# THE MAGNETIC MOMENT OF THE FIRST-EXCITED $2^+$ STATE IN $^{18}O$

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The magnetic decoupling method, applied to highly ionized nuclear-excited $^{18}O$ atoms, has yielded for the 198 MeV $2^+$ state the value $|g| = 0.35 \pm 0.04$. In conjunction with the recently determined negative sign, this value agrees well with weak *j-j* coupling predictions.

The study of hyperfine interactions in isolated ions has been extended in recent years to the highest ionization states of light atoms ($Z = 6 - 12$) [1,2]. The large magnetic fields associated with the single-electron ionic ground-state [3] have enabled the determination of nuclear magnetic moments for levels with lifetimes in the $10^{-12}$ s range [4].

Indeed, the *g*-factor of the $^{18}O\ (2^+)$ level was the first to be determined in such an environment [5]. In that measurement, the time-integral version of the PAC technique was applied to magnetically separated $^{18}O^{7+}$ ions recoiling into vacuum. As the fraction of ions in the ground state (with which the large HF field of 86 MG is associated [3]) is not very well known, the *g*-factor could only be determined within rather broad limits ($|q| = 0.20 - 0.36$). As these limits depart considerably from the *j-j* coupling prediction of $-0.76$ for a pure $d_{5/2}^2$ neutron configuration, a determination of the sign and precise absolute magnitude were called for. A recent measurement utilizing the transient field effect on recoil in polarized iron has shown the sign to be negative [6].

The following describes a PAC measurement of $|g|$ by means of the magnetic decoupling method, in which the HF-interacting ionic system is subjected to an external magnetic field, applied along the beam direction. A preliminary result has been reported in ref. [16]. In the field range intermediate between free HF coupling and the Paschen-Back effect (which corresponds to an unperturbed correlation) the perturbation is governed by the ratio of the nuclear and electron magnetic moments. The method has recently been successfully implemented in determining the *g*-factor of the $^{16}O\ (3^-)$ level in ions of low charge [7]. It has the advantage over the time-integral version of PAC (as far as data interpretation is concerned) of reduced sensitivity [4] to the abundances of the perturbing electron configurations in the ionic ensemble.

The $^{18}O$ first $2^+$ level was populated in the reaction $^4He(^{18}O, \alpha)^{18}O$ using a $^{18}O^{6+}$ beam of 200 nA at a bombarding energy of 44 MeV from the Köln FN

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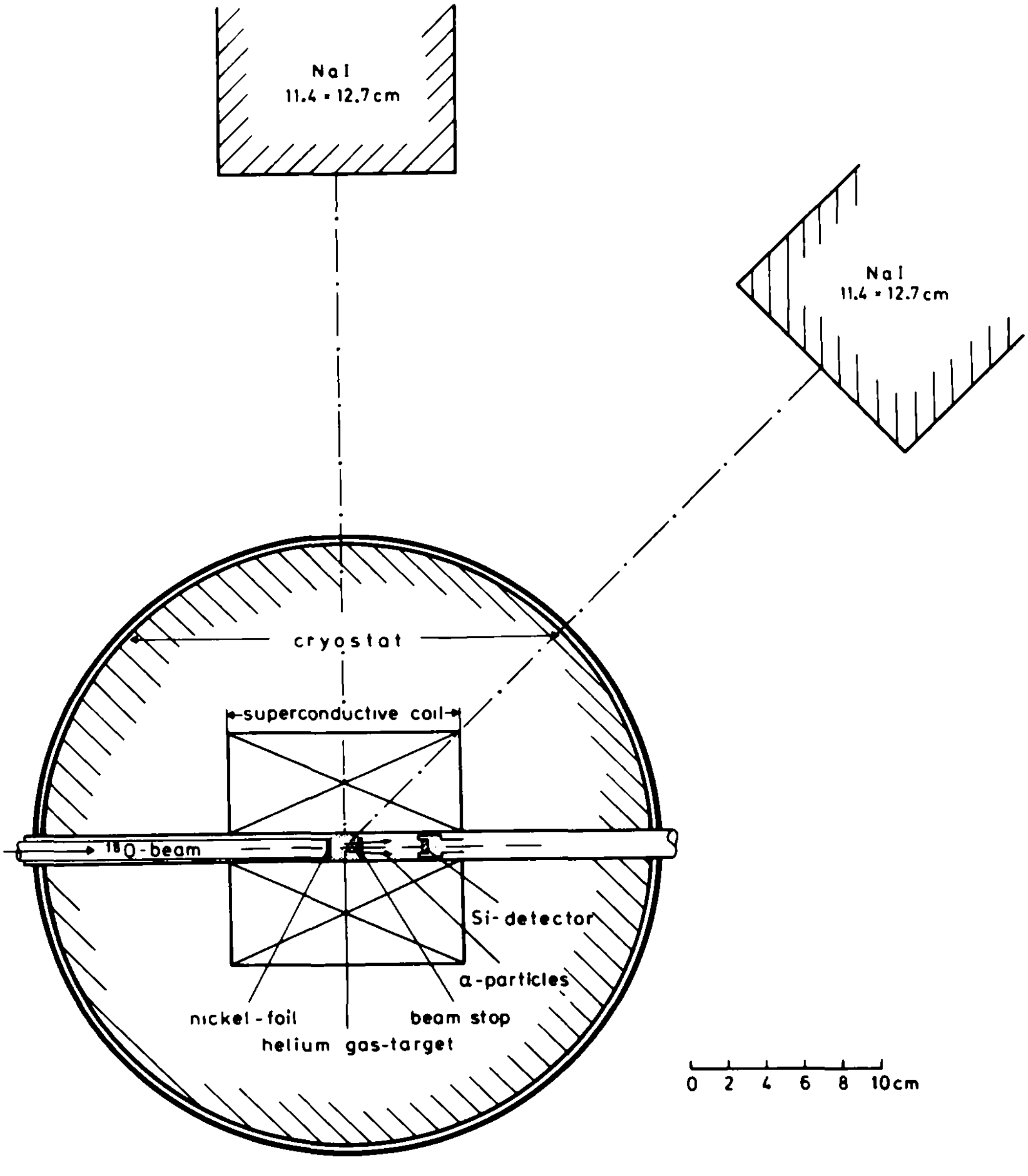

Fig. 1. Schematic view of the experimental set-up

Tandem accelerator. The $^4$He gas target was contained between a nickel entrance window (500 $\mu$g/cm$^2$ thick) and a gold beam stop (40 mg/cm$^2$ thick). The 1.98 MeV $\gamma$-rays were detected in two 11.4 × 12.7 cm NaI (Tl) scintillators in coincidence with inelastic knock-on $\alpha$-particles leading to the first excited state, observed in a 500 $\mu$m thick silicon surface-barrier detector located 40 mm from the centre of the target. The target and particle-detector assembly was mounted inside the 12 mm diameter room-temperature bore of a 100 kG superconducting magnet (fig. 1) The scintillators were placed at a face distance of 40 cm from the target. This distance was dictated by the residual fields at the photomultipliers (despite elabo-

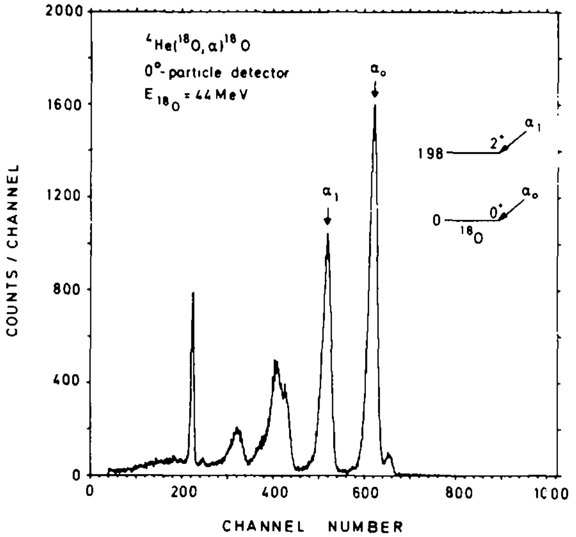

Fig. 2. Spectrum of knock-on α-particles

rate magnetic shielding) rather than by finite-geometry considerations. No influence of the external field on the particle detector was observed. A typical particle spectrum is shown in fig. 2. The maximum gain change of the scintillators over the whole field range was 20% and no long-term magnetization effects were encountered. The fast timing of 5 ns FWHM resolution was stable to within 2 ns throughout. The constancy of the relative scintillator efficiency was verified with singles spectra of a $^{60}$Co source at each field setting before and after the coincidence run.

The experiment consisted in measuring the coincident γ-ray counting rate ratio $R(45°/90°)$ as function of the applied longitudinal field, which was varied between 0 and 82 kG. The absolute anisotropy $W(45°)/W(90°)$, plotted in fig. 3 as a function of the external field, was determined by normalizing each counting-rate ratio to the zero-field value measured in absorption-free conditions (without the magnet). A small correction for the motion of the γ-ray source was also applied.

The anisotropy of the unperturbed correlation was measured on recoil in a metal backing. This was accomplished with the aid of a $^4$He target (4 μg/cm$^2$ thick) implanted at 60 keV into a 4.5 mg/cm$^2$ thick nickel foil. The target was bombarded at the same $^{18}$O energy and in identical detector geometry in a highly pure $^3$He

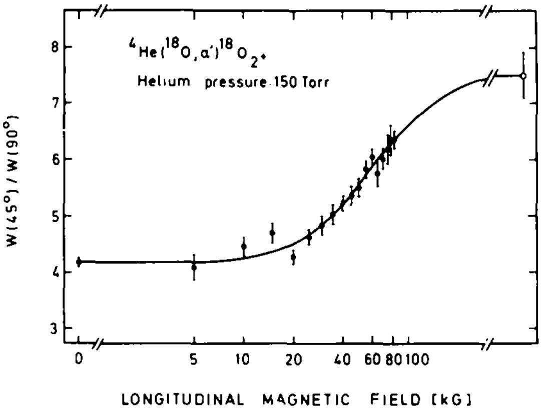

Fig. 3. Gamma-ray anisotropy versus applied magnetic field. The unperturbed value (open circle) was obtained on recoil in nickel. The solid line is a least-squares fit to the data.

environment (for cooling) at a pressure of 40 torr. Under these conditions, no deterioration of the thickness or position of the $^4$He layer in the Ni foil were detectable over a two-day running period with a beam of 200 nA. The sharp energy dependence of the particle yield ratio $\alpha_1/\alpha_0$ served to set and monitor the effective bombarding energy.

For such a short-lived nuclear level ($\tau_{2^+}$ = 3.4 ps [8,9]) it has been demonstrated [4,5] that the perturbation in free ions is almost exclusively associated with the single-electron-ion ground-configuration. Indeed, the strong zero-field perturbation observed in the present work confirms this and implies that about 40% of all ions occupy this configuration over the nuclear lifetime. This value is in line with known charge-state abundances [10] and the well-established predominance of ionic ground-state formation [4]. In this context, it should be borne in mind that the $^{18}$O ions emerge from the nickel entrance window into the gas at a velocity $v_i$ = 0.073 $c$ and are abruptly decelerated to $v_f$ = 0.048 $c$ in the nuclear collision. Subsequent ion-atom collisions within the nuclear lifetime can be considered infrequent and insignificant at the operating helium pressure of 150 torr on the basis of the following external data:

a) measured charge-exchange cross sections [11];

b) a very weak pressure dependence of the perturbation observed in similar ions [12].

The external field therefore acts on an ensemble of nuclear-excited ions undergoing static hyperfine coupling.

As outlined in ref. [7], the deduction of the $g$-factor from the data involves the diagonalization of the following Hamiltonian for each value of the applied field:

$$\mathcal{H} = a(\boldsymbol{I}\cdot\boldsymbol{J}) - H_{\mathrm{ext}}(\boldsymbol{\mu}_I + \boldsymbol{\mu}_J)_z$$

where $\boldsymbol{I}(\boldsymbol{\mu}_I)$ and $\boldsymbol{J}(\boldsymbol{\mu}_J)$ are the nuclear and electron angular momentum (magnetic moment) operators and $a$ is the free-ion HF coupling constant (for the single-electron oxygen-ion ground state, $a = 5.40 \times 10^{-4} \times g_I$ [eV] [3]). The external field is applied along the beam direction which, in this detector geometry, coincides with the symmetry axis of nuclear alignment (chosen for convenience as the $z$-direction).

The interacting system is not isotropic, as the external field introduces a preferred direction. Consequently, in the intermediate coupling region, the angular correlation:

$$W(\theta_\gamma) = \sum_{k,k'} A_k(\alpha) A_{k'}(\gamma) G_{kk'} P_{k'}(\cos\theta_\gamma)$$

includes terms with $k \neq k'$.

The curve through the data in fig. 3 represents a least-squares fit with the nuclear $g$-factor $|g_I|$ and the effective occupation probability $\alpha(1\mathrm{s})$ of the single-electron-ion ground state as parameters. This yields $|g_I| = 0.35 \pm 0.04$ and $\alpha(1\mathrm{s}) = 0.38 \pm 0.02$. The error matrix shows that these values are virtually uncorrelated [13]. Moreover, the interpretation is insensitive to the precise values of characteristic time parameters such as the nuclear lifetime and atomic feeding times. The value and precision of the $g$-factor is unaffected in this particular case by the inclusion of the unperturbed value in the fit, although a factor of two improvement in precision would be obtained for a similar improvement in the unperturbed value.

The deduced value of $|g_I|$ is in good agreement with weak $j$-$j$ coupling calculations of Ellis and Engeland [14], in which the predominant $d^2_{5/2}$ neutron configuration is accompanied by sizeable admixtures of other configurations. This calculation predicts correctly the magnetic moments of the first $2^+$ and $4^+$ [15] levels and also their mean lifetimes, which are related to the E2 matrix elements for the transitions $4^+ \rightarrow 2^+$ and $2^+ \rightarrow 0^+$.

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