Study of the mass yield distributions in $^{35}Cl+^{176}Yb$ and $^{35}Cl+^{165}Ho$ reactions

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Introduction

After the observation of flat-top mass distribution of beta delayed fission of ^{180}Tl [1], a large number of studies have been carried out to understand the role of shell effects in the pre-actinide region. Fission fragment mass distribution studies in the sub-lead and pre-actinide region carried out by Bogachev *et al*. [2] and Kozulin *et al*. [3] proposed that the asymmetric components in this mass region mainly arises from the proton shells corresponding to Z≈36 and 38 (referred as A1 mode), 45 and 46 (referred as A2 mode) and 28/50 (referred as A3 mode). Fission fragment mass distribution studies in fissioning systems ^{205,207,209}Bi, ^{208,210,212}Po and ^{213}At by Itkis *et al*. [4] showed the contribution from both SI and SII modes. The mass region around 200 becomes significant in order to obtain a comprehensive understanding of the shell effects, in which the shells manifesting in the neutron rich actinide region as well as neutron deficient sub-lead region can be observed. The semi-empirical code GEF [5,6] can be useful in investigating the role of different shells in governing mass distribution by comparison with experimental results.

In this study, fission product (FP) mass distribution (MD) has been measured in $^{35}Cl^{+176}Yb$ reaction at 167.1 MeV to investigate the role of shell effects. The experiment was carried out using the recoil catcher technique followed by the off-line γ-ray spectrometry for the measurement of charge and mass identified FPs. The obtained MD was compared to that obtained in $^{35}Cl+^{165}Ho$ reaction at 161.7 MeV [7]. Also, the mass distributions of both the fissioning systems were compared with the GEF calculations to investigate the contribution from various fission modes and any shell effect present, in addition to that considered by GEF.

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Experimental Details

The experiments were carried out at the BARC-TIFR Pelletron-LINAC facility, Mumbai. For $^{35}Cl+^{176}Yb$ reaction, a self-supporting ^{176}Yb target (~2.2 mg/cm^2) along with Pb as forward catcher foil (~17.5 mg/cm^2) was placed on a target stand. The backward catcher foil (6.75 mg/cm^2 Al) was placed before the target as a cone by mounting it on the inner surface of a conical support with a 5 mm hole at the centre for beam to pass. The target was irradiated with ^{35}Cl beam of energy 167.1 MeV for ~63 hrs. The E_{CM}/V_C and E* values were 1.04 and 61 MeV, respectively. Post-irradiation, the target and the catcher foils were mounted on a perspex plate and subjected to off-line high-resolution γ-ray spectrometry over a cooling period ranging from ~10 mins to ~70 days. The acquired γ-ray spectra were analyzed using PHAST [8] to obtain γ-ray peak areas. The FPs were identified based on the γ-ray energies as well as their half-lives. The experimental details for $^{35}Cl+^{165}Ho$ reaction can be found in ref. [7].

Results and Discussion

The activities at the end of irradiation were calculated using the γ-ray peak areas which in turn were used to obtain the cross-section of the FPs. The cross-sections were corrected using the charge distribution parameters, Z_P and σ_z to obtain the corresponding mass yields. The width parameter σ_z as well as ν_T were varied to obtain the best agreement of the ratio of theoretical yields with the experimental yields of the following parent-daughter pairs, i) $^{72}Zn \rightarrow ^{72}Ga$; ii) $^{91}Sr \rightarrow ^{91}Y^m$; iii) $^{95}Zr \rightarrow ^{95}Nb^g$ and iv) $^{97}Zr \rightarrow ^{97}Nb^g$ for $^{35}Cl+^{176}Yb$ reaction while i) $^{91}Sr \rightarrow ^{91}Y^m$; ii) $^{95}Zr \rightarrow ^{95}Nb^g$ and iii) $^{97}Zr \rightarrow ^{97}Nb^g$

for $^{35}Cl+^{165}Ho$ reaction. The experimental yields were obtained by fitting the measured activity of the daughter at different cooling times, which gives cumulative yield of the parent and independent yield of the daughter. The value of σ_Z was obtained as 0.56±0.01 and 0.74±0.01 for $^{35}Cl+^{176}Yb$ and $^{35}Cl+^{165}Ho$ reaction, respectively, which were found to agree with the GEF. The experimental mass distributions for both the systems have been shown in Fig.1.

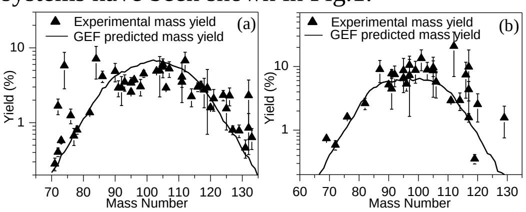

Fig. 1. Mass distributions of (a) $^{35}Cl+^{176}Yb$ reaction and (b) $^{35}Cl+^{165}Ho$ reaction with GEF calculations.

The mass distribution in $^{35}Cl+^{176}Yb$ fission showed a broad Gaussian behaviour showing dominant contribution from symmetric fission. However, significant positive deviations were observed from the Gaussian behaviour in the mass region around 124-126, 132-133 and its complimentary in the lower mass region. The mass distribution in $^{35}Cl+^{165}Ho$ fission showed flat-top nature indicating significant asymmetric fission contribution. The GEF predicts the contribution from the asymmetric mode corresponding to Z≈38 for both the fissioning system. Although the experimental mass distributions are in gross agreement with the GEF, some of the experimental mass yields show large deviations without any specific trend, making it difficult to conclude about the shell effects. This deviation may be the result of the combined effect of additional shell effects than that considered by GEF or the deviation of Z_P from that estimated using the UCD hypothesis. Therefore, Z_P estimated using UCD hypothesis was varied in the range of ±1.5 units while performing the charge distribution correction to obtain best agreement of the experimental mass yields with the GEF. The mass distributions for both the reaction has been shown in Fig. 2. After allowing the variation of Z_P, most of the FP mass yields coincides with the GEF except few mass yields deviate from the GEF (more than 50%) even with minimum charge distribution correction, mainly in mass region corresponding to Z≈52,55 in $^{35}Cl^{+176}Yb$ reaction while Z≈50,55 in $^{35}Cl^{+165}Ho$ reaction, which appear to be similar to those observed in the actinide region.

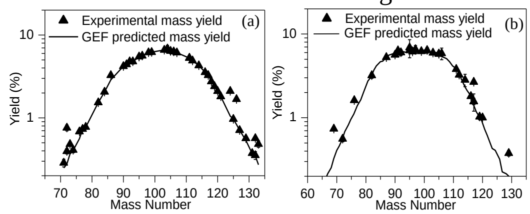

Fig. 2. Mass distributions of (a) $^{35}Cl+^{176}Yb$ and (b) $^{35}Cl+^{165}Ho$ reaction with GEF calculations after allowing the variation of Z_P values within ±1.5 unit.

Conclusions

FP mass distributions have been measured for $^{35}Cl+^{176}Yb$ and $^{35}Cl+^{165}Ho$ reactions at 167.1 and 161.7 MeV, respectively. The mass distribution for $^{35}Cl+^{176}Yb$ reaction showed broad Gaussian behaviour indicating dominant symmetric fission while, that for $^{35}Cl+^{165}Ho$ reaction showed flat-top nature indicating significant contribution from asymmetric fission. The obtained mass distributions were in gross agreement with the GEF predicting contribution from asymmetric fission mode corresponding to Z≈38. However, few deviations were observed from the GEF in the mass region corresponding to Z≈50-52 and Z≈55 which indicates that the conventional SI and SII asymmetric modes present in actinide region manifest in this mass region in addition to that considered by GEF at Z≈38.

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