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 5 cm-wide detectors. Six parameters are simultaneously determined: three positions, two $\Delta E$-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 $\pm$ 0.10 MeV.

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. $\Delta E$ 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 background effects. The six parameters recorded actually provide two extra checks of the identification.

First, the redundancy on the measurement of $\Delta E$ (it's well documented and now widely used) in the present case it eliminates inelastic events occurring in one of the proportional counters. A consistency requirement on the two measurements of $\Delta E$ dramatically cleans the $\Delta E$-$E$ bidimensional display obtained from the recorded events which is used to select nuclei of different nature.

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 mrad. 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 $\Delta E$-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, $\Delta E$-$E$ bidimensional displays and identification-gated position spectra 1).

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: 1) an inelastic interaction in the exit foil of the double proportional counter, or 2) 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 empirically 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 kinematically-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_exotic isotopes of C, N and O known to be bound but with yet unreported mass excess.

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 gas, 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-oxidized 90\% \(^{18}\)O-enriched Al\(_2\)O\(_3\) of typically 100 kg/cm\(^2\) thickness.

Nuclei emitted at 10\(^o\) are analyzed by the magnetic spectrometer described in paragraph 2 with solid angles ranging between 0.5 and 1 mrad.

The isotopes readily observed from the \(^{18}\)O+\(^{18}\)O interaction are \(^{9}\)O\(_{6+}\), \(^{9}\)Be\(_{10+}\), \(^{11}\)Be\(_{10+}\), \(^{12}\)C\(_{11+}\), \(^{14}\)N\(_{11+}\), \(^{15}\)O\(_{13+}\).

The use of the redundancy of the six parameters recorded for each event leads to a strong reduction of the background in the \(\Delta E-E\) bidimensional display, as discussed in paragraph 3. Evidence is then obtained for the occurrence of \(^{17}\)C, \(^{17}\)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\(_{6+}\)\(^{18}\)O\(_{6+}\)\(^{19}\)N reaction which corresponds to a mass excess of 15.8\pm 0.1 MeV for \(^{19}\)N. This value has to be compared to the predicted values reported as 15.5 - 15.6 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 mass of).

The \(^{18}\)O\(_{6+}\)\(^{17}\)O\(_{6+}\)\(^{17}\)N reaction is also observed but with a cross section at least five times smaller. The ground state transition has not been positively identified yet.

\[ \text{Fig. 2: The upper figure shows part of the } \Delta E-E \text{ display of the recorded events in the region where } ^{19}\text{N ions are expected. All the procedures to reduce background were used as described in paragraph 3. The nature of the ions observed is indicated in the sketch drawn below. For channels where more than 10 counts are recorded symbols are used. Their meaning is indicated at the top of the figure.} \]
At last preliminary indication of $^{18}O(^{18}O, ^{21}O)^{15}O$
transitions is obtained. Although the $^{21}O$ ions corre-
responding 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 iden-
tification of $^{21}O$ excited states at about 1.3 MeV
and 3.7 MeV.

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 $\Delta E$ and $E$ measurements are
made with the best possible resolution. This requi-
res 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 kinematically-displaced focal plane as described
in paragraph 4.

Thus one cannot optimize both particle identifica-
tion and mass measurement. In the present case,
emphasis was put on the second choice and identi-
fication 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 developed,
and will provide the same redundancy on $E$ as
already available on $\Delta E$.

References

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