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A Study of the Target Residues from the Interaction of ^{181}Ta with 45 MeV/A ^{12}C Ions

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Cross sections and recoil properties were measured for target residues from the interaction of ^{181}Ta with 45 MeV/A ^{12}C ions by using thick target-thick catcher foil techniques. The mass yield distribution measured experimentally was compared with a statistical multi-fragmentation model. A comparison of the linear momentum transfer calculated from the average forward recoil ranges with our previous results indicates that in 45 MeV/A ^{12}C-induced reactions, the linear momentum transfer in central collisions increases with target mass, which is in good agreement with the calculations based on leading particle models.

We have studied the mass yield distribution of the target residues and the linear momentum transfer of the interactions of Cu and ^{93}Nb with the intermediate-energy ^{12}C ions [1-3]. As part of the work, this paper presents the result obtained from the investigation of the interaction of ^{181}Ta with the 45 MeV/A ^{12}C ions.

The irradiation was performed on the Heavy Ion Research Facility (HIRFL) at the Institute of Modern Physics. The target used for the irradiation consists of a 99.999% pure metal tantalum foil with thickness of 51.6 mg/cm^2. The ^{181}Ta target was covered on both sides with 10.5 mg/cm^2 of Mylar foils. Mylar foils were used as forward and backward recoil catcher foils. The energy of ^{12}C ions was 47 MeV/A when delivered from HIRFL and 44.8 MeV/A at the center of the target. The irradiation lasted for 30 hours, with the total beam flux being 746 μC or 7.8×10^{14} ^{12}C ions. After the irradiation, the γ-activities of the forward and backward catcher foils and the ^{181}Ta target were measured with a HPGe detector. The measurement lasted for two months. The details of the experiment and the data analysis were described previously [1].

The production cross sections were determined for 81 residues in this work. According to the assumption of a Gaussian charge distribution

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$$\sigma(Z,A) = \sigma_A(2\pi\sigma_z^2)^{-1/2}\exp\{-[Z - Z_p(A)]^2/2\sigma_z^2\}^{[1]},$$

the independent yields calculated from the experimental cross sections were reasonably fitted to the Gaussian charge distribution function by adjusting the most probable charge $Z_p(A)$ as a function of mass number and the width parameter σ_Z of the charge distribution for each of the mass groups. Thus the mass yield σ_A can be determined for a given mass chain and the resulted mass yield curve of the target residues is shown in Fig. 1. At the mass number slightly below the target mass, one can see a large hump consisting of the heavy target residues, which often appear during the interaction of non-fissionable targets with the intermediate energy ^{12}C ions [1,3]. At the mass number slightly below half of the target mass number, however, there is an additional small peak, which can be attributed to the asymmetry fission from target-like fragments. This conclusion can be proved by the much larger recoil range and much smaller forward-to-backward emission ratio F/B of these products than those of heavy residues.

A statistical model describing the disassembly of hot nuclei created in intermediate energy heavy ion collisions has successfully reproduced the mass distributions of the target residues for the 35 MeV/A ^{12}C + Cu[4], 44 MeV/A ^{12}C + Cu[1] and 46 MeV/A ^{12}C + ^{93}Nb reactions [3]. In this work the theoretical calculations are given in Fig. 1 as a form of histograms for the 45 MeV/A ^{12}C + ^{181}Ta reaction. As shown in Fig. 1, the calculations agree quite well with the experimental mass distribution in the heavy residue region. Moreover, the theoretical calculations seem to have reproduced the mass distribution around the fission product region, although the calculated peak is shifted by almost 10 mass units to the low mass side. However, two peaks in the mass regions of A ~ 45 and A ~ 110, which were not found in the experimental measurement, appear in the theoretical calculations. This discrepancy may be due to the fact that the model overestimates the effect of the shell structure. It seems that the statistical multi-fragmentation model needs to be modified in order to improve the description of the interaction of fissionable targets with heavy ions at intermediate energies.

In this work the average forward-projected recoil range FW for the residues was measured by using the thick target recoil technique, where F is the fraction of the total activity of a given nuclide collected in the forward catcher, and W is the target thickness. By using the conventional approach the FW values were converted into the average recoil velocity $v_{//}$ of the nuclide in the beam direction [1,5]. In the calculation the effect of the particle evaporation on the recoil velocity of the nuclide is negligible and the effect of the angular distribution is not taken into account. The relative velocities $v_{//}/v_{CN}$ associated with the formation of residue with mass number A are plotted versus the mass loss ΔA from the target in Fig. 2, where v_{CN} is the recoil velocity of the nuclide formed by complete fusion, and ΔA is the difference between target mass A_T and residue mass A_R, i.e., $\Delta A = A_T - A_R$.

One can see from Fig. 2 that the $v_{//}/v_{CN}$ values increase steadily with increasing ΔA from about 20% for products close to the target to 64% for products with mass loss $\Delta A \approx 20$. When ΔA increases further (before fission region) a "plateau" of the $v_{//}/v_{CN}$ values appears for the lighter products, with relative velocity remaining as a constant. The dependence of the $v_{//}/v_{CN}$ values on the mass loss ΔA is similar in shape to those measured in the interaction of the lighter non-fissionable target nuclide with the intermediate-energy heavy ions [1,2,6]. If we consider the initial interaction between ^{12}C and ^{181}Ta an incomplete fusion, the particles with total mass Δm, which are not fused with the target nuclide, escape at 0° with the beam velocity. When Δm is far lighter than the mass of the putative complete fused nucleus, the relative velocity $v_{//}/v_{CN}$ is approximately the linear momentum transfer in the initial collisions. So the $v_{//}/v_{CN}$ values corresponding to the "plateau" in Fig. 2 can be regarded as the maximum linear momentum transfer at a given bombarding energy, and be marked as $p_{//}^{max}$. It is reasonable to assume that the $p_{//}^{max}$ is most relevant to central collisions with heavy ions [1,2,6]. In other words, the $p_{//}^{max}$ value is the most probable value of the linear

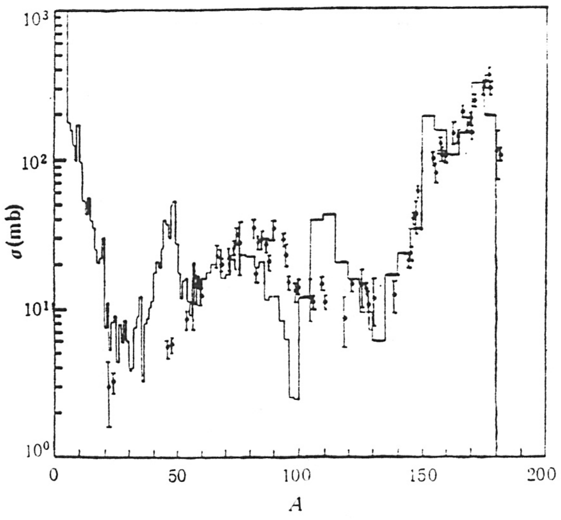

Fig. 1
Comparison of the experimental mass yield distribution with the statistical multi-fragmentation model for the 45 MeV/A ^{12}C + ^{181}Ta reaction.

momentum transfer $p_{//}^{mp}$ obtained from experimental measurements of the angular correlation between fission fragments [7]. The average value of the linear momentum transfer $<p_{//}>$ is obtained as 0.45 ± 0.05 by weighing the $v_{//}/v_{CN}$ values of nuclides for each mass number from the mass yield distribution. This quantity represents the average result integrated over all impact parameters from central to peripheral collisions.

The dependence of the linear momentum transfer on the target mass may provide useful information for the study of the projectile-target interactions in heavy ion collisions. There seems to be evidence indicating that the linear momentum transfer increases with increasing target mass.

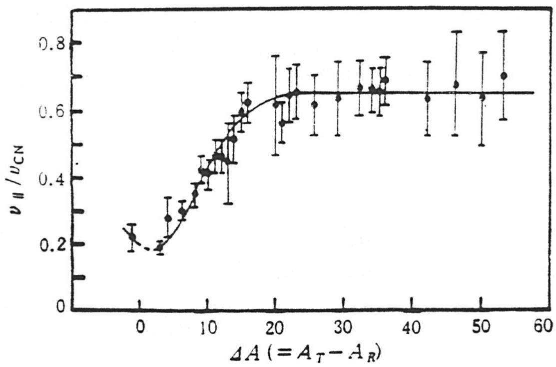

Fig.2
Dependence of relative velocity $v_{//}/v_{CN}$ on mass loss ΔA from target.

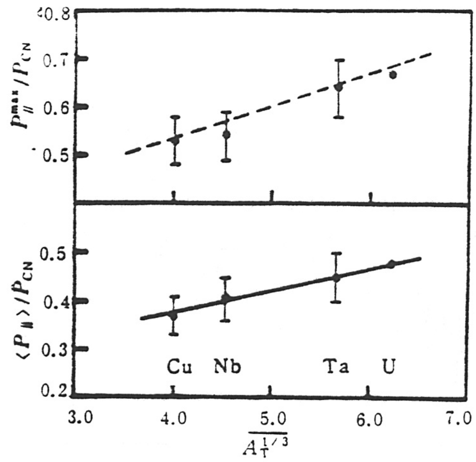

Fig. 3
Dependence of $p_{//}^{\max}$ (top) and $<p_{//}>$ (bottom) on target masses.
The dashed line is the theoretical calculations.

However, these data involve two different mass regions, i.e., intermediate mass region and heavy fissionable mass region. Different experimental methods were used in these two regions. Thus a systematic deviation arising from different methods cannot be ruled out. In this work the results measured by the recoil range technique has been expanded to the heavy mass region of A = 181. Therefore, it is possible to observe such dependence of the linear momentum transfer on target masses in a wider region.

Fig. 3 shows the target mass dependences of the $p_{//}^{\max}$ and $<p_{//}>$, respectively, for the reactions induced by the 45 MeV/A ^{12}C ions. The results for Cu and ^{93}Nb are from our previous work [1,2] and the uranium data are from Ref. [7]. A correction up to 2% was made for the slight differences of incident energies. As seen from Fig. 3, both $p_{//}^{\max}$ and $<p_{//}>$ show strong target mass dependences for the same incident heavy ions. The fact that $p_{//}^{\max}$ increases with increasing target mass agrees quite well with the theoretical calculations on the basis of the leading particle models for nucleon-nucleon collisions [8]. Although there is at present no model prediction for the dependence of $<p_{//}>$ on target masses, the result of this work agrees well with the conclusion drawn by Batcsh *et al.* i.e., the $<p_{//}>$ increases with increasing target masses [5]. Besides, our work extends the measurements to a heavier mass region.

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