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Study of the β-decay of ^{20}Mg

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Abstract

We propose to perform a detailed study of the β-decay of the dripline nucleus ^{20}Mg. This will provide important information on resonances in ^{20}Na relevant for the astrophysical rp-process as well as improved information for detailed comparison with state of the art Shell-Model calculations and for comparison with the mirror β-decay of ^{20}O.

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1 Physics motivation for studying the decay of ^{20}Mg

^{20}Mg is situated at the proton-dripline as the lightest isotope in the Magnesium chain (Z=12). Along the N=8 chain it is situated between the unbound ^{19}Na and ^{21}Al with ^{22}Si being the most proton rich bound nucleus. ^{20}Mg β-decays in allowed decays to 1^+ states in ^{20}Na with a total half life of 90.8(24) ms.

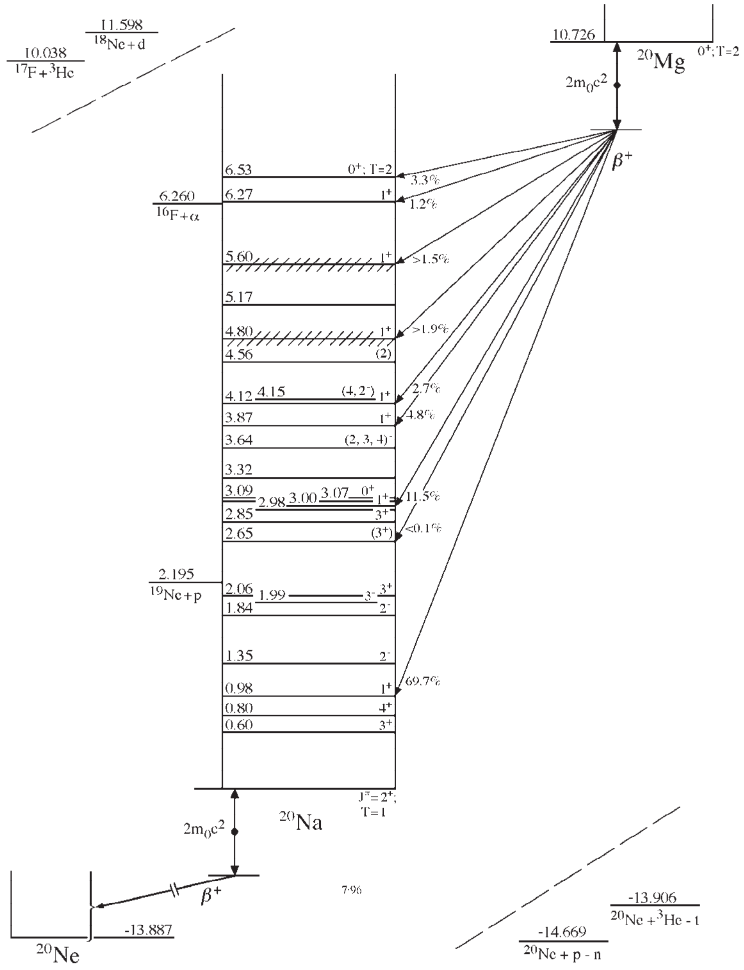

Figure 1: β-decay of ^{20}Mg as compiled in the latest evaluation.

The physics motivation for studying ^{20}Mg is three-fold:

1. Determination of the spin and parity of a level situated at 2.645(6) MeV in ^{20}Na, or 450 keV above the ^{19}Ne+p threshold. This resonance is situated in the Gamow-window for the ^{19}Ne(p,γ)^{20}Na reaction in the breakout from the hot CNO cycle. Its properties have been under intense scrutiny during the past 20 years. The most likely spin values for the this state are 1^+ and 3^+. In the former case the state can be populated in allowed decays of ^{20}Mg.
2. Studying the mirror-symmetry by comparing to the decay of ^{20}O to ^{20}F.
3. ^{20}Mg is the lightest bound T=2 nucleus and its decay properties can therefore be reliably calculated with modern Shell-Model calculations. This allows e.g. to study the quenching of the Gamow-Teller strength.

These three points will be further discussed in the following.

1.1 Properties of the 2645(6) keV level

The 2645(6) keV level is the first excited state in ^{20}Na above the ^{19}Ne+p threshold. Its spin and parity were first assigned as 1^+ using (^{3}He,t) and (p,n) reactions, see [1] and references therein. The confirmation of this assignment by observing this state populated in the β-decay of ^{20}Mg has been attempted at RIKEN [1], MSU [2] and most recently at GANIL [3], but only upper limits on the branching ratio to the state resulted from these measurements. However, the present upper limit of 0.1% corresponds only to $\log ft > 6.2$, which does not completely exclude a 1^+ assignment; such weak allowed transitions are e.g. known in the decays of ^{17}N, ^{17}Ne and ^{18}N.

An upper limit of the resonance strength of the 2645 keV state has been placed by direct measurement of the ^{19}Ne(p,γ)^{20}Na reaction at Louvain La Neuve [4], but this does not allow to choose between the suggested assignments of the spin and parity of the state [5] .

The most recent β-decay study of ^{20}Mg suggested that a measurement at an ISOL facility should be able to significantly improve the sensitivity in the search for the 2645 keV state and thereby either find the state or place an upper limit, which excludes the 1^+ assignment. This can be done by using much thinner detectors with little or no β-response in the energy region around 450 keV where the delayed proton line is expected. All previous studies were performed at fragmentation facilities where ^{20}Mg was implanted in rather thick Si detectors. If the state can be identified the secondary goal will be to determine proton- and γ-widths of the state.

As will be argued later, we now have the possibility of achieving this goal at ISOLDE due to the development of the new SiC target and the RILIS for Mg beams.

1.2 Mirror asymmetry and comparison to the Shell-Model

The almost complete charge independence of nuclear forces infers that isospin-mirrored β-decays should have nearly equal $\log ft$ values. Population of only two states are known in the decay of ^{20}O due to its lower Q-value of 3.814 MeV, namely the 1^+ states at 1057 keV and 3488 keV in ^{20}F. For the latter the mirror asymmetry in the B_{GT} values is among the largest observed for all nuclei with the β^- strength being 2.69 times larger than the β^+ strength [3]. It might be that this problem could be solved by observing the ^{20}Mg decay under much improved experimental conditions at ISOLDE as compared to the fragmentation facilities.

In the most recent β-decay work at GANIL [3] the experimental results were compared to Shell-Model calculations in an *sd*-model space. Allowing for a quenching factor for the Gamow-Teller strength the agreement was fair for the observed states up to 3 MeV. The Shell-Model predicts the Gamow-Teller giant resonance at 4.8-7.2 MeV, but there the experimental information did not give sufficient information. This region can also be much better studied at ISOLDE.

2 Detection system

The main experimental problem in the decay of ^{20}Mg is that in ca. 70% of the decays the β-decay daughter will be populated in bound states and the subsequent decay of ^{20}Na produces a wide spectrum of α-particles and ^{16}O recoils in the energy region 0-6 MeV. This problem will naturally be agrevated if ^{20}Na is directly produced as a contaminant as well. Therefore in order to extract the delayed proton spectrum from the decay of ^{20}Mg one must be able to discriminate between protons and other charged particles. In the

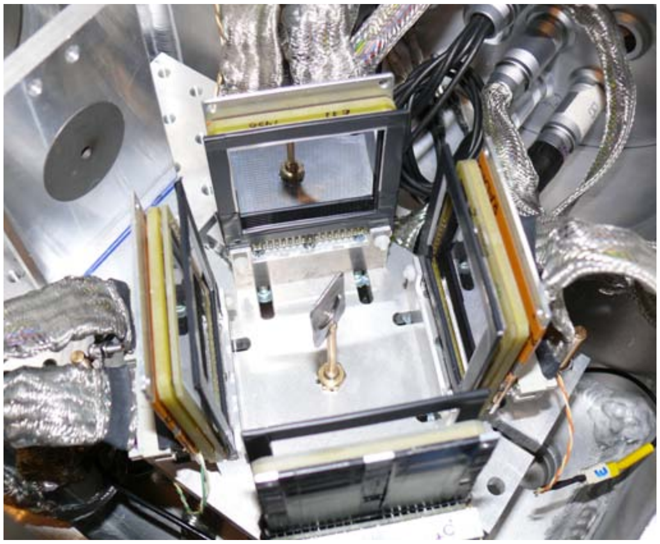

Figure 2: A look inside the chamber containing the proposed setup: Four DSSSDs backed by unsegmented silicon detectors surrounding the carbon foil in the center. The beam comes in from the left through a 5 mm collimator.

previous works [1, 2, 3] the delayed α-particle contribution was simply subtracted from the total spectrum, which can lead to large systematic errors.

We plan two measurements. In the first measurement we will use a setup focused at searching for the population of the 2645 keV state. We plan to implant the ^{20}Mg beam in the window of a Gas-Si telescope with a thin ca. 50μm Si detector. This setup allows to separate protons from α- and β-particles, and recoils. This kind of setup has previously been used by our collaboration to detect deuterons and tritons with even lower energy than is the case here. We will also place an efficient Ge-detector in a compact geometry close to the collection point.

In the second measurement we will use a compact setup with four double-sided Si strip detectors as illustrated in Fig. 2. This will allow to collect a high statistics sample of data and will also allow us to apply advanced analysis techniques. As an example Fig. 3 shows the spectrum of delayed α-particles from the decay of ^{20}Na as measured with the same setup we will use at ISOLDE. The figure illustrates that by measuring in coincidence the α-particles and recoils one can measure very weakly populated branches at low energy - much below the present upper limit of 0.1% upper limit for the population of the 2645 keV level in the decay of ^{20}Mg. These weak branches are impossible to identify in the single spectrum due to the intense recoil-peaks. The high statistics data will also permit us to use the line shape from the β-neutrino recoil to assign the observed proton peaks [6]. Here we wil also use a compact setup of Ge detectors to support the assignments.

3 The proposed production method

We require a SiC target with the W ion source and RILIS. No measurement of the yield of ^{20}Mg from this target and ion-source exists at ISOLDE, but the Collaps experiment has observed 2×10^4 ^{21}Mg/μC in their set-up from the SiC targets and W ion source/RILIS. From the production cross-sections, there is a factor 10 drop going from ^{21}Mg to ^{20}Mg. One should not expect significant extra losses for release efficiency since the half-lives are very similar. ^{20}Na contamination is to be expected, some orders of

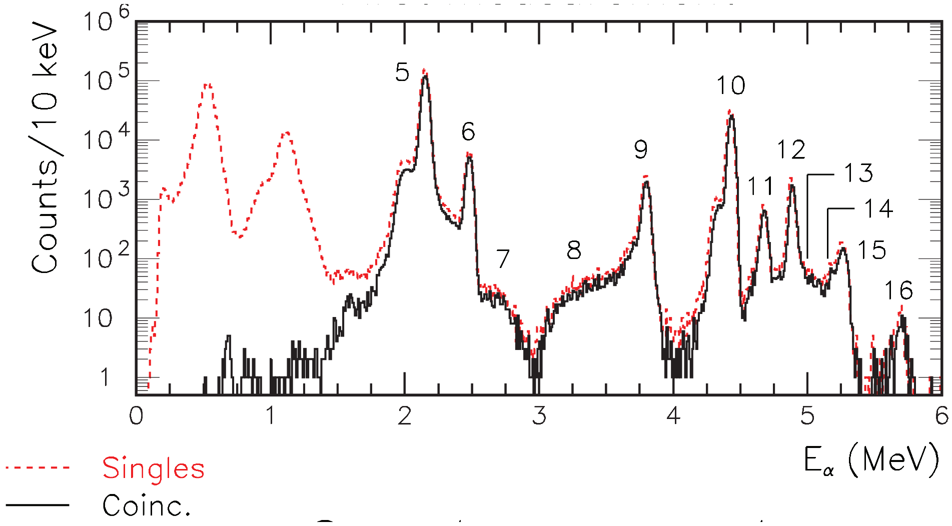

Figure 3: β-Delayed α spectra of ^{20}Na. The solid black line is the α-^{16}O coincidence spectrum. The dashed red line is the singles spectrum.

magnitude more than the Mg yields.

From the ratio $\frac{M}{\Delta M}$=1740, and Mg being heavier than Na, one should be able to clean away the Na contaminant and keep decent Mg fractions using slits and the HRS. We have an optical aberration of the HRS towards low masses, so that will not induce too much cross contamination of ^{20}Na in the heavier Mg. Had ^{20}Mg been lighter than ^{20}Na, that would have been a different story.

It may also be possible to increase the ^{20}Mg to ^{20}Na ratio, if necessary, by exploiting the fact that ^{20}Mg has a half life five times shorter than ^{20}Na.

In conclusion, figures of close to $1{\times}10^3$ ^{20}Mg/μC, and strong reduction of ^{20}Na contaminants is possible at ISOLDE.

4 Summary and Beam request

We ask for 2 days of beam time for measurements with the Gas-Si telescope where 1 day will be used for beam cleaning and optimization, and 4 days for measurements with the DSSD setup including 1 day for tuning. If both measurements can be scheduled back to back at LA1 and LA2 we will only need one of the two days for tuning. In total we ask for six days of radioactive beam time (18 8h shifts) .

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