PRELIMINARY RESULTS OF THE SEARCH FOR EXOTIC NUCLEI IN THE $^{18}O + ^{18}O$ REACTION. MASS OF ^{19}N.

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Abstract :

A system has been built to identify low-cross section products of nuclear reactions and to accurately measure their energy. It includes a magnetic spectrometer and a detecting system in its focal plane consisting of two resistive-wire proportional counters and a set of four position-sensitive 5cm-wide detectors. Six parameters are simultaneously determined : three positions, two ΔE-values, and the residual energy. This over-determination of the nature and energy of the detected nucleus is used to discriminate against background effects. In an experiment with a 91 MeV ^{18}O beam from the Orsay MP-Tandem, ^{19}N nuclei from the $^{18}O(^{18}O,^{19}N)^{17}F$ reaction were observed and the mass excess of ^{19}N was measured as 15.81 ± 0.10 MeV.

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1. Introduction

The precise measurement of the mass excess of an exotic nucleus emitted in a two-body nuclear reaction requires the solution of two experimental problems : i) the unambiguous identification of the detected nucleus in spite of its extremely small cross section, as much as 8 orders of magnitude smaller than the total reaction cross section ;
ii) the determination of the reaction Q-value with sufficient accuracy.

An experimental system is described which can simultaneously satisfy to both these requirements.

2. Experimental Apparatus

The nuclei emitted from the target are analyzed by an n = 1/2 index 180-degrees magnetic spectrometer of 70 cm radius. The maximum solid angle compatible with the accuracy requirements of this experiment is 1 msr. Fig. 1 is a sketch of the detecting devices located in the magnet focal plane. They consist of a double charge- division resistive-wire proportional counter operated at 70 Torr propane pressure and of a set of four Si position-sensitive 5 cm-wide detectors. For a detected nucleus, six parameters are measured which give three positions, two ΔE-values and the residual energy E left in one of the Si detectors. The data are stored on tape for subsequent off-line analysis, although a limited on-line computer-operated treatment of the data allows a control of the experiment through the constitution of E-spectra, ΔE - E bidimensional displays and identification-gated position spectra $^{1)}$.

3. Identification of nuclei

After magnetic analysis, and in spite of the various charge states possible for a given isotope, only two parameters, e.g. ΔE and E, are a-priori needed to identify a detected nucleus.

However, very rare events such as those investigated here require redundant information to discriminate against back-ground effects. The six parameters recorded actually provide two extra checks of the identification.

First, the redundancy on the measurement of ΔE is well documented $^{2)}$ and now widely used $^{3)}$. In the present case it eliminates inelastic events occuring in one of the proportional counters. A consistency requirement on the two measurements of ΔE dramaticaly cleaned the ΔE-E bidimensional display obtained from the recorded events which is used to select nuclei of different nature.

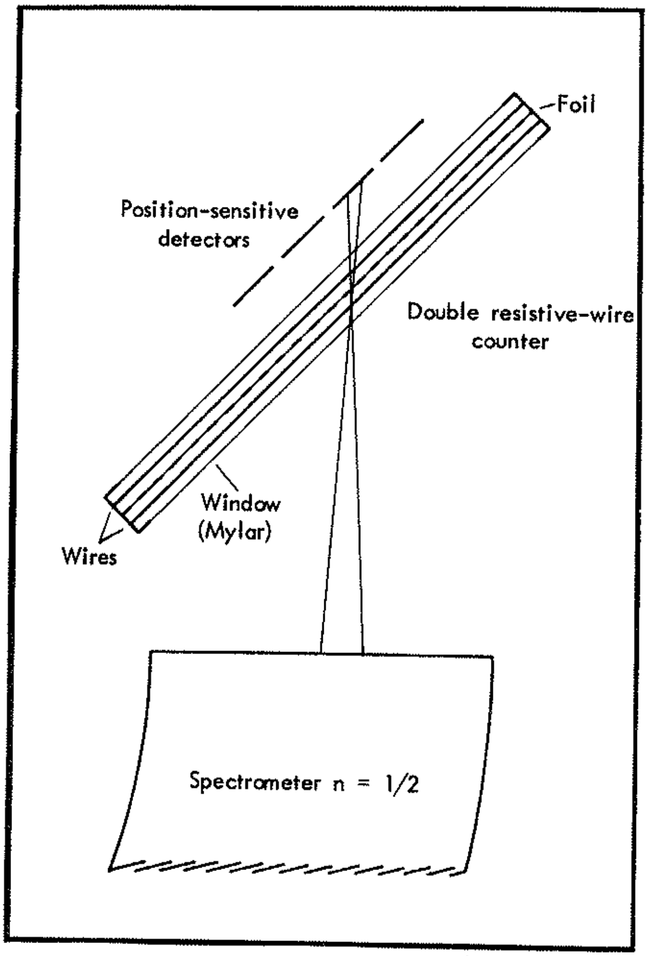

Fig. 1 : Sketch of the detecting devices in the focal plane of the magnetic spectrometer

Another source of spurious identification lies in the sometimes deficient measurement of the residual energy E which can arise from two sources: i) an inelastic interaction in the exit foil of the double proportional counter, or ii) a deficit in the efficiency of the Si detectors. Little can be done presently against the first problem if no significant change occurs in the trajectory of the detected ion. The second problem is reduced by eliminating events recorded at the extreme edges of the detectors.

At last a sizable reduction of the background is achieved by using the redundancy of the three position measurements collected for one detected ion : the events corresponding to aberrant trajectories are rejected through a consistency test on those positions.

4. Measurement of Q-values

Once an ion is properly identified as described above, the measurement of the corresponding reaction Q - value is derived from the measurement of a position.

In that respect, it is observed that the position measurements in the proportional counters slightly depend upon the amount of ionization created by the detected nucleus. This effect, which is mainly felt for low - Z ions can be empiricaly corrected. It is hardly detectable for ions above carbon in the conditions of this experiment, but the position calibration must take this effect into account.

Optimal resolution in the Q-value measurement, hence in the determination of the mass excess of the exotic nucleus, requires that the position of the ion is measured in the kinematicaly-displaced focal plane where trajectories emitted at different angles for the same Q-value converge although they correspond to different energies.

5. Experimental results

The interaction of two neutron-rich ^{18}O nuclei is used to search for high-T_z isotopes of C, N and O known to be bound but with yet unreported mass excess$^{4)}$.

A 91 MeV $^{18}O_{6^+}$ beam is delivered by the Orsay MP-Tandem operated at 13 MV terminal voltage. With a 20 % ^{18}O-enriched gaz, the typical intensity available on the target is about 600 nA. It is reduced to 300 nA to insure a longer life of the target.

The self-supported target consists of anode-oxydized 90 % ^{18}O-enriched Al_2O_3 of typicaly 100 $\mu g/cm^2$ thickness.

Nuclei emitted at 10° are analyzed by the magnetic spectrometer described in paragraph 2 with solid angles ranging between 0.5 and 1 msr.

The isotopes readily observed from the $^{18}O + {}^{18}O$ interaction are $^{6-8}$Li , $^{7,9-11}$Be , $^{10-14}$B , $^{12-16}$C , $^{14-18}$N , $^{15-20}$O.

The use of the redundancy of the six parameters recorded for each event leads to a strong reduction of the background in the ΔE-E bidimensional display, as discussed in paragraph 3. Evidence is then obtained for the occurence of ^{17}C, ^{19}N (fig. 2) and ^{21}O.

The position spectrum of the ^{19}N events is shown in fig. 3. It leads to the Q-value measurement of the $^{18}O(^{18}O, ^{19}N)^{17}F$ reaction which corresponds to a mass excess of 15.81 ± 0.10 MeV for ^{19}N. This value has to be compared to the predicted values reported $^{7)}$ as 15.32 MeV from a shell-model based calculation and 16.27 MeV from the transverse Garvey-Kelson formula. The cross section for this reaction is about 800 nb.sr^{-1} (100 nb.sr^{-1} in the center of mass).

The $^{18}O(^{18}O, ^{17}C)^{19}Ne$ reaction is also observed but with a cross section at least five times smaller. The ground state transition has not been positively identified yet.

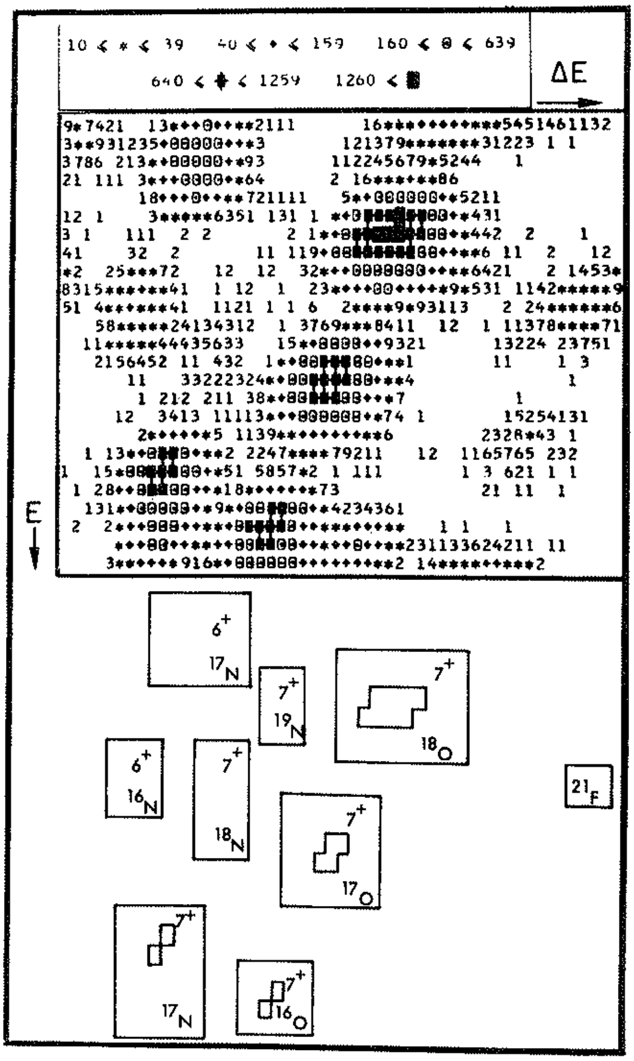

Fig. 2 : The upper figure shows part of the ΔE-E display of the recorded events in the region where ^{19}N ions are expected. All the procedures to reduce background were used as described in paragraph 3. The nature of the ions observed is explicited in the sketch drawn below. For channels where more than 10 counts are recorded symbols are used. Their meaning is indicated at the top of the figure.

At last preliminary indication of $^{18}O(^{18}O,^{21}O)^{15}O$ transitions is obtained. Although the ^{21}O ions corresponding to the ground state transition reach the focal plane outside of the detectors, the use of the reported [8] mass of ^{21}O allows the tentative identification of ^{21}O excited states at about 1.3 MeV and 3.7 MeV.

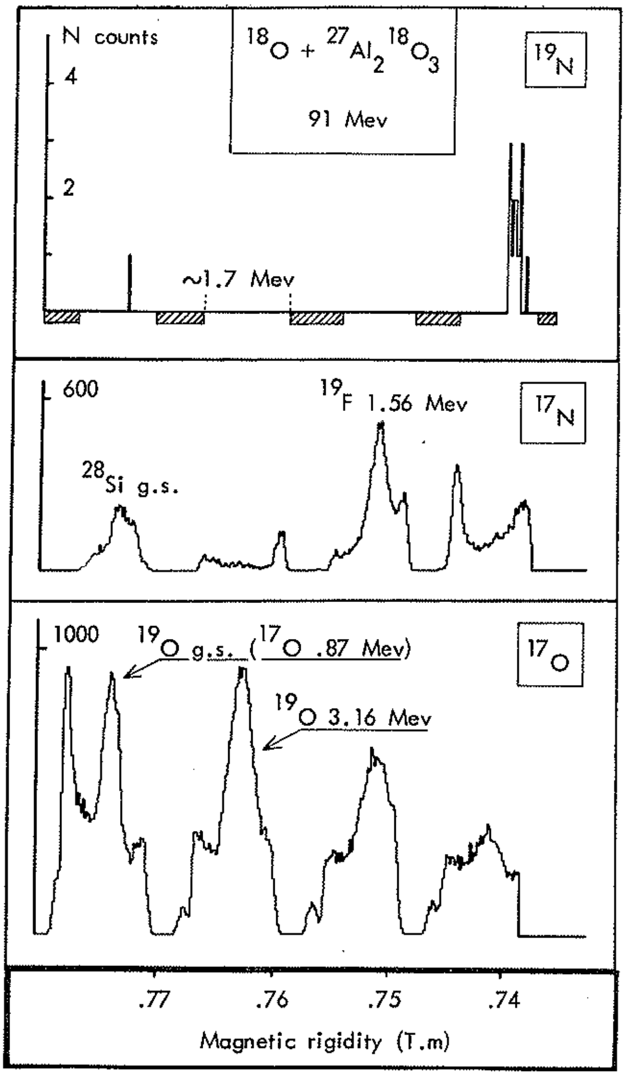

Fig. 3 : Position spectra of the particles identified as ^{19}N, ^{17}N and ^{17}O (see fig. 2). The two last vues are used to calibrate the position on the first proportional counter versus the magnetic rigidity of the detected particle. The width of the peaks, which are labelled by the residual nucleus and its excitation energy, varies with kinematical effects which are different from one reaction to another. One clearly sees the edges of the Si detectors which are requested to be in coïncidence with the proportional counter.

The most stringent conditions discussed in paragraphs 3 and 4 are applied to select "valid" ^{19}N events. There is a cluster of events which is assigned to the $^{18}O(^{18}O,^{19}N)^{17}F$ ground state transition. (Note that particle energy increases from right to left). The magnetic rigidity of this peak is determined with a $\pm 5 \times 10^{-4}$ accuracy. A similar uncertainty affects the position calibration which is determined by eleven points such as those provided by the ^{17}N and ^{17}O spectra.

6. Conclusions

As it now stands, the experimental apparatus has allowed the measurement of the mass excess of ^{19}N from the reaction $^{18}O(^{18}O,^{19}N)^{17}F$.

However, one intrinsic difficulty of this system must be emphasized. As discussed in paragraph 3, the ambiguity in the identification of a detected ion is minimized if the ΔE and E measurements are made with the best possible resolution. This requires for all ions of a given nature detected at a given position after magnetic analysis to have the same energy E. Therefore the detectors must be located along the true focal plane of the magnet.

But on the other hand optimal resolution in Q-value measurements requires them to be located in the kinematicaly-displaced focal plane as described in paragraph 4.

Thus one cannot optimize both particle identification and mass measurement. In the present case, emphasis was put on the second choice and identification was still sufficient, but obviously one extra parameter will be needed for the unambiguous identification of higher-A ions in reactions with severe kinematical corrections. The most efficient addition to the system is the measurement of the particle time of flight, which is being developped, and will provide the same redundancy on E as already available on ΔE.

References

1) A detailed account of the experimental method, and of the problems involved in the identification of the nuclei and the measurement of Q-values (paragraphs 3 and 4) is given in F. Naulin, These de 3ème cycle (I.P.N. Orsay, 1976, unpublished).

2) Among the first reports on this technique, see J. Cerny et al. Phys. Rev. Lett. 16 (1966) 469, and G. Bruge et al. Colloquium on particle identification, I.P.N. Lyon, Lycen-6738 (1967) p.28 (unpublished).

3) See e.g. G.T. Hickey et al., contribution A11 to this Conference.

4) C. Thibault, report at this Conference.

5) These targets were made by Mr. Laurent (Paris VII University) with the technique described in ref. [6]. The authors are indebted to Mr. Laurent and Prof. Amsel for their cooperation.

6) G. Amsel, Thèse d'Etat, Université de Paris (1964) unpublished.

7) N.A. Jelley, J. Cerny, D.P. Stahel and K.H. Wilcox, Phys. Rev. C.11 (1975) 2049.

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