STATISTICAL BINARY DECAY OF $^{35}\text{Cl} + ^{24}\text{Mg}$

AT $\approx 8$ MEV/NUCLEON

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Abstract

The properties of the two-body channels in the $^{35}$Cl $+ ^{24}$Mg reaction at a bombarding energy of 275 MeV, have been investigated by using fragment-fragment coincident techniques. The exclusive data show that the majority of events arises from a binary-decay process. The rather large number of secondary light charged-particles emitted from the two excited exit fragments are consistent with the expectations of the Extended Hauser-Feshbach Method. Therefore no evidence for the occurrence of ternary break-up events is observed.

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The systematic trends of the fusion-fission (FF) process in the \(40 \leq A_{\text{CN}} \leq 60\) mass region is at present well established \([1,2]\). In general, calculations using the transition-state model formalism \([1]\) reproduce the basic properties of the binary fragments providing evidence for a FF mechanism.

In this note \(^{35}\text{Cl} + ^{24}\text{Mg}\) experimental coincident results are presented and discussed within an alternative model \([3]\). The data have been obtained with a 275 MeV \(^{35}\text{Cl}\) beam (well above the FF energy threshold \([2]\)) provided by the Saclay Booster Tandem facility. The reaction products were detected in singles mode between \(-45^\circ\) and \(85^\circ\) and, in a coincident mode, between \(-37^\circ\) and \(95^\circ\), by seven ionization chambers, at a pressure of 52 torrs of CF\(_4\) gas, followed by a 500 \(\mu\)m thick Si(SB) detector. On an event-by-event basis, corrections were applied for energy loss in the target and window foils and for the pulse-height defect in the Si detectors.

The elemental \(Z\) distribution of integrated fully-damped and evaporation residues (ER) cross sections (points) extracted from the singles yields are plotted in Fig.1 with statistical model calculations using the Extended Hauser-Feshbach Method (EHFM) and EHFM+CASCADE \([3,4]\). The total FF and ER cross sections are \(\sigma_{\text{FF}} = 137 \pm 5\) mb and \(\sigma_{\text{ER}} = 722 \pm 197\) mb respectively in excellent agreement with the previous inclusive study of Cavallaro et al. \([5]\). EHFM assumes the fission decay width to be proportional to the available phase space at the scission point. It starts with the compound nucleus (CN) formation hypothesis and then follows the system which is allowed to decay by first-chance binary fission or fusion-evaporation. Subsequent light-particle emissions from the fully-accelerated fission fragments are explicitly taken into account. The full procedure including secondary emission is denoted as EHFM+CASCADE \([3,4]\). For this calculation the simple case without deformation has been chosen. The diffuseness parameter is \(\Delta = 1\) \(\hbar\) and critical angular momentum \(L_{\text{crit}} = 44\) \(\hbar\). The neck length parameter of the scission-point parametrization is \(d = 3.8\) fm according to the systematics \([3]\).
In Fig.1 EHFM+CASCADE clearly shows that the effects of secondary particle emission play an important role in the deexcitation scheme. The small displacement between the calculations and experimental points for ER’s in the Fig.1 may be due to the deformation of the $^{59}$Cu CN [3].

The experimental “missing charge distributions” extracted from the coincident yields are shown in Fig.2 as solid histograms and compared to the predictions of the full EHFM+CASCADE calculations which are displayed for chosen angle settings as dashed histograms. The average missing charge $\Delta Z$ which is around 4 charge units, in agreement with the recently established systematics [4,7], is most likely lost through particle emission from either the excited composite system or a secondary sequential evaporation from both binary-reaction partners. The small shoulder which is observed in Fig.2 for $Z = 12$ is due to a C contamination of the Mg target. This has been verified by studying the reaction $^{35}$Cl + $^{12}$C at $E_{\text{lab}} = 278$ MeV [4].

The possible occurrence of ternary processes that involve three massive fragments in competition with the binary-decay mechanisms has been searched for. No strong evidence is observed for the onset of ternary processes in the $^{35}$Cl + $^{24}$Mg reaction data for incident energies lower than 10 MeV/nucleon as recently claimed in ref. [8] for more massive systems. More quantitatively the average $<Z_1 + Z_2>$ calculated from the EHFM+CASCADE code can be compared with the experimental data in Fig.3. The agreement between the calculations and the data is quite satisfactory. Naturally this comparison is only relevant for mechanisms assuming a full-energy damping as in the case of CN and/or orbiting deep-inelastic processes. As a consequence the discrepancies observed in Fig.3 in the region $Z_1 = 13$ to 16 may indicate that these products have a different but still unknown origin.
In summary, the comparison of fragment-fragment coincidence data with the predictions of the Extended Hauser-Feshbach Method indicates that the majority of events arises from a binary-decay process with rather large numbers of secondary light charged-particles emitted from the two excited exit fragments. No evidence for the occurrence of a three-body process is clearly observed at this energy. In addition, the good agreement between the experiment and the statistical model may indicate that pre-scission emission of light particles from the dinuclear system might be weak in this mass region in contrast to heavier reactions.
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FIGURES

FIG. 1. $^{35}\text{Cl} + ^{24}\text{Mg}$ elemental distribution (points) at 275 MeV compared with EHFM (dashed histograms) and EHFM+CASCADE (solid histograms) calculations. The open circles are the inclusive data measured at 280 MeV[5].

FIG. 2. The missing charge distributions (solid histograms) as measured for $^{35}\text{Cl} + ^{24}\text{Mg}$ reaction for each charge ($Z_1 = 5$ to 12). The dashed histograms are EHFM+CASCADE calculations under the same conditions $Z_{1,2} \geq 5$.

FIG. 3. Average sum $<Z_1 + Z_2>$ plotted as a function of $Z_1$ for $^{35}\text{Cl} + ^{24}\text{Mg}$. The solid line shows EHFM+CASCADE results.