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(Addendum to experiment IS410)

Coulomb excitation of ^{32}Mg

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We propose to study the collective properties of the neutron-rich $N = 20$ nucleus ^{32}Mg via Coulomb excitation of a beam of ^{32}Mg nuclei provided by the REX-ISOLDE facility. In addition, to confirm the $B(E2; 0^+_{\mathrm{gs}} \rightarrow 2^+_1)$ value of ^{30}Mg from the current analysis of IS410, which is unexpectedly low and contradicts previous measurements, we propose to remeasure the $B(E2; 0^+_{\mathrm{gs}} \rightarrow 2^+_1)$ value of ^{30}Mg with increased statistics on a different target material.

We request a total of 11 days of ^{30,32}Mg beam at 3.1 MeV/u.

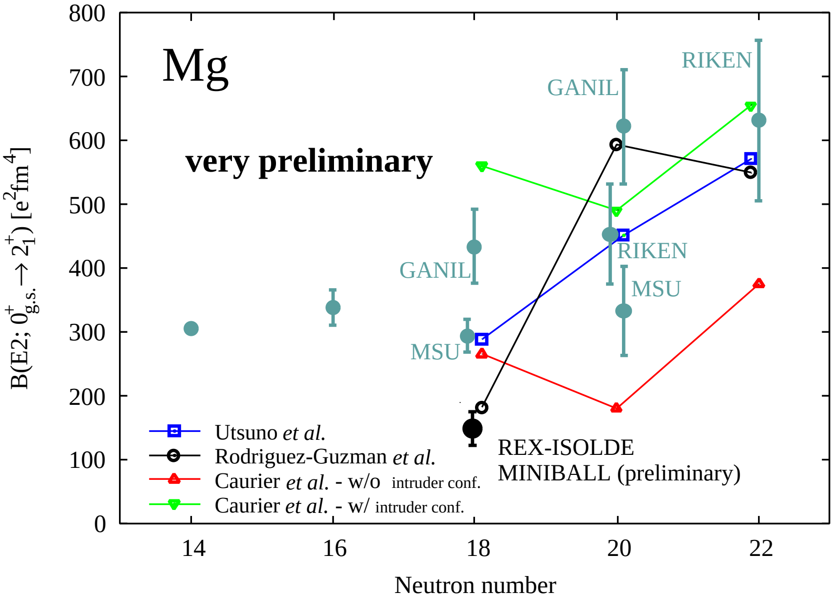

Figure 1. Experimental (solid points) and theoretical $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ values for the neutron-rich even-even magnesium isotopes. The references are: Utsuno [4], Rodriguez-Guzman [5], Caurier [6], GANIL [7], MSU [8], RIKEN [9,10].

1. Introduction

After a preliminary analysis of the Coulomb excitation of ^{30}Mg (IS410,[1,2]) it became apparent that the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of ^{30}Mg is about a factor of two smaller than so far reported (see Fig. 1). This might imply that measurements at intermediate energies — all the data points for ^{30,32,34}Mg (except for the REX/MINIBALL result) stem from experiments performed at intermediate energies ($>$ 30 MeV/u), well above the Coulomb barrier — are not as accurate as previously thought. If confirmed this might be due to Coulomb-nuclear interference effects not considered properly in the analysis of these experiments or due to unobserved feeding from higher lying states. At REX-ISOLDE, both of these uncertainties are not present, or strongly suppressed, depending on the choice of the target material and beam energy.

It is therefore of utmost importance to firmly establish the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of the $N = 20$ nucleus ^{32}Mg by Coulomb excitation using beams with energies well below the Coulomb barrier to obtain a firm and model independent result.

2. Physics Goals

The goals of the proposed experiment are

- the determination of the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of ^{32}Mg, and
- a remeasurement of the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of ^{30}Mg with increased statistics on a different target nucleus, to obtain a more precise result than in our previous measurement (IS410).

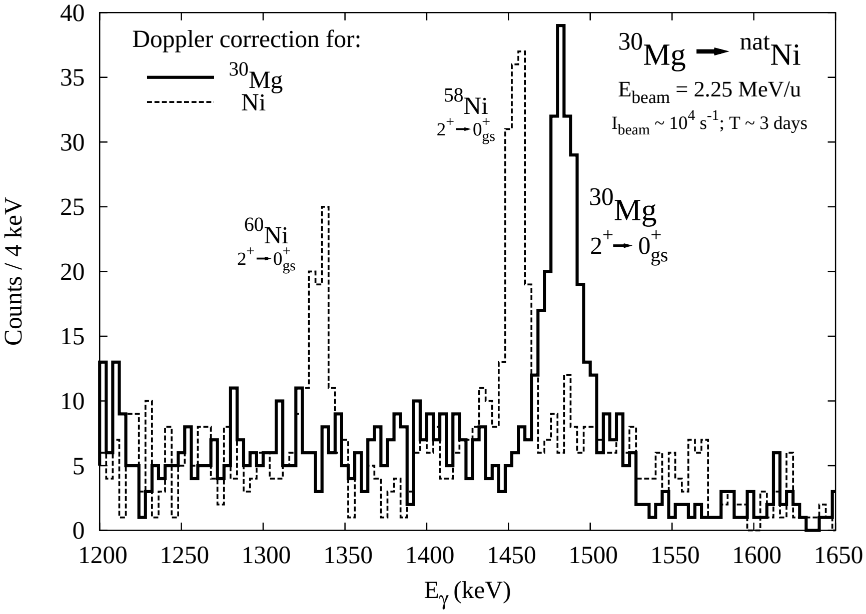

Figure 2. First analysis of IS410 yields the shown γ energy spectrum. The same data are analyzed twice: first by performing the proper Doppler correction for ^{30}Mg (solid curve) and secondly by performing the proper Doppler correction for the recoiling Ni nuclei (dashed curve). By comparing the γ yields the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value can be extracted from the known $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ values of ^{58,60}Ni.

The same data for ^{30}Mg could probably be used to determine the lifetime of the first excited 2^+ state of ^{30}Mg via an analysis of the γ line shape.

3. Experimental Method

3.1. Coulomb Excitation

The current analysis of IS410 was carried out by taking into account that not only the ^{30}Mg beam nuclei, but also the target nuclei ^{58,60}Ni are Coulomb excited, as shown in Fig. 2. Target and projectile excitation can be distinguished by the different Doppler shift of the deexcitation photons due to the kinematics of ejectile and recoil, measured in coincidence with the γ rays, as shown by the solid and dashed spectrum in Fig. 2, respectively. Since the lifetimes of the first excited 2^+ states, and therefore the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ values, of the target nuclei is well known, the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of ^{30}Mg can be determined relative to that of ^{58,60}Ni, yielding the preliminary result shown in Fig. 1. The advantage of this method is that all uncertainties of the target thickness, integrated beam current, and beam energy do not enter the calculation.

The main uncertainty of the current analysis is the beam purity. The ^{30}Al contamination present in the beam also Coulomb excites the Ni nuclei, resulting in a too small $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value for ^{30}Mg. Nevertheless, a first estimate, deduced from the analysis of a run with the RILIS LASER (used to ionized the Mg atoms) periodically switched on and off, showed that this contamination is less than 20%, which cannot resolve the discrepancy between our preliminary result and the previous measurements [7,8].

To check this procedure the same analysis was performed to extract the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value of ^{22}Ne (measured in a separate run, using the residual gas from the EBIS), yielding the correct value. Here, however, beam impurities are extremely small and can be neglected.

To remove the uncertainty due to the beam impurities in the forthcoming beam times a ΔE detector will be installed in the MINIBALL target chamber to continuously monitor the composition of the beam. All particles arriving at the MINIBALL target chamber have the same A/Q and the same velocity. Therefore a Z identification via a ΔE measurement is sufficient to identify the beam particles.

3.2. Lifetime Measurement

Since the lifetime of the first excited 2^+ state of ^{30}Mg, of about 2 ps, corresponds roughly to the timescale for electronic stopping in a suitable target material a variation of the thick target method [3] can be applied to measure the lifetime directly via an analysis of the γ line shape, resulting in a determination of the $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ value, which is completely independent of the Coulomb excitation measurement. The principle idea of this measurement is that γ rays emitted from a nucleus with a longer lifetime will show a much reduced Doppler shift than γ rays emitted from a nucleus with a shorter lifetime, due to the slowing down of the beam particles in the target material.

The modifications in comparison to the original method are:

- The γ detectors are arranged in a highly efficient geometry around the target and not at 0°, and
- the beam particles must not be stopped in the target, so that the radioactive beam can reach the beam dump and the scattered particles must be detected by the CD detector[1] to allow a coincidence measurement, which is mandatory at these low beam intensities.

These modifications result in a much more complicated γ line shape and an extensive simulation is needed to show that this method indeed yields the desired result, given the low statistics in experiments with radioactive beams.

3.3. Experimental Setup

The standard MINIBALL setup at the 65° beamline of the REX accelerator will be used. For details see [1] and references therein.

4. Beam Time Request

To estimate the number of shifts required the γ yield relative to the ^{30}Mg measurement (IS410) is given below. Crucial for the success of the experiment is the higher beam energy of the REX accelerator of 3.1 MeV/u (previously 2.2 MeV/u). Assuming a MINIBALL target with $Z \sim 50$ and the same $B(E2; 0^+_{\rm gs} \rightarrow 2^+_1)$ for ^{32}Mg and ^{30}Mg the gain/loss in γ yield shown in the table below will result. The exact target material will be chosen after careful evaluation of possible target materials, such that the target excitation does not hinder the measurement, but can be used as a normalization for the projectile excitation.

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[1] This is a double side silicon strip detector for particle detection, covering laboratory angles from 15° to 50°. See [1] and references therein for details.

	^{32}Mg	^{30}Mg
beam intensity	0.03	1
lifetime of projectile	0.5	1
CE cross section	5	2
MINIBALL ϵ_γ	2	1
target thickness	2	2
total	0.3	4

Note that these numbers are safe and realistic:

- The factor in beam intensity for ^{32}Mg corresponds to a recent measurement of the yield of ^{33}Mg/^{31}Mg[11]. The ratio of beam intensities of ^{32}Mg to ^{30}Mg should be larger than that.
- The factor of 0.5 for the lifetime is probably too small, since most decay losses, due to the shorter lifetime of ^{32}Mg, are already included in the beam intensity; only the decay losses due to the trapping and breeding time should be considered ($t_{\frac{1}{2}}(^{30}\mathrm{Mg}) = 335$ ms, $t_{\frac{1}{2}}(^{32}\mathrm{Mg}) = 120$ ms).
- The efficiency of the RILIS ion source and the REX accelerator might be improved.
- The same $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ values were assumed for ^{32}Mg and ^{30}Mg. The $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value for ^{32}Mg might be considerably larger, as suggested by the data shown in Fig. 1. (The largest measurement so far gives a $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value for ^{32}Mg, which is four times larger than our preliminary result for ^{30}Mg.)

The spectrum shown in Fig. 2 was taken in three days. Therefore in five days the $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value of ^{32}Mg can be determined with about half of the statistics[2], which is sufficient to establish its value with reasonable precision.

In five days, with a ^{30}Mg beam, the statistics for ^{30}Mg will be increased by at least a factor of five, resulting in a more precise determination of the $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value for ^{30}Mg. Due to the proposed use of the ΔE detector the purity of the beam can be determined very accurately, removing this major uncertainty from the analysis.

Possibly, the lifetime of the first excited 2^+ state might be extracted via the analysis of the Doppler line shape.

We request a total of **11 days** of ^{30,32}Mg beams with an energy of 3.1 MeV/u (one day for setup and beam tuning). In addition two days of residual gas beamtime with ^{22}Ne (similar 2^+ energy and lifetime as ^{30}Mg) is requested to test the γ line shape analysis, if the simulation shows that it is in principle feasible.

Even though the experiment is currently possible we request target development for fast release and increased yield of neutron-rich Mg isotopes with the goal to eventually extend these studies to ^{34}Mg.

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[2] If the $B(E2; 0^+_{\mathrm{gs}} \to 2^+_1)$ value of ^{32}Mg is indeed much larger than that of ^{30}Mg, as is expected, the statistics will be correspondingly larger.

REFERENCES

1. H. Scheit *et al.*, *Evolution of single particle and collective properties in the neutron-rich Mg isotopes*, Proposal IS410 to the INTC, 2002 `http://greybook.cern.ch/programmes/experiments/IS410`.
2. H. Scheit *et al.*, Proceedings of the RNB6 conference, Argonne, USA, 2003 `http://arxiv.org/abs/nucl-ex/0401023`.
3. D. Pelte and D. Schwalm, *In-beam gamma-ray spectroscopy with heavy ions* in R. Bock (Editor) *Heavy ion collisions* (North Holland Publishing Company, 1982).
4. Y. Utsuno *et al.*, Phys. Rev. **C60**, 054315 (1999).
5. R. Rodriguez-Guzman *et al.*, Phys. Lett. **B474**, 15 (2000).
6. E. Caurier *et al.*, Nucl. Phys. **A693**, 374 (2001).
7. V. Chiste *et al.*, Phys. Lett. **B514**, 233 (2001).
8. B.V. Pritychenko *et al.*, Phys. Lett. **B461**, 322 (1999).
9. T. Motobayashi *et al.*, Phys. Lett. **B346**, 9 (1995).
10. H. Iwasaki *et al.*, Phys. Lett. **B552**, 227 (2001).
11. K. Blaum, private communication, Dec. 2003.