Charge and Mass Transfer in the Reaction $^{136}$Xe + $^{208}$Pb at Energies Close to the Coulomb Barrier

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Mass and charge transfer was investigated for the system $^{136}$Xe + $^{208}$Pb at 5.9 MeV/nucleon incident energy with a $\Delta E$-E-time-of-flight telescope. The angle and energy integrated cross section for the strongly damped events was found to be 510 mb, very close to the total reaction cross section. The width of the mass distribution as function of the total kinetic energy loss was measured and is compared to the width of the corresponding charge distribution. An upper limit of 1 pb has been found for processes with very large mass transfer.

I. Introduction

Many experiments have been performed during the last years in order to investigate the nucleon flow in strongly damped heavy ion collisions [1]. In most of the experiments energy and charge of the outgoing particles were measured for incident energies well above the Coulomb barrier. Only a few data exist so far where mass and charge of the reaction products were determined [2-6] simultaneously, mainly by radiochemical methods. From the shape of the charge distributions for strongly damped collisions values for the nucleon drift and diffusion coefficients can be deduced [7, 8]. However no measurement of the mass distribution as a function of the energy loss has been performed so far for reactions involving projectiles heavier than $^{86}$Kr. We report here on an experiment in which charge and mass of the outgoing particles were measured for the reaction $^{136}$Xe + $^{208}$Pb by means of a $\Delta E$-E-time of flight technique.

The system $^{136}$Xe + $^{208}$Pb was chosen mainly for three reasons:

(i) $^{208}$Pb as a target helped to keep the contribution from sequential fission small. Thus complications in the analysis of the reaction products in the mass region around $A \approx 130$ are avoided.
(ii) The neutron to proton ratio of the combined system is large.
(iii) Theoretical calculations in the framework of the fragmentation theory show [9] that in heavy ion collisions those exit channels should be preferred, where at least one of the outgoing particles is a closed shell nucleus. Thus under the assumption of a binary reaction the detection of ejectiles with $A \approx 40$ would point to the production of a nucleus in the proposed island of stability around $A \approx 300$.

The bombarding energy was chosen to be close to the Coulomb barrier in order to keep excitation energy and angular momentum of the exit channels as low as possible.

II. Experimental Details

The experiments were performed at the heavy ion accelerator UNILAC of the GSI Darmstadt. An 800 MeV $^{136}$Xe$^{28+}$ beam with an intensity of about 1 particle nA and a duty cycle of 10-25 % was used. The beam was collimated with a set of circular
apertures to a diameter of 3 mm on the target foil, positioned in the center of a multipurpose scattering chamber. The target was a selfsupporting 680 μg/cm² thick 208Pb foil; this thickness corresponds to an energy loss of about 16 MeV for the incoming 136Xe particles. The beam was monitored by two detectors mounted at θlab = 14° and 20°. The outgoing particles were detected with a ΔE-E-time of flight telescope consisting of a 50 mm² area 8.7 μm thick surface barrier ΔE-detector and a 150 mm² area 176 μm thick E-detector separated by a flight path of 215 mm. With this telescope mass and charge of the outgoing particles could be determined. The solid angle of the telescope was ~1 msr. The thickness of the ΔE-detector was chosen in order to obtain an optimum resolution in the mass range between A = 40 and 60. The small angle scattering losses in the ΔE-detector were measured and taken into account in the analysis. The ΔE and E-detector used in the experiment were selected for fast rise time, cooled to 0°C and operated at about 50 % overbias. The time resolution obtained was 200 psec FWHM and was mainly determined by the poor collection properties of the surface barrier detectors for ions as heavy as Xe. The mass resolution was therefore limited to about 4–5 %. The ΔE-detector was covered with a 1.1 mg/cm² thick Ni-foil in order to stop low-energetic recoil particles which would increase the counting rate especially at angles near θlab = 90°. The total energy resolution was about 5 % mainly determined by the kinematic spread due to the large acceptance angle of the telescope (Δθ = 2°).

The mass and charge calibration of the telescope was obtained by using recoil particles from elastic scattering of 134Xe ions from a mixed nuclide target consisting of a sandwich of Sc, Cu, Nb, Ag and Pb layers with a total thickness of 500 μg/cm². Figure 1a shows a contour plot of the energy loss ΔE versus the residual energy ER measured at θlab = 65°. In order to convert the ΔE-ER distributions to a charge scale we used a ΔE-E-Z table generated from the measured energy losses of the recoil particles from the mixed nuclide target. The energy of the strongly damped Xe-like fragments falls on the low energy side of the Bragg curve. This fact, together with inhomogeneities in the thickness of the ΔE-detector limited the Z-resolution for the low energetic Xe-like ions to about 10 %.

The mass of the reaction products was determined from the energy signal ER in the E-detector and the time of flight t between the ΔE and the E-detector, using the relation m~ ER t². Figure 1b shows the contour plot of mass versus ER. In this plot all elements from the mixed nuclide target are well separated even for small values of ER. Figure 1c shows the resulting contour plot of charge versus mass for the mixed nuclide target in the mass range A = 30–150 amu.