Local Equilibration and Diffusive Phenomena in $^{40}$Ar + $^{27}$Al and $^{14}$N + $^{27}$Al Heavy Ion Reactions

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Extensive analysis of the energy dissipation and nucleon exchange has been done with heavier systems. Here we choose the two light systems $^{40}$Ar + $^{27}$Al ($E_{\text{lab}} = 340$ MeV) and $^{14}$N + $^{27}$Al ($E_{\text{lab}} = 100$ MeV) in order to study the correlation of the energy dissipation with the variance of the charge distributions as a function of total kinetic energy loss bins. Considerable energy damping is found to occur in the approach phase which cannot be explained by a simple Fokker-Planck diffusion model. Indeed a model which interprets the collision as a local equilibration followed by diffusive phenomena is more appropriate to fit the data.

I. Introduction

Heavy ion deep inelastic collisions (DIC) can be investigated by looking at various reaction steps as a function of the interaction time. In the case of heavy systems [1] a procedure has been suggested, which allows to investigate correlations between mass exchange and energy loss. The main point in such an approach is to define a mean interaction time, related to the angular momentum. Such a time can be deduced easily from the angular distributions because a focusing of the cross section is observed. Assuming this time scale, experimental diffusion coefficients can be deduced and compared with theoretical values.

We report here on correlations between energy dissipation and nucleon transfer in $^{40}$Ar + $^{27}$Al and $^{14}$N + $^{27}$Al reactions. Such light systems are different because most of the cross section is observed at forward angles. Such a study presents an opportunity of gaining insight into the mechanism of energy damping, particularly in the initial stage of the reaction.

II. Experimental Data

We have studied the $^{40}$Ar + $^{27}$Al system at 340 MeV incident energy using the Alice facility of the I.P.N. Orsay Laboratory. The measurements concerning the $^{14}$N + $^{27}$Al reaction were performed at the I.S.N. isochronous cyclotron of Grenoble, at 100 MeV incident energy. In both cases, a charge identification of the reaction products (fusion + DIC fragments) has been obtained. Details of the experimental set up and of the data analysis are given in Ref. 2. In the $^{14}$N + $^{27}$Al case, coincidence between light particles (alpha or protons), and fragments, as well as coincidence between the two DIC fragments have been performed. We will focus mainly on the singles data, and refer to the coincidence measurements when necessary.

First we present in Table 1 the main characteristics of the two reactions. We are clearly dealing with systems very different from heavier ones, with a large bombarding energy above the interaction barrier. Evaporation residues measurements show that a large number of low I values leads to fusion, up to the critical I value $I_{\text{crit}}$. This feature is reflected by the entrance channel potentials (nuclear + Coulomb

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Table 1. Characteristic quantities of the studied reactions

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$E_i$ (MeV)</th>
<th>$E_{CM}/B$</th>
<th>$\eta'$</th>
<th>$\sigma_{tot}$ (mb)</th>
<th>$l_{cr}$ (h)</th>
<th>$l_{max}$ (h)</th>
<th>$l_{cr}$ (calc)</th>
<th>$\theta_e$ (CM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N + Al</td>
<td>100</td>
<td>3.8</td>
<td>6.2</td>
<td>1,500 ± 200</td>
<td>830 ± 100</td>
<td>27 ± 2</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td>Ar + Al</td>
<td>340</td>
<td>3.7</td>
<td>14.4</td>
<td>1,690 ± 200</td>
<td>760 ± 100</td>
<td>50 ± 4</td>
<td>82</td>
<td>54</td>
</tr>
</tbody>
</table>

Fig. 1. Contour plots of $d^2 \sigma/dE_d\theta$ in $E_{CM}$ versus $\theta_{CM}$ plane for $Z = 17, 15$ in the Ar case and for $Z = 6, 3$ in the case. The deflection function has been drawn (dashed lines) in Figs. 1a and d.

Figs. 2 and 3. Differential cross sections as a function of $Z$ for various kinetic energy loss bins. For Ar + Al the dotted lines represent the cross section corrected for the evaporation of particles + rotationnal) of the two ions, computed within the proximity approximation [3]. Consequently, the dissipative phenomena occur in a rather narrow $l$ range between $l_{cr}$ and $l_{max}$ ($l_{max}$ being defined as the classical $l$ value for the inelastic flux by the quarter point method). We observe the change in the Wilczynski plot in Fig. 1, from forward peaked for $P$ and $C$ to rather flat distributions, as the reaction products require more mass exchange, as for instance in Cl and Li fragments cases. As pictured in Figs. 1a, d, the