EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

Low temperature nuclear orientation with NICOLE setup,

[15.1.2014]

M.Veskovic[1], N.J.Stone[2,3], T.Ohtsubo[4], J.Nikolov[1], G.Audi[5], C.R. Bingham[6,7], C, Gaulard[5], U. Köster[8], K. Nishimura[9], Z. Podolyak[10], L. Risagari[5], S.Roccia[5], J.R.Stone[2,3], P. M. Walker[10,7] and W.B. Walters[11]

1. Department of Physics, University of Novi Sad, 21000 Novi Sad, Serbia.
2. Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA.
3. Department of Physics, University of Oxford, Oxford, OX1 3PU, United Kingdom.
4. Department of Physics, Niigata University,
5. CSNSM, F-91405 Orsay, France
6. Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
7. CERN, CH-1211 Geneva 23, Switzerland
8. Institute Laue Langevin, F-38042 Grenoble, France.
9. Faculty of Engineering, Toyama University
10. Department of Physics, University of Surrey
11. Department of Chemistry and Biochemistry, University of Maryland, College Park MD 207 40, USA

CERN-INTC-2014-025 / INTC-SR-036
15/01/2014

Abstract

This Status Report describes results and present situation for two experiments, IS460 and IS 503. IS460 is incomplete. Although results for the magnetic dipole moment of $^{177}Hf^{m2}$ and g_R factors for bands in the decay of this isotope have been submitted for publication, extraction of an accurate moment for $^{180}Hf^{m}$ awaits a final run, delayed by problems with the NICOLE dilution refrigerator, now repaired. IS503 resulted in publication in Physical Review Letters in 2012 of the magnetic dipole moment of 49Sc, significant in completing, for the first time, the full sequence of moments for all even-N isotopes between two major neutron subshells (N = 20 to 28) for an element having one proton outside a closed major shell.

Experiments and remaining shifts: IS460 - 12 shifts, IS503 – finished.

Experimental setup/technique

The NICOLE On-Line Nuclear Orientation facility comprises a large $^{3}He/^{4}He$ refrigerator with room temperature side access through which an ion beam from ISOLDE can be introduced to impinge upon a suitable metallic foil maintained at temperatures down to below 10 milikelvin. Using ferromagnetic foils, the implanted nuclei experience hyperfine magnetic fields of order 20 – 200 T, sufficient to produce large degrees of nuclear polarization subject to a spin-lattice relaxation time which can vary between hours and milliseconds. The system has been applied to the study of nuclei of many elements with $Z > 20$, lighter nuclei experiencing rather weaker fields giving small degrees of orientation. Nuclear alignment can also be achieved through interaction of the nuclear electric quadrupole moment with the large electric field gradient existing in certain non-cubic metals.

The angular distribution of the decay of the polarized or aligned nuclei, whether by alpha, beta, gamma or direct or beta-delayed particle emission, shows, in general, large anisotropy with respect to the orientation axis of the system. This axis is defined either by a small field to magnetize the ferromagnetic foil or by the axis of the electric field gradient. The anisotropy is measured using either external detectors for emissions which emerge from the cryostat (gamma, high energy beta, neutrons) or internal detectors for less penetrating emissions (alpha, beta and protons). Measurement of the anisotropy as a function of the degree of orientation, e.g. of nuclear temperature (determined by a nuclear orientation thermometer), yields information concerning the level spin sequence and the multipolarities/partial wave amplitudes involved in the decay. The orientation of the sample means that this valuable information is obtained by singles counting, with no coincidence requirement, and samples having decay rates as low as a hundred s^{-1} can be studied.

Disturbance of the angular distribution caused by exposing the oriented system to an RF field at the nuclear hyperfine splitting frequency is a sensitive detector of NMR in the radioactive parent nuclear ground state and is used to determine this frequency with typical precision of order 0.1%. NMR on Oriented Nuclei (NMR/ON) has been applied to measure the nuclear magnetic dipole moments of a wide range of isotopes from scandium to polonium.

The NICOLE dilution refrigerator has been recently repaired and now we are waiting for the HIE-ISOLDE work on the mezzanine to finish in order to make re-installation off-line and on-line tests. At this time the refrigerator is at ISOLDE in secure boxes.

Status report for IS460

Title: Magnetic moments of High-K isomeric states in Hf isotopes (original proposal with 2 addendums)

Spokesperson: N.J. Stone

Accepted isotopes: ^{169}Hf, ^{177m2}Hf, ^{179}Hf, ^{180m}Hf and ^{182m}Hf

Performed studies: In 2007 and 2009.

For experiment IS460, Magnetic moments of High-K isomeric states in Hf isotopes, there have been three presentations to date (original proposal in 2007, first addendum in 2009 and second addendum at the end of 2010 for 2011). The second addendum was fully accepted, however we have not been able to use the approved shifts because of the problems with a fridge leak.

In the first addendum we reported observed gamma anisotropies in ^{177}Hf isomeric decay and resonance of the ^{177m2}Hf isomer. There had been some problems and more time was requested to explore resonance in ^{179}Hf, ^{180m}Hf and ^{182m}Hf, which was granted.

In the second addendum we reported that we had seen resonance in ^{180m}Hf in Ni. To extract a good ^{180m}Hf moment we asked for time:

(1) to make resonance of ^{177m}Hf in Ni to get a good filed value. That time was also granted and is still on the Isolde books. Attempts to work on ^{182m}Hf were frustrated by weak beams caused by our being scheduled at Isolde II with the buncher in the line;

(2) for exploration of ^{169}Hf in Fe and

(3) for preparation of a ^{179}Hf*Fe* sample to be run-off line.

These are still of interest. The second leads the way to study of lighter Hf isotopes and the third should allow NMR measurement of the ^{179}Hf 25/2- 25 d isomer moment. We wish to make all three measurements, forming a final experiment on proposal IS 460.

Both ^{180m1}Hf and ^{179m2}Hf were part of the original IS 460 experiment. The short look at the lighter isotope ^{169}Hf was not, but makes sense since the equipment and personnel will all be in place. It will establish the viability, or otherwise, of a follow-up proposal for study of light Hf isotopes.

Unfortunately, since the presentation of the second addendum we have not been able to run because of fridge problems. And now we re-affirmed the remaining shifts from the second addendum.

A complete paper with the ^{177m2}Hf magnetic moment and discussion of the g_R factor findings has been recently submitted to Physical Review C.

Future plans with <u>available</u> shifts:

(i) Envisaged measurements and requested isotopes

As it was written in the second addendum to Proposal IS460, request was made and approved for a final two-part experiment under IS 460. The first part, of 6 shifts, will seek NMR/ON of ^{177m2}Hf in nickel to complete the ^{180m1}Hf experiment. The second part, of 6 shifts, will include (1) a first, pilot, measurement of orientation in iron of the ground state of ^{169}Hf, by study of the temperature dependence of the 493 keV gamma anisotropy and (2) preparation of a weak sample of the ^{179}Hf in iron, implanted on-line, for subsequent off-line measurement of the 25 d, 25/2-, isomeric activity, as in the original IS 460 proposal.

It is very important that new Hf experiment be set-up on GPS (there were serious problems in 2010 when the run was set at HRS as the beams were many times weaker than in the 2009 run).

(ii) Have these studies been performed in the meantime by another group?

No

(iii) Number of shifts (based on newest yields) required for each isotope

isotope	yield (/uC)	target – ion source	Shifts (8h)
^{177m2}Hf in nickel	6.1E+04	Ta- hot plasma and CF4 leak	6
^{169}Hf, ^{179}Hf in iron	5.6E+05 4.6E+04	Ta- hot plasma and CF4 leak	6

Total shifts: 12

Status report for IS503

Title: Magnetic dipole moment of the doubly closed-shell plus one proton nucleus ^{49}Sc

Spokesperson: T. Ohtsubo

Accepted isotopes: ^{49}Sc

Performed studies: August 3-11 2010

The experiment has been carried out in August 3-11 2010. The first successful on-line NMR/ON resonance of a ^{49}Sc nucleus in Fe was found using the unique ISOLDE ^{49}Ca beam. The change to ^{49}Ca beam from the originally planned ^{49}K beam was made because concern about unwanted neutron emission that could be damage the detectors close to the body of the fridge. The change of beam meant an order of magnitude lower intensity, but was still sufficient for a successful experiment. The NICOLE fridge operated at fully on-line temperatures around 10mK throughout, low enough to produce almost complete polarization of the implanted ^{49}Sc that experienced the full hyperfine field of 13.17(5) T in the iron sample.

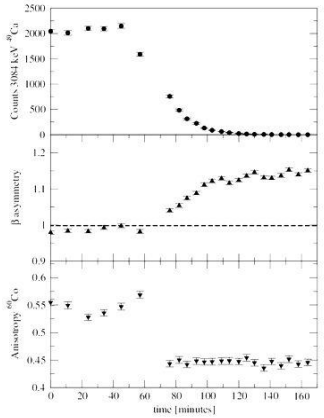

Fig.1 Beta anisotropy during cooldown (top); temperature measured with ^{60}Co (bottom)

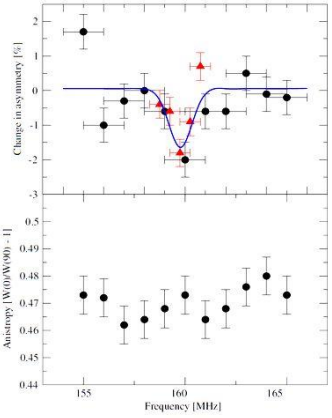

Fig.2 Resonance signal as function frequency (top); beta anisotropy (bottom)

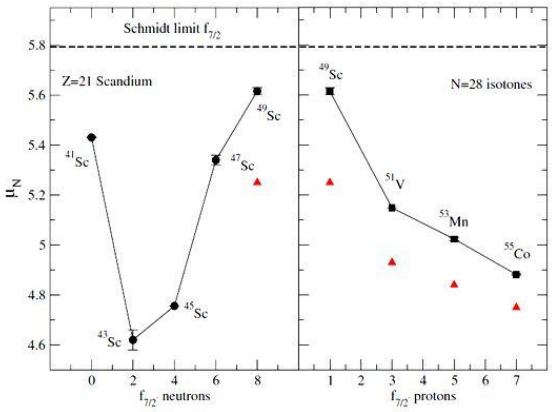

Fig. 3 Magnetic moments of odd-A Sc isotopes (left) and N=28 isotones (right). For details see Ref.1

Analysis of the beta anisotropy (see Fig.1) as a function of applied RF frequency (Fig.2) yielded a magnetic dipole moment $\mu(^{49}\text{Sc})$ = (+) 5.616(25) μ_N. Regardless a somewhat limited statistics, the moment, interpreted in terms of a detailed theory of the structure of the magnetic moment operator, showed excellent agreement with calculated departure from the $f_{7/2}$ Schmidt limit extreme single-particle value.

The results were published: T.Ohtsubo et al., Phys.Rev.Lett. 109, 032504 (2012) (Ref.1).
We regard IS503 experiment as closed.

Future plans with <u>available</u> shifts: We regard IS503 experiment as closed.

References:

[1] Original proposal Magnetic moments of High-K isomeric states in Hf isotopes, 2007.

[2] First addendum to Proposal IS460, 2009.

[3] Second addendum to Proposal IS460, 2010.

[4] Original proposal Magnetic dipole moment of the doubly closed-shell plus one proton nucleus ^{49}S, IS503, 2010.

[5] T. Ohtsubo, N.J. Stone, J.R. Stone et al., Phys. Rev. Let. 109, 032504 (2012).

[6] M. Honma, T. Otsuka, B. A. Brown, and T. Mizusaki, Phys. Rev. C 69, 034335 (2004); M. Honma (private communication).

[7] J. Rikovska et al., Phys. Rev. Lett. 85, 1392 (2000).

Appendix

IS460:

Publications

S. Muto, N. J. Stone, C. R. Bingham, J. R. Stone, P. M. Walker, G. Audi, C. Gaulard, U. Koster, J. Nikolov, K. Nishimura, T. Ohtsubo, L. Risegari, G. S. Simpson, M. Veskovic and W. B. Walters, The magnetic properties of ^{177}Hf and ^{180}Hf in the strong coupling deformed model, submitted to Phys.Rev.C

Theses

Jovana Nikolov, PhD thesis in Serbian

IS503:

Publications

T. Ohtsubo, N. J. Stone, J. R. Stone, I. S. Towner, C. R. Bingham, C. Gaulard, U. Koster, S. Muto, J. Nikolov, K. Nishimura, G. S. Simpson, G. Soti, M. Veskovic, W. B. Walters and F. Wauters, Magnetic Dipole Moment of the Doubly-Closed-Shell Plus One Proton Nucleus ^{49}Sc, Phys.Rev.Letters 109, 032504 (2012).

Theses

Jovana Nikolov, PhD thesis in Serbian