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PROPOSAL TO THE ISOLDE AND NEUTRON TIME-OF-FLIGHT COMMITTEE

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

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Abstract

It is proposed to measure the magnetic moment of ^{49}Sc by the Nuclear Magnetic Resonance on Oriented Nuclei (NMR-ON) method using the NICOLE on-line nuclear orientation facility. ^{49}Sc is the neutron rich, doubly closed-shell, nucleus ^{48}Ca plus one proton. Results will be used to deduce the effective g-factors in the ^{48}Ca region with reference to nuclear structure and meson exchange current effects.

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1. Introduction

The nuclear magnetic moment is a sensitive probe for the study of nuclear structure. The electromagnetic properties of nuclei that are doubly closed-shell plus or minus one nucleon are expected to be most approachable by theory, are most approachable to theory. Experimental ground state magnetic moments of such configurations deviate from single-particle shell model estimates by often significant amounts arising from inaccuracy of the description of the single-particle nuclear state and of the one-body magnetic moment operator. Corrections for these inadequacies, mainly requiring rather involved modeling of second-order core polarization, isobar-current and meson-exchange current effects [1], are treated differently in different models leading to different predictions for magnetic moments of the doubly-closed-shell plus or minus one nucleon, as demonstrated in Fig.1

Honma et al. [2] used an effective GXPF1 interaction in their large-scale shell model calculation in the full pf shell. This interaction contains empirical monopole and pairing corrections to the part of the interaction derived from the nucleon-nucleon potential, however these corrections proved insufficient to account for core excitations across the N or Z=28 shell gap. Their calculation is exact for Sc isotopes (with no truncation of the model space). Both free-nucleon and effective single-particle g-factors were used in their magnetic-dipole moment operator which did not include specifically second-order correction terms. The predictions for the heavy odd-A Ca, Sc and Ti nuclei in this model deviate from experiment by plus/minus 6% on average that is plus/minus 0.3 μ_N in the estimate for ^{49}Sc.

The work of Speidel et al. [3] describes shell model calculations with four effective interactions, FPD6, KB3, VHG and FPY. The configurations included where the full $f_{7/2}$ sub-shell, allowing particle excitations to $p_{3/2}$, $f_{5/2}$ or $p_{1/2}$. Core polarization effects were studied both in shell model diagonalisation and in first-order perturbation theory. These methods were used to interpret the trends in experimental g-factors of the first 2^+ states in even-even Ti, Cr and Fe nuclei in this region. Using the results of this study, odd-A g-factors were deduced for ^{49}Sc for the four interactions, with a range shown in Fig.1 [KB3 and VHG gave the same, central, result]. The uncertainty is of order 0.4 $\mu_{N.}$ Speidel et al. also estimated the dependence upon the number of particles excited from the $f_{7/2}$ subshell to the remainder of the fp shell. This effect, considered only for the FPD6 interaction, produced a smaller additional spread in moment predictions of plus/minus 0.07 μ_N for one, two and three particles excited outside the $f_{7/2}$

subshell.

A precise measurement of the magnetic moment of the ground state of ^{49}Sc may well inspire a more microscopic calculation, applicable at present only to isotopes having single nucleons outside a double-magic core, of the effective g-factors in the fp shell in the spirit of Towner and Khanna [1], similar to that performed for ^{67}Ni [4] as well as contribute to improvement of the large scale shell model calculation in the fp shell outlined above.

To add valuable new input near ^{48}Ca we propose measurement of the magnetic moment of ^{49}Sc (I^{π} = 7/2^{-}, $T_{1/2}$ = 57 m) by the Nuclear Magnetic Resonance on Oriented Nuclei (NMR-ON) method using the NICOLE on-line nuclear orientation facility.

2. Experimental Background

We propose to measure the magnetic moment of ^{49}Sc with good precision. Table 1 gives a list of the known magnetic moments of odd-*A* Sc isotopes. Figure 1 shows these values with several theoretical shell model calculations of ^{49}Sc [2,3].

Table 1: Magnetic moments of odd-*A* Sc isotope ground states – all single 7/2^{-} proton.

A	Neutrons	$T_{1/2}$	magnetic moment [μ_N]
41	$(7/2^{-})^{0}$	596 ms	5.431(2)
43	$(7/2^{-})^{2}$	3.891 h	+4.62(4)
45	$(7/2^{-})^{4}$	Stable	+4.756487(2)
47	$(7/2^{-})^{6}$	3.345 d	5.34(2)
49	$(7/2^{-})^{8}$	57.2 m	to be measured

Table 2: Magnetic moments of odd-Z, 7/2- ground states, N = 28 isotopes.

Isotope	*Protons:*I^{π}	$T_{1/2}$	magnetic moment [μ_N]
^{49}Sc	$(7/2^{-})^{1}$ 7/2^{-}	57.2 m	to be measured
^{51}V	$(7/2^{-})^{3}$ 7/2^{-}	3.891 h	+5.1487057(2)
^{53}Mn	$(7/2^{-})^{5}$ 7/2^{-}	Stable	+5.024(7)
^{55}Co	$(7/2^{-})^{7}$ 7/2^{-}	3.345 d	+4.882(3)

Table 2 shows the systematic variation of magnetic moments of other, f-subshell, 7/2^{-} ground state magnetic moments. This valuable series will also be completed, with the inclusion of the $(7/2^{-})^{1}$ element, by the measurement of ^{49}Sc.

Recently we observed NMR-ON resonances for several Sc isotopes in iron [5,6]. The hyperfine field at Sc in iron was also measured. The observed hyperfine field for ^{47}Sc is $B_{hf}(^{47}\mathrm{Sc}Fe)$ = –13.17(5) T [5]. This precise field value means that observation of NMR/ON in ^{49}Sc will yield the moment with an accuracy of better than 1.0 % [any hyperfine anomaly between the two isotopes will be less than 0.1%]. The expected frequency, based on this field and the model moment estimates is about 156 MHz, well within the range accessible at NICOLE.

An essential of standard On-Line Nuclear Orientation experiments is that the half-life of the isotope under study is comparable with or longer than the spin-lattice relaxation time with which the nuclei cool to the iron lattice temperature. We observed the effective relaxation time for ^{47}Sc which has the same spin and parity as ^{49}Sc, to be $T_1'(^{47}\mathrm{ScFe})$ = 350(70) s at 10 mK with the external magnetic field of B_0 = 0.2 T. For ^{49}Sc, the relaxation time is expected to be similar to this value, since the magnetic moment of ^{49}Sc is expected to be close to that of ^{47}Sc and is thus adequately shorter than its half-life of 57.2 m.

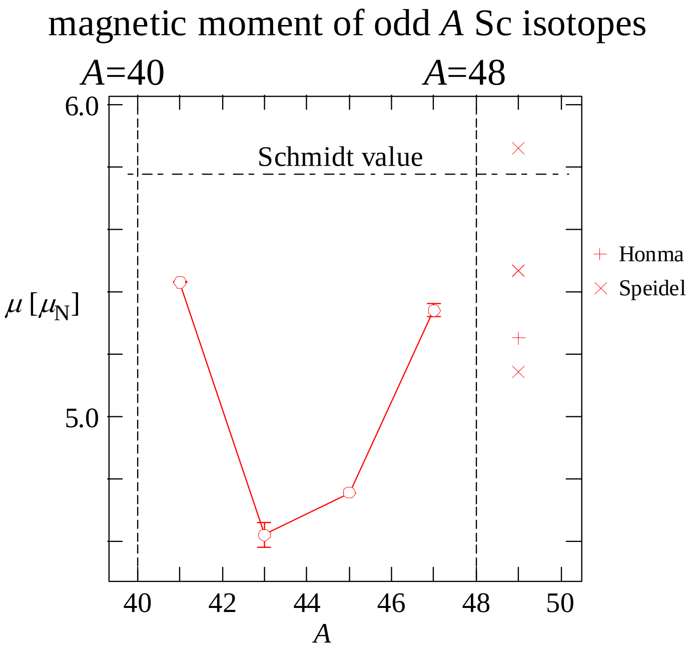

Figure 1: Magnetic moments of odd-*A* Sc isotopes and model predictions for ^{49}Sc [2,3].

Production of Sc beams

Table 2 shows the yields for the Sc isotopes from the ISOLDE yield database. However the numbers for the heavier isotopes are for a Ta target. There is no data for the pure beta emitter ^{49}Sc because of the presence of many activities at the mass 49 position from multiply charged ion species from which any ^{49}Sc component cannot be separated. Such a beam, with unknown, complex contamination, would not be acceptable for an NMR/ON experiment dependent upon beta detection. Instead we propose to use either a Ti foil target plus CF_4 leak plus plasma source for which the estimated yield is 1 10^6/μC beam, or a standard UCx target with surface ionizer which produces ^{49}K ($T_{1/2}$ 1.24 s) and ^{49}Ca ($T_{1/2}$ 8.8 m) with estimated rates such as to produce ~ 5 10^5/μC of ^{49}Sc by decay [7]. The beta activities from these parent isotopes will not orient as their lifetimes are shorter than their relaxation times and they will thus not contribute to the measured polarization or to resonance detection. Should the contaminant beta activity prove troublesome a source will be accumulated, then the beam closed off, whereupon the longer lived ^{49}Sc rapidly dominates the detected beta decay, this cycle being repeated as necessary.

Table2: Yields of Sc isotopes at ISOLDE.

Nucleus	yield at ISOLDE (ions/μC)	target material
^{47}Sc	3.0E+7	Ti
	2.5E+6	Ti
^{48}Sc	3.0E+7	Ta
^{50}Sc	3.6E+3	Ta

3. Nuclear Orientation Experiment

We propose to use the NMR-ON method, detecting resonant destruction of asymmetry of the β rays from ^{49}Sc nuclei, implanted at low temperature in a pure iron ferromagnetic host. Figure 2 shows the decay scheme of ^{49}Sc nucleus. Although the spins/parities of ^{49}Sc and ^{49}Ti are both $7/2^-$, their isospins are respectively 7/2 and 5/2. The allowed beta transition is dominated by the Gamow-Teller matrix element and is estimated to show a 0°/180° asymmetry of about 30% at 15 millikelvin, based on the known field and an estimated moment of 5.3 μ_N

The NICOLE ^{3}He/^{4}He on-line dilution refrigerator will be used with β-ray detectors inside the cryostat at 0° and 180° to the polarization axis, as was done for on-line NMR/ON of ^{67}Ni at ISOLDE [4]. External plastic scintillators may alternatively, or in addition, be used for detection of the high energy betas which can penetrate the thin cryostat windows [8]. External HP Ge detectors at 0° and 90° to the polarization axis will be used for gamma detection. A modulated RF field produces resonant absorption between the hyperfine-split substates of the oriented nuclei. This resonance can be detected by reduction in the observed β-ray asymmetry. The temperature of the sample will be monitored using γ-transitions in an oriented ^{60}Co*Fe* sample soldered to the cold-finger of the dilution refrigerator.

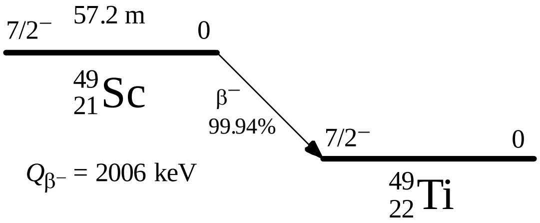

Figure 2: Decay scheme of ^{49}Sc.

4. Experimental Procedure and beam time request

We need time to set up the beam and to observe the asymmetry as the dilution refrigerator is cooled from close to 1 K in order to get good base temperature knowledge of β-ray asymmetry from the somewhat mixed source. Once this is established, the resonance search can be initiated. A reasonable estimate for the experiment is 8 shifts. We propose to collect a source of 3.345d ^{47}Sc, cold implanted into iron, for subsequent off-line NMR-ON measurement for careful calibration of the system. For this collection we request 4 shifts, giving a total of 12 shifts.

Support from CERN: For the experiments proposed here, we will need liquid nitrogen for the detectors and liquid nitrogen and liquid helium for the ^{3}He/^{4}He dilution refrigerator.

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