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 $^{58}$Ni on Be$^9$ and $^{181}$Ta 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 $P_{Z_s}(b)$. b is $P_{N_s,Z_s}(b) = P_{N_s}(b)P_{Z_s}(b)$. The PLFs produced at different 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 $\Delta b$. 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

$$\sigma_{a,N_s,Z_s} = \sum_i \sigma_{a,N_s,Z_s,T_i}$$

where

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

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 $M_{N_s}^{N_s,Z_s,T_i}$. 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

$$\sigma_{n,z} = \sum_{N_s,Z_s,T_i} M_{n}^{N_s,Z_s,T_i} \sigma_{a,N_s,Z_s,T_i}$$
REFERENCES

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.

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 \( A_s = 33 \), whereas 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.

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

References