Transfer angular distributions in ^{12,13}C + ^{232}Th and ^{13}C + ^{206,208}Pb reactions at $E_{\rm Beam}$=75 MeV

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Introduction

Heavy-ion reactions, in particular, single nucleon or multi-nucleon transfer, play an important role in understanding the nuclear structure effects [1]. A vast amount of experimental data have been accumulated over the years to address the transfer reaction mechanism as well as to gain insight on the nuclear structure [2]. Nevertheless, multi-nucleon transfer study is of current research interest, in particular, close to the drip lines of nuclear chart. The multi-nucleon transfer angular distributions, in general, are characterized by the target-projectile combination and the beam energy. Relative cross sections for different reactions are predominantly determined by the reaction Q-values, however, the shape of angular distribution is influenced by the nuclear structure effects for which the understanding is still scarce. In the present paper, we report measurements on transfer angular distributions for ^{13}C + ^{232}Th and ^{13}C + ^{206,208}Pb reactions, and their comparison with earlier measurements on ^{12}C + ^{232}Th reaction [3].

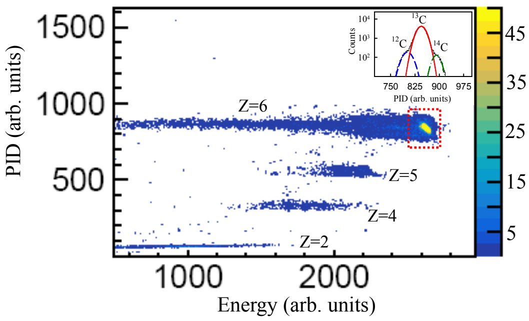

FIG. 1: A two-dimensional plot of PID versus energy for ^{13}C (75 MeV) + ^{232}Th reaction at a laboratory angle of 85° (see text).

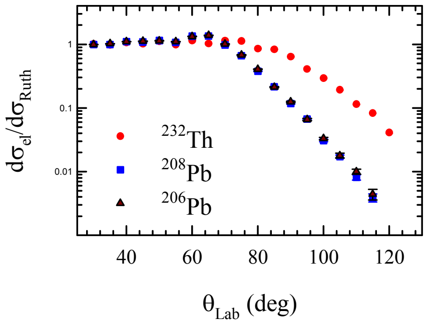

FIG. 2: Ratios of differential cross sections for elastic to the Rutherford as a function of scattering angle for the reactions induced by ^{13}C (75 MeV) beam with three different targets.

Experimental Details and Data Analysis

The experiment was performed using ^{13}C beam of energy 75 MeV from BARC-TIFR 14-MV Pelletron accelerator facility at Mumbai. Isotopically enriched (>99%) targets of ^{206,208}Pb with thickness of ∼600 μg/cm^2 on ^{12}C backing (∼30 μg/cm^2) and a self-supporting metallic foil of ^{232}Th (∼1.6 mg/cm^2) were used as the targets. Five telescopes, comprising of Silicon Surface Barrier (SSB) detectors with $\triangle$E (30 μm)-E (1 mm), were mounted on a movable arm to detect the projectile like fragments (PLFs). Two SSB detectors, mounted at angles of 20° on both sides of the beam were used as monitors for Rutherford normalization purpose. Angular distribution data were taken in an angular range of 30° to 120° with a step size of 5°. Particle identification (PID) spectrum was constructed using the algorithm;

$$\mathrm{PID} = (E + \Delta E)^{1.75} - E^{1.75} \qquad (1)$$

A typical two-dimensional plot of PID versus energy from a telescope at a laboratory angle of 85° is shown in Fig. 1, where, particles of different Z produced in ^{13}C (75 MeV) + ^{232}Th reaction appear in different horizontal

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TABLE I: Q-values for possible cases which lead to Z=5 and Z=4 events in the ^{12,13}C + ^{232}Th reactions.

Reaction	^{10}B MeV	^{11}B MeV	^{12}B MeV	^{13}B MeV
^{12}C + ^{232}Th	- 16.942	-10.710	-13.869	-14.539
^{13}C + ^{232}Th	-15.767	-10.434	-12.287	-13.936
Reaction	^{7}Be	^{9}Be	^{10}Be	^{11}Be
^{12}C + ^{232}Th	-25.712	-16.820	-15.305	-21.439
^{13}C + ^{232}Th	-24.504	-15.221	-14.954	-19.750

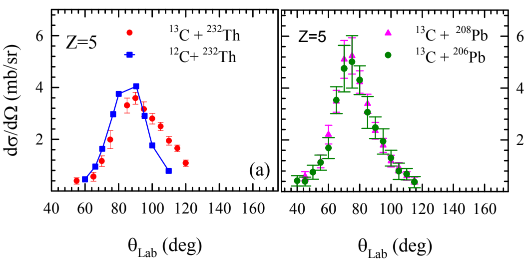

FIG. 3: Transfer angular distributions for the events involving the ejectile to be Z=5 in the ^{12,13}C (75 MeV)+^{232}Th reactions (left panel) and ^{13}C (75 MeV)+^{206,208}Pb reactions (right panel).

bands. The spectrum in the inset of Fig. 1 shows Y-Projection of the Z=6 band for the energy region marked by the rectangular box (dotted, red-colored line). In order to obtain pure elastic events, yields were determined using Gaussian peak fitting. In the inset of the Fig. 1, the different lines represent Gaussian peak fittings for ^{12}C, ^{13}C, and ^{14}C. Ratios of differential cross sections for elastic to the Rutherford as a function of scattering angle for the ^{13}C + ^{232}Th and ^{13}C + ^{208,206}Pb reactions are shown in Fig. 2. It is observed that this ratio remains almost same for ^{13}C + ^{208,206}Pb reactions in the measured angular range. Absolute cross sections for different reaction channels were obtained after normalizing the data with the elastic scattering events measured at forward angles.

Results and Discussion

Transfer angular distributions for Z=5 and Z=4 events in ^{12,13}C + ^{232}Th and ^{13}C + ^{206,208}Pb reactions at a beam energy of 75-MeV are shown in Figs. 3 and 4, respectively, where the data on ^{12}C (75 MeV) + ^{232}Th reaction were adopted from Ref. [3]. It is interesting to note how an additional neutron in ^{13}C makes shapes of angular distributions to appear much different than that of ^{12}C for both Z=5 and Z=4 events (Figs. 3 and 4). These differences cannot be explained in terms

TABLE II: Same as Table I, while the reactions are: ^{13}C + ^{206,208}Pb.

Reaction	^{10}B MeV	^{11}B MeV	^{12}B MeV	^{13}B MeV
^{13}C + ^{206}Pb	- 14.452	-10.458	-13.975	-17.184
^{13}C + ^{208}Pb	-18.815	-12.499	-13.734	-16.315
Reaction	^{7}Be	^{9}Be	^{10}Be	^{11}Be
^{13}C + ^{206}Pb	-26.060	-16.055	-16.901	-23.368
^{13}C + ^{208}Pb	-29.922	-19.602	-18.798	-22.847

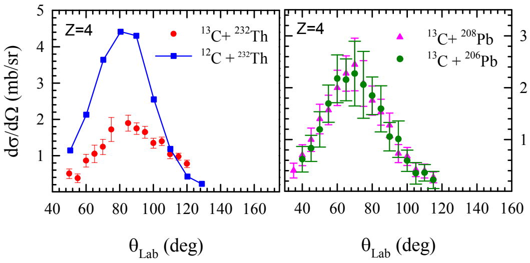

FIG. 4: Same as Fig. 3, but for the Z=4 events in the ejectile channel.

of reaction Q-values. Table I shows Q-values for possible cases which lead to Z=5 and Z=4 events in ^{12,13}C + ^{232}Th reactions. One can note from Table I that although the Q-values are not very much different for both, ^{12}C and ^{13}C induced reactions, still the angular distributions differ substantially.

On the other hand, the angular distributions in ^{13}C + ^{206,208}Pb reactions are observed to be virtually identical for the Z=4 as well as Z=5 events. However, one can note from Figs. 3 and 4 that the cross section for the Z=5 events is seen to be almost twice as for the Z=4 events in both the reactions. This may be explained in terms of reaction Q-values as shows in Table II for the possible cases. Overlapping transfer angular distributions in the ^{13}C + ^{206,208}Pb reactions for the Z=4 as well as Z=5 events cannot be explained purely in terms of reaction Q-values. One has to invoke coupled channel calculations to understand these results quantitatively.

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