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► **To cite this version:**

D. Scott, C. Cardinal, P. Fisher, P. Hudson, N. Anyas-Weiss. ONE, TWO AND THREE-NUCLEON TRANSFER REACTIONS INDUCED BY ^{12}C IONS ON ^{12}C , ^{16}O AND ^{40}Ca . *Journal de Physique Colloques*, 1971, 32 (C6), pp.C6-275-C6-277. 10.1051/jphyscol:1971664 . jpa-00214882

HAL Id: jpa-00214882

<https://hal.science/jpa-00214882>

Submitted on 4 Feb 2008

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ONE, TWO AND THREE-NUCLEON TRANSFER REACTIONS INDUCED BY ^{12}C IONS ON ^{12}C , ^{16}O AND ^{40}Ca

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Résumé. — Les réactions de transfert de un, deux et trois nucléons ont été étudiées à 114 MeV sur des cibles de ^{12}C , ^{16}O et ^{40}Ca . Une caractéristique frappante de toutes les réactions est la population sélective de certains niveaux des noyaux résiduels dans un domaine d'énergie d'excitation de 50 MeV. Les excitations peuvent être expliquées par un argument semi-classique.

Abstract. — One, two and three nucleon transfer reactions have been studied at 114 MeV on targets of ^{12}C , ^{16}O and ^{40}Ca . A prominent feature of all the reactions is the selective population of levels in the residual nuclei, in an excitation range covering 50 MeV. The excitations can be explained by a semiclassical argument.

The processes of single-nucleon, deuteron, ^3He , t and alpha-particle transfer induced by heavy ions are under extensive study at the present time. So far there have been few investigations of two proton or two neutron transfer. The two-proton transfer reaction enables a study to be made of levels previously accessible only to the (^3He , n) reaction. In this paper we present initial results on the transfer of two protons, a neutron and proton, and two neutrons by means of the reactions (^{12}C , ^{10}Be), (^{12}C , ^{10}B), (^{12}C , ^{10}C) on targets of ^{12}C , ^{16}O and ^{40}Ca . The one-nucleon transfer reaction (^{12}C , ^{11}B), (^{12}C , ^{11}C) and the three-nucleon transfer (^{12}C , ^9Be) were investigated simultaneously.

A $^{12}\text{C}^{4+}$ beam with intensity 30 nA and energy 114 MeV from the A. E. R. E. Harwell Variable Energy Cyclotron was used to irradiate 100 $\mu\text{g}/\text{cm}^2$ targets of calcium oxide, on 30 $\mu\text{g}/\text{cm}^2$ backings of ^{12}C . The reaction products were identified in a telescope of silicon semiconductor surface-barrier detectors comprising two ΔE detectors, denoted ΔE_1 and ΔE_2 of 75 μ and 50 μ thickness, an E detector of thickness 2 mm and a rejection detector for long range particles traversing the first three counters. Two independent identifications of each particle, stopping in the system and satisfying a fast coincidence requirement, were made on the basis of the rate of energy loss and total energy of the particle using the method of Fisher and Scott [1]. One identification, PI 1, was based on ΔE_1 as the ΔE -signal and the summed pulse ($\Delta E_2 + E$) as the E -signal, while the second identification, PI 2, was based on ΔE_2 and E . An example of the spectrum of signals from PI 1 is given in figure 1, which shows that the lower yield reaction products are superimposed on the tails of adjacent higher yield groups making separation difficult. The tails are due to anomalous energy loss in

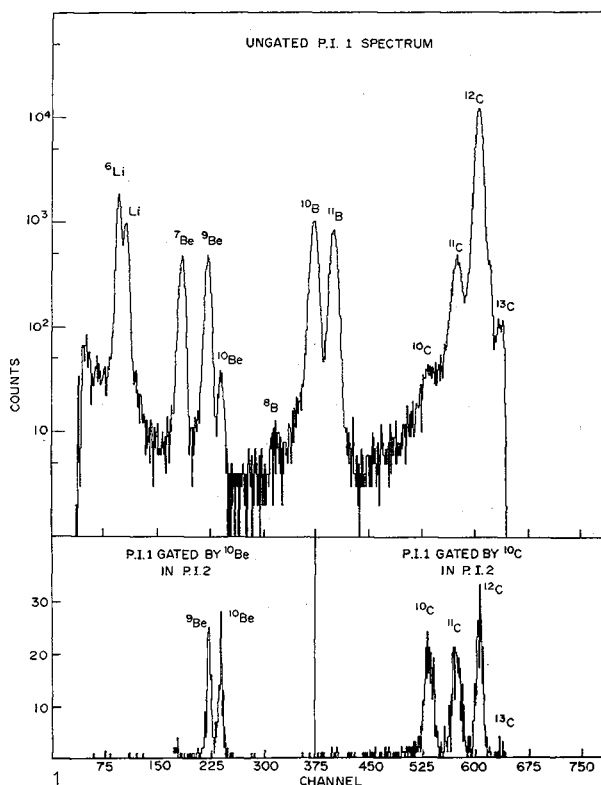


FIG. 1. — Particle identifier spectra taken in reactions with 114 MeV ^{12}C ions on targets of ^{12}C , ^{16}O and ^{40}Ca .

the ΔE counter, and since the probability of such anomalous losses being repeated by the same particle in a second ΔE detector is small, two successive identifications greatly improve the reliability of particle separation. This is illustrated in the bottom half of the

figure, which shows the result of gating the identifier PI 1 with single channel analyzer windows set in the region of ^{10}Be and ^{10}C in PI 2. A second set of single channel windows was set on the groups in PI 1. Coincident events in the two windows set on the PI spectra were used to generate pulses which routed the corresponding energy spectra into one of eight 1024 channel subgroups of a Laben pulse height analyzer.

Energy spectra of the two nucleon transfer reactions are shown in figure 2. A prominent feature of all the

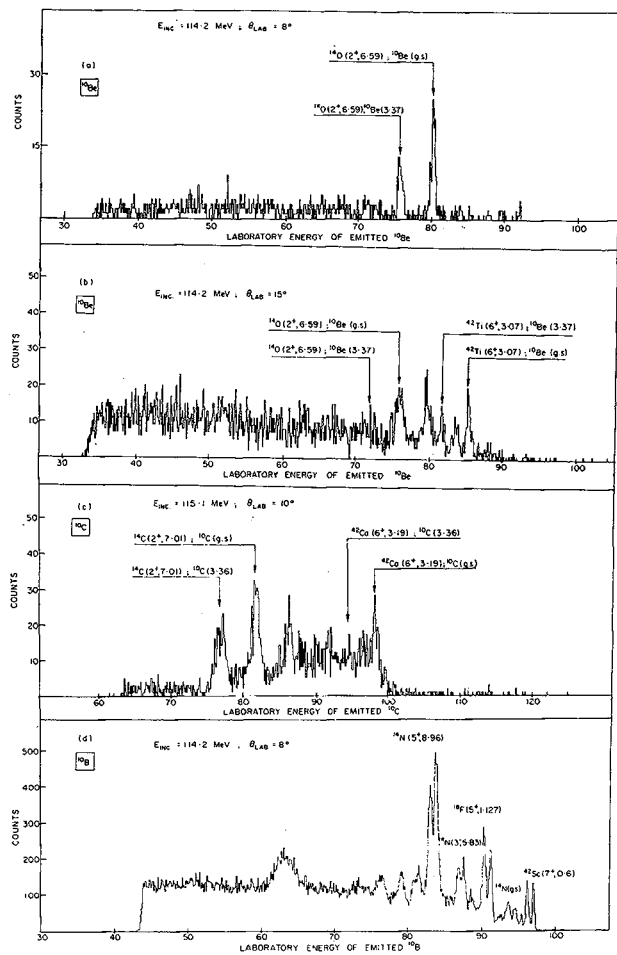


FIG. 2. — Energy spectra of the reactions (^{12}C , ^{10}Be), (^{12}C , ^{10}C) and (^{12}C , ^{10}B) produced by ^{12}C ions of 114.2 and 115.1 MeV on targets of ^{12}C , ^{16}O and ^{40}Ca .

spectra is the selectivity in excitation of levels in the residual nuclei over a total excitation range of about 50 MeV. Such a preferential population of levels has been observed by Harvey et al. [2] in (α , d) transfer reactions, which these workers explain as simple two particle configurations, formed by the transfer of two nucleons into orbitals favoured by the angular momentum of the incident nucleon at the nuclear surface. The transfer of nucleons in heavy ion reactions, which are likely to proceed dominantly by a surface interaction mechanism, should be even more susceptible to this simple semiclassical interpretation. At the incident energy of 114 MeV, corresponding approximately

to 10 MeV/nucleon, the most probable angular momentum transfer at the nuclear surface is $2\hbar$ for reactions on ^{12}C and ^{16}O and $3\hbar$ for ^{40}Ca . On the basis of this semiclassical model we expect the strongest excitations in mass 14 and mass 18 should be (d) 2 , and (f) 2 in mass 42.

Figure 2d shows that the (^{12}C , ^{10}B) reaction preferentially excites the (8.96 MeV, 5^+) level in ^{14}N , and the (1.127 MeV, 5^+) level in ^{18}F , both of which are known to be pure ($d_{5/2}$) 2 configurations (3). In ^{42}Sc , the only strong excitation is (0.6 MeV, 7^+), which is dominantly ($f_{7/2}$) 2 . It should be noted that each level has a doublet structure due to the outgoing ^{10}B being left in its ground state or in its first excited state at 0.717 MeV. In ^{14}N the ground state and (5.83 MeV, 3^-) levels are also excited, and since these are dominantly ($p_{1/2}$) 2 and ($p_{1/2} d_{5/2}$) configurations [3], an appreciable $l = 1$ component must be available for the reaction on ^{12}C . These results on ^{14}N are in agreement with the work of Sachs et al. [4] on the $^{12}\text{C}(^{11}\text{B}, ^9\text{Be})^{14}\text{N}$ reaction.

Figure 2b and c shows the spectra for the 2p and 2n transfers. Isospin conservation allows only the population of $T = 1$ states, and on the basis of the above model we expect the strongest excitations in ^{42}Ti and ^{42}Ca to be the ($f_{7/2}$) 2 configurations 0^+ , 2^+ , 4^+ , 6^+ , of which only the ground state has been previously located in ^{42}Ti by the (^3He , n) reaction [5]. In ^{42}Ca the (3.19 MeV, 6^+) level could be reliably identified in spectra taken at several angles. The strong excitation

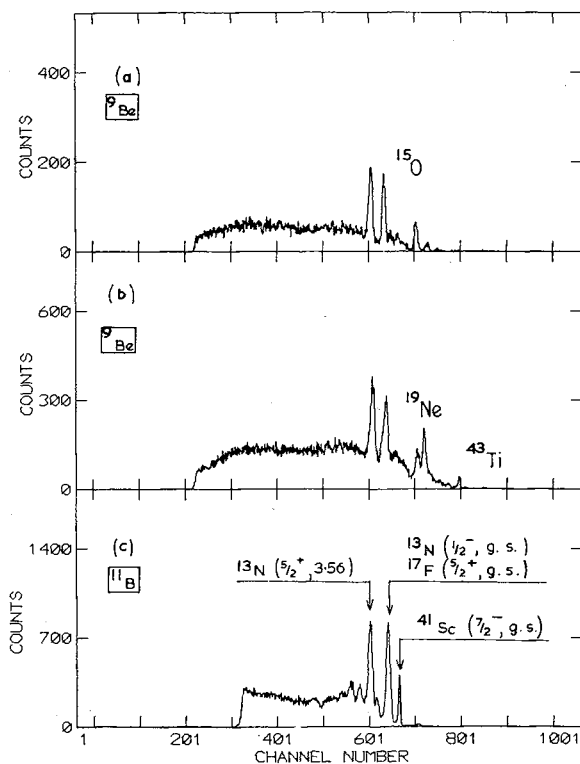


FIG. 3. — Energy spectra of the reactions (^{12}C , ^9Be) and (^{12}C , ^{11}B) produced by ^{12}C ions of 115.1 MeV on targets of ^{12}C , ^{16}O and ^{40}Ca .

in ^{42}Ti is therefore also likely to be the 6^+ , and this is identified in figure 2*b* at 3.07 MeV, although there is an error of about 150 keV on this initial determination. In most spectra the lines were observed to have a doublet structure corresponding to ^{10}C and ^{10}Be being left in their ground or first excited states at 3.36 and 3.37 MeV. The two-proton transfer reaction on ^{12}C leads to a single level in ^{14}O . This is shown in figure 2*b* and more clearly in 2*a*, which was taken with a pure ^{12}C target. Only one level in ^{14}C was excited in the two neutron transfer, which we assume to be the analogue of the level observed in ^{14}O . These are labelled in figure 2*b* and *c* as the 6.59 MeV and 7.01 MeV analogue excitations, although the corresponding level in ^{14}N at 9.17 MeV does not (3) have the $(d_{5/2})^2$ configuration which the semiclassical interpretation of the reaction mechanism should favour. A further investigation with better resolution is in progress. The remaining strong

excitation in the spectra of 2*b* and *c* corresponds to the 4^+ levels in ^{18}Ne and ^{18}O , which have dominant $(d_{5/2})^2$ configurations.

The validity of the semiclassical model for the two-nucleon transfer reaction is also shown in the one-nucleon transfer reactions ($^{12}\text{C}, ^{11}\text{B}$), ($^{12}\text{C}, ^{11}\text{C}$). Figure 3*c* is a spectrum for the ($^{12}\text{C}, ^{11}\text{B}$) proton transfer reaction and shows that the strongest excitations are consistent with the addition of a single proton into the $d_{5/2}$ level for reactions on ^{12}C and ^{16}O , and into the $f_{7/2}$ level for ^{40}Ca , producing the well known single particle levels in ^{13}N , ^{17}F and ^{41}Sc . The three nucleon transfer reaction ($^{12}\text{C}, ^9\text{Be}$) is illustrated in figure 3*a* for a pure ^{12}C target and in 3*b* for the composite target of ^{40}Ca , ^{16}O and ^{12}C . A preferential population of levels is also observed, and they are likely to be explicable by the addition of three $d_{5/2}$ nucleons to ^{12}C and ^{16}O , and three $f_{7/2}$ nucleons to ^{40}Ca .

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