Mass excess and excited states of 14B and 18N from the (14C, 14B) and (18O, 18N) reactions

F. Naulin, C. Détraz, M. Bernas, D. Guillemaud, E. Kashy, M. Langevin, F. Pougheon, Pierre Roussel, M. Roy-Stephan

Tome 41 N° 4 15 FÉVRIER 1980

LE JOURNAL DE PHYSIQUE - LETTRES

Classification
Physics Abstracts
21.10D — 25.70

Mass excess and excited states of ^{14}B and ^{18}N from the (^{14}C, ^{14}B) and (^{18}O, ^{18}N) reactions

F. Naulin, C. Détraz, M. Bernas, D. Guillemaud, E. Kashy (*), M. Langevin, F. Pougheon, P. Roussel and M. Roy-Stephan

Institut de Physique Nucléaire, B.P. n° 1, 91406 Orsay, France

(*Reçu le 21 décembre 1979, accepté le 3 janvier 1980*)

Résumé. — Les réactions (^{14}C, ^{14}B) et (^{18}O, ^{18}N) sur le noyau ^{14}C ont été utilisées pour mesurer l'excès de masse des noyaux ^{14}B et ^{18}N. Un état excité de ^{18}N est observé à 575 ± 25 keV.

Abstract. — The (^{14}C, ^{14}B) and (^{18}O, ^{18}N) reactions on a ^{14}C target have been utilized to determine the mass excess of the ^{14}B and ^{18}N nuclei. An excited state of ^{18}N is observed at 575 ± 25 keV.

1. **Introduction.** — Neutron rich odd-odd light nuclei with $T = 2$, such as ^{14}B and ^{18}N, are much less known than a number of neighbouring isotopes further away from the valley of β-stability.

Although this series of nuclei is only a single charge-exchange reaction away from stable isotopes, experimental information is scarce and sometimes contradictory. This is due to two reasons. The first one is that the charge-exchange reaction has to be of the (n, p) or (t, ^{3}He) kind with light particles, which carries obvious experimental difficulties. The second one lies with the somewhat high density of low-lying excited states of the residual odd-odd nucleus, which makes the characterization of the ground and individual excited states sometimes ambiguous.

A progress in this situation requires the use of heavy ion beams, as long as good particle identification is achieved and an effort is made towards the best possible energy resolution.

The qualities of the heavy-ion beams which result from the recent equipment of the Orsay MP tandem with a Laddertron charge system, together with recent improvements in the experimental apparatus have allowed the collection of low-background, good energy resolution data bearing on the mass excess and excited states of ^{14}B and ^{18}N, which are presented in this paper.

(*) On leave from Michigan State University, East Lansing, Michigan, U.S.A.

2. **Available information on ^{14}B and ^{18}N.** — The mass excess and the energies of the first excited states of ^{14}B have been measured once only, through the ^{14}C(^{7}Li, ^{7}Be)^{14}B reaction [1]. Another study of ^{14}B through a different nuclear reaction seems worthwhile. The situation for ^{18}N is more complicated. An early ^{18}O(t, ^{3}He)^{18}N experiment [2] observed a single broad peak in the proton energy spectrum, corresponding to a 13.274 ± 0.030 MeV mass excess for ^{18}N. An even earlier measurement [3] of the β end-point energy in the decay of ^{18}N had determined a 13.1 ± 0.4 MeV mass excess. Recently the (d, ^{2}He) reaction on ^{18}O was used [4] to further study the energy spectrum. Again a broad peak centred around the mass excess value of ref. [2] was observed. However the height of the background precluded any firm conclusion although there was indication that the broad peak might consist of at least 3 peaks seen as *shoulders*.

3. **Experimental method.** — Low statistics are unavoidable when one studies nuclei far from the valley of β-stability since their formation requires the use of exotic nuclear reactions. To turn the few observed events into a meaningful quantitative measurement supposes first an unambiguous identification of the ions detected and second an optimization of the peak-to-noise ratio in their energy measurement. This second requirement is pursued by obtaining the best possible energy resolution and drastically reducing the background. Hence three experimental factors are of

major importance : 1) ion identification, 2) energy resolution, 3) height and nature of the background. Items 1 and 2 are dealt with in the next section. Item 3 deserves a few comments.

In the experiments under consideration, the mass excess of an exotic nucleus is deduced from the measurement of the Q-value of a A(a, b)B so-called *two-body* reaction, where the mass excess of b or B is unknown. If the residual nucleus B is the exotic neutron-rich species under study, the (a, b) reaction is found, for all practical cases, to have a Q-value which is more negative than all the A′(a, b)B′ reactions which can take place on the possible A′ isotopic or chemical contaminants in the A target. Hence the energy spectra of interest for particle b sits on top of the energy spectra due to these contaminants. On the contrary, if the exotic nucleus under study is the detected b particle, the Q-values of the A′(a, b)B′ reactions are more negative, and the energy spectrum of b is free of any background due to contaminants.

This is the reason why ^{14}B and ^{18}N are investigated in the present study through the (^{14}C, ^{14}B) and (^{18}O, ^{18}N) reactions.

The only setback of this method lies with the study of the excited states of the exotic nuclei. If, in the A(a, b)B reaction, b is formed in a bound excited state, the kinematics of the reaction corresponds to a $Q = Q_{\text{g.s.}} - E_{\text{excitation}}$ value, and the energy of b is accordingly affected. However, since the b nucleus decays in flight by emission of a γ-ray, its detected energy peak is Doppler-broadened. For the light nuclei studied here, this loss in energy resolution is rather important. Its order of magnitude is a fifth of the γ-ray energy. Furthermore, only the bound energy levels can be observed in this way. Those which decay by particle emission no longer give rise to the observation of a b nucleus. For instance, while excited states up to nearly 3 MeV have been observed [1] in ^{14}B, this nucleus is bound by only 976 ± 30 keV in its ground state. Hence only the reported 0.74 ± 0.04 MeV excited state can be observed by detecting ^{14}B in the nuclear reaction.

4. **Experimental apparatus.** — The recently developed ^{14}C beam [5] from the sputtering ion-source of the Orsay MP-Tandem can reach an intensity on target of up to 100 nA of $^{14}C^{5+}$ ions. The ^{18}O beam is also produced by sputtering. The energies used are 87.4 MeV and 92.2 MeV, respectively. The beams are incident on a 70 μg/cm^2 self supported carbon target with an 80 % isotopic abundance of ^{14}C. As in previous studies of ^{19}N [6], ^{17}C [7] and ^{21}O [8], the ions emitted are analysed within a large (4.8 msr) solid angle by a 180° double-focusing magnetic spectrograph. The focal plane detectors measure several parameters (ΔE, E, position) to determine the nature and energy of the ion. However several major improvements over previous experiments are achieved.

The ^{14}C(^{14}C, ^{14}B)^{14}N and ^{14}C(^{18}O, ^{18}N)^{14}N reactions suffer from a very severe kinematical effect, i.e. angular dependence of the energy of the emitted ion, which tends to worsen the energy resolution. Therefore, the detectors must be set in a displaced focal plane distinct from the genuine focal plane corresponding to $K = \frac{1}{p}\,\mathrm{d}p/\mathrm{d}\theta = 0$. But this is not usually sufficient. For a wide angular aperture, K cannot be considered as constant ($\mathrm{d}^2p/\mathrm{d}\theta^2$ is not negligible) and the displaced focal planes are different for the various reactions of interest. Therefore, a ray reconstruction procedure has to be used. For each event, two successive radial positions X_1 and X_2 are measured at the exit of the magnet. Elastic scatterings and reactions with known Q-values observed at various angles are used to establish general calibration functions $B\rho(X_1\ X_2)$ (magnetic rigidity) and $\theta(X_1\ X_2)$ (angle of reaction). These in turn determine the reaction Q-value of the event. From the raw parameters of each event, a Q-value spectrum is built in this way (see, e.g. Fig. 1).

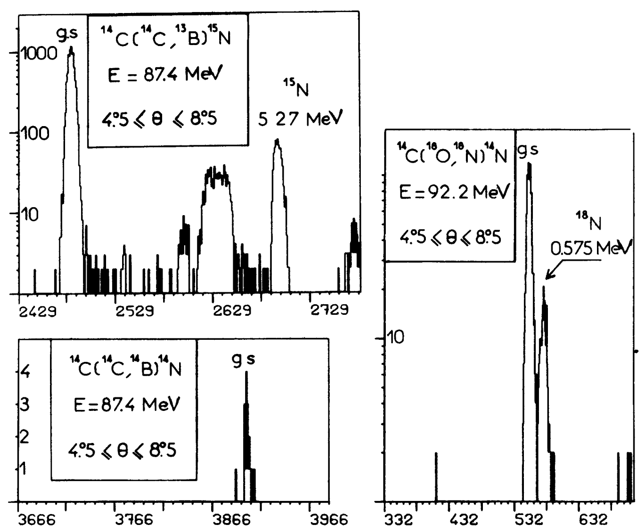

Fig. 1. — Energy spectra of ^{13}B, ^{14}B and ^{18}N produced in the labelled reactions. The abscissa is proportional to the reaction Q-value (see text). In two cases, note the logarithmic scale. The energy range of the spectra corresponds to the width of the ionization chamber.

But again, this is not usually sufficient since, unless the beam has a negligible energy dispersion and a negligible geometrical emittance, the reaction angle at the target does depend on the angle of the incident ion trajectory with respect to the exit ion trajectory. Hence, two correlations, angle/position and energy/position, coupled one to the other, must be achieved on the target in order to preserve the existence of a focus in the displaced focal plane of the magnet [9]. These correlations are obtained by i) focusing the incident beam at a point distinct from the target and ii) giving a predetermined value to the linear dispersion.

The detectors in the focal plane of the magnet consist of two proportional counters and an ionization chamber. The two position-sensitive counters are set 27 cm apart one from the other in order to perform the necessary ray reconstruction [10] but, contrary to previous experiments, the two ΔE informations from these counters are not used for ion identification. These informations are obtained from the ionization chamber itself where the anode is sliced into three parts to measure the energy lost by the ion along three successive segments of its trajectory in the chamber. The first two measurements provide the redundant ΔE information. To avoid distortion of the electric field established between the anode and the cathode near the thin mylar windows of the chamber, those are coated with thin horizontal strips of aluminum which insure the regularity and parallelism of isopotential surfaces. At last, the vertical location of the trajectory can be determined by measuring the time difference between the signals of a proportional counter and of the cathode of the ionization chamber. The difference arises from the slowness of the drift of the charges collected in the chamber. This is used to correct the observed systematic dependence of the E signal with the vertical location of the trajectory.

With these improvements, the low energy tail of the E signal is negligible and typical resolutions of 2 % for ΔE and 1 % for E are routinely achieved. A detailed account of the performances of this ionization chamber will be published elsewhere [11].

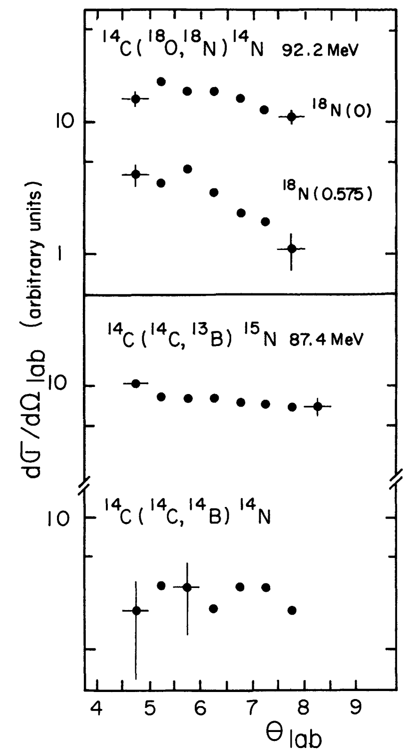

Fig. 2. — Four partial angular distributions within the angular aperture of the magnet. Each point corresponds to the events observed within a half degree bin, as obtained by the ray tracing procedure (see text). Typical uncertainties are given. There is an overall uncertainty of 0.6° over the absolute value of the angle.

5. **Results.** — Figure 1 shows the energy spectra of ^{13}B, ^{14}B and ^{18}N. The energy resolution of nearly 200 keV results, under the present conditions of a strong kinematical effect, from the angular uncertainty (0.25°) of the ray tracing. An energy calibration is provided by the (^{14}C, ^{13}B) and (^{18}O, ^{17}N) reactions. The angular distributions reconstructed from the ray tracing procedure [10] are shown in figure 2. Within the angular range covered, sharp differences are observed between the shapes of these distributions, some of which are flat while the cross section of the ^{18}N excited state decreases by a factor of 4.

Only one peak appears in the energy spectrum of ^{14}B. It corresponds to a cross section of $d\sigma/d\Omega$ (C.M.) = 0.9 $\mu b . sr^{-1}$ and a mass excess of 23 590 ± 60 keV. While 18 events are assigned to the ground state transition, no event is observed at the expected location of the first excited state of ^{14}B at 0.74 MeV which was populated in the (^{7}Li, ^{7}Be) reaction with a cross section only a factor of 2 or 3 smaller than the ground state [1]. The suggested [1] spins and configurations for the ^{14}B states provide no straightforward explanation for its non-observation in the (^{14}C, ^{14}B) reaction.

Two peaks are observed in the ^{18}N energy spectrum with centre of mass cross sections of 16.5 and 3.3 $\mu b . sr^{-1}$. Within the limitations due to the nearly 200 keV energy resolution, they show no evidence of being due to more than one state. The assigned ground state peak corresponds to a mass excess of

Table I. — *Experimental results and analysis of the uncertainties.*

	Mass excess (MeV)		Contribution to the total uncertainty (keV)				
Nucleus	This work	Previous value	Incident energy	Angle of reaction	Ray tracing	Calibration from different magnetic fields and targets	Peak position
$^{14}B_{g.s.}$	23.590 ± 0.060	23.657 ± 0.030	—	—	30	30	40
$^{18}N_{g.s.}$	13.217 ± 0.040	13.274 ± 0.030	5	25	30	—	—
	Excitation energy (keV) (this work)						
$^{18}N^*$	575 ± 25		—	—	25	—	—

13 217 ± 40 keV for ^{18}N, while an excited state is found at 575 ± 25 keV. The results of (p, p′) and (d, d′) scattering on ^{18}O, mentioned in a meeting abstract [12] and never published suggested that two $T = 2$ levels of ^{18}O might be located at 16.40 and 17.02 MeV (± 30 keV). A calculation of Coulomb energy differences makes possible that the lower one is the analog of the ^{18}N ground state. Furthermore, the energy difference between these tentative $T = 2$ states of ^{18}O is close to the energy of the ^{18}N excited state measured in the present work.

Table I summarizes the results and the origin of the uncertainties.

6. **Conclusion.** — The present results confirm the mass of ^{14}B. They contribute to finally clarify the situation for ^{18}N since they are in agreement with the early result of Stokes and Young [2]. An excited state is observed for the first time in ^{18}N while the only reported bound excited state of ^{14}B is not observed. To discard any doubt as to its reality, another measurement of the (^{14}C, ^{14}B) with better statistics is in order to take advantage of the very low background attained in this experiment.

Further knowledge of the $T = 2$, $A = 4n + 2$ nuclear states could result from the observation of the analog $T = 2$ states in e.g. ^{14}C and ^{18}O. No unambiguous result has been obtained yet, but the availability of a ^{14}C beam makes it possible to at last characterize these states in nuclear reactions.

References

[1] BALL, G. C., COSTA, G. J., DAVIES, W. G., FORSTER, J. S., HARDY, J. C. and MCDONALD, A. M., *Phys. Rev. Lett.* **31** (1973) 395.

[2] STOKES, R. H. and YOUNG, P. G., *Phys. Rev.* **178** (1969) 1789.

[3] CHASE, L. F., GRENSCH, H. A., MCDONALD, R. E. and VAUGHN, F. J., *Phys. Rev. Lett.* **13** (1964) 665.

[4] DE MEIJER, R. J., STAHEL, D. P., BICE, A. N., JAHN, R. and CERNY, J., Lawrence Berkeley Laboratory, Nuclear Science Annual Report 1977-1978 L.B.L. 8151 (1978) 9.

[5] DUMAIL, M., *Nucl. Instrum. Methods* **163** (1979) 61.

[6] DÉTRAZ, C., NAULIN, F., LANGEVIN, M., ROUSSEL, P., BERNAS, M., POUGHEON, F. and VERNOTTE, J., *Phys. Rev.* **C 5** (1977) 1738.

[7] NAULIN, F., DÉTRAZ, C., KASHY, E., BERNAS, M., LANGEVIN, M., POUGHEON, F. and ROUSSEL, P., in *Physics of Medium Light Nuclei* (Topical Conference) ed. Editrice compositori, Bologna, 1978, p. 65.

[8] NAULIN, F., DÉTRAZ, C., BERNAS, M., KASHY, E., LANGEVIN, M., POUGHEON, F. and ROUSSEL, P., *Phys. Rev.* **C 17** (1978) 830.

[9] KASHY, E. and ROUSSEL, P., to be published.

[10] ROUSSEL, P., BERNAS, M., DIAF, F., NAULIN, F., POUGHEON, F., ROTBARD, G. and ROY-STEPHAN, M., *Nucl. Instrum. Methods* **153** (1978) 111.

[11] NAULIN, F., ROY-STEPHAN, M. and KASHY, E., to be published.

[12] NERO, A. V., OHANIAN, R. S., SONEIRA, R. and ADELBERGER, E. G., *Bull. Am. Phys. Soc.* **19** (1974) 470.