FIZIKA, 7 (1975) 23—29

THREE-BODY BREAKUP OF ^{14}N INDUCED BY FAST NEUTRONS

M. TURK, B. ANTOLKOVIĆ and D. WINTERHALTER

Institute „Ruđer Bošković" and University of Zagreb, Zagreb

Received 29 October 1974

Abstract: The correlation spectra of the three-body breakup of the n + ^{14}N system have been studied at incident neutron energies of 14.4 MeV and 18.2 MeV. The Dalitz-plot analysis shows that the sequential decay proceeds either through the ground state of ^{8}Be or the 8.9-, 9.2-, 11.3-, 12.6- and 14.0--MeV states of ^{11}B, the last three being excited with 18.2-MeV neutrons. The relative contributions of the various decay modes are given.

1. Introduction

Multiparticle final-state reactions, which have been recently studied in kinematically complete experiments, give information on various reaction processes, such as sequential decay, quasifree scattering, and simultaneous breakup. In the n + ^{14}N → $\alpha + \alpha +$ ^{7}Li reaction the sequential decay would exhibit resonances of $\alpha - \alpha$ or $\alpha -$ ^{7}Li intermediate systems corresponding to excitations of ^{8}Be and ^{11}B, respectively.

Experiments performed by Schmidt et al.[1] have shown that at incident neutron energies of 14.1 MeV and 15.7 MeV the ^{14}N (n, ^{7}Li) 2α reaction is a sequential decay proceeding mainly through intermediate states of ^{11}B, while the remainder decays via the ground state of ^{8}Be. No evidence has been found for the reaction via the 2.9-MeV state of ^{8}Be, though the decay through this channel was observed by Fujiwara[2] in a kinematically complete measurement of the ^{11}B (α, ^{7}Li) 2α reaction leading to the same three particles in the final state.

In the present work the neutron-induced three-body breakup of ^{14}N was studied in a kinematically complete experiment at incident energies of 14.4 MeV and 18.2 MeV using nuclear emulsions in a 4π geometry covering almost the whole momentum space.

2. *Experimental procedure*

Ilford K2 emulsions were bombarded with 14.4-MeV neutrons from a Cockcroft-Walton accelerator and with 18.2-MeV neutrons from a Van de Graaf accelerator. The plates were processed by the standard two temperature technique. Three-prong stars were analysed by measuring the length, dip angle, and the azimuthal angle of each prong. The data were processed with the aid of an off-line CAE 90-40 computer code. The identification of the stars pertaining to the $^{14}N(n, {}^{7}Li)\,2\alpha$ reaction was performed by a method[3,4] suitable for reactions in which all emitted particles are detectable. In this case the system is highly overestimated: of 9 measured variables, only 5 are kinematically independent, and both the energy and momentum balance should give the correct energy and momentum of the incident neutron. The latter two values were calculated taking successively one prong as a ^{7}Li nucleus and the remaining two as alpha particles. Thus, three sets of values were obtained for each star, but only the set that satisfied the kinematics of the reaction with minimum error in both energy and momentum was taken into further consideration.

The fact that two criteria had to be satisfied is important in selecting the events, because three-prong stars from the $^{12}C(n, n')\,3\alpha$ reaction are more abundant in the emulsion than those from the $^{14}N(n, {}^{7}Li)\,2\alpha$ reaction. Moreover, the Q-values for the two processes differ only by 1.55 MeV and therefore a large overlap exists. However, only one condition is available for identification in the case of the reaction on ^{12}C in which one neutral particle is emitted. Therefore, by imposing a rigid criterion it is possible to select stars pertaining to the reaction on ^{14}N from the rather large background of stars coming from the reaction on ^{12}C. The loss of events, which might occur in this procedure, would be important for the evaluation of the absolute cross section.

For each star the energy of the incoming neutron was computed on the basis of the $^{14}N(n, {}^{7}Li)\,2\alpha$ reaction (E_n) as well as on the basis of the $^{12}C(n, n')\,3\alpha$ reaction (E_n') and compared with the known energy E_0. After eliminating the events pertaining to the reaction on ^{12}C within an error $|\Delta E_n'| \leq 1$ MeV, a star was accepted if the following conditions were satisfied; the error in energy $|\Delta E_n| \leq 1$ MeV, the error in momentum $|\Delta p| \leq 2$ (in units where the nucleonic mass is equal to one) and $|\Delta E_n'| - |\Delta E_n| \geq 0.5$ MeV.

Since all three emitted particles are charged and can therefore be measured, it is possible to compute the excitation energy of the intermediate system in two ways, either from the data on the two particles forming the intermediate nucleus or from the data on the incoming particle and the first emitted particle. The values thus obtained differ because of the experimental errors. The accuracy of measurement may vary for each of the three prongs of a star. Bearing this in mind, from the two values of the excitation energy it is possible to choose that one which is based on more realiable measurements, as in the case of longer and less steep prongs of a star.

In the ^{14}N (n, ^{7}Li) 2α reaction the ^{7}Li particle is not necessarily emitted in the ground state. The presence of events with ^{7}Li emitted in the first excited state (at 0.478 MeV) causes only an enlargement in the calculated neutron spectrum around the point $E_n = E_0 - 0.478$ MeV, because the energy difference between the two states is too small to be separated satisfactorily in nuclear emulsions. Therefore, for all events in this region of the spectrum, $E^*_{^{11}B}$ and $E^*_{^{8}Be}$ were computed only from the data involving α particles (i. e., the first emitted α particle and the incoming neutron and two α particles, respectively). Thus they are unaffected by the state of ^{7}Li.

3. *Results and discussion*

The data are displayed in two-dimensional Dalitz diagrams in the $E^*_{^{8}Be}$ vs. $E^*_{^{11}B}$ representation (Figs. 1 and 2). Since two identical particles are emitted, each event is represented twice. The loci of the α-^{7}Li intermediate states are, therefore, along straight lines orthogonal to the $E_{^{11}B}$ axis or they are along diagonal lines (Fig. 2d). In the spectrum projected onto the $E^*_{^{11}B}$ axis the former events are contained inside distinct peaks superimposed to the continuum formed by the latter and by the events decaying via α-α intermediate states. The predominance of the decay via ^{11}B resonances is clearly visible at either incident energy. Arrows in the projected spectra indicate the known excited levels of ^{11}B taken from Ref.[5]. (The broad levels at 11.0 MeV and 12.0 MeV have been omitted.) In the projected spectrum the excitation energy of the ^{8}Be and ^{11}B intermediate systems has been replaced by the corresponding energy of the first emitted particle ($E^{CM}_{^{7}Li}$ and E^{CM}_{α}, respectively).

Fig. 1 shows the results obtained at 14.4 MeV. Only 13% of the breakup cross section is due to the sequential decay via the ground state of ^{8}Be. The projected ^{8}Be excitation spectrum in which events decaying via ^{11}B have been subtracted (thin line) demonstrates the absence of the decay via the 2.9-MeV level of ^{8}Be. This is in agreement with previous results obtained in a cloud chamber[1]. Enhancements at excitation energies of 8.9 MeV and 9.2 MeV in ^{11}B are apparent, though the latter peak is probably composed of events decaying both to the levels at 9.19 MeV and 9.27 MeV.

The results of the experiment performed at a neutron energy of 18.2 MeV are shown in Fig. 2. In this case the decay via $^{8}Be_{g.s.}$ occurs less frequently, i. e., only in 5% of the events. Again, the decay via the 2.9 MeV state of ^8Be is not present. Enhancements at several loci corresponding to the excited states of ^{11}B are clearly visible in the two-dimensional plot as well as in the projected spectrum. The

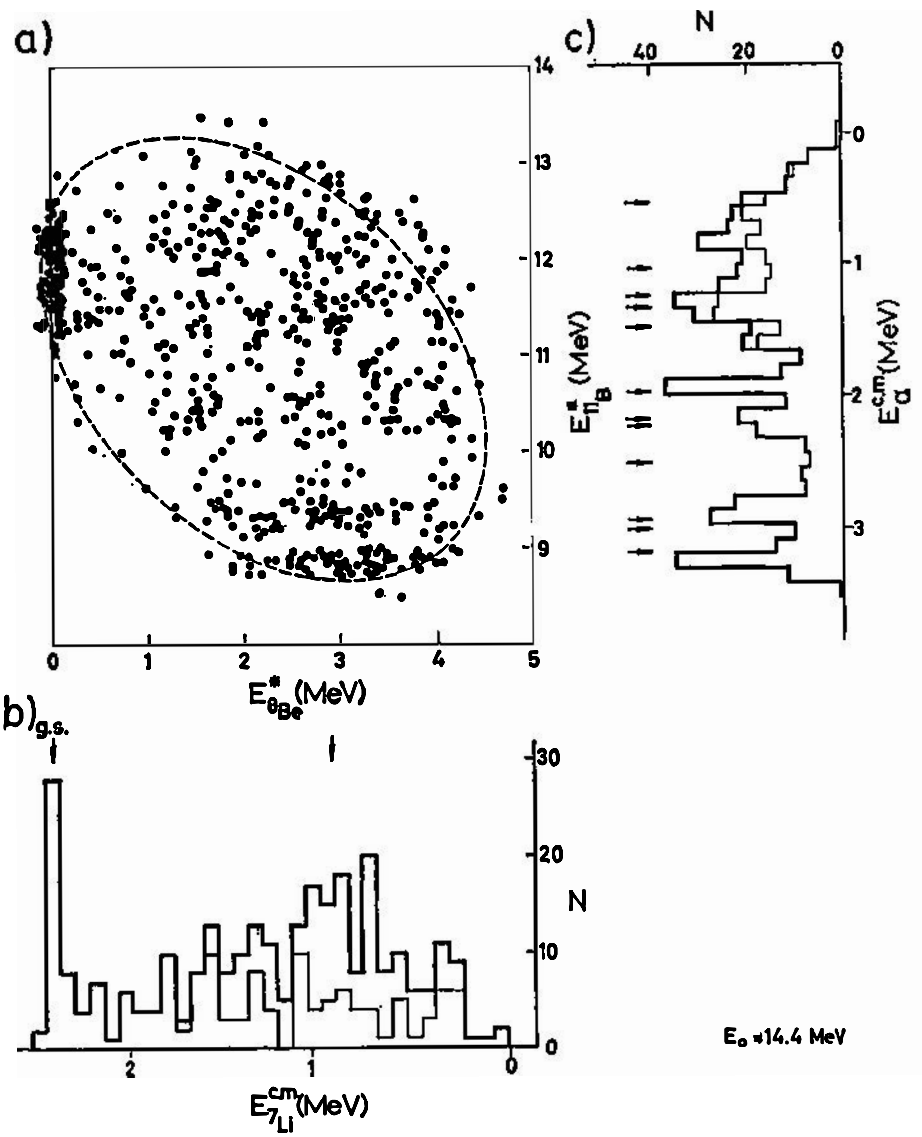

Fig. 1. $E^*_{^8Be}$ vs. $E^*_{^{11}B}$ Dalitz diagram of the events observed at an incident energy of 14.4 MeV (a) and the projected spectra (b and c). The thin line in the $E^*_{^8Be}$ spectrum was obtained after subtracting the data populating the distinct peaks in the $E^*_{^{11}B}$ spectrum. Similarly, the events clustering around the ground state of ^8Be were subtracted from the $E^*_{^{11}B}$ spectrum (thin line in diagram c).

full line in the projected spectrum was drawn to separate the continuum spectrum from the distinct peaks, thus dividing the area under the spectrum in two parts. Since the contribution of the decay via $^8Be_{g.s.}$ is small, the two parts are almost equal. By comparing the area under the peaks (down to the full line) it was possible to estimate the relative contributions to the total yield from the various sequential processes. The results are given in the Table.

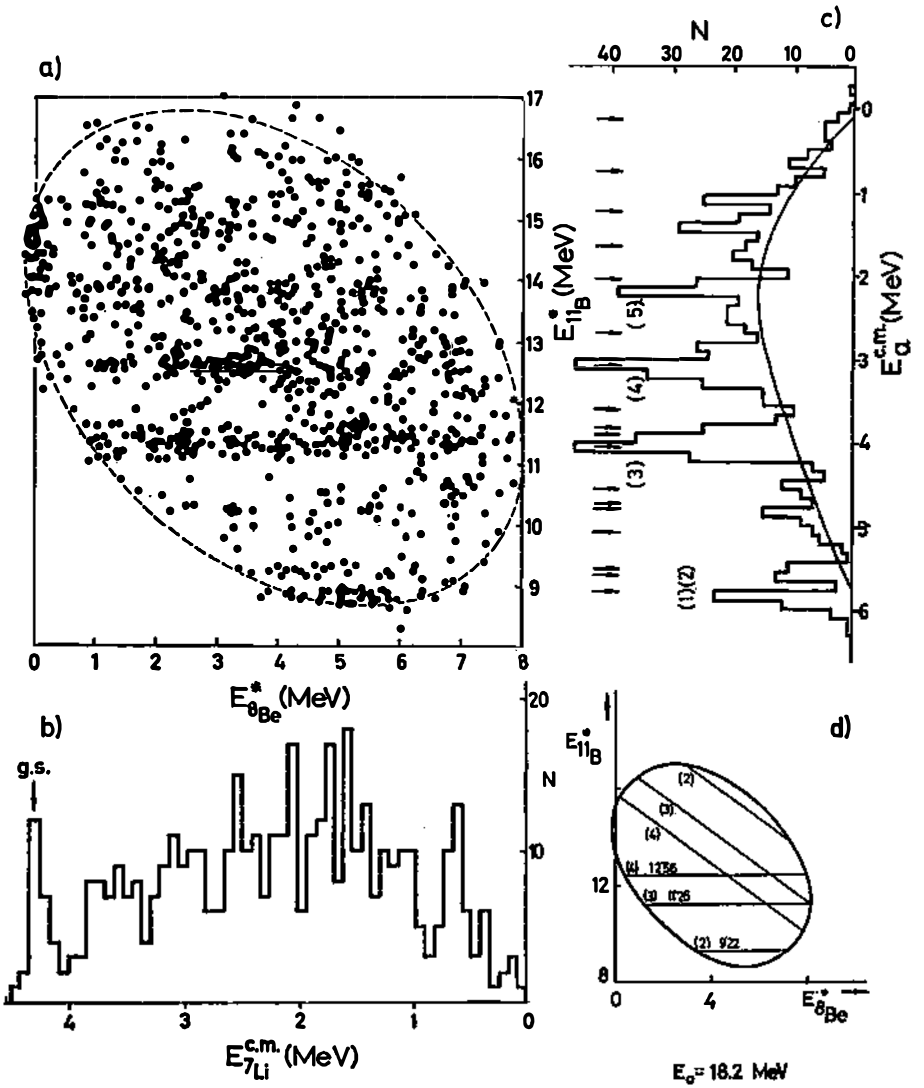

Fig. 2. $E^*_{^8Be}$ vs. $E^*_{^{11}B}$ Dalitz diagram of the events observed at an incident energy of 18.2 MeV (a) and the projected spectra (b and c). Diagram (d) is a sketch of the kinematical loci calculated for several known states of ^{11}B.

Peak (1) corresponds to the first level above the ^7Li-α threshold in ^{11}B. This level at 8.925 MeV and also the levels at 9.185 MeV and 9.274 MeV have been found in many two-body reactions[5]. The latter two resonances (peak (2)) could not be resolved in the present experiment. Above this excitation energy, up to the $^{10}B + n$ threshold at 11.456 MeV, several excited states are known; among these, the 9.87-MeV state has been recently confirmed to decay via the $^7Li + \alpha$ channel[6]. However, Fig. 2 shows that in the present experiment only a few three-body decays were observed at the excitation of about 10 MeV in ^{11}B. A strong peak (3) appears around 11.3 MeV with possible contributions from the decays via the 11.27-MeV and 11.46-MeV states.

TABLE

Relative contributions to the total breakup of ^{14}N induced by 18.2-MeV neutrons

Intermediate nucleus	^8Be	^{11}B				
Peak number		1	2	3	4	5
Excitation energy (MeV)	g. s.	8.9	9.2	11.3	12.6	14.0
Percentage Statistical error	5.5 ± 1.1	9.5 ± 1.5	5.1 ± 1.1	22.2 ± 2.2	16.8 ± 2.0	8.6 ± 1.4

A level in ^{11}B at an excitation of 12.56 MeV (peak (4)) was first observed by Groce et al.[7] in the $^9Be(^3He, p)\,^{11}B$ reaction. Since this state was absent from the $^{10}B(d, p)\,^{11}B$ reaction, they assumed that it was the lowest $T = 3/2$ state in ^{11}B. This state was tentatively identified as an analog of $^{11}Be_{g.s.}$[8]. However, the presence of this resonance in the $^7Li(\alpha, \alpha)\,^7Li$ reaction[9], as well as in the present experiment, suggests that it also contains some $T = 1/2$ admixtures.

Peak (5) corresponds to the broad resonance at 14.04 MeV found in the ^{10}B (n,n) and $^7Li(\alpha, \alpha)$ reactions and recently discussed in a study of high excited states of ^{11}B[10]. Above this excitation energy the kinematical loci intersect in such a way (Fig. 2d) that the separation of the distinct peaks from the continuum becomes increasingly more difficult.

No evidence has been found for the simultaneous breakup into three particles.

Acknowledgement

The authors are indebted to Professor M. Bormann for offering the facilities of the Van de Graaff accelerator at Institut für Experimentalphysik, Hamburg and to Dr. W. Scobel for performing the irradiation of the plates.

References

1) G. Schmidt, J. Mossner and J. Schintlmeister, Nucl. Phys. **A173** (1971) 449;
2) N. Fujiwara, J. Phys. Soc. of Japan **27** (1969) 1380;
3) G. M. Frye and J. H. Gammel, Phys. Rev. **103** (1956) 328;
4) B. Antolković, Nucl. Instr. and Meth. **100** (1972) 211;
5) F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **A114** (1968) 1;
6) D. E. Alburger and D. H. Wilkinson, Phys. Rev. **C3** (1971) 1492;
7) D. E. Groce, J. H. McNally and W. Whaling, Bull. Am. Phys. Soc. **8** (1963) 486;
8) J. W. Olness, E. K. Warburton, D. E. Alburger and J. A. Becker, Phys. Rev. **139** (1965) B512;
9) R. Y. Cusson, Nucl. Phys. **86** (1966) 481;
10) J. M. Cox, H. D. Knox, R. O. Lane and R. W. Finlay, Nucl. Phys. **A203** (1973) 89; S. L. Hausladen, C. E. Nelson and R. O. Lane, Nucl. Phys. **A217** (1973) 563.

RASPAD JEZGRE ^{14}N NA TRI ČESTICE INDUCIRAN BRZIM NEUTRONIMA

M. TURK, B. ANTOLKOVIĆ i D. WINTERHALTER

Institut „Ruđer Bošković" i Sveučilište u Zagrebu, Zagreb

Sadržaj

Mjerena je reakcija $n + {}^{14}N \rightarrow \alpha + \alpha + {}^{7}Li$ u kinematski kompletnom eksperimentu metodom nuklearnih emulzija. Analiza pomoću Dalitzovih dijagrama pokazuje da je ovaj proces sukcesivni raspad preko intermedijarnih jezgara ^{8}Be i ^{11}B. Pri upadnoj energiji neutrona od 14.4 MeV reakcija se odvija preko osnovnog stanja ^{8}Be i pobuđenih stanja ^{11}B na 8.9 MeV i 9.2 MeV. Pri upadnoj energiji od 18.2 MeV izraženi su još i vrhovi koji odgovaraju stanjima ^{11}B na 11.3 MeV, 12.6 MeV i 14.0 MeV. Relativni doprinosi pojedinih procesa induciranih neutronima energije od 18.2 MeV dani su u tablici.