Isospin Effects on Observables for Heavy Ion Reactions Using Constant Mass Projectiles and Targets

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Enhancement in production of even-Z products from fissioning nuclei has been studied for proton-rich nuclei. A study of odd-Z nuclei has shown that the unpaired proton preferentially remains with the heavier fragment leading to even-Z enhancement for the lighter fragment [1]. The enhancement of even-Z reaction products is not restricted to studies of fission fragments. Studies of heavy ion fragmentation reactions have also shown a higher cross section for production of even-Z fragments [2,3,4]. Odd-even effects have also been seen by examination of yield ratios for Intermediate Mass Fragments (IMF). A study comparing the ratio of yields for different IMFs showed an enhancement in the even-Z nuclei production for Fe + Fe and Ni + Ni reactions at forward angles [5].

This odd-even effect has been studied by changing the N/Z ratio of the reacting system while maintaining constant mass for both the target and projectile at a constant bombarding energy. The reactions of ^{40}Ar, ^{40}Cl, and ^{40}Ca on ^{58}Fe and ^{58}Ni at both 25 and 53 MeV/nucleon were studied using the MSU 4π detector array [6] which was enhanced with silicon detectors at 14°, 40°, and 140°. Isotopic ratios measured in this experiment have been previously published [7].

When the ratio of the total numbers of each element detected are taken for the different systems this odd-even effect is seen clearly. Figure 1 shows the ratio of the yield for each element at 40 degrees for different reactions at 25 MeV/nucleon normalized to one at helium.

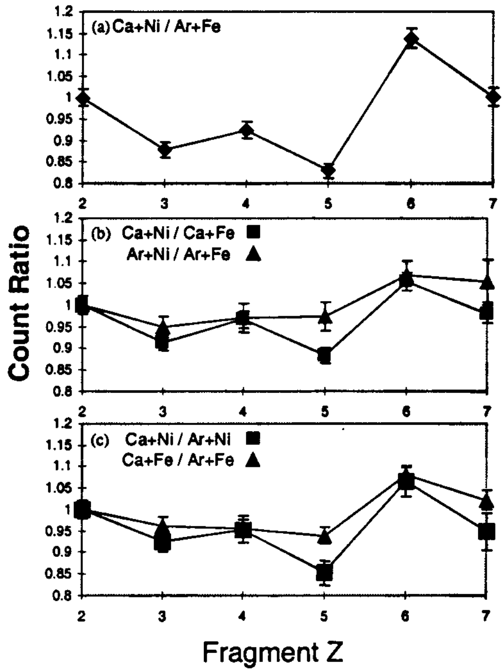

Figure 1: (a) The ratio of the yields for Ca + Ni / Ar + Fe systems. (b) The ratio of the yields for the Ca + Ni / Ca + Fe (square) and Ar + Ni / Ar + Fe (triangle) systems. (c) The ratio of the yields for the Ca + Ni / Ar + Ni (square) and Ca + Fe / Ar + Fe (triangle) systems.

Panel 1(a) shows the ratio of yields for each Z for the reactions Ca + Ni / Ar + Fe. These systems represent the maximum difference in the N/Z of the compound system. An odd-even effect is seen here where the ratio is enhanced for particles with even-Z. Panel 1(b) shows the dependence on the projectile by comparing the Ca + Ni / Ca + Fe and Ar + Ni / Ar + Fe systems. The systems with the more neutron-poor Ca projectiles have a lower N/Z and show an enhanced odd-even effect relative to the comparison of systems with the more neutron-rich Ar projectile. Panel 1(c) is similar except that the projectiles are held constant while different targets are compared. As in panel 1(b) the more neutron-poor system (Ni targets) shows an enhanced odd-even effect.

The average N/Z was calculated for each element by dividing the total number of neutrons by the number of protons in the particles detected for any particular Z. The <N/Z> calculation for helium is provided as an example.

$$\langle N/Z \rangle_{He} = \frac{[{}^{3}He + 2*{}^{4}He + 4*{}^{6}He]}{2*[{}^{3}He + {}^{4}He + {}^{6}He]}$$

The <N/Z> value was then plotted as a function of Z for this data. As can be seen from Figure 2, the <N/Z> is sensitive to the N/Z of the compound system; however, Beryllium shows the greatest sensitivity. Additionally it should be noted that the odd-even effect can also be observed here. Elements with an even-Z had a consistently lower <N/Z>.

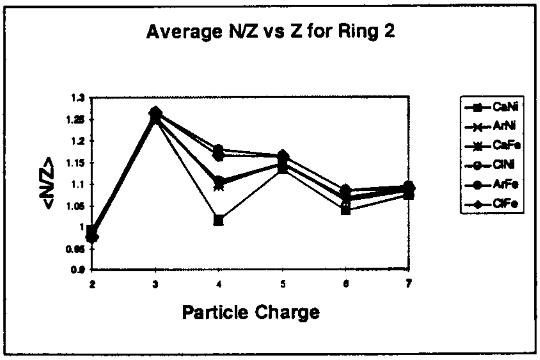

Figure 2: The average N/Z of detected particles as a function of the element Z for all systems.

If the availability of isotopes is examined as a function of Z, it can be noted that elements with odd-Z have fewer relatively stable isotopes with lower N-Z values such as those available for even-Z. In the table below the most neutron-poor particle-stable isotopes for odd-Z can be seen to generally have a higher values of N-Z than those of the neighboring even Z nuclei.

N-Z	-2	-1	0	1	2	3	4
Z=1	→	^{1}H	^{2}H	^{3}H			
Z=2		^{3}He	^{4}He		^{6}He		
Z=3		→	^{6}Li	^{7}Li	^{8}Li		
Z=4		^{7}Be		^{9}Be	^{10}Be	^{11}Be	
Z=5		→	^{10}B	^{11}B	^{12}B	^{13}B	
Z=6	^{10}C	^{11}C	^{12}C	^{13}C	^{14}C	^{15}C	^{16}C
Z=7	→	^{13}N	^{14}N	^{15}N	^{16}N	^{17}N	^{18}N
Z=8	^{14}O	^{15}O	^{16}O	^{17}O	^{18}O	^{19}O	^{20}O

Table 1: Relatively stable isotopes with mass defects less than 23MeV listed by Z and N-Z values.

Thus, fragments with an even-Z can have a lower <N/Z> because there are more isotopes available which have low N/Z values. A system which is neutron-poor will preferentially form isotopes which are neutron-poor. Because the even-Z elements have more neutron-poor isotopes available it is reasonable that more neutron-poor even-Z elements would be formed, leading to the odd-even effect observed. Because there is no odd-even variation in availability of neutron-rich isotopes it follows that the neutron-rich systems produce less of an odd-even effect.

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