Effect of N/Z in pre-scission neutron multiplicity for 16,18O+194,198Pt systems

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Abstract. This paper report the summary of the experimental results of pre-scission neutron multiplicities from four compound nuclei, namely ^{210,212,214,216}Rn, and statistical model analysis of the corresponding data. The compound nuclei ^{210,212,214,216}Rn having N/Z values as 1.441, 1.465, 1.488, 1.511 respectively are populated through the ^{16,18}O+^{194,198}Pt reactions at excitation energies of 50, 61, 71.7 and 79 MeV. The measured neutron multiplicities are further analyzed with the statistical model of nuclear decay where fission hindrance due to nuclear dissipation is considered. The N/Z dependence of the dissipation strength at lowest excitation energy of the compound nuclei suggests shell closure effects. However, such effects are not observed at higher excitations where the variation of the dissipation strength with N/Z does not show any specific trend. The variation of N/Z in fission time scale is also shown.

1 Introduction

Viscosity is a basic property of nuclear matter and it describes the coupling between the intrinsic and the collective degrees of freedom. One approach to the observation of nuclear viscosity is to measure the time scale of the fission process, and it is well established that the pre-scission neutron multiplicity is one of the most efficient probes to study the fission time scale in heavy-ion induced fusion-fission reactions [1]. It has been observed that the experimental multiplicities of pre-scission neutrons were in clear excess of the predictions of the standard statistical model of the compound nuclear decay [1]. The excess in multiplicities indicates the presence of dynamical hindrance of the fission process and the fission dynamics of an excited compound nucleus is dissipative in nature at high excitation energies. The problem of the origin and the nature of nuclear dissipation is presently one of the most

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interesting questions in nuclear physics at low and intermediate energies. It is therefore of considerable interest to explore the effect of N/Z in compound nuclei for a given element on the strength of nuclear dissipation. Measurement of pre-scission neutron multiplicities from an isotopic chain will be a suitable tool for the above purpose. The compound nuclei ^{210,212,214,216}Rn having N/Z values as 1.441, 1.465, 1.488, 1.511 respectively are populated through the ^{16,18}O+^{194,198}Pt reactions at a different set of excitation energies in the present work.

The fragment-neutron correlation experiment for the reactions ^{16,18}O+^{194,198}Pt were carried out at 15UD Pelletron + LINAC and the National Array of Neutron Detectors (NAND) facility at Beam Hall-II of Inter University Accelerator Centre (IUAC), New Delhi. The details of the experiment and the analysis procedure can be found in reference [2,11].

2 Analysis

The experimentally obtained neutron multiplicities were checked for consistency with the energy balance equation prior to the analysis by theoretical model. Assuming the compound nucleus decay only by neutron and γ- ray emission, the number of neutrons emitted (x) is related to $E_x(CN)$ by the well known energy balance equation: $E_x(CN) = E_\gamma(PN) + \sum_{i=1}^{x}\left(B_n^i + E_n^i\right)$, where B_n^i and E_n^i are the binding and kinetic energy for neutron I, and $E_\gamma(PN)$ is the energy removed by γ-ray emission from the product nucleus after neutron emission. The total available decay energy can also be defined by : $E_x(f) = E_\gamma(f) + \sum_{i=1}^{x}\left(8.07 + E_n^i\right)$. Where $E_x(f)$ is total available decay energy for fission fragments. Again assuming that all available decay energy is removed by neutron and γ-ray emission, we can equate M_{tot} with x in the above energy balance equation to compare the experimental data consistency. In Figure 1, such comparison is presented.
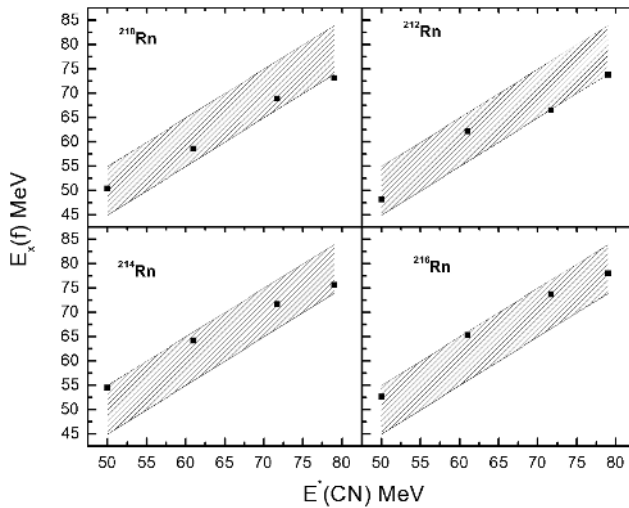

Figure 1. Variation of total available decay energy $E_x(f)$ (here x represents M_{tot}) calculated from energy balance equation w.r.t excitation energy of compound nuclei for ^{16,18}O+^{194,198}Pt reactions. The shaded areas show the ± 5 MeV error to the excitation energy in energy balance calculations.

3 Statistical model analysis

From Figure 2 (a) it is clear that the pre-scission neutron multiplicity (M^{pre}) increases with N/Z at the three higher excitation energies, a minimum is observed for ^{212}Rn at the lowest excitation energy. Since the numbers of neutrons in the ^{210,212,214,216}Rn nuclei are 124, 126, 128, and 130 respectively, we can expect that the appearance of the above minimum is due to the shell closure effect at N = 126 for ^{212}Rn. As the experimental M^{pre} values at the higher excitation energies agree with prediction, the appearance of the minimum at the lowest excitation energy remains to be explained. We therefore perform statistical model calculations in order to study the detailed nature of the experimental data.

In the statistical model calculation, emission of light particles (neutron, proton, and α) and giant dipole resonance (GDR) γ-rays are considered as decay channels for an excited compound nucleus in addition to fission. The light particle and the GDR partial widths are obtained from the Weisskopf formula [3]. The fission width is calculated following the work of Kramers [4] where the dynamics of the fission degree of freedom is considered similar to that of a Brownian particle in a heat bath. The temperature of the heat bath which represents all the other nuclear degrees of freedom is given by the compound nuclear temperature T. The driving force in a thermo dynamical system such as a hot nucleus is provided by the free energy of the system [5, 6]. The rotational energy of the compound nucleus is obtained using the shape-dependent rigid body moment of inertia and is included in the FRLDM potential [7].
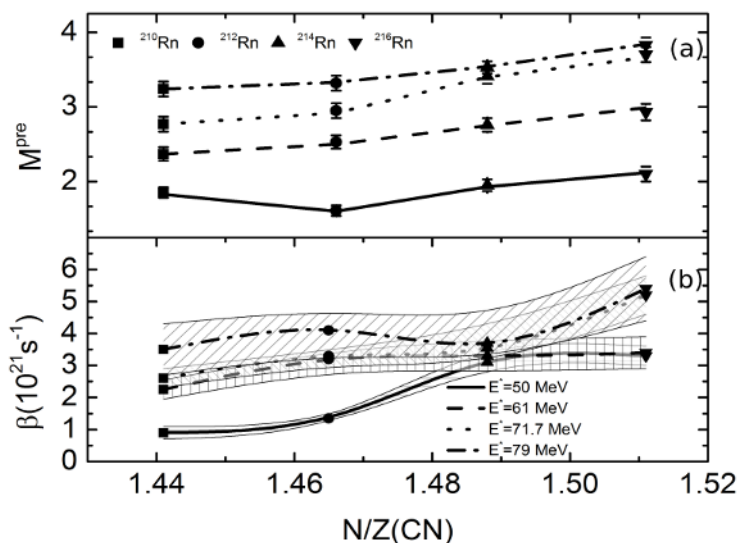

Figure 2. (a) Variation of M^{pre} w.r.t N/Z value of compound nuclei. (b)Variation of the best-fit values of β with N/Z of the compound nuclei at different excitation energies. The shaded areas represent the uncertainty in β associated with the experimental error in M^{pre}.

In the statistical model calculations the level density parameter is taken from the work of Ignatyuk et al. [8]. For a fission event, the compound nucleus can emit further neutrons (or other particles) during its journey from saddle to scission which contributes to the pre-scission multiplicity. The numbers of such neutrons are also calculated by using the saddle-to-scission time interval [9]. The best-fit β (β is the dissipation coefficient) values which match the experimental pre-scission neutron multiplicity (M^{pre}) at each excitation energy for each compound nucleus are given as a function of N/Z in Fig. 2(b). In this plot, the shaded area corresponds to the uncertainty in the fitted β values due to the experimental error in M^{pre}. It is noted in this figure that the best-fit β has a minimum at ^{212}Rn for the lowest excitation energy, though at higher excitation energies, N/Z dependence of β does not show any specific trend. It is of further interest to note that the N/Z dependence of β is similar to the N/Z

dependence of M^{pre} (Fig.2(a)) at the lowest excitation energy. And a minimum in β with respect to N/Z appears for ^{212}Rn for lowest excitation energy. Since ^{212}Rn has a closed neutron shell at N = 126, the above N/Z dependence of β is also expected from the microscopic theory of one-body dissipation [10], where incoherent particle-hole excitations cause dissipation. These results are valid only at excitation energies where the shell structure persists. The present results for the pre-scission neutron multiplicities and best fit values for dissipation strength thus suggest presence of shell effects at the lowest excitation energy.

From the measured neutron multiplicity and statistical model fission time scale was extracted and plotted with respect to N/Z along with few available systems in the literature [12]. It is shown that time scale decreases with N/Z value of $^{210, 212, 214,216}$Rn [11].
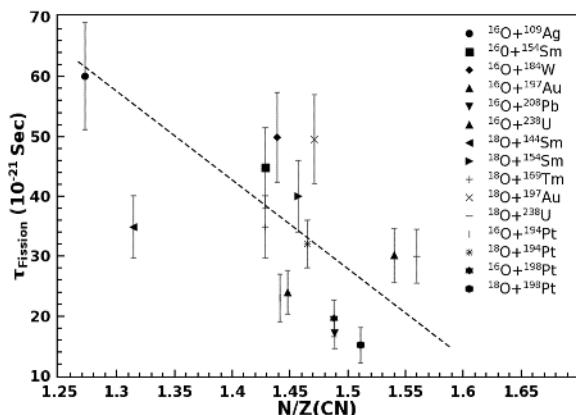

Figure 3, Variation of total fission delay against N/Z (CN) ratio for ^{16,18}O+^{194,198}Pt reactions along with data of Ref- [12]. For ^{16,18}O induced reactions.

5 Conclusions

The measured neutron multiplicities form the reactions ^{16,18}O+^{194,198}Pt are analyzed with the statistical model of nuclear decay where fission hindrance due to nuclear dissipation is considered. In the statistical model calculations dissipation strength is treated as an adjustable parameter in order to fit the experimental data. The N/Z dependence of the dissipation strength at the lowest excitation energy of the compound nuclei suggests shell closure effects. However, such effects are not observed at higher excitation energies where the variation of the dissipation strength with N/Z does not show any specific trend.

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