Deformations at the saddle point from fission fragment angular distribution measurements in A~200 mass region

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Introduction

According to the Statistical Saddle Point Model (SSPM), the fission fragment angular distribution depends on the angular momentum (J) distribution, effective moment of inertia (\(\mathcal{I}_{\text{eff}}\)) and temperature (T) at the saddle point of the fissioning nuclei [1]. The effective moment of inertia (\(\mathcal{I}_{\text{eff}}\)) is related to the shape of the fissioning nuclei at the saddle point. Möller and Sierk [2] have illustrated the importance of the saddle point shape in controlling the dynamics of heavy ion induced fusion-fission reaction. Experimental information about the saddle point shape will have a great ramification for the production of super heavy element.

It has been observed that the measured fission fragment anisotropy values are significantly larger than those predicted by SSPM for \(^{12}\text{C} + ^{198}\text{Pt}\) system, whereas measured anisotropy values for \(^{12}\text{C} + ^{194}\text{Pt}\) system agree well with the SSPM predictions [3]. It was conjectured that the shell effect in the potential energy surface results in reduced \(\mathcal{I}_{\text{eff}}\) in comparison to liquid drop value which leads to larger anisotropies. It is of interest to extend the measurement to some more systems to investigate the microscopic variation of \(\mathcal{I}_{\text{eff}}\). With this motivation, measurement of fission fragment angular distributions for \(^{12,13}\text{C} + ^{192,194,196}\text{Pt}\) systems has been carried out.

Measurement Details

The fission fragment angular distributions for the above-mentioned systems have been measured using the BARC-TIFR 14 UD Penletron accelerator at Mumbai. The measurements have been carried out in the laboratory energy range from 60 to 80 MeV, using self-supporting rolled foils of \(^{192}\text{Pt} (57.0\%), \(^{194}\text{Pt} 26.2\%, \(^{195}\text{Pt} 11.2\%, \(^{196}\text{Pt} 4.7\%\) thick), \(^{194}\text{Pt} (97.4\% \text{ enriched}, 0.98 \text{ mg/cm}\^2 \text{ thick}), \(^{196}\text{Pt} (96.2\% \text{ enriched}, 1.7 \text{ mg/cm}\^2 \text{ thick)}. Fission fragment angular distributions were measured from 80° to 170° in laboratory using four \(\Delta E\)-E telescopes consisting of Si surface barrier detectors (thicknesses \(\Delta E\) 10-22 \(\mu\)m, E 300 \(\mu\)m).

Other experimental details are similar as in Ref. [4]. In case of \(^{192}\text{Pt}\) target, contributions coming from other isotopes are corrected. Contribution of \(^{194}\text{Pt}\) and \(^{196}\text{Pt}\) isotopes are estimated using the measured data for those isotopes. Contribution of \(^{195}\text{Pt}\) isotope is estimated by interpolating the data for \(^{194,196}\text{Pt}\) isotopes. Fission fragment angular anisotropies for \(^{12,13}\text{C} + ^{192,194,196}\text{Pt}\) are compared in Fig. 1.

Results and discussion

Fission fragment angular anisotropy values are calculated according to SSPM using the \((E^*, J)\) distributions of the fissioning nuclei for each chance. The exact expression for angular distribution has been used to calculate fission fragment anisotropy values as discussed in Ref [5]. The \((E^*, J)\) distributions of the fissioning nuclei are obtained using PACE [6] after reproducing fission probabilities (\(\sigma_{\text{fus}}/\sigma_{\text{fus}}\)) and prefission neutron multiplicities. Measured fusion cross sections (\(\sigma_{\text{fus}}\)) for all the systems are not available and are obtained using the coupled channels code CCFULL after fitting the fusion excitation functions for \(^{12}\text{C} + ^{194,196}\text{Pt}\) systems [7]. Anisotropy values calculated using values of \(\mathcal{I}_{\text{eff}}\) from RFRM [8]
are found to differ from data. Good agreement could be obtained by normalising the RFRM $\mathcal{I}_{eff}$ values with energy independent factor.

Fig. 2 (a) and (b) show the weighted average ground state shell corrections ($\Delta_{WA}$) and weighted average ground state quadrupole deformation ($\beta_{WA}^2$), respectively. Weighted averaging has been done over the distribution of fissioning nuclei at $E_{cm} = 65$ MeV. The values of $\beta_2$ have been taken from Ref. [9]. Fig. 2 (c) shows the multiplicative factors ($k_I$) to RFRM $\mathcal{I}_{eff}$ values required to fit the experimental anisotropy data. Experimental anisotropy data for $^{12}$C+$^{192,194,196}$Pt [3] and $^{13}$C+$^{198}$Pt [4] are also included in the analysis. Value of $k_I$ larger (smaller) than unity implies more (less) compact saddle shape as compared to RFRM prediction. While the value of $-\Delta_{WA}$ increases monotonously as mass number increases, a correlation between $\beta_{WA}^2$ and $k_I$ has been observed. As $\beta_{WA}^2$ goes from $+ve$ (prolate) to $-ve$ (oblate), $k_I$ goes from larger than unity to smaller than unity (more compact to less compact saddle shape as compared to RFRM prediction).

References

FIG. 1: The fission fragment angular anisotropy (A) values plotted as a function of excitation energy for $^{12}$C+$^{192,194,196}$Pt systems. The lines are to guide the eye.

FIG. 2: Weighted average value of ground state (a) shell corrections and (b) quadrupole deformation of the fissioning nuclei. (c) Multiplicative factor to RFRM $\mathcal{I}_{eff}$ values required to fit the experimental anisotropy data.