Complex fragments emission in $^{20}Ne + ^{112,116,124}Sn$

Payel Karmakar[1,2], Samir Kundu[1,2,*], T. K. Rana[1,2], S. Manna[1,2], R. Pandey[1], C. Bhattacharya[1,2], S. Bhattacharya[1,#], T. K. Ghosh[1,2], P. Roy[1,2], G. Mukherjee[1,2], S. Mukhopadhyay[1,2], Arijit Sen[1,2], J. K. Meena[1], S. Dalal[1], A. K. Saha[1], R. M. Saha[1], J. K. Sahoo[1], M. Shaikh[2], S. Nandi[2,†], D. Paul[2]

[1]*Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700064, INDIA*
[2]*Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai 400094, INDIA*
. *email: skundu@vecc.gov.in, #Retired, †Present address: Argonne National Laboratory, USA

Introduction

Emission mechanism of charged reaction products released in heavy ion reaction is an interesting topic and many studies were done in the past, though detailed understanding is still missing [1]. In this paper we have reported our recent study on reaction mechanism and the effect of isospin on the emission of fragments in $^{20}Ne + ^{112,116,124}Sn$.

Experiment

The experiment was performed using accelerated neon beam from K130 cyclotron at VECC. The fragments emitted from reactions ^{20}Ne (162.6 MeV) + ^{112}Sn, ^{20}Ne (160, 192 MeV) + ^{116}Sn, ^{20}Ne (157.4, 192 MeV) + ^{124}Sn were detected isotopically using a ΔE(50μm)-E(1034 μm) telescope of ChAKRA [2] consisting of two silicon strip detectors which covered an angular range of 20^0-35^0.

Results

The centroids of the measured energy spectra of the different fragments were compared with the energy calculated using Viola systematics assuming asymmetric fission [3] of respective composite. It was found that in each case, this calculated energy was lower than the measured energy. This indicates that the fragments are emitted from a non-equilibrated source. The Angular distributions of the fragments were fitted well with the equation, $\frac{d\sigma}{d\Omega} \propto \frac{C}{sin\theta_{c.m.}} e^{-\frac{\theta_{c.m}}{\omega_{DI}}}$. The details of this equation may be found in reference [4]. The angular distributions also indicate that fragments are emitted from deep inelastic (DI) collision. The average Q-values also decrease with the increase of scattering angle for all fragments. The time scale (τ_{DI}) of the emission was extracted by following the method described in reference [4] using the fitted value of $\omega\tau_{DI}$. Typical emission time scale of different DI fragments emitted in reaction ^{20}Ne (160MeV) + ^{116}Sn are plotted in Fig. 1. It was found that emission time scale decreases with increase of mass of the fragments for all reactions. It is expected as lighter fragment needs more exchange of nucleon hence more time. The order of the time scale is ~10^{-22}-10^{-23}s.

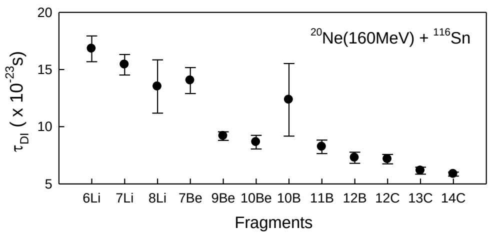

Fig. 1 Emission time scale of different DI fragments.

Discussion

The energy distributions, angular distributions, Q-value distributions and emission time scale show that all the fragments emitted in all the reactions under present study are originated primarily from DI collision. Similar to energy, angular momentum is also not fully dissipated in DI collisions. Angular momentum dissipation factors, *f*, the ratio of final angular momentum (L_f) and initial angular momentum (L_i) have been extracted using equation $E_k = V_N(\mathrm{d}) + f^2 \frac{\hbar^2 L_i(L_i+1)}{2\mu d^2}$ where E_k is the kinetic energy of the emitted fragments, $V_N(d)$ is the contribution from Coulomb and nuclear forces at dinuclear separation *d*. L_i was taken to be equal to the critical angular momentum for fusion, L_{cr}. Details of this equation and method of calculations may be found in Ref. [4]. Mean angular momentum dissipation factor, *f*, has been extracted using *d* calculated from the scission point configuration using Viola energy and plotted in Fig. 2. The results are compared with the sticking and rolling limit predictions. It was observed that in all systems, *f* matches to sticking limit predictions for the lighter fragments but gradually increase (dissipation decreases) with the increase of fragment mass relative to the sticking limit predictions. Finally, it crosses the rolling limit predictions. Microscopically, friction is generated due to stochastic exchange of nucleons between two reacting nuclei through a window

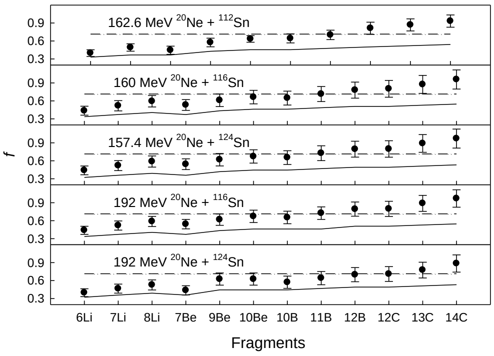

Fig. 2 Variations of angular momentum dissipation factor *f* with DI fragments. The solid lines and dashed-dot-dashed lines represent the sticking and rolling limit predictions, respectively.

formed at the overlapping region. More nucleon exchange means more friction as in case of lighter fragments. Hence they are originated from deeper collision, for which interaction time is also large as shown in Fig. 1. The total cross sections as well as relative cross sections of different isotopes emitted from reactions ^{20}Ne (160 MeV) + ^{116}Sn, ^{20}Ne (157.4 MeV) + ^{124}Sn are plotted in Fig. 3. It was observed that cross section of the isotopes of a particular element emitted from ^{20}Ne (157.4 MeV) + ^{124}Sn are more than the same isotopes emitted in ^{20}Ne + ^{116}Sn except the isotopes having less N/Z than most abundant naturally available isotopes. The ratio of the cross sections for each fragments emitted from ^{20}Ne + ^{124}Sn (N/Z = 1.4) and ^{20}Ne (160 MeV) + ^{116}Sn (N/Z = 1.27), respectively increases with neutron number of the isotopes. This is because of larger N/Z ratio in ^{20}Ne + ^{124}Sn than ^{20}Ne + ^{116}Sn. It was also observed that mean N/Z of the fragments are ~1.14 for ^{20}Ne + ^{116}Sn and ~1.19 for ^{20}Ne + ^{124}Sn at excitation energy ~120 MeV. All these observations indicate that N/Z is equilibrated in the composites from where fragments are emitted.

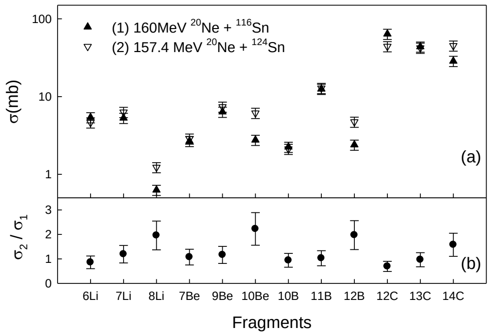

Fig. 3 (a) Total and (b) ratio of cross sections of same isotopes emitted in reaction (1) and (2) as indicated in the figure.

Summary and conclusion

The emission mechanism of fragments ^{6,7,8}Li, ^{7,9,10}Be, ^{10,11,12}B and ^{12,13,14}C emitted from the hot composite formed by reactions ^{20}Ne (162.6 MeV) + ^{112}Sn, ^{20}Ne (160, 192 MeV) + ^{116}Sn, ^{20}Ne (157.4, 192 MeV) + ^{124}Sn has been studied and the fragments have been found to be emitted by DI process. It was observed that the average N/Z value of the fragments is more for the fragments emitted from the composite having more N/Z. This indicates that isospin was equilibrated in all reactions under present study. It was observed that in all systems, mean angular momentum dissipation factor, *f*, matches with sticking limit predictions for the lighter fragments but gradually increases with the increase of fragment mass relative to the sticking limit predictions. This implies that more friction is there in case of lighter fragments.

References

[1] T. K. Rana et al., Phys. Rev. C **103**, 034614 (2021) and references therein.
[2] S. Kundu et. al., Nucl. Inst. and Meth. A **943** (2019) 162411
[3] V. E. Viola, K. Kwiatkowski, and M. Walker, Phys. Rev. C **31**, 1550 (1985).
[4] S. Kundu et al., Phys. Rev. C **85**, 064607 (2012)