral collisons and for different assumptions on the density dependence of the ISO-EOS. We distinguish between "asy-stiff" and "asy-soft" behaviour depending on the steepness of the density dependence at the saturation density. Predictions for the ISO-EOS cover a large range of behaviours.

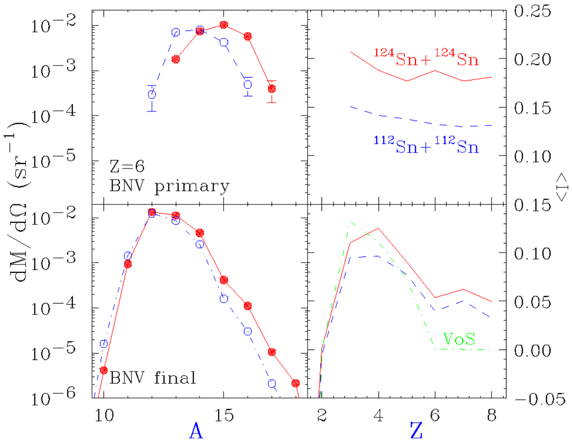
Examples of these calculations are shown in Fig.1 for central and peripheral collisions of $^{124}Sn+^{124}Sn$ collisions for an asy-stiff EOS. The panels in the figures show the following results: Left column: time evolution of (a) mass of liquid ($Z \geq 3$, solid with dots) and gas (solid and squares) phase; (b) asymmetry ($I = \frac{N-Z}{A}$) in the gas central (solid and squares), gas total (dashed and squares), liquid central (solid and dots), and for IMF ($3 < Z < 15$, stars); (c) mean fragment multiplicity. Right column: distributions of primary fragments of (d) charge; (e) asymmetry, and (f) fragment multiplicity.

Such figures give a detailed representation of the dynamics of the reaction, and in particular of the isospin dynamics. The asymmetry evolution displayed in panel (b) shows the complex behaviours during the different phases of the reaction. Especially one sees in the final breakup phase that the liquid becomes more symmetric while the gas is more neutron rich, as expected (isopin fractionation). The final distributions in panel (e) show, for the central reaction, the larger symmetry of the heavier fragments. For the peripheral reaction this is also true for the target- and projectile-like fragments. However, the lighter intermediate mass fragments (IMF) show a much larger asymmetry. This is understood from the fact that these fragments originate from the neck and remain for a rather large time in contact with the sprectators, during which protons flow to the more dense system (isospin migration). These effects depend on the neutron rich- or poorness of the system and on the stiffness on the ISO-EOS. They therefore give a handle to investigate its low density dependence.

However, these primary fragments are still excited by several MeV per particle on the average. The statistical decays leads to cold fragments on the stability line and to further light particles. This statistical decay is expected to wash out the signatures of the fragmentation on the ISO-EOS. However, this has to be taken into account when comparing to experimental data.

We have started a comparison with experimental data on central collisions of the same system, obtained at the NSCL/MSU [4]. As an example we show in Fig. 2 the isotope distribution for $Z = 6$ (carbon) (left) and the charge distribution of the asymmetry I (right) for the primary (upper) and final (lower) fragments for the two systems. The large difference in the primary and secondary distributions is seen. The final distributions are found to be in reasonable agreement with the data. In the more detailed analysis it is seen that there is a sensitivity of the asymmetries of the final isotope yields on the ISO-EOS, which favors slightly an iso-stiff EOS.





References

[1] H. Mueller, B.D. Serot, Phys.Rev. **C52** (1995) 2072.
[2] V. Baran, M. Colonna, M. DiToro, V. Greco, Phys.Rev.Lett **86** (2001) 4492.
[3] M. Colonna, M. Di Toro, A. Guarnera, S. Maccarone, M. Zielinska-Pfabe, H. H. Wolter, Nucl.Phys. **A650** (1999) 97.
[4] T.X. Lin, *et al.*, MSU-preprint.