The transfer reaction $^{11}\text{B}(^{13}\text{N},^{12}\text{C})^{12}\text{C}$

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Summary. — The transfer reaction $^{11}\text{B}(^{13}\text{N},^{12}\text{C})^{12}\text{C}$ has been investigated at the two laboratory energies $E_{\text{lab}}=45$ MeV and $E_{\text{lab}}=29.5$ MeV. Particle-particle coincidences have been measured. The coincidence between a heavy ion and the 15.1 MeV $\gamma$-ray emitted from $^{12}\text{C}$ shows transition to the $^{12}\text{C}^{*}(E=7.64$ MeV) and $^{12}\text{C}^{*}(E=7.64$ MeV) exit channels. These indicate the mixed ground-state structure of $^{13}\text{N}$. DWBA calculations have also been performed. Analysis of particle-particle coincidence data revealed the presence of transfer channels also to unbound states of $^{12}\text{C}$ such as $^{12}\text{C}^{*}(E^{*}=7.64$ MeV) and $^{12}\text{C}^{*}(E^{*}=7.64$ MeV). The angular distributions have been extracted for these two channels. Six-alpha-particle events have also been analyzed. Some of these events have been identified as coming from $^{11}\text{B}(^{13}\text{N},^{12}\text{C})^{12}\text{C}$ reaction. An enhancement in the six-$\alpha$ cross-section is observed at an excitation energy for the compound nucleus $^{24}\text{Mg}$ close to the 46 MeV resonances observed in $^{12}\text{C}+^{12}\text{C}$ inelastic scattering. These six-alphas events are generated mostly from the break-up of $^{12}\text{C}(3\pi^{-})+^{12}\text{C}(3\pi^{-})$ and therefore seems not to be associated with the six-alphas chain state.

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The reaction $^{11}\text{B}(^{13}\text{N},^{12}\text{C})^{12}\text{C}^*$ has been investigated in order to study the structure of $^{13}\text{N}$ and how this structure influences the transfer mechanism. The $^{13}\text{N}$ nucleus has a low proton separation energy ($S_p = 1.94$ MeV). The proton transfer to a $^{11}\text{B}$ nucleus forms two $^{12}\text{C}$ which can be excited to several states. By detecting coincidences between charged particles and γ-rays one can study the effect of the nuclear structure of $^{13}\text{N}$ on the reaction mechanism. The experiment was performed at the Radioactive Ion Beam Facility in Louvain la Neuve. Charged particles were measured using two large-area silicon strip detectors $300\mu$m thick. The forward detector (LEDA Louvain-Edinburgh-Detector-Array) [1] consisted of 8 sector detectors each containing sixteen strips covering the angular range $6^\circ \leq \theta \leq 15^\circ$ and an azimuthal angular range $0^\circ \leq \phi \leq 360^\circ$. The detector placed at larger angles (Lampshade LAMP) consisted of six sectors angled forward at $45^\circ$, to give larger solid angle acceptance. In this case the angular range covered by each sector was $20^\circ \leq \theta \leq 70^\circ$ and $0^\circ \leq \phi \leq 360^\circ$. Gamma-rays were detected using 21 BaF$_2$ crystals, part of the multidetector TRASMA of LNS [2].

The proton transfer to different excited states in $^{12}\text{C}$ and the double excitation, where the incoming $^{12}\text{C}$ core of $^{13}\text{N}$ is left in an excited state, have been analyzed and the cross-section has been extracted at two laboratory energies $E_{\text{lab}} = 29.5$ MeV and $E_{\text{lab}} = 45$ MeV. The coincidence between a heavy ion plus a 15.1 MeV γ-ray gives evidence of the one proton transfer reaction on $^{11}\text{B}$, forming $^{12}\text{C}$ in the 15.1 MeV excited state. When gating on this γ-ray peak two different transitions are observed with different Q-values. These transitions have been interpreted as originating by $^{12}\text{C}_{\text{gs}} + ^{12}\text{C}_{15.1}^{12}$ and $^{12}\text{C}_{4.44} + ^{12}\text{C}_{15.1}^{12}$ in the exit channel and indicate the mixed ground-state structure of $^{13}\text{N}$:

$$\alpha|^{12}\text{C}(0^+) \otimes 1p_{1/2} \rangle + \beta|^{12}\text{C}(2^+) \otimes 1p_{3/2} \rangle.$$  

The angular distributions have been extracted for the $0^+$ and the $2^+$ transitions and are shown in fig. 1a, b) for the two runs. A fit of the angular distribution for such exit channels has been performed by means of DWBA calculation [3]. The results of such a calculation are shown in fig. 1a) and fig. 1b) in which two different sets of optical-model parameters are used to better reproduce both data at $E_{\text{lab}} = 29.5$ MeV and $E_{\text{lab}} = 45$ MeV [4].

As shown in fig. 1, the optical-model parameters seem to be energy dependent. The agreement with the experiment is good with the exception of the $^{12}\text{C}_{4.44} + ^{12}\text{C}_{15.1}$ transition at the lower beam energy, which is significantly underestimated by the calculation, suggesting a contribution from a different reaction mechanism.

An analysis of particle-particle coincidence data revealed the presence of transfer channels to unbound states of $^{12}\text{C}$. In particular the transfer channels $^{12}\text{C}_{\text{gs}}, + ^{12}\text{C}^* (E^* > 7.27$ MeV) and $^{12}\text{C}_{4.44} + ^{12}\text{C}^* (E^* > 7.27$ MeV) were identified by investigating coincidences between a $^{12}\text{C}$ nucleus + three $\alpha$-particles. Figure 2 shows the Q-value spectrum for one $^{12}\text{C}$ + three-α events. In this spectrum the peaks labelled g.s. and 4.44 correspond to the $^{12}\text{C}_{\text{gs}}, + 3\alpha$ and $^{12}\text{C}_{4.44} + 3\alpha$ channels, respectively. The major structure at Q-value $\sim -7$ MeV corresponds either to the channel $^{12}\text{C}_{15.1} + ^{12}\text{C}^*$ and to fusion evaporation events. Gating on the Q-value peak corresponding to the g.s. and the 4.44 MeV states in $^{12}\text{C}$, results in the angular distributions shown in fig. 3. No optical-model calculations have been performed for these two cases.

Interesting results have also emerged from the analysis of events with high charged-particle multiplicity. Charged-particle multiplicity as high as six has been analysed.

This analysis was performed because of the recent interest in the resonant behaviour occurring in a number of exit channels following the $^{12}\text{C} + ^{12}\text{C}$ scattering. In particular several resonances have been found in the excitation energy region of 46 MeV for the