Brief Reports

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On-line nuclear orientation of cesium isotopes and the magnetic moment of $^{118}Cs^m$

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Cesium isotopes have been oriented in iron, following on-line implantation at temperatures down to 8 mK. Analysis of results on transitions in the decay of $^{119}Cs^m$, $^{120}Cs^g$, and $^{121}Cs^m$ yields the hyperfine field $B_{hf}(CsFe) = (+)40.8(7)$ T. A repeated sequence of short pulse implantation followed by relaxation has been used to measure the Korringa constant, $C_K = 0.059(15)$ K s for $^{121}Cs^m$ in iron. The magnetic moment of $^{118}Cs^m$ ($T_{1/2} = 17$ s), previously unknown, is deduced to be $|\mu| = 5.4(11)$ μ_N, which identifies the presence of the $g_{9/2}$ intruder Nilsson orbital.

Low temperature nuclear orientation provides a powerful method for measuring magnetic dipole moments of nuclei far from stability, provided (i) rapid (i.e., on-line) implantation into a cold host can be performed, (ii) the implanted atoms experience a sufficiently large and well-defined hyperfine magnetic field, and (iii) the thermal relaxation time of the implanted ions is short compared to their half-life. The first of these requirements is satisfied at the Daresbury On Line Isotope Separator—Cryogenic On Line Device (DOLIS—COLD) facility,[1] which facilitates continuous implantation into a metal sample, the sample being cooled to temperatures as low as 7.6 mK by attachment to the mixing chamber of a $^3He/^4He$ dilution refrigerator. The present paper reports on the establishment of the latter two requirements for cesium ($Z = 55$) isotopes for the first time, together with a magnetic moment measurement of the metastable state ($T_{1/2} = 17$ s) of the highly neutron-deficient isotope $^{118}Cs^m$.

The cesium activities were produced by the reactions of 165–175 MeV $^{32,34}S$ ions on a ^{93}Nb target which formed the entrance window of a FEBIAD (Ref. 2) ion source. Beams of Cs^+ ions are extracted with efficiency $\geq 50\%$, accelerated to 60 keV, mass separated and implanted into a polycrystalline rolled annealed iron foil soldered to the cold finger of the dilution refrigerator. The iron was polarized by an external magnetic field of 0.7 T. Gamma-ray intensities were measured with four high-resolution Ge detectors ($\sim 25\%$ relative efficiency) 7.8 cm from the implanted foil; two detectors were axially symmetric with respect to the magnetic field and two were perpendicular to this axis (equatorial). The hyperfine field acting on cesium in iron was deduced from axial/equatorial intensity ratios [anisotropy $= \{W(0)/W(90) - 1\}\%$, where $W(\theta)$ is the normalized count rate at an angle θ to the orientation axis], measured as a function of temperature, for three relatively long-lived cesium isotopes with known magnetic moments,[3] $^{119}Cs^g$ ($T_{1/2} = 44$ s), $^{120}Cs^g$ ($T_{1/2} = 64$ s), and $^{121}Cs^m$ ($T_{1/2} = 120$ s), for which the finite relaxation time (see below) is not a significant problem. The specific transitions used for the field measurement are listed in Table I. The table also includes the observed anisotropy at 10 mK, and the field deduced in each case. The temperature-dependent anisotropies were analyzed using the simple model of a fraction f of implants which experience the full hyperfine field, with the remainder in zero field. Four examples of the fits obtained are shown in Fig. 1. The weighted average result, corrected for applied field, is $B_{hf}(CsFe) = (+)40.8(7)$ T, with $f \sim 50\%$. (The precision of the f value is limited by lack of detailed decay scheme knowledge; this, however, has little effect on the fitted B_{hf} result.) This hyperfine field is about 50% greater than that reported previously from Mössbauer studies, which gave the positive sign assumed here.[4] The difference in magnitude is not at present understood. From a pragmatic point of view, however, we can use the new field to extract magnetic moments from measurements on other isotopes by the same nuclear orientation technique.

TABLE I. The γ transitions used to determine the Cs*Fe* hyperfine field.

Isotope	E_γ	$I_i \rightarrow I_f$	Anisotropy (%)	B_{hf} deduced (T)
$^{121}Cs^m$ $(\frac{9}{2}^+)$	196	$\frac{7}{2}^- \rightarrow \frac{5}{2}^+$	+25(1)	36.1(2.4)
$\lvert\mu\rvert = 5.41(3)\ \mu_N$	179	$\frac{7}{2}^+ \rightarrow \frac{5}{2}^+$	+80(1)	40.7(1.0)
	460	$\frac{7}{2}^+ \rightarrow \frac{5}{2}^+$	+180(3)	41.0(1.1)
	280	$\frac{7}{2}^+ \rightarrow \frac{7}{2}^+$	−30(3)	51.2(7.2)
	234	$\frac{9}{2}^+ \rightarrow \frac{5}{2}^+$	+105(5)	38.3(2.6)
$^{120}Cs^g$ (2^+)	322	$2^+ \rightarrow 0^+$	−12.5(0.6)	38.0(2.6)
$\lvert\mu\rvert = 3.88(2)\ \mu_N$	473	$4^+ \rightarrow 2^+$	−25(1.5)	42.3(3.1)
$^{119}Cs^g$ $(\frac{9}{2}^+)$	176	$\frac{7}{2}^- \rightarrow \frac{5}{2}^+$	+20(2)	41.8(6.6)
$\lvert\mu\rvert = 5.46(3)\ \mu_N$	225	$\frac{7}{2}^+ \rightarrow \frac{5}{2}^+$	+65(2)	44.9(2.2)

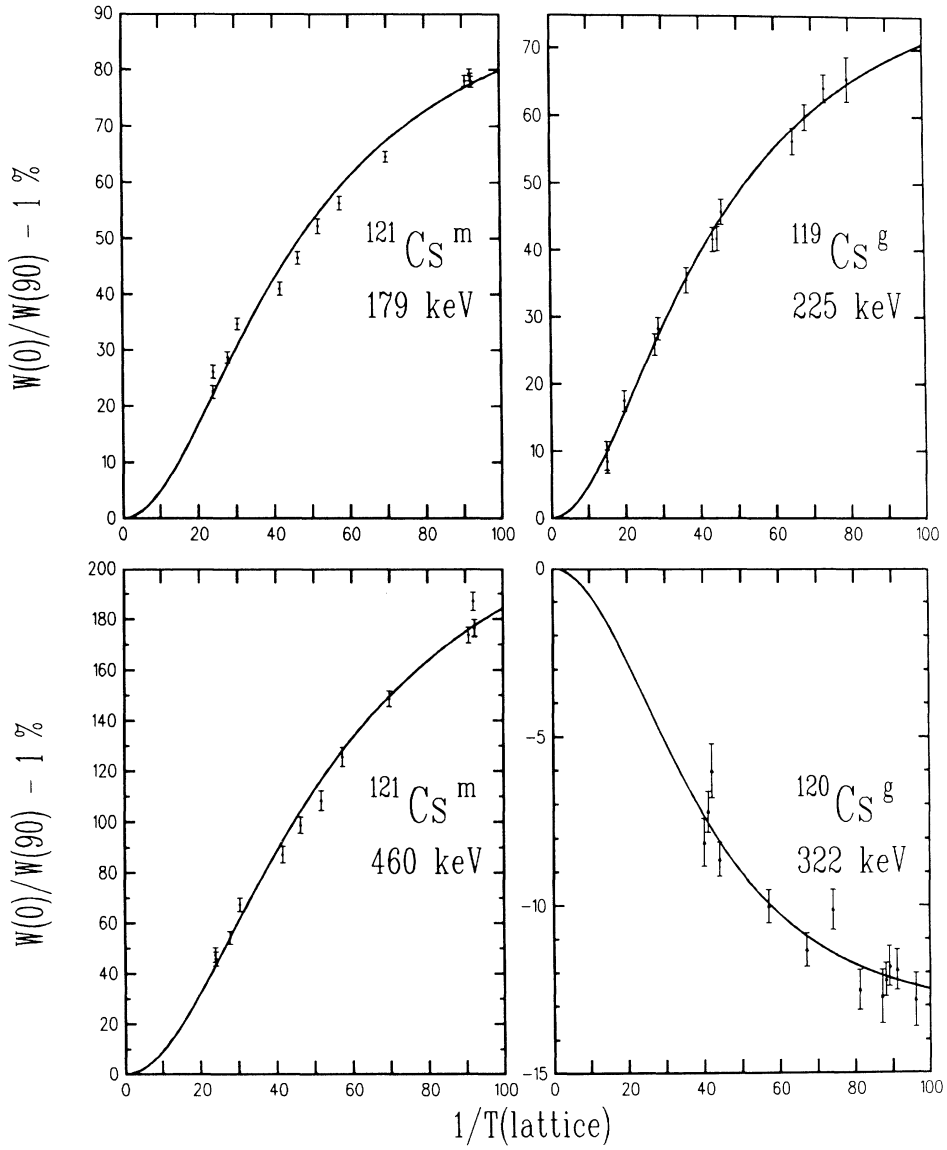

FIG. 1. Orientation data on $^{119}Cs^g$, $^{120}Cs^g$, and $^{121}Cs^m$ which yield B_{hf}(Cs*Fe*)= +40.8(7) T.

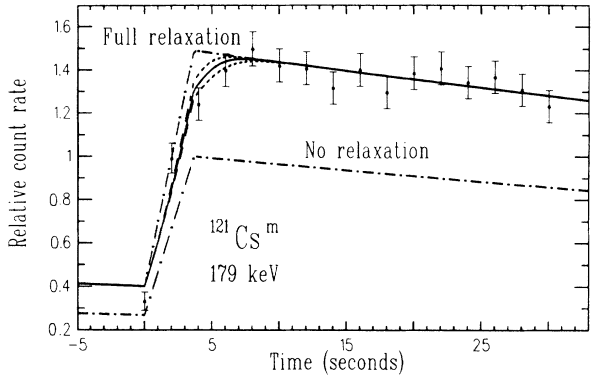

FIG. 2. Relaxation of $^{121}Cs^{m}$ implanted into iron at 8 mK. The full (and dotted) lines correspond to a fit to the data points, with $T_1 = 2 \pm 1$ s, to be compared with the upper and lower dot-dashed lines, corresponding to the limiting cases of full and no relaxation, respectively.

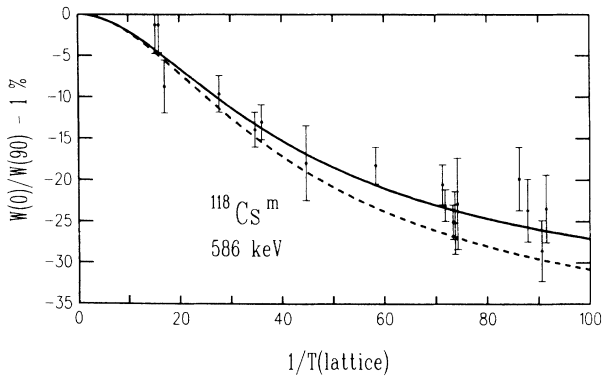

FIG. 3. Orientation data on $^{118}Cs^{m}$ fitted for the nuclear magnetic dipole moment. For details see the text.

In aiming to extend magnetic moment measurements to other isotopes with shorter half-lives, it is necessary to know the spin-lattice relaxation time, T_1, of the implanted nuclei. This arises since, unless $T_1 \ll$ the isotope half-life, correction must be made for nuclei which decay prior to reaching the temperature of the cold iron foil. Relaxation occurs via the conduction electrons, and the rate is characterized by the Korringa constant C_K;[5] once C_K is measured for one Cs isotope (1) in an iron host, its value for any other isotope (2) is given by $C_K(2) = (g_1/g_2)^2 C_K(1)$ (where $g = \mu/I$). Estimates suggest T_1 of order seconds for cesium in iron close to 10 mK.[6]

To establish C_K a new slow pulsing technique of source preparation was applied to $^{121}Cs^{m}$, chosen for its high yield and large anisotropies (see Table I). In a repeated cycle, activity was implanted for a period of 4 s into the cold foil at 8 mK, then the beam was shut off and the axial count rate observed as the source cooled and decayed. This was repeated at intervals of 240 s for several hours, the data obtained in successive cycles being added together. The summed data (see Fig. 2) showed the effective relaxation time to be of order 2 s, and the fully fitted curve yielded $C_K = 0.059$ (15) K s for $^{121}Cs^{m}$ in iron.

This value of C_K, duly scaled for nuclear spin and extracted magnetic moment of $^{118}Cs^{m}$, was then used, with B_{hf} of (+)40.8(7) T, to fit the observed temperature dependence of the anisotropy of the 586 keV 6^+ to 4^+ transition in the decay of $^{118}Cs^{m}$ ($T_{1/2} = 17$ s) (see Fig. 3). The magnetic moment is found to be $\mu = \pm 5.4(11)\ \mu_N$. Correction for incomplete relaxation was clearly required in this case, and in the figure the full curve includes the correction, whilst the dotted curve is the expected anisotropy for the same moment value for the case of immediate relaxation.

This is the first measurement of the moment of $^{118}Cs^{m}$. It is clear that this isomer has high spin (probably $I = 6$) from its decay to high spin states in ^{118}Xe, and the high moment, despite its relative inaccuracy, clearly establishes that the proton part of the nuclear configuration comes from the $g_{9/2}$ intruder Nilsson state $\pi\frac{9}{2}^+[404]$, which is brought close to the Fermi surface only at large deformation (≥ 0.25). Large deformation in high spin isomers has been deduced in heavier Cs isotopes from measured isotope shifts. Shape coexistence has been demonstrated, for example, at mass 122 in that the metastable $I = 8$ isomer is considerably more deformed than the $I = 1$ ground state.[3] Recent data at mass 118 show, however, that the $I = 2$ ground state is also strongly deformed,[7] so at this mass all states having close to spherical configurations must be at higher excitation.

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