EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN INTC-2006-025
INTC-P-183, Add. 1
24 April 2006

Addendum to the Proposal INTC-P-183
(Experiment IS427 – Status report and beam time request)

Nuclear moments and charge radii of magnesium isotopes from N=8 up to (and beyond) N=20.

K. Blaum, M. Kowalska, R. Neugart
Institut für Physik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

K. Flanagan, P. Himpe, G. Neyens, N. Vermeulen, D. Yordanov, Marieke De Rydt
Instituut voor Kern- en Stralingsfysika, K.U. Leuven, B-3001 Leuven, Belgium

P. Lievens
Laboratorium voor Vaste-Stoffysica en Magnetisme, K.U. Leuven, B-3001 Leuven, Belgium

Spokesperson: K. Blaum (blaum@uni-mainz.de)
Co-Spokesperson: G. Neyens (Gerda.Neyens@fys.kuleuven.be)
Contactperson: M. Kowalska (Kowalska@cern.ch)

1. Introduction

The proposal P-183 for experiment IS427, submitted in October 2003, contained nuclear moments and charge radii measurements of neutron deficient and neutron rich magnesium isotopes, mainly ^{21,29,31,33}Mg for which 35 shifts of radioactive beam time were allocated. The physics to be addressed are related to:

* the properties of mirror nuclei (e.g. ^{21}Mg – ^{21}F being members of a T=3/2 multiplet)
* the evolution of shell structure and deformation with isospin.
* changes in the shell structure in the 'island of inversion' around ^{32}Mg and along the N=9 isotones.

Several runs have meanwhile been performed on the neutron rich magnesium isotopes with remarkable results, especially concerning the spin and magnetic moment of ^{31}Mg [1,2]. More publications are already available in the open literature or presently in print or under preparation [3-5]. Another run on ^{33}Mg is scheduled for end of April 2006. In case the run is successful, the β-NMR work on ^{29,31,33}Mg is mainly done.

Due to unexpected new physics requiring more statistics than previously assumed in our proposal P-183 and due to rather low production rates of ^{31,33}Mg, all the allocated shifts were used up for the runs on the neutron-rich Mg isotopes. Here we report on the progress we have achieved and on the reason why we ask for an additional beam time allocation of **24 radioactive beam shifts** and for one target test run to check for ^{21}Na contaminations and to measure the ^{21}Mg yield. With the runs we would like to perform the isotope shift measurements on both neutron-rich and neutron-deficient Mg isotopes and beta-asymmetry measurements on ^{21}Mg. Preliminary isotope shift measurements have already been performed close to stability using optical fluorescence detection. This needs to be extended to the even isotopes as far as possible. For the short-lived odd isotopes we will be able to use the sensitive beta-asymmetry detection also to perform isotope shift work, which has become possible by the success in theoretically simulating the optical pumping signals.

2. Status of the Experiment

In three longer runs using a thick UC2 target and the resonance laser ion source for the production of the short-lived Mg isotopes, the ground state spins and magnetic moments of the exotic nuclei ^{27,29,31}Mg have been measured with the collinear laser-spectroscopy setup COLLAPS. Also isotope shifts between stable ^{24,25,26}Mg and radioactive ^{27}Mg have been measured. To this end, two experimental techniques, based on the atomic hyperfine structure and on the nuclear interaction with external magnetic fields, have been combined and two detection methods where used: optical detection of the resonant fluorescence on the high-intensity beam of ^{27}Mg and β-asymmetry detection on polarized ^{29,31}Mg beams. Polarized beams of $^{29,31}Mg^+$ ions were implanted into a crystal, where the angular asymmetry in the β-decay is detected. The polarization is achieved through optical Zeeman pumping with a circularly polarized laser beam propagating along the fast ion beam. Via the hyperfine interaction and adiabatic decoupling of the electron and nuclear spins, the resonantly induced electron polarization is partly transferred to the nucleus. By varying the velocity of the ions, applying a tunable voltage to the interaction zone, the hyperfine structure was scanned. The optically induced resonances are observed through the asymmetry in the β-decay of the polarized Mg nuclei, after implementation into a MgO single crystal placed in a transverse magnetic field *B*. Figure 1 shows for the case of ^{31}Mg the β-decay asymmetry as a function of the scanned acceleration voltage. The obtained results for $^{27,29,31}Mg$ are summarized in Tab. 1. A surprising result was obtained for the spin of the ^{31}Mg ground state, which appeared to be $I_\pi=1/2^+$. The results and an updated level scheme with tentative spin/parity assignments to the lowest states are presented in [1]. Based on literature a spin of 3/2 or 5/2 was expected and therefore it took much longer to find the corresponding resonances then expected in the original proposal. In addition, the asymmetry was rather weak requiring a lot of statistics to obtain the high-precision data. Calculations using the most recent shell-model interactions for the *sd-pf* shell could not reproduce the experimentally observed level ordering. However, A. Poves reported recently, that this problem is now solved and the level-ordering reproduced.

To summarize, the results obtained so far for the neutron-rich Mg isotopes are providing a key element for further investigating the shell gap evolution in this region of the nuclear chart and further measurements on ^{33}Mg are highly desirable. Another run to measure the ground state spin and magnetic moment of ^{33}Mg is scheduled for end of April 2006. In a previous run we could already demonstrate the polarization and measure the hyperfine structure, from which we can already rule out some spin/parity assignments for the ^{33}Mg ground state spin (e.g. spin ½ is excluded and also positive parity seems very unlikely). However, a firm assignment requires a measurement of the *g*-factor using β-NMR, such that in combination with the HFS data we get both *g*-factor and magnetic moment independently.

Table I : Results obtained so far for the neutron-rich odd Mg isotopes.

Isotope	*N*	I^π	$T_{1/2}$	$\mu_{exp}(\mu_N)$	Q_{exp}(mb)
^{27}Mg	15	1/2+	9.46 m	-0.4110(15)	/
^{29}Mg	17	3/2+	1.3 s	-0.9795(15)	–107(25)
^{31}Mg	19	1/2+	230 ms	-0.88355(15)	/

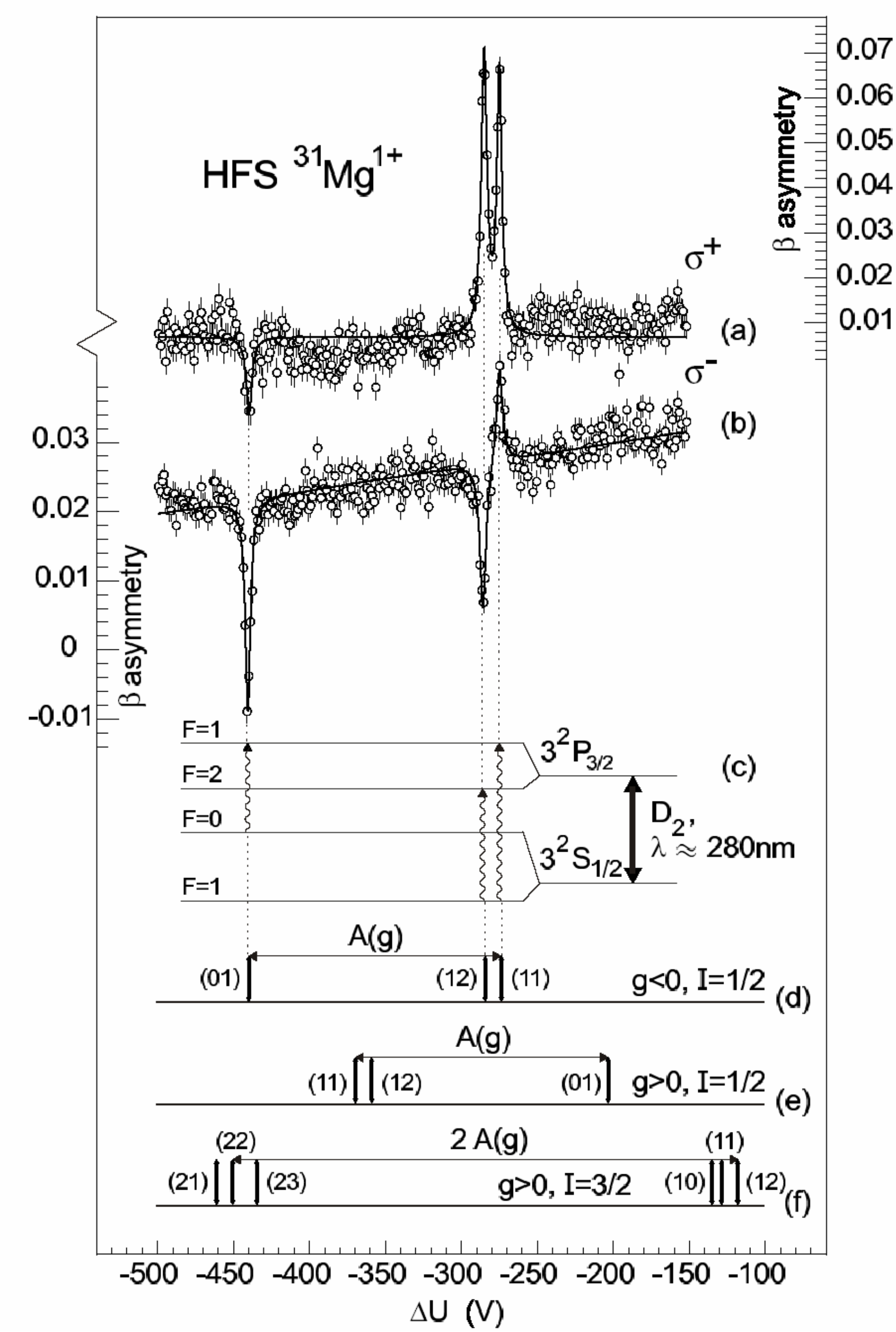

Figure 1: (a), (b) Hyperfine structure (HFS) spectra of σ^+/σ^- optically polarized $^{31}Mg^+$ ions, observed via the asymmetry in the nuclear β decay after implantation into MgO. (c) Hyperfine structure in the transitions $3s\,^2S_{1/2} \rightarrow 3p\,^2P_{3/2}$ (D_2 line) assuming a nuclear spin I=1/2. (d)-(f) Simulated spectra assuming I=1/2 or I=3/2), using the absolute g factor measured by NMR. The allowed transitions are labeled by the total angular momenta F of the ground- and excited-state hyperfine levels.

3. Additional beam time request

As we have used all our allocated beam time requested in P-183, we ask for an additional allocation of **24 radioactive shifts to be taken in three runs**, in order to produce high-quality measurements of g-factors and quadrupole moments of ^{21,23}Mg, to clearly assign the spin for ^{21}Mg, as well as to perform isotope shift measurements on the short-lived isotopes using also the sensitive beta-asymmetry detection for the odd nuclei. Each of the three runs should be of 7-9 shifts, where the first 2-3 shifts are to be used to optimize and calibrate the experimental conditions on the stable ^{25}Mg isotope. Prior the run on ^{21}Mg we ask for one test run in order to find the proper target ion-source combination and to check for possible ^{21}Na contaminations.

References

[1] Measurement of the spin and magnetic moment of ^{31}Mg – Evidence for a strongly deformed intruder ground state
G. Neyens, M. Kowalska, D. Yordanov, K. Blaum, P. Himpe, P. Lievens, S. Mallion, R. Neugart, N. Vermeulen, Y. Utsuno, and T. Otsuka
Phys. Rev. Lett. 94, 022501 (2005)

[2] Laser and β-NMR spectroscopy on neutron-rich magnesium isotopes
M. Kowalska, D. Yordanov, K. Blaum, D. Borremans, P. Himpe, P. Lievens, S. Mallion, R. Neugart, G. Neyens, and N. Vermeulen
Eur. J. Phys. A 25, s01, 193-197 (2005)

[3] Spin and magnetic moment of the optically polarized 31Mg determined via b-decay asymmetry measurements
D. Yordanov, M. Kowalska, K. Blaum, P. Himpe, P. Lievens, S. Mallion, N. Vermeulen, R. Neugart and G. Neyens
Proc. Of the Balkan School on Nuclear Physics, Bodrum, Turkey, Sept. 2004
Special Issue of Balkan Physics Letters, 358-362 (2004)
ISSN 1301-8329

[4] Laser spectroscopy and β-NMR measurements of short-lived Mg isotopes
M. Kowalska for the IS427 collaboration at ISOLDE/CERN
Proceedings of the V Int. Workshop on “Prospects for the development of laser methods in the study of nuclear matter”, Poznan/Poland 2004
Hyp. Int., in print (2006)

[5] Isotope shift, spin, and magnetic moment measurements of neutron-rich magnesium isotopes
M. Kowalska, D. Yordanov, K. Blaum, P. Himpe, P. Lievens, S. Mallion, R. Neugart, G. Neyens, N. Vermeulen
Manuscript in preparation (2006)