Study of the charge, mass and isotopic distribution in projectile fragmentation reactions.

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Projectile fragmentation is an important technique for studying the reaction mechanisms in heavy ion collisions at intermediate and high energies. In this work we develop a projectile fragmentation model and apply the model for studying the charge, mass and isotopic distributions for Ni^{58} on Be^9 and Ta^{181} reactions at 140 Mev/nucleon energy.

The model for projectile fragmentation reaction consists of three stages: (i) abrasion, (ii) multifragmentation (iii) evaporation. In heavy ion collision, if the beam energy is high enough then at a particular impact parameter three different regions are formed: (i) participant (ii) projectile like fragment (PLF) and (iii) target like fragment (TLF). Here we are interested in the fragmentation of the PLF. Using straightline geometry, we can calculate the PLF volume $V_s(b)$ at different impact parameters (b). If the original volume of the projectile is V_0 and the original number of neutrons and protons are N_0 and Z_0 respectively, then the average number of neutrons in the PLF is $\langle N_s(b)\rangle = (V(b)/V_0)N_0$ and the average number of protons is $\langle Z_s(b)\rangle = (V(b)/V_0)Z_0$. These will usually be non-integers. Since in any event only an integer number of neutrons and protons can appear in the PLF we use minimal distribution to get integer numbers. From minimal distribution, let the probability of producing PLF with Z_s proton at impact parameter b is $P_{Z_s}(b)$, similarly for neutron it is $P_{N_s}(b)$. Therefore the probability of production of PLF with Z_s proton and N_s neutron from impact parameter b is $P_{N_s,Z_s}(b) = P_{N_s}(b)P_{Z_s}(b)$. The PLFs produced at diferent impact parameter have different temperatures. The impact parameter dependence of temperature is considered as $T(b) = D_0 + D_1(A_s(b)/A_0)$ where $A_s(b) = N_s(b)+Z_s(b)$ and $A_0 = N_0+Z_0$; with $D_0 = 7.5$ MeV and $D_1 = -4.5$ MeV. This parametrisation of temperature profile is obtained by looking at many pieces of data from many nuclear collisions. We divide the interval b_{min} to b_{max} into small segments of length Δb. Let the mid-point of the i-th bin be $\langle b_i\rangle$ and the temperature for collision at $\langle b_i\rangle$ be T_i. The total cross-section of abraded nucleus having Z_s protons and N_s neutrons is

$$\sigma_{a,N_s,Z_s} = \sum_i \sigma_{a,N_s,Z_s,T_i} \qquad (1)$$

where

$$\sigma_{a,N_s,Z_s,T_i} = 2\pi\langle b_i\rangle \Delta b P_{N_S,Z_s}(\langle b_i\rangle) \qquad (2)$$

This is the abrasion stage calculation.
The multifragmentation stage calculation of each PLF (formed at different impact parameters) is done separately by using the Canonical Thermodynamical Model (CTM) [1] which is based on equilibrium statistical mechanics and involves the calculation of partition functions. The freeze-out volume in multifragmentation is $V_f(b) = 3V(b)$. For an abraded system N_s, Z_s at temperature T_i, CTM allows us to compute the average population of the composite with neutron number n, proton number z when this system breaks up (this composite is at temperature T_i). We denote this by $M_{n,z}^{N_s,Z_s,T_i}$. It then follows, summing over all the abraded N_s, Z_s that can yield n, z, the primary cross-section for n, z is

$$\sigma^{pr}_{n,z} = \sum_{N_s,Z_s,T_i} M_{n,z}^{N_s,Z_s,T_i}\sigma_{a,N_s,Z_s,T_i} \qquad (3)$$

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Finally, the decay of excited fragments n, z at temperatures T_i are calculated by recently developed evaporation model [2] based on Weisskopf's formalism.

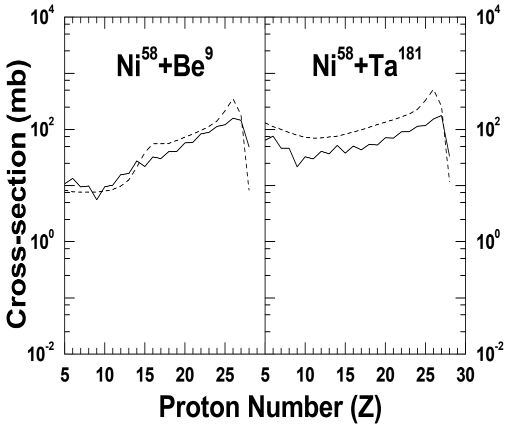

FIG. 1: Theoretical charge distribution (dashed lines) for Ni^{58} on Be^9 (left panel) and Ni^{58} on Ta^{181} (right panel) compared with experimental data (solid lines).

For Ni^{58} on Be^9, the projectile is significantly larger than the target. So at central collision, Be^9 can drive only some nucleons. In this case the PLF $Z_s = 16$ and $A_s = 33$, where as that from most peripheral collision has $Z_s = 28$ and $A_s = 58$. Therefore $Z < 16$ and $A_s < 33$ regions in the charge distribution (left panel of Fig-1) and mass distribution (left panel of Fig-2) respectively are populated by multifragmentation only. On the other hand, for Ni^{58} on Ta^{181}, at central collision there is no PLF.Z_s of the produced PLFs vary from 0 (remains zero till a finite impact parameter) to 28 (similarly A_s vary from 0 to 58). So the abraded system itself covers the entire range of the composites. Therefore the role of the multifragmentation is to modify the cross-sections in the charge distribution (right panel of Fig.-1) and mass distribution (right panel of Fig.-2) respectively. The calculated isotopic distributions at $Z = 9, 15, 18, 21, 24, 27$ for Ni^{58} on Be^9 reaction is compared with experimental data [3] and shown in Fig.-3.

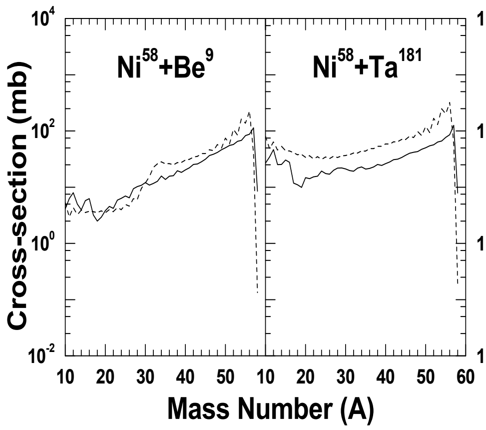

FIG. 2: Theoretical mass distribution (dashed lines) for Ni^{58} on Be^9 (left panel) and Ni^{58} on Ta^{181} (right panel) compared with experimental data (solid lines).

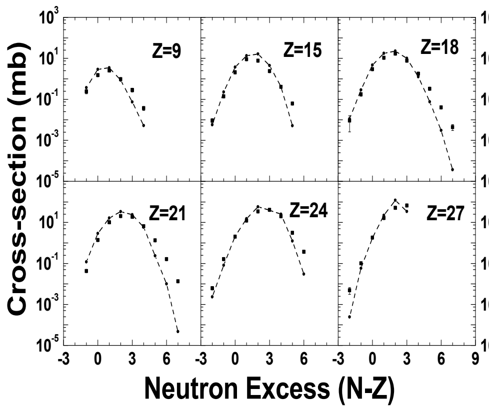

FIG. 3: Theoretical isotopic distributions (dashed lines) for Ni^{58} on Be^9 compared with experimental data (solid squares).

Hence we can conclude that the charge, mass and isotopic distributions are nicely reproduced by the projectile fragmentation model.

References

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