EIGHT-NUCLEON TRANSFER AND MULTIPARTICLE EXCITATION BY THE (14N, 6Li) REACTION

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EIGHT-NUCLEON TRANSFER AND MULTIPARTICLE EXCITATION BY THE (^{14}N, ^{6}Li) REACTION

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Résumé. — Les fonctions d'excitation et les distributions angulaires de l'état fondamental et des premiers états excités du ^{20}Ne obtenues à 52 MeV, à haute résolution, montrent le caractère principalement direct de la réaction ^{12}C(^{14}N, ^{6}Li)^{20}Ne. Les états de spin élevé sont excités préférentiellement. La section efficace du premier état 4^+ du ^{20}Ne est la seule qui ait une structure résonante dans la région entre 50 et 53 MeV où la fonction d'excitation a été mesurée.

Abstract. — Excitation functions of low-lying states and angular distributions at 52 MeV with spectra of high resolution show the mainly direct character of the 8-nucleon transfer by the ^{12}C(^{14}N, ^{6}Li)^{20}Ne reaction. High-spin states are preferentially excited. In the region measured, 50-53 MeV, only the yield to the first 4^+ state of ^{20}Ne reveals a resonance structure in the excitation function.

One of the most striking features of heavy-ion reactions is the fact that they allow to study in many cases otherwise inaccessible nuclear configurations. Besides the possibility of a cluster transfer in such reactions, the involved large angular momenta permit the selective population of relatively sharp high-spin states in the continuum of the residual nucleus. And it is the structure of just these states, which is of particular interest and which is also the purpose of our investigation. We report herein a continuation of our studies [1] of the 8-nucleon transfer by the (^{14}N, ^{6}Li) reaction on ^{12}C target leading to the sd-shell nucleus ^{20}Ne. A similar experiment has lately been reported by Nagatani et al. [2].

Since Litherland et al. [3] have shown that its lowest energy levels can be placed into rotational bands, ^{20}Ne has been regarded as a typical example of a light nucleus having collective characteristics. The level schemes of such nuclei were described by both the collective model of a simple rigid rotor and the SU3 classification [4] of the shell model. The latter description has had its great triumph very recently, when the carefully measured $E2$ transition probabilities in the ground-state band of ^{20}Ne up to the 8^+ level [5] were found to be well described. However, there are still a lot of open questions concerning reaction mechanism and the configurations of most of the ^{20}Ne states. We have chosen the (^{14}N, ^{6}Li) reaction for the study of ^{20}Ne since it has all the mentioned advantages of a heavy-ion reaction. Moreover, the mechanism of this reaction was expected to be dominantly direct because of the high ^{6}Li emission threshold. Opposite to many other reactions with heavy-ions, this fact results in a small cross section for the ^{6}Li decay from compound nucleus. And indeed, the expected direct character of the ^{12}C(^{14}N, ^{6}Li)^{20}Ne reaction was confirmed by our measurements.

The experiment was performed with a 52 MeV ^{14}N beam of the Heidelberg MP Tandem van de Graaff. The experimental procedure and the identification of the ^{6}Li particles with $\Delta E - E$ counter telescopes was described elsewhere [1]. We have continued these measurements using the multigap magnetic spectrograph and detecting the ^{6}Li nuclei on photographic plates with polyethylene absorber foils of suitable thicknesses. A high-resolution spectrum of the latter experiment is given in figure 1 for a forward angle of 9.5° (lab). The laboratory energy resolution was about 65 keV, permitting the complete separation of all observed states, except the 3^- and 0^+ at 7.17 and 7.20 MeV, respectively.

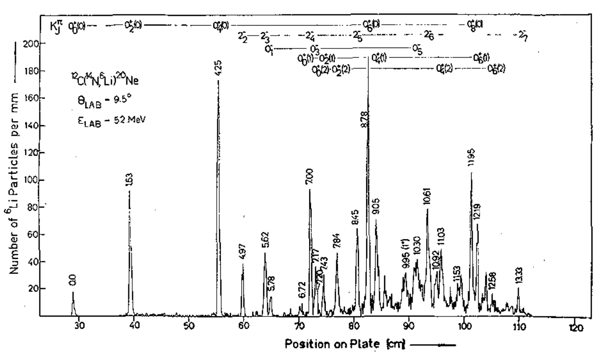

FIG. 1. — ^{6}Li spectrum for the reaction ^{12}C(^{14}N, ^{6}Li)^{20}Ne observed with the multigap spectrograph at 9.5° (lab.) A level classification with the appropriate K quantum number for five known rotational bands in ^{20}Ne is given at the top of the figure.

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As one can see from figure 2, the shapes of the angular distributions of the first few excited states in ^{20}Ne obtained at 52 MeV with the detectors are similar to those of direct reactions, e. g. they are forward peaked and the maxima become a little broader and move slowly to larger angles with increasing angular momentum transfer. This similarity can be understood if one realizes that in our transfer process the projectile ^{14}N is separated into two nearly equal parts,

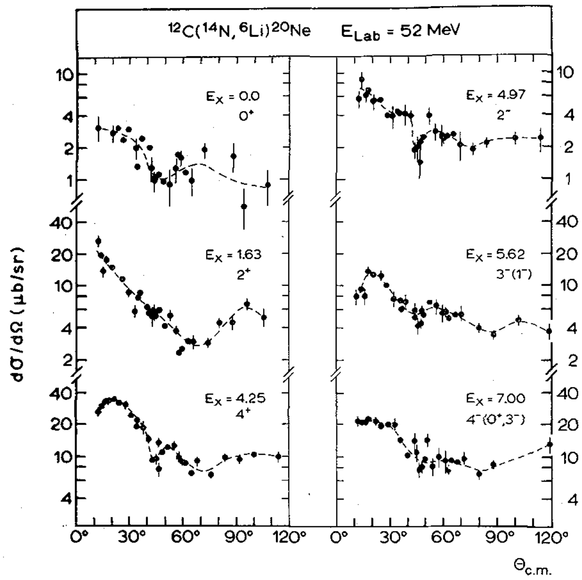

FIG. 2. — Angular distributions of low-lying states in ^{20}Ne obtained at 52 MeV with counter telescopes for the (^{14}N, ^{6}Li) reaction on ^{12}C.

like the deuteron in a (d, p) stripping process. A further hint for the mainly direct transfer mechanism is the fulfilled linearity between the total cross sections and the spins of the states according to the $(2\,J + 1)$ rule. Figure 3 exhibits the excitation functions between 50 and 53 MeV for three ^{20}Ne states and for the α-yield at the laboratory angles 10°, 20° and 35° in steps of 300 keV (lab). With the exception of the 4^+ member of the g. s. band, which shows a resonance-like structure of a width of about 1 MeV, the excitation functions are relatively flat for all measured angles, again supporting the hypotheses of a direct transfer. Lastly, the relatively large cross section for the 8-nucleon transfer which lies between 10 and 20 μb/sr is an indication for the preferentially direct transfer with only very small contributions from compound-nucleus formation. Compared to the 7- and 5-nucleon transfer (^{9}Be and ^{7}Be yield), the ^{6}Li yield is about 5 and 2.5 times larger.

A detailed comparison of the 8-nucleon transfer with the α-transfer reactions (^{6}Li, d) and (^{7}Li, t) [6], [7] leading also to ^{20}Ne is given in ref. [1]. The $K^\pi = 0^+$ g. s. rotational band is strongly excited in both 4- and 8- nucleon transfer. On the other hand, a significant difference was observed for both transfers in the

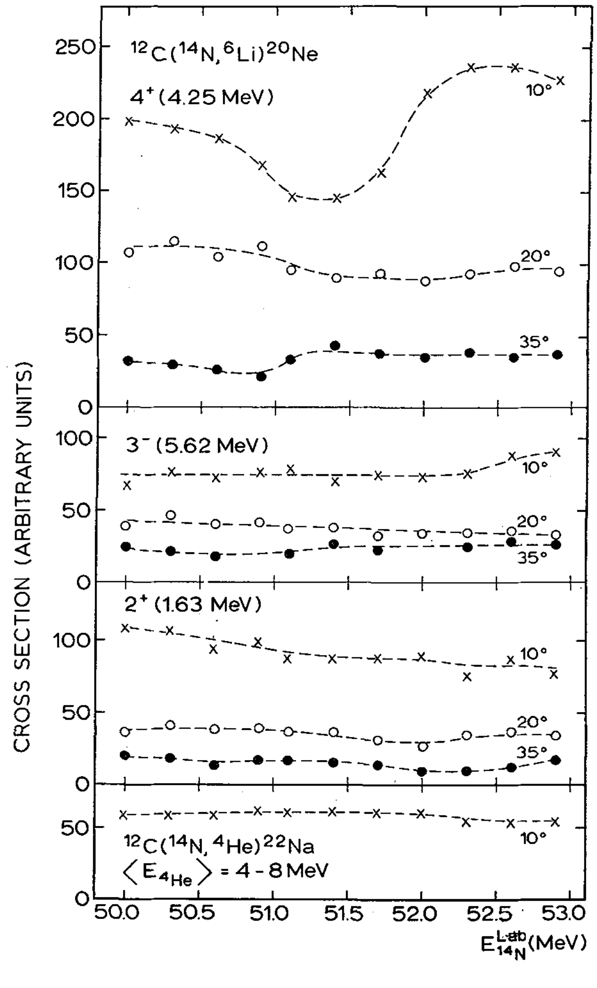

FIG. 3. — Excitation functions of low-lying states in ^{20}Ne and of the α-yield between 50 and 53 MeV for the three indicated angles.

population strength of the bands with $K^\pi = 0^-$ with 1^- bandhead at 5.78 MeV and with $K^\pi = 2^-$ with its 2^- bandhead at 4.97 MeV. Whereas the strongest peaks in the spectra of the 4-nucleon transfer belong to the $K^\pi = 0^-$ band, which is explained as 4-particle rotational states built on an inert ^{16}O core, this band is only weakly populated in our reaction. On the other hand, the strong excitation of the $K^\pi = 2^-$ band with alternating natural and unnatural parity states in the (^{14}N, ^{6}Li) reaction seems to be an indication that in the interaction of the ^{14}N with the ^{12}C nuclei 8 nucleons are transferred in a { 4 } { 31 } Young symmetry. It is just this component of the transfer amplitude which encourages us to look experimentally for the 10^+ state of the g. s. rotational band. Calculations of Pittel [8] which assume that one particle of the 4 valence nucleons around the inert ^{16}O core is lifted into an unbound continuum level are in favour of the existence of a 10^+ state in ^{20}Ne and against the shell model band cut off at $J = 8$. In order to see how the spectra look at much higher excitation energies, a ^{12}C(^{14}N,

^{6}Li)^{20}Ne measurement was made with the Orsay heavy-ion cyclotron at 80 MeV bombarding energy. In the excitation region of ^{20}Ne from 14 to 26 MeV, which is around the position of the 10^+ proposed by Pittel [8], there are apparently some strong peaks, one of which might be the 10^+. That the (^{14}N, ^{6}Li) could be a possible way for the excitation of the 10^+ is also supported by the strong excitation of the 8^+ level in this reaction. Its very weak population by the 4-nucleon transfer is in agreement with the small α-width of the 8^+ state recently measured by the Chalk River group [5]. These authors noted decreasing α-widths with increasing J-values, and this shows, together with the different excitation strengths of the 8^+ by the 4-nucleon transfer compared to the 8-nucleon transfer, that the configuration of the higher band members changes in the region of the proposed band cut off loosing nearly completely its α-cluster configuration. An additional question is which one of the two bands, starting with O^+ levels at 6.72 and 7.20 MeV, respectively, is the theoretically proposed band with the 8p-4h configuration. The somewhat weaker excitation of the third O^+ band which has also the smaller α-particle widths [9] lead to the conclusion that it is the O^+ band starting at 6.72 MeV which has probably (sd)^4 configuration, whereas the other band at 7.20 MeV should be the expected 8p-4h $K^\pi = O^+$ band. Most probably the states belong together in bands as indicated in figure 1.

In conclusion, we emphasize that the direct 8-nucleon transfer by the (^{14}N, ^{6}Li) reaction provides a practical method for the nuclear spectroscopy of highly excited states with relatively simple configurations.

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