<N/Z> Content of Fragments Emitted From Excited Nuclear Systems

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A phase transition associated with excited asymmetric nuclear systems has been proposed to be second order, with the added parameter involving isospin content [1]. In this study, we look at the effect of separation into phases with different isospin content on the fragmentation distribution. First, we assume that a fractionation into a neutron-rich gas and a relatively more symmetric liquid occurs. Next, consider that light fragments may condense from the neutron rich gas and heavy fragments may evaporate off of the more symmetric liquid. The fragment distribution resulting from such a system should contain smaller fragments with more neutrons than protons and larger fragments with a more symmetric isospin content. Using helium as an example, the average neutron to proton value is calculated as follows, where ^{3}He is the number of ^{3}He detected or the measured cross section and likewise for the other helium isotopes;

$$\left\langle \frac{N}{Z} \right\rangle = \frac{^3He + 2(^4He) + 4(^6He)}{2(^3He + ^4He + ^6He)}.$$

Figure 1 shows the <N/Z> of fragments emitted from a high energy proton on Xe gas system reported by the Purdue group [2] as calculated using the above equation and plotted as a function of Z. The energy of the proton beam is 80 to 350 GeV. Data were reported in terms of isotopically resolved normalized differential cross sections that were summed over all energies. Error bars reflect statistical error, only. One can observe a trend in the <N/Z> values that begins high in lower Z and levels out toward higher Z.

The proton on Xe reaction was modeled using two statistical codes, Gemini [3] and SMM [4]. The initial conditions for both codes were set to reflect the total mass and charge of the target and projectile of the system and excitation energy of 1 GeV. While Gemini breaks up the compound system in a series of binary decays, SMM breaks up the compound system into many fragments at one time. The output from the codes was fed through a filter that simulated the energy thresholds and angle of detection limitations of each system. Gemini does a good job of predicting the <N/Z> behavior in the proton on Xe system for Z ≥ 5. SMM matches the trend well in the proton on Xe system, but underestimates the <N/Z> values.

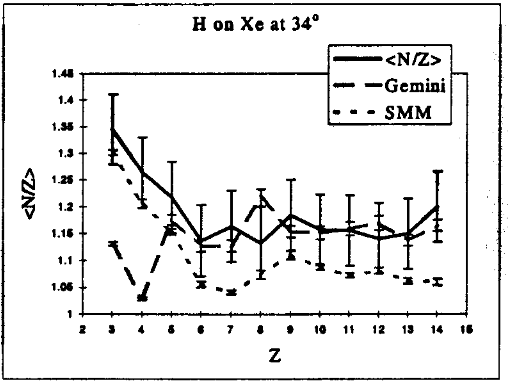

Figure 1 Average neutron to proton ratio vs. fragment charge for data cited in ref 2.

Other trends are observed in the neutron to proton ratio of fragments emitted from excited systems. The average neutron to proton ratio of fragments emitted from excited nuclear systems is seen to vary with several parameters including the total mass of the compound system, the neutron to proton ratio of the compound system, the angle of fragment detection and the energy of the projectile. An example of the trend in <N/Z> as a function of (N/Z) of the compound system is shown in Figure 2. Each element's <N/Z> has a proportional dependence on the (N/Z) of the compound system. Beryllium shows a unique sensitivity to every parameter mentioned, which will be briefly discussed.

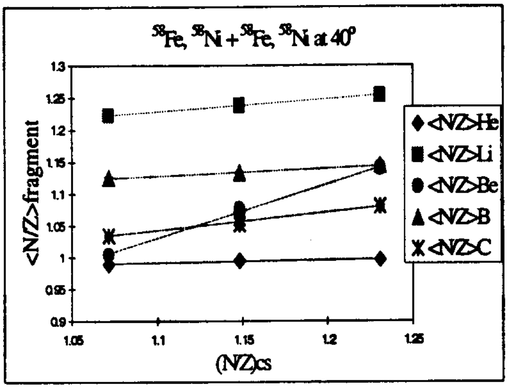

Figure 2 Work done by Ramakrishnan, et al., [5] showing the <N/Z> of each element vs. the N/Z of the compound system. All projectiles are at 30MeV/nucleon.

The exaggerated dependence of the <N/Z> of Be on the total mass of the system, the (N/Z) of the compound system and the angle of detection could be explained by the absence of ^{8}Be. For a rough comparison, the data taken in for the 30 MeV/nucleon ^{58}Ni on ^{58}Ni is plotted in Figure 3 as a function of (N/Z) of the compound system for just the isotopes of carbon detected. In one instance, all isotopes are included in the <N/Z> calculation. In the other two examples shown in Figure 3, ^{12}C and then both ^{12,13}C are taken out of the <N/Z> calculation. As the most abundant isotopes of carbon are excluded from the reaction, the slope or dependence of the <N/Z> of carbon on the (N/Z) of the compound system increases rapidly. The enhanced dependence of the <N/Z> of Be on the (N/Z) of the system may be partly explained by the absence of ^{8}Be.

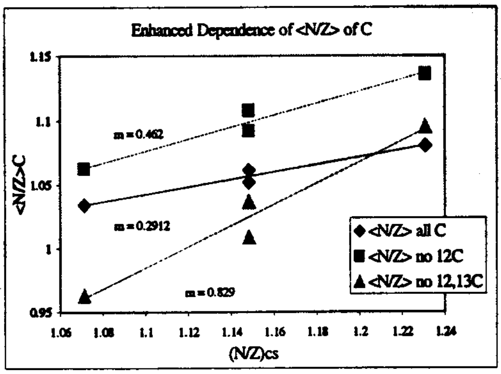

Figure 3 shows the enhanced dependence of <N/Z> of carbon as the most abundant isotopes are excluded from the <N/Z> calculation.

In conclusion, the average neutron to proton ratio is seen to change with several parameters, including the total mass and (N/Z) of the compound system, the angle of detection, and very slightly with the energy of the projectile over the range of 30 to 47 MeV/nucleon. In all cases, Be displays an exaggerated dependence, which may be explained by the absence of detection of ^{8}Be. The two-phase bifurcation of excited nuclear matter into a more symmetric liquid and a neutron rich gas proposed by Muller and Serot may explain the trend observed in the <N/Z> ratios of fragments emitted from excited nuclear systems. That trend in the <N/Z> of these fragments is shown to have higher <N/Z> values in lower Z and lower <N/Z> values for higher Z.

References

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