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Target fragment angular distributions for the interaction of 25.2 GeV ^{12}C with ^{197}Au

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The target fragment angular distributions for the interaction of 25.2 GeV ^{12}C with ^{197}Au were measured. The data are generally in agreement with predictions based on the two step model and thick target-thick catcher recoil data.

[NUCLEAR REACTIONS Au(^{12}C,x), $E_{^{12}C}$=25.2 GeV, $\sigma(\theta)$, comparison of data with two step model, firestreak model.]

One of the least well understood aspects of relativistic nucleus-nucleus collisions is the momentum transferred to the target nucleus during the collison. There have been several studies of this problem with heavy target nuclei utilizing radiochemical techniques[1–5] and physical measurements.[6–8] From these studies we know that the target fragments may be divided into three general classes, fission fragments (produced with low to intermediate momenta), spallation products (whose momenta increase with increasing mass loss from the target), and the light fragments ($A<60$) whose momenta in high energy heavy ion reactions is the greatest of all the fragments. Heckman[9] has shown the relative magnitudes of the momenta of the light fragments and fission fragments can be understood in terms of a simple kinematic model that assumes the reaction takes place in two steps, a fast initial interaction between the projectile and the target and a second slow deexcitation step. Some of the assumptions of this model have been verified by Kaufman *et al.*[7] However no current theoretical model of relativistic heavy ion collisions correctly predicts the magnitudes of the target fragment momenta.[3,4]

In this Brief Report, we shall present additional information about the kinematic properties, i.e., the angular distributions, of these fragments and the class of fragments not studied by physical techniques, the spallation products. In particular, we shall report an extension of the previous measurements[10] of target fragment angular distributions in the reaction of 3 and 12 GeV ^{12}C with ^{197}Au and ^{238}U to the case of 25.2 GeV ^{12}C interacting with ^{197}Au.

The experiment was performed at the LBL Bevalac using a 2.1 GeV/nucleon ^{12}C beam. The target fragment angular distributions were measured utilizing exactly the same techniques, target thicknesses, etc., that have been described previously.[10] The total beam fluence was $\sim 10^{12}$ particles over a period of 10 h.

The measured fragment angular distributions are shown in Fig. 1. In qualitative agreement with previous[2] thick target-thick catcher recoil studies, one observes very forward-peaked distributions for nuclides with $145 \leqslant A \leqslant 171$ (thought to be deep spallation products), a slightly forward-peaked distribution for a possible fission product (^{97}Ru), and a nearby isotropic distribution for the light fragment (^{44}Sc^m). In all distributions the first point (23°) is considerably elevated with relation to the other three points in the distribution.

It is of interest to compare the measured fragment angular distributions to those predicted by the two step model of nuclear reactions and relevant recoil data.[2,11] Porile *et al.*[12] have shown that the fragment angular distributions can be expressed in terms of the two step model recoil parameters η_{11} and b/a as

$$F_L(\theta_L)=\frac{1+(b/a)\cos^2[\theta_L+\sin^{-1}(\eta_{11}\sin\theta_L)]}{1+b/3a}\times\frac{[\eta_{11}\cos\theta_1+(1-\eta_{11}{}^2\sin^2\theta_L)^{1/2}]^2}{(1-\eta_{11}{}^2\sin^2\theta_L)^{1/2}}\,, \quad (1)$$

where $F_L(\theta_L)$ is the laboratory differential cross section at

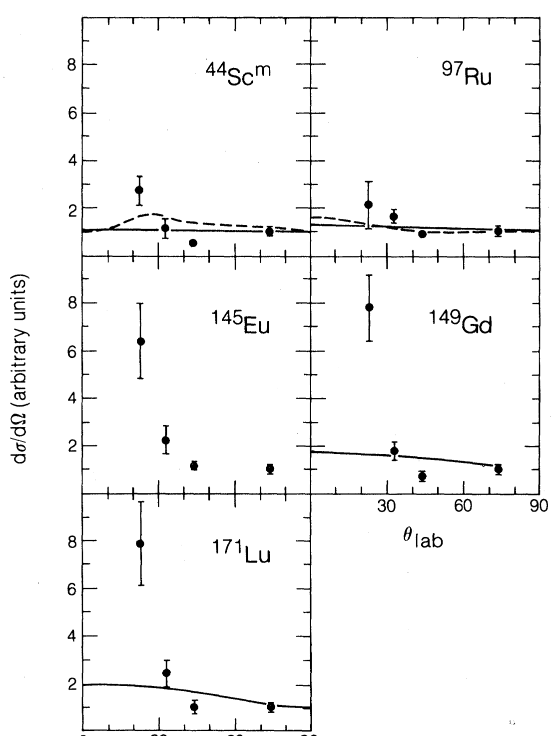

FIG. 1. Fragment angular distributions (in the laboratory system) for the interaction of 25.2 GeV ^{12}C with ^{197}Au. Solid lines indicate predictions of the two step model, while dashed lines represent firestreak model predictions.

angle θ_L. Taking η_{11} from Refs. 2 and 11 (and assuming $b/a=0$), Eq. (1) was used to calculate the distributions shown in Fig. 1. Apart from the point at 23°, the predicted and measured distributions are in general agreement, indicating some general validity for the use of the two step model to describe average fragment properties.

It is also of interest to compare the predictions of a current theoretical model of relativistic heavy ion collisons, the nuclear firestreak model, with the measured distributions. To do this we used the firestreak model as implemented by McGaughey[13] to predict the momenta of the emerging primary targets from the ^{12}C-^{197}Au interaction. (In making this calculation, we used realistic nucleon-nucleon scattering cross sections. The model predicted a total reaction cross section of 2931 mb, in good agreement with the "soft spheres"[14] estimate of 2825 mb and the Bradt-Peters[15,16] estimate of 3169 mb.) The final fragment velocity and angular distribution was calculated from the primary distribution using the Dostrovsky, Fraenkel, and Friedlander code as modified by McGaughey and Morrissey.[13] This code allows deexcitation of primary fragments by particle emission and fission and allows one to calculate the effects of these processes upon the fragment velocities and direction of motion. The resulting distributions for $39 \leq A \leq 49$ and $92 \leq A \leq 102$ are shown in Fig. 1. The distributions predicted by the firestreak model and the two step model have qualitatively different shapes, especially for the light fragments where the firestreak model predicts a distribution peaking at intermediate angles. The data, unfortunately, do not permit any definitive statements about the relative merits of the two sets of predicted distributions.

All of the distributions do show an elevated point at the most forward angle which, if taken at face value, would imply a shape of the deep spallation distributions that varies as $\sin^{-n}(\theta_L)$ where $n \simeq 2$–2.5. It is important to note that at the same time the distributions described in this paper were measured, measurements were made of the fission fragment angular distributions from the interaction of 25.2 GeV ^{12}C with ^{238}U. These measurements showed isotropic fragment distributions, indicating no systematic effects in the experiment or data analysis leading to artifically elevated differential cross sections at forward angles. In all candor, we must state that we do not understand the process leading to these elevated differential cross sections at the most forward angles but we are convinced that because we do not observe such effects in the other systems we have studied using these techniques they are not artifacts.

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