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Proposal to the ISOLDE and neutron Time-of-Flight Experiment Committee

Study of the β-delayed particle emission of ^{17}Ne

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Abstract

We intend to investigate the charged particle decay modes from the excited states of ^{17}F populated in the β^+ decay of ^{17}Ne. In particular, we propose to study the proton decay branches to ^{16}O states which are unstable to α decay. We plan to use the recently developed ISOLDE Si-ball detector array in order to efficiently detect the charged particles in a wide solid angle. We ask for a total of 12 shifts, including 9 shifts for ^{17}Ne and 3 shifts for stable beam and calibrations. We request the use of a Mg oxide target coupled to a plasma ion source with cooled transfer line or, if possible, to the new MINIMONO-ECRIS. We would like to make use of the ISOLDE VME DAQ and CERN data storage system.

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1 Introduction

The nucleus ^{17}Ne has been subject of experimental and theoretical studies during the last years [1, 2, 3, 4, 5]. It is a borromean nucleus in the sense that none of its binary subsystems is bound, and it has been considered as a candidate of two-proton halo nucleus [6, 7, 8]. Direct two-proton emission from *excited* states of ^{17}Ne to ^{15}O has been proposed as well [9, 10, 11]. Many theoretical efforts have been devoted to the description of the contributions from the $1s_{1/2}$ and $0d_{5/2}$ components to the ground state wave function of ^{17}Ne [11, 12, 13, 14, 15]. The s-wave contribution may be the key for the understanding of the asymmetry between the first-forbidden beta decay of ^{17}Ne into the first excited state of ^{17}F and its mirror decay (^{17}N into ^{17}O) [3, 16]. The measured branching ratio is twice larger than the mirror decay branch, and the $log(ft)$ value is rather low. Both these states in ^{17}Ne and ^{17}F have been quoted as candidates for halo states [7].

The interest on ^{17}Ne has also arisen from the population by β-delayed proton decay of states in ^{16}O of astrophysical importance. The two main contributing reactions during the helium-burning phase of massive stars are the triple-α, which forms ^{12}C, and the subsequent ^{12}C(α,γ)^{16}O reaction [17, 18]. The ratio of these two processes determines the amount of ^{12}C and ^{16}O after helium burning, which in turn influences the amount of heavier nuclei that are created starting from each of these two. In the ^{12}C(α,γ)^{16}O reaction, the strength of the E1 and E2 components are strongly affected by the reduced α widths of the 1^- and 2^+ under the ^{12}C $+\alpha$ formation threshold. Such ^{16}O states lay at 6.917 and 7.117 MeV excitation energy, and both of them are populated in the β-delayed proton decay of ^{17}Ne. Thus, the investigation of this decay mode provides information on the role of such sates.

Beta decay has proven to be a very useful method to obtain information of nuclei far from stability. In particular, the region of β-delayed proton emitters where ^{17}Ne is located allows for the study of isobaric analog states and the search for the correlated particle emission. The investigation nuclei close to the particle driplines has been improved with the development of experimental devices with the capability of detecting charged particles and precisely determining their energy, angular distribution and nature. We propose to use in this study one of these devices, the Silicon Ball recently developed at ISOLDE [19]. At its present stage it consists of a compact, self-supporting 2π structure with 36 standard 51×51 mm^2 1-mm-thick Si detectors, which in turn are segmented in 4 equal quadrants for better granularity (see Figure 1). This amounts to a total of 144 segments, each of them subtending a solid angle of about 0.21% (total efficiency 30%). The detection of β particles with such a detector array covering a large solid angle, does not pose a problem due to the reduced summing probability. Moreover, the large amount of segments allows for a good efficiency for coincidence events. The β-delayed emitted protons from the decay of ^{17}Ne can be totally stopped in the Si detectors. The detector system is placed inside vacuum in a spectroscopy chamber that allows the combination with other type of detectors and it is cooled to a constant temperature of -10 ^{o}C. In addition to the interest of studying ^{17}Ne, this proposal intends to be a benchmark for future proposals on multiparticle decays, by proving the capabilities of the Si-ball.

2 Physics case

As shown in Figure 2, the Q_β for the β^+ decay of ^{17}Ne is 14.53 MeV. The allowed β^+-decay of ^{17}Ne ($J^\pi = 1/2^-$) populates $J^\pi = 1/2^-$ and $J^\pi = 3/2^-$ states in ^{17}F. The daughter nucleus ^{17}F is only bound against proton decay by 600.5 keV, so most of the states populated in ^{17}F will decay by proton emission to ^{16}O. States in ^{17}F above 7.762

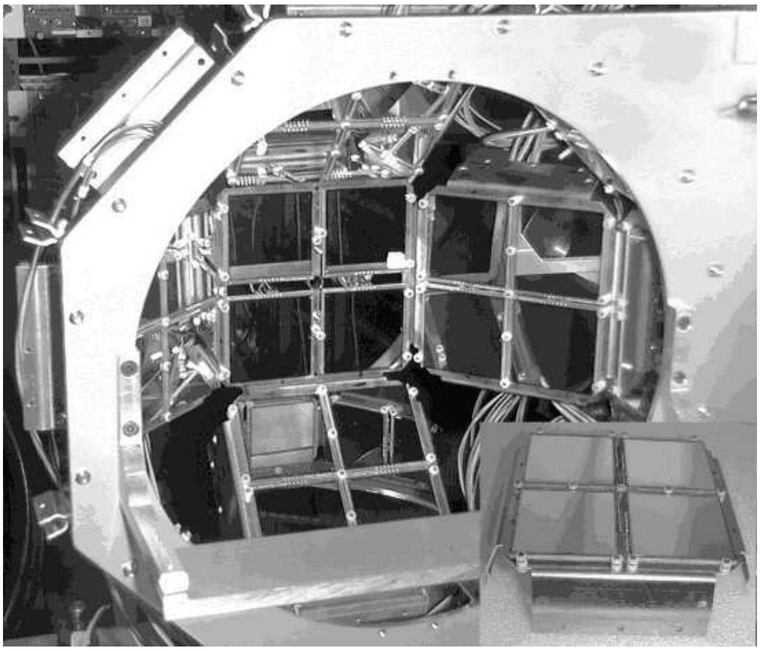

Figure 1: Partial assembly of the first phase of the ISOLDE Silicon Ball in its aluminum frame. The frame itself consists of interchangeable modules, similar to that shown in the bottom right corner, in which four segmented square Si detectors are fixed.

MeV can decay to states in ^{16}O unbound against α decay to ^{12}C. The tails of the 6.917 MeV and 7.117 MeV states, under the threshold may contribute to this decay mode as well. Similarly, the decay from states in ^{17}F above 5.819 MeV can proceed through α emission to states in ^{13}N, which in turn may decay to ^{12}C. Therefore, the detection in coincidence of an α particle and a proton is needed to obtain information on the decay mode and the intermediate states.

2.1 Access to weak decay branches and decay via the IAS in ^{17}F

The two particle channels involving protons and α particles can provide valuable information by means of the identification of all β-decay branches and the efficient measurement of the beta strength. We propose a optimized setup with high resolution and reduced random coincidences by using the Si-ball and a beta plastic scintillator. This allows for ToF identification of the particles, with a good enough time resolution from the Si detectors to separate alpha and protons at the relevant energies. The absolute beta detection efficiency for the scintillator is larger than 25%, thus about the same as for the Si detectors. The efficiency for triple coincidences $\beta - p - \alpha$ with good time resolution is therefore larger than 2%. This will allow to obtain a high quality triple and quadruple coincidence spectrum.

The use of this high efficiency setup will allow us to detect coincidences of an α particle, a proton and the recoiling ^{12}C corresponding to the decay from the IAS in ^{17}F. Table 1 summarizes the present knowledge of the branching ratios from this level. About 10% of the ^{17}F IAS (11.193 MeV) decay proceeds via $p - \alpha$ branches. The states involved are the wide 9.585 MeV level and the tails of the 7.117 and 6.917 MeV levels in ^{16}O and the 2.365 MeV, 3.502 MeV and 3.547 MeV levels in ^{13}N. The most favored channel to access the 7.117 in ^{16}O is precisely the decay from the IAS at 11.193 MeV in ^{17}F. In the case of the decay of the IAS via the 9.585 MeV ^{16}O state we can expect $\sim$20 detected

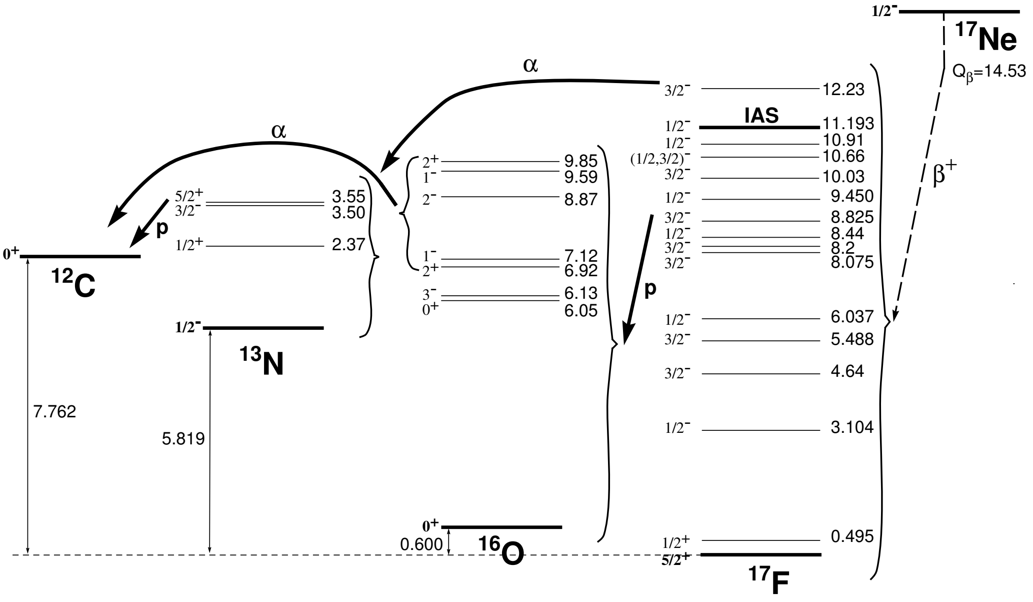

Figure 2: Partial level scheme for the β-delayed particle decay of ^{17}Ne ($T_{1/2}$=109.2 ms).

events/hour assuming a production of 1000 atoms/μC from a plasma ion source with cooled transfer line. The decay from the tail of the 7.117 MeV state is reduced by 3 to 4 orders of magnitude. In order to significatively study the contribution of this state a yield orders of magnitude higher is needed.

Table 1: Branching ratios (in %) for the decay of the IAS of ^{17}F (11.193 MeV)

Decay branch	E* (MeV)	Ref. [1]	Refs. [2, 3]	Ref. [4]
α + ^{13}N	3.502+3.547		–	0.2(1)
	2.365		29(9)	8.9(7)
	g.s.		1.1(5)	0.3(1)
p + ^{16}O	9.585	–	–	1.9(5)
	8.872	–	–	15.7(26)
	7.117	44(4)	18(3)	23.8(13)
	6.917	24(6)	<4	0.56(19)
	6.130	22(2)	25(2)	31.9(13)
	6.049	<3	11(3)	5.8(4)
	g.s.	9.3(13)	10.7(6)	8.2(5)
γ	0.495		3.4(15)	
Total		99(8)	95(11)	97.3(34)

2.2 Spectroscopic properties of ^{17}F levels

We propose to extract spectroscopic properties of the levels, and specially the IAS, by means of the $\beta-\nu$ recoil broadening of the proton decay lines to narrow states in ^{16}O. When the parent nucleus ^{17}Ne β-decays the emission of the e^+ and ν leaves ^{17}F nucleus with a recoiling energy of the order of 250 eV to 1 keV. When ^{17}F decays by particle emission in flight the recoiling energy is transmitted to the emitted particles, which suffer a kinematic shift [20, 21, 22]. This shift is enhanced compared to the original one by a factor of roughly the ratio between the momenta of the outcoming particles (^{13}Ne + α, ^{16}O + p). The broadening of the proton lines can give hold of spectroscopic information on the intermediate states. The decay transition to the IAS of ^{17}F ($\mathrm{J}^{\pi}, T = 1/2^{-}, 3/2$) has a main Fermi component, case in which the broadening is larger. The amount of Gamow-Teller component influences the observed broadening of the line.

The isospin mixing of the IAS in ^{17}F has not been clarified. Previous measurements have assigned a main Fermi component in the decay, but they have not fully excluded a Gamow-Teller component. Hardy and coauthors [1] limit the amount of B(GT) to 5%, Borge et al. [2] obtain a low B(GT)=0.01, whereas recent work by Morton et al. [4] assumes B(F)=3 and obtains B(GT)=0.51. In the case of transitions between analog states the Fermi decay strength can be written as

$$B(F) = a^2\{T(T+1) - T_z(i)T_z(f)\}, \tag{1}$$

where a^2 takes into account the amount of isospin mixing ($a^2 \leq 1$). Therefore, the upper limit of the Fermi component from the beta decay of the g.s. in ^{17}Ne can be found by assuming a pure Fermi decay ($a^2 = 1$). Using T=3/2, $T_z(i) = 3/2$, $T_z(f) = 1/2$ in previous equation this value is found to be B(F)=3. With a well defined experimental response function one can determine the limit of the Fermi / Gamow-Teller mixing in the decay to the IAS by using the $\beta - \nu$ recoil shift. Other properties of levels in ^{17}F, as spins and widths, can be accesible with this technique.

3 Experimental details

In order to obtain information about the spectroscopic properties of the ^{17}F states and on the decay branches, we propose an experimental setup as sketched in Figure 3. It consists basically of the Si-Ball together with a 3-mm-thick BICRON BC-408 plastic scintillator placed as close as possible to the beam collection point. This detector provides the starting time for β-particle coincidences, with enough flight path (15 cm) to allow for particle identification via time of flight. The ToF between hits in the different Si detectors themselves will provide extra coincidence events. Beta events in the Si detectors should be distinguishable from the particle hits via ToF as well. We intend to include a gamma HPGe detector in order monitor the activity coming to the setup.

For the ^{17}Ne production we propose a Mg oxide target coupled to a plasma ion source with cooled transfer line, for which a yield of 1000 atoms/μC can be expected. This means about 2000 decays/s from ^{17}Ne, from which about 0.75 % go to the IAS in ^{17}F (15 decays/s). Assuming an absolute beta efficiency for the scintillator $\geq$25% and an efficiency of the Si-ball for double particle hit of $\sim$9%, our proposed setup will be able to detect more than 100 $\beta - p - \alpha$ events per hour corresponding to the breakup of the IAS.

Nevertheless, it would be of great interest to take advantage of the new electron cyclotron resonance ion source MINIMONO [23] from GANIL, presently under test at ISOLDE. It can provide higher yields compared to the plasma ion source, due to its higher efficiency for noble gases.

4 Summary and Beam time request

We propose an investigation of the beta decay of ^{17}Ne to achieve a better understanding of the structure of ^{17}F and the particle decay branches to ^{16}O and ^{13}N. The

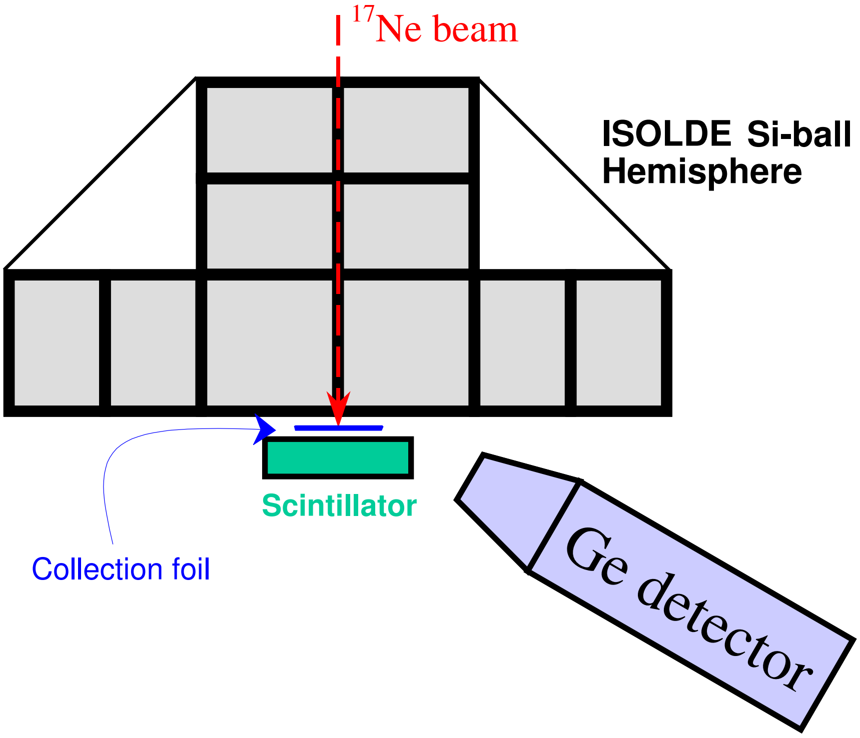

Figure 3: Sketch of the proposed setup (upper view).

identification of $p + \alpha + ^{12}$C final states is one of the main objectives. We intend the study of the isospin mixing in the decay from ^{17}Ne to the IAS ^{17}F. We request 9 shifts for online measurement plus 3 shifts for stable beams and calibrations on the HRS. We plan using a Mg oxide target coupled to a cooled plasma ionizer or if possible to the MINIMONO-ECRIS. We request to work in the LA2 beamline, already suited for the Si-ball setup. We also request ISOLDE VME data acquisition and CERN data storage system.

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