

Isospin equilibration in Fermi-energy heavy-ion nuclear collisions

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The nuclear equation-of-state (EoS) has been well studied for symmetric nuclear matter at nuclear saturation densities. However, there are not strong constraints on the density dependence of the symmetry energy at sub-saturation densities. Nucleon transport, which includes isospin drift and diffusion, describes the interaction and movement of nucleons between projectile and target in a nuclear reaction. Isospin diffusion, the transport of nucleons due to differences in isospin content, can be used to further constrain the density dependence of the symmetry energy by examining the degree of isospin equilibration that takes place between projectile and target in nuclear collisions [1,2].

Experimental data was collected for the systems of 35 MeV/nucleon $^{70}\text{Zn}, ^{64}\text{Ni}+^{64}\text{Zn}$ and $^{64}\text{Zn}+^{70}\text{Zn}, ^{64}\text{Ni}$ in order to supplement the 35 MeV/nucleon $^{70}\text{Zn}+^{70}\text{Zn}, ^{64}\text{Zn}+^{64}\text{Zn}$, and $^{64}\text{Ni}+^{64}\text{Ni}$ data collected by Z. Kohley [3]. All experimental data were measured using the NIMROD-ISiS array, briefly described below. With the addition of the previously acquired systems, a complete data set of 7 reaction systems was formed and used to perform the isospin equilibration analysis.

The isoscaling technique scales the yield of individual isotopes from a neutron-rich source relative to the yield of the same isotope from a neutron-poor source. The resulting yield ratios of all isotopes follow the relations seen in Eqs. 1 & 2 where the yield ratio R is exponential with the neutron and proton number of the isotope. The scaling parameters α and β refer to the slope of the fit lines and separation between the fit lines, respectively. The α parameter specifically has been proposed to be linearly dependent on the source asymmetry [2].

$$R_{21}(N, Z) = C \exp(\alpha N + \beta Z) \quad (1)$$

$$R_{21}(N, Z) = Y_2(N, Z) / Y_1(N, Z) \quad (2)$$

Using the fragments from reconstructed quasi-projectiles (QP) [4,5] and by fitting the yields of the most prominent isotopes from $Z=4-8$ (similar to that of Tsang *et al.* in Ref. [2] and shown on the left side of Fig. 1), an α parameter was extracted from the fits. This α value was then used to produce the comparisons seen on the right side of Fig. 1. Here the α value for the fit from the isoscaling of each system relative to the $^{64}\text{Zn}+^{64}\text{Zn}$ (most neutron-poor system) is plotted as a function of the composite system isospin asymmetry. Using the method described by Tsang *et al.* [2] an equilibration value was extracted for the two separate sets of reactions: the $^{70,64}\text{Zn}+^{70,64}\text{Zn}$ reactions and the $^{64}\text{Zn}, \text{Ni}+^{64}\text{Zn}, \text{Ni}$. It was found that the QPs from the $^{70,64}\text{Zn}+^{70,64}\text{Zn}$ set of reaction systems experienced $77\pm 5\%$ equilibration while the QPs from the $^{64}\text{Zn}, \text{Ni}+^{64}\text{Zn}, \text{Ni}$ set of reactions experienced $83\pm 5\%$ equilibration. This compares to a reported equilibration of “about 50%” from the Tsang *et al.* work for 50 MeV/nucleon $^{112,124}\text{Sn}+^{112,124}\text{Sn}$.

While the equilibration seen in this data is higher than that reported by Tsang *et al.* [2] the result is consistent when noting that this work is at a lower beam energy which should experience more equilibration due to longer contact time as shown by Johnston *et al.* [6].

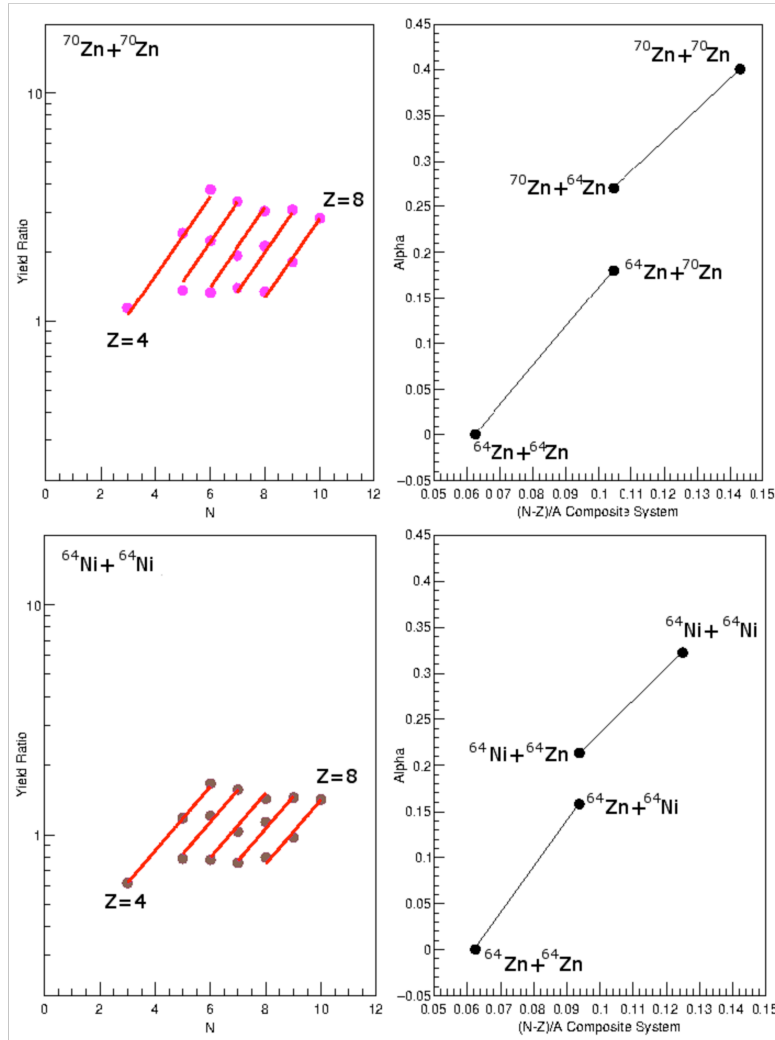


FIG. 1. Top left: Example isoscaling plot for $Z=4-8$ for the ${}^{70}\text{Zn}+{}^{70}\text{Zn}$ versus ${}^{64}\text{Zn}+{}^{64}\text{Zn}$ reaction systems. Bottom left: Example isoscaling plot for $Z=4-8$ for the ${}^{64}\text{Ni}+{}^{64}\text{Ni}$ versus ${}^{64}\text{Zn}+{}^{64}\text{Zn}$ reaction systems. Top right: Extracted isoscaling alpha parameter as a function of composite system asymmetry for the ${}^{70,64}\text{Zn}+{}^{70,64}\text{Zn}$ reactions. Bottom right: Extracted isoscaling alpha parameter as a function of composite system asymmetry for the ${}^{64}\text{Zn},{}^{64}\text{Ni}+{}^{64}\text{Zn},{}^{64}\text{Ni}$ reactions.

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