Isospin Non-Equilibration

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The question of whether or not an excited nuclear system reaches an equilibrium state before decaying is of importance when studying heavy ion reactions.

In an earlier study of the four systems of ^{40}Ar and ^{40}Ca on ^{58}Fe and ^{58}Ni, the isobaric ratios of ^{7}Li/^{7}Be, ^{10}Be/^{10}B and ^{11}B/^{11}C were investigated as a function of the (N/Z) of the compound system and beam energy [1]. It was demonstrated that as the (N/Z) of the compound system increases, so does the neutron content of the fragments. More importantly, there is an indication of an onset of isospin non-equilibrium seen in these data. If hot nuclear matter has had a chance to become equilibrated before emitting fragments, then the isobaric ratios plotted for two different systems having identical (N/Z) content, such as the case in the Ar on Ni and Ca on Fe systems, will be equal to one another. In the 33 MeV/A data, the data suggest that fragments are emitted from an equilibrated source. On the other hand, in the 45 MeV/A data, the data suggest fragments are being emitted from a non-equilibrated source. This tells us that the isospin equilibration is dependent on energy of the projectile and that the onset of non-equilibration for these systems lies between 33 and 45 MeV/A.

Further work was done using BUU to predict the isospin equilibration of systems over a range of energies [2]. Using BUU, the number of protons and neutrons stemming from reactions of 25, 35, 45, and 55 MeV/nucleon ^{40}Ar on ^{58}Ni are plotted as a function of time and of emission direction. At low energies, the neutrons and protons oscillate toward equilibrium and have very similar isospin content in both the forward and backward of the center of mass. At higher energies, there is an isospin asymmetry seen between the nucleons forward of the center of mass and the nucleons backward of the center of mass, indicating that isospin equilibrium had not yet been reached when fragmentation began. Therefore, for these calculations, isospin equilibration begins to fail between 35 and 45 MeV/nucleon.

In a later experiment, the isospin equilibration of ^{96}Ru and ^{96}Zr at 400 MeV per nucleon has been studied [3]. Using the symmetric systems as a calibration, the factor of R_Z is calculated to determine the degree of transparency.

$$R_Z = \frac{2(Z_{det}) - Z_{det}^{Zr} - Z_{det}^{Ru}}{Z_{det}^{Zr} - Z_{det}^{Ru}}$$

Z_{det} is the number of protons present in a given cell in momentum space. R_Z is equal to twice the number of protons in a selected cell of momentum space less the number of protons in detected in the symmetric Ru and Zr systems divided by the difference in protons detected between the symmetric Zr and Ru systems. In the symmetric systems, R_Z takes the value of +1 for the Zr on Zr and -1 for Ru on Ru. R_Z takes a value of zero when the emitting source is in full isospin equilibrium. It was shown that the mixed reactions of Zr and Ru at a projectile energy of 400 MeV/nucleon are never equilibrated and as the collisions become more peripheral, the system becomes less and less equilibrated.

Isospin equilibration has been shown to occur at low energies and to fall off at higher energies. In the first example, fragments were analyzed to give isospin equilibration information. In the last example, the nucleons in a given cell were used to probe the isospin equilibration question. It is our intention to further investigate the transition between equilibrium and non-equilibrium behavior using ^{58}Fe and ^{58}Ni mixed systems at intermediate energies with the methodology in the last example, R_Z, and also with isobaric ratios. Data on the following was taken in spring of 2000 on the NIMROD apparatus: 35 and 45 MeV/nucleon ^{58}Fe and ^{58}Ni on ^{58}Fe and ^{58}Ni, as well as 35 MeV/nucleon ^{64}Ni and ^{54}Fe on ^{58}Fe and ^{58}Ni. Calibrations and analysis will begin presently.

References

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