$^{17}O^-$ photodetachment microscopy and hyperfine structure

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Laser photodetachment of O^- ions just above the threshold ($\epsilon \cong 0 - 1$ cm^{-1}) has been performed in the presence of a uniform electric field ($F \cong 1 - 4$ V/cm) using a high spatial resolution electron detector set half a meter from an O^- ion beam to map out the ejected electron's wave function. Propagation does not alter the stationary structure of the electron wave function in the direction orthogonal to the detachment motion. The observed dark and bright rings of the electron current density pattern are interpreted as direct imaging on an enlarged scale of the wave function of the electron just at the exit of the negative ion. This is why the device is called a "photodetachment microscope" [1]. The images of O^- resulting from s-wave photodetachment can also be viewed as direct experimental representations of the Green function of the uniform acceleration problem, without any particular link to atomic physics. Close agreement of the measured distributions with the exact expression of this wave function is observed in the case of ^{16}O and ^{18}O, and this method was successfully applied for the determination of the electron affinities and the isotopic shift of these isotopes [2, 3].

Detachment of $^{17}O^-$ presents special interest owing to hyperfine structure due to the nuclear spin $I = 5/2$ of this atom. Despite its weak abundance (0.037%) and the low intensity of the ion beam (<1pA), some images could be obtained with one-hour recordings. A CW single-mode sapphire-titanium laser provides the excitation light (848.5 nm, 1 W). The absolute laser wavenumber is measured accurately by a lambdameter, which compares the laser wavelength to the one of an I_2-stabilised He-Ne laser. Elimination of the unknown Doppler angle between the laser beam and the ion beam is achieved by a double-pass scheme of the laser beam with light focussing both at the forth and back crossings.

Surprisingly, the recorded images exhibit contrasted rings in spite of the expected blurring due to hyperfine structures of the ground states of $^{17}O^-$ and ^{17}O. Accurate measurements of the hyperfine structure of the ^{17}O ground state have been achieved by means of tunable far-infrared spectroscopy [4], but there exist presently no experimental results on the $^{17}O^-$ ground state.

The hyperfine parameters have been evaluated using the *ab initio* multiconfiguration Hartree-Fock wave functions of ref. [3] for both the neutral atom and the negative ion. The agreement between theory (present work) and experiment [4, 5] for the magnetic dipole hyperfine parameter A_J is rather good for ^{17}O $2p^4\ ^3P_2$, but less satisfactory for the $J = 1$ component due to

strong cancellation between the spin-dipole and (orbital + contact) contributions. The combination of the *ab initio* electric field gradient with the experimental electric quadrupole hyperfine constant [5] allows to extract the nuclear quadrupole moment, in good agreement with previous work [6].

The same computational strategy was adopted to evaluate for the first time the hyperfine parameters of the ground state $2p^5\ ^2P^o_{3/2,1/2}$ of the negative ion $^{17}O^-$. Convergence of the A_J parameters has been achieved to the 1% level of accuracy, which is enough to interpret the photodetachment microscope ring patterns.

In order to exploit the observed images, we have calculated the relative intensities of the 14 hyperfine components of the $^{17}O^-$ detachment threshold in the pure Russell-Saunders coupling scheme. Photodetachment arises from one of the hyperfine components of the $^{17}O^-\ ^2P^o_{3/2}$ ground term $|\alpha_1(S_1L_1)J_1, I, F_1\rangle$ to an excited state, which combines the $^{17}O\ ^3P_2$ ground state and the ejected electron state $\langle\alpha_2((S_2L_2)J_2I)F_2, (sl)j, F|$. As the electron ejected just above threshold is a pure s-wave ($j = s$), we derive with the standard Racah method [7] an expression of the relative intensities by means of $12-j$ symbols

$$I(F_2, F_1) \propto (2F_2+1)(2F_1+1)\sum_F (2F+1)\left|\begin{Bmatrix} s & F & 1 & L_2 \\ F_2 & F_1 & L_1 & S_2 \\ J_2 & I & J_1 & S_1 \end{Bmatrix}\right|^2 .$$

The calculated ratios for the 14 components have been compared to the values derived from the alternative method developed by Engelking and Lineberger [8]. Despite the fundamental differences between the two methods, the results are identical.

The introduction of the calculated hyperfine structure and intensities in the fitting procedure gives a satisfactory compatibility with the experimental results. Due to the weak number of recorded images and their poor signal-to-noise ratio, an uncertainty of ± 0.04 cm^{-1} is estimated on the measured value of the ^{17}O electron affinity (provisional value: 11784.623 cm^{-1}).

Finally, the specific mass shift parameters calculated in [3] have been used for evaluating the theoretical electron affinity isotope shifts ^{17}O-$^{(16,18)}O$. Within experimental uncertainties, the measurements are consistent with theory, confirming the anomalous isotope shift found in [2, 3].

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