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MEASUREMENT OF THE NUCLEAR $g_\text{n}$ FACTOR BY LASER OPTICAL PUMPING AND LARMOR PRECESSION IN A FAST ATOMIC BEAM

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The extraction of the nuclear dipolar magnetic moment $M_n$ from the hyperfine structure constants requires the calculation of the electronic contribution and this limits the accuracy which moreover depends on the hyperfine anomaly. To overcome these difficulties, we present an original method of determining the nuclear Landé factor $g_\text{n}$ for diamagnetic atoms. This new technique is illustrated with two experiments using respectively the odd-A isotopes $^{135,137}$Ba ($I = \frac{3}{2}$ - test experiment /1/) and the odd-A isotopes $^{213,225}$Ra ($I = \frac{1}{2}$ - this experiment was carried out at C.E.R.N. on line with the ISOLDE mass separator). The method, based on the fast atomic beam laser spectroscopy technique, consists of detecting the in-flight Larmor precession of the nuclear magnetic moment in a static field, via the fluorescence induced by a resonant laser light.

The experiments are as follows (see Figure 1) : $\text{Ba}^+$ ions ($\text{Ra}^+$) accelerated to energies in the neighbourhood of 60 keV are converted into a quasi-monokinetic neutral beam in a charge-exchange cell. The atomic beam is overlapped by a collinear light beam from a single mode C.W. dye laser, resonant with the transition $^1S_0(F=3/2) \rightarrow ^1P_1(F'=1/2)$ ($^1S_0(F=1/2) \rightarrow ^1P_1(F'=1/2)$). The optical pumping produced by the $\Pi$-polarised ($c^\star$-polarized) light depletes the Zeeman sublevels $M_F = \pm \frac{1}{2}$ ($M_F = -1/2$), leading to a very weak fluorescence signal if the laser power is sufficient to induce several pumping cycles before the observation zone (see Figure 2).
A static magnetic field $B_0$ perpendicular to the quantization axis which determines the $\Pi$ or $\sigma^+$ character of the light, is applied just before the observation zone. The in-flight precession of the aligned (oriented) nuclear magnetic moment $\vec{M}_n$ around $\vec{B}_0$ repopulates the sublevels $M_F = \pm 1/2 \ (M_F = -1/2)$ periodically as a function of $B_0$ at the exit of the electromagnet, and the fluorescence signal appears as a fringed pattern from which the $g_I$-value can be deduced. More precisely the fluorescence signal takes the form:

$$S = A + B \cos(2\phi)$$

where $\phi = (g_I \mu_N B_0 / 2\hbar \nu) \int f(x) dx$. $\mu_N$ is the nuclear magneton, $\nu$ the atomic velocity, $B_0 f(x)$ the magnetic field at position $x$ along the beam path, $B_0$ being the maximum field in the electromagnet where $f(x) = 1$. To avoid the very arduous determination of $f(x)$, we adopt a comparative method where the fringed pattern of a second atom or isotope, for which the $g_I$-value is known, is used to calibrate the magnetic field.

Typical recording of the fluorescence signal for the $^{225}{\text{Ra}}$ isotopes is displayed in Figure 3. $^{137}{\text{Ba}}$ and $^{139}{\text{Ba}}$ isotopes were used to calibrate the magnetic field during the Ra-experiment which is the first direct measurement of the nuclear magnetic moments of $^{213,223}{\text{Ra}}$. The results $\mu_I(213{\text{Ra}}) = 0.6133(18) \ \mu_N$ and $\mu_I(225{\text{Ra}}) = -0.7338(15) \ \mu_N$ provide an accurate test of ab-initio and semi-empirical calculations from optical hyperfine structures in Ra I and Ra II. This work, submitted to Physical Review Letters, was carried out in collaboration with: E. ARNOLD $^1$, W. BORCHERS $^1$, H.T. DUONG $^2$, P. JUNCAR $^3$, S. LIBERMAN $^2$, W. NEU $^1$, R. NEUGART $^1$, E.W. OTTEN $^1$, J. PINARD $^2$, G. ULM $^4$, K. WENDT $^1$ and the ISOLDE Collaboration, C.E.R.N. Geneva, Switzerland.
Figure 3: Fluorescence signal obtained with $^{225}$Ra as a function of the magnet current.

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Reference