EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Experiments Committee for Experiments with HIE-ISOLDE

β-delayed spectroscopy of laser-polarized beams

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Abstract

We intend to develop the technique of β-delayed γ spectroscopy, utilizing the strong nuclear orientation produced by optical pumping. This method will extend the reach of collinear laser spectroscopy to new physics by introducing the capability of measuring spins and parities of ground and excited nuclear states. We aim first at the neutron-rich nuclei in the island of inversion beyond N=20 as probes to establish the principle. Our choice is driven by compelling and unresolved questions about the structure of nuclei in that region. With critical improvements in production rates and beam quality HIE-ISOLDE is the most favorable host for this kind of experiments.

1. Introduction

Collinear laser spectroscopy by β detection on optically polarized beams is a well established method [1-3] for studying the atomic hyperfine structure and therefore the spin and electromagnetic moments of nuclear ground states. Combining this technique with nuclear magnetic resonance removes any ambiguity on the determination of the above properties. Such a powerful tool will certainly remain on the front line of experimental nuclear physics in the foreseeable future. However, it has limitations, the most apparent of which is that the information in the β decay on excited nuclear states is not considered. Furthermore, the method offers no direct information on the parity of the studied ground states. We propose the β-delayed spectroscopy of polarized beams [4] as a means to overcome these limitations.

2. Physics case

The island of exotic neon, sodium and magnesium nuclei around *N*=20, known as “island of inversion” has been extensively studied since its discovery by mass measurements [5]. Today, more than three decades later the interest is at its peak, but there are ever fewer experiments possible with the yields currently available at any accelerator facility in the world. HIE-ISOLDE with its improved beam handling and higher production rates offers a unique opportunity to resume the studies. At present, the majority of unambiguous model-independent data in the island [1-3, 6-8] originate from collinear laser spectroscopy by laser-induced nuclear orientation. So far these studies have been hampered by rapidly decreasing yields near the *N*=20 shell closure. Herewith, we propose to measure for the first time the spins and electromagnetic moments of ^{32}Na and ^{33}Na as well as the quadruple moment and the rms charge radius of ^{33}Mg. In such a way we will provide sensitive probes of the nuclear structure beyond the *N*=20 shell closure. The measurements on ^{33}Mg, in particular, will show to what extent this shell closure gives rise to the characteristic kink in the trend of the charge radii. Furthermore, ^{33}Mg is the only isotope in the island for *Z*=12 with a ground-state spin allowing access to the quadrupole moment and therefore to the deformation.

Most appealing is the possibility to investigate the β decays of the *A*=33 isobars in the island of inversion ^{33}Na→^{33}Mg→^{33}Al using polarized beams. Previous experiments on ^{33}Na [9] and ^{33}Mg [10] showed large ground-state-to-ground-state branches suggesting identical parity, which would appear to be positive, according to the systematics and the g-factor measurement in ^{33}Al [11]. On the contrary, the spin and negative magnetic moment of ^{33}Mg [8] are consistent with a negative-parity state represented in the spherical shell model by two-particle-two-hole excitations, or in terms of deformation, by coupling the odd neutron to a prolate-deformed core [12]. The discrepancy in the parity assignment can be resolved by the proposed method. In the case of ^{33}Mg, the β-asymmetry parameter will be measured and compared with the value derived from the branching ratios and spins of the states in ^{33}Al. The weak link in such comparison is the ground-state decay strength, which accumulates most of the systematic uncertainties [13], and therefore, is the one to be analyzed. In this manner, one will be able to examine the previously-reported ground-state branch of 37(8)% [10], and therefore, explore the credibility of the positive-parity assignment to ^{33}Mg from the same work.

Reaction experiments [14, 15] indicate that the 484 keV level in ^{33}Mg has the same parity as the ground state. With less than 1.2% feeding to this level in the β decay of ^{33}Na [9] the ground-state branch of 20(10)% needs to be confirmed as well.

The results from the β-delayed measurements on polarized ^{33}Na and ^{33}Mg will be combined with the conclusions drawn from their spins and electromagnetic moments to provide a comprehensive picture of the near magic, yet, deformed nuclei in the island of inversion. The rms charge radius of ^{33}Mg and the ground-state properties of ^{32}Na would also make important contributions to that picture.

3. Experimental setup

The methods of collinear laser spectroscopy by β detection [1-3, 7, 8] and β-delayed spectroscopy on polarized beams [4] are well established and need no detailed description in this letter. We intend to apply at HIE-ISOLDE what is in essence a combination of both. The first method will record the hyperfine structure, provide high-precision magnetic and quadrupole moments from NMR, and determine the ground-state spin. Applying the β-delayed technique would require an upgrade of the existing apparatus as indicated in Fig. 1. Telescopes with thin and thick scintilators, γ detectors and an event-by-event acquisition system will have to be introduced. Unlike presented in the Fig.1, which is intended only as a sketch of the principle, the γ-detectors position will be optimized for maximum detection efficiency. Depending on the resolution required, either scintillation or germanium detectors will be used, or possibly a mixture of both types. With the newly introduced facilities one will be able to utilize the large (typically tens of percents) and theoretically predictable [2, 3] nuclear polarization from optical pumping. The essence of this technique lies in the discrete behavior of the partial β asymmetries to the states in the daughter nucleus. These quantities will be measured by gating on gammas, or for the ground state by making energy cuts in the β spectrum. In this manner spin changes will be determined, and as the spin of the mother nucleus will be known from the initial

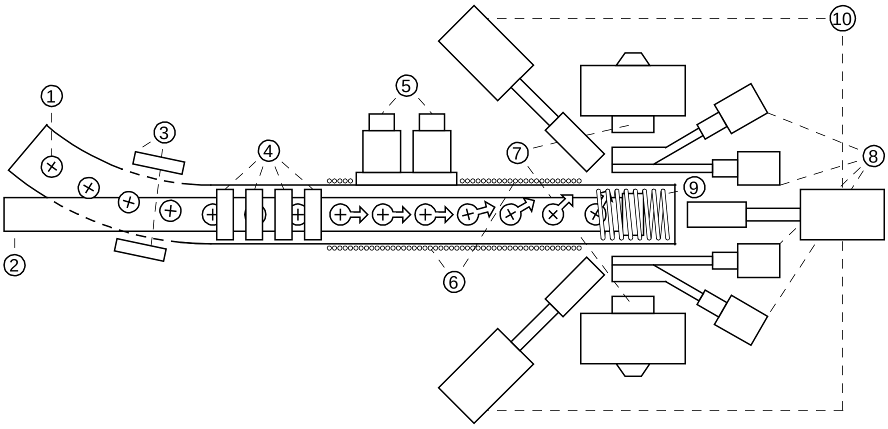

Figure 1: Collinear laser spectroscopy setup planned at HIE-ISOLDE
1. Ion beam; 2. Laser beam; 3. Deflection plates; 4. Post-acceleration lenses; 5. Photomultiplier tubes; 6. Guiding-field coils; 7. Magnet; 8. Scintillation detectors; 9. Host crystal and RF coil; 10. γ detectors;

hfs/NMR measurements, spins will be effectively measured for all detectable states in the daughter. Virtually no additional space is required in the experimental hall for the proposed installations.

4. Beam requirements

nucleus	ions/μC	kV	pulsed	ΔEγ/E (%)	beam size	no. shifts
^{32}Na	5.6×10^{2}	60	no	2	> 4mm FWHM	12
^{33}Na	5.2×10^{1}	60	no	2	> 4mm FWHM	>18
^{33}Mg	1.2×10^{4}	60	no	2	> 4mm FWHM	10

The yields of HIE-ISOLDE are assumed a factor of four higher compared to ISOLDE. A reduction in the emittance may improve the laser-ion beam overlap and increase the transmission through the apparatus. The feasibility of the ^{33}Na moments is not easily predictable without an adequate knowledge on the β asymmetry and the yield.

5. Safety aspects

The technical developments discussed in this letter will bring no additional safety risks at the current setup for collinear laser spectroscopy.

6. References

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