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Letter of Intent to the ISOLDE and neutron Time-of-Flight Experiment Committee

Tilted-foils polarization at REX-ISOLDE

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Abstract

With this letter of intent we would like to establish the collaboration interested in the study and the application of nuclear spin-polarization, using the tilted-foils technique at REX-ISOLDE, and request the endorsement of the INTC for the installation of the beta-NMR setup after REX. Additionally 5 days of stable-beam machine time as well as 2 days of radioactive beam are requested for first tests.

Introduction

The possibility of obtaining spin-polarized nuclei is an essential asset for performing experiments with radioactive nuclei. The two main directions of research where these highly sensitive probes are usually used are nuclear structure studies (e.g. nuclear moment measurements) and the application of nuclear methods in solid-state physics investigations.

Magnetic moments of nuclei provide an important input to the understanding of nuclear structure since they can provide precise and unique information regarding the single particle nature of the particular nuclear level under investigation. In the last few years, much focus has been drawn to probing nuclear structure at extreme isospin, using the various new developments in rare-isotope-beam facilities and in ancillary detection systems. In particular, measurements of ground-state magnetic moments in short-lived, proton-rich nuclei can shed much light on the evolution of shell structure as approaching the proton drip line. In the beta-NMR method, widely used in such measurements with radioactive nuclei, the nuclei are polarized using various possible mechanisms such as reaction polarization, optical pumping and low-temperature orientation [1-3]. The resulting asymmetric distribution of the beta-decay is monitored in the presence of an external static magnetic field and a perturbing rf field. The particular method chosen for polarizing given nucleus depends mostly upon its properties such as life times and atomic structure. With the present collaboration we would like to establish at REX-ISOLDE the Tilted-Foils (TF) technique as a method of obtaining spin-polarized nuclei.

Additionally to the use of an ensemble of polarized nuclei for nuclear moment measurements it may provide essential complement in its application in nuclear reactions. As an example one can cite the use of polarized nuclei in Coulomb excitation experiments on odd-mass nuclei where the left-right asymmetry, induced by the polarized nuclear spins, can give information on the mutlipolarity of the de-exciting transition [4].

Another possible use of polarized nuclei at ISOLDE is in solid-state physics studies. Provided that the polarization is of the order of 10% or higher this would present a great advantage for solid-state physics experiments since a beta-NMR experiment with polarized nuclei increases the sensitivity over a conventional NMR by more than 10 orders of magnitude. This would provide the ability to probe, for example, surface states and thin film layers, such as those increasingly being considered for next-generation magnetic devices, e.g. single molecule magnets [5]. Similarly, the technique may be applied for example in the study of binding of transition metal ions such as Cu^+ (which is invisible to most standard spectroscopic techniques) to proteins. This would require tests of the feasibility as well as technical modifications to allow for beta-NMR measurements on liquid solutions, but if successful it would represent an introduction of a completely new technique in the field of bioinorganic chemistry.

The technique that we would like to apply here in order to obtain an ensemble of polarized nuclei is the Tilted Foils (TF) technique [6, 7] in which an atomic spin-polarization is obtained via the surface interaction of ions traversing a multifoil stack at an oblique angle. The atomic polarization thus produced is subsequently transferred to the nuclear spins. The TF polarization technique has been used up to now for nuclear-moment measurements [6, 7] and the experimentally observed polarization has been of the order of 1%. The advantages of the application of the Tilted-Foils technique for obtaining a polarized nuclear ensemble are in the simplicity of its application, compared to some other techniques (e.g. optical pumping), and in its universality (e.g. there is no chemical dependence of the TF polarization observed). It is worth mentioning that the TF and the optical pumping are in way complementary techniques since the former one is more suitable for higher-spin states while with the latter one a higher level of polarization is easier to be obtained for lower-spin states.

<u>Experimental considerations</u>

In the TF technique the polarization is initially obtained for the spins of the ionic electrons and is subsequently transferred to the nuclear spins. The atomic polarization is induced by the interaction of the electrons with the surface upon the exit of the ions from a thin foil, tilted at an oblique angle with respect to the beam direction. The atomic polarization is in the direction ***n*** x V, where ***n*** is the unit vector perpendicular to the outgoing surface of the foil and V is the ion velocity. The nuclear polarization, induced by the hyperfine interaction, can be enhanced, especially for high-spin states, by the use of a stack of multi-foils spaced at distances allowing significant precession of the nuclear spins around the total angular momentum in the flight between the successive foils.

The TF technique has been previously applied at ISOLDE for studying the ground-state magnetic moments of the T=1/2 and T=3/2 nuclei in the s-d shell, ^{23}Mg and ^{17}Ne [6, 7]. The High-Voltage platform (HVP) has been used at 200 kV in order to increase the energy of the ions coming from the target at 60 keV. This boost in energy is essential in order to provide for the nuclei under study sufficient energy to traverse one or two carbon foils tilted at 75^{o} to the beam direction. In the first experiment, due to the high yield of ^{23}Mg, it was possible to use the 10 times scarcer 2^+ charge state in order to obtain a total of 520 keV. However, for nuclei far-from-stability, the beam intensity usually does not allow the use of ions with charge states other than 1^+. For ^{17}Ne, due to the lower Z, singly-charged ions were used. Much higher energies are needed for ions with Z > 12 and therefore we propose to use REX-ISOLDE. This would also allow obtaining much more favourable conditions for the application of the TF technique, achieving beam energies of about 1 MeV/u. Therefore we are planning to install a TF setup after REX-ISOLDE followed by a beta-NMR setup, provided by HMI, Berlin.

The new setup will alleviate numerous conceptual and technical issues that hampered previous experiments at ISOLDE on the HVP. The TF polarization is an atomic effect, depending on the hyperfine interaction of the atomic configurations in the particular charge states emerging from the tilted surface at a given velocity. Using the HVP, this velocity is fixed at a low value. REX-ISOLDE will provide the opportunity to probe the induced TF polarization at a wide velocity range and thus find the optimum conditions for any particular nucleus, or region of nuclei, under study, greatly enhancing the sensitivity of the method. The needed energies for the TF polarization may vary in a wide range, from values of fractions of a MeV/A up to 1-3 MeV/A.

Additional advantage of the use of REX-ISOLDE for the TF polarization is its modularity. We are envisaging the installation of a stack of foils right after the RFQ (300 keV/A). In order to preserve the polarization obtained after the passage of the ions through the REX LINAC a noble-gas-like charge state should be selected. One of the test cases we consider is the use of ^{83}Kr (g.s. $I^{\pi} = 9/2^+$). After its post-acceleration through the LINAC (in a Ne-like charge state 26^+, A/Q = 3.19) it can be Coulomb excited at the Miniball setup and the degree of the polarization determined through the left-right asymmetry similarly to ref. [4]. This is a type of a measurement that can be performed with stable rest-gas beam from REX-EBIS. Provided that a significant level of polarization could be obtained and preserved in the post-acceleration this would open an important niche of the use of post-accelerated radioactive beams for nuclear reactions.

Physics case

The present status of the REX ISOLDE facility provides radioactive beams with energies from 300 keV/A to 3 MeV/A, allowing heavier-mass nuclei to pass through several tilted foils at various charge state and atomic configuration. This will allow a selection of beam energy to obtain possibly higher atomic (and hence, nuclear) polarization. The present results therefore pave the way for future determinations of magnetic moments in, e.g., proton-rich nuclei in the Fe-Ga region of the f shell for which virtually no information exists on magnetic moments of N=Z-1 nuclei and of mirror pairs. As examples we cite the cases of ^{57}Cu that is one-proton removed from the closed ^{58}Ni nucleus and the self-conjugate ^{58}Cu. Special interest to the region is attracted lately, when in a recent measurement [8] the magnetic moment of ^{57}Cu appears to differ significantly, compared to the previously reported value [9]. Another region of much interest are the mirror T=3/2 pairs in the s-d shell such as ^{21}Mg.

Requirements and request

The extension of the ISOLDE hall with the move of the REX bending magnet into it provides ample place for the installation of the beta-NMR setup. The magnet, together with the detectors and the vacuum chamber of the setup can be installed on a movable platform on the second beam-line. Addition of extra beam-optics elements (e.g. quadrupole magnet provided by HMI) and a beam-diagnostic box might appear necessary in order to allow the positioning of the beta-NMR setup far enough from the Miniball setup and avoid any possible conflict points. Electrical-power and cooling-water supplies would be necessary for the beta-NMR magnet. The installation of the present setup will profit from the infrastructure, required by the LoI on g-factor measurements in transfer reactions at REX-ISOLDE (CERN-INTC-2008-034 / INTC-I-079), already endorsed by the previous INTC. Both setups have similar infrastructure requirements and would be installed, on a temporary base, at the second beamline after the REX bending magnet.

With the present LoI we ask for the endorsement of the INTC for the installation of the beta-NMR setup after REX. **5 days** of *stable beam* from REX are requested for testing the possibility of post-acceleration of polarized nuclei through the LINAC. This test would be done using the Miniball setup. Additionally **2 days** of *radioactive beam* are requested for testing the beta-NMR setup. The best suited cases will be discussed with the ISOLDE Physics Coordinator.

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