Silicon electron affinity measured by photodetachment microscopy

C. Delsart, C. Blondel and F. Goldfarb

Laboratoire Aimé Cotton, C.N.R.S. II
bâtiment 505, F-91405 Orsay cedex, France
Tel +33-1-69352055, Fax +33-1-69352100
E-mail: christian.delsart@lac.u-psud.fr, Website: http://www.lac.u-psud.fr

"Photodetachment microscopy" consists in direct imaging, on a high spatial resolution electron detector set half a metre from the interaction region, of the ejected electron's wave function after the laser detachment of a negative ion just above the threshold in the presence of a uniform electric field [1]. Within the "free electron" or "plane-wave" approximation and in the case of s-wave photodetachment, the observed bright and dark rings of the electron current density pattern are interpreted as direct experimental representations of the Green function of the uniform acceleration problem, without any particular link to atomic physics. The recorded images of O^- have proved to agree closely with this interpretation, and the method was successfully applied for the determination of the electron affinities and the isotopic shift of ^{16}O and ^{18}O [2].

The silicon negative ion appears as an appropriate probe of the reliability of the plane-wave approximation. Core and rescattering effects may arise first because $^{28}Si^-$ is heavier than $^{16}O^-$. Another cause would be that both the ^2D and the ^2P excited terms of the p^3 configuration are bound with respect to the atomic ground state [3, 4, 5]. Moreover, the ^2P term has a weak binding energy [235(40) cm^{-1}]. The question is open for a possible perturbation of the ejected electron wavefunction by these Si^- bound states in the vicinity of the first threshold.

The experimental set-up is the one previously used for O^- [2]. A highly collimated beam of silicon ions was built up from a hot cathode discharge source, which is fed with a gaseous mixture of Ar and silane SiH_4. Negative ions are extracted with a 1200 eV kinetic energy. A Wien velocity filter selects the $^{28}Si^-$ ions. A decelerator brings the ion kinetic energy down to 300-500 eV just before the interaction region. A CW single-mode sapphire-titanium laser provides the excitation light (874-892 nm, 0.8 W) which beam is quasi-parallel to the electric field, and quasi-perpendicular to the ion beam in the interaction chamber. The absolute laser wavenumber, compared by means of a lambdameter to the reference wavelength of a I_2-saturated absorption stabilised He-Ne laser, is measured with an accuracy of 0.002 cm^{-1}. The electron detector, set 0.51 m from the interaction region, consists of microchannel plates followed by a resistive anode encoder.

Several electron images have been recorded with the electric field values $\epsilon = 180$ and 423 V/m, and with electron kinetic energies from $F = 0.3$ to 1.2 cm^{-1} above the three detachment thresholds corresponding to the fine structure of the Si ^3P-ground term. Surprisingly, the theoretical formula for the Green function [1] fits perfectly the experimental distributions, without any divergence. This is a remarkable result that the free-electron approximation remains valid for silicon as for oxygen and that no perturbation due to the Si^- bound states can be detected.

As for oxygen, we are then able to apply our method to perform a new measurement of the electron affinity of ^{28}Si, which can be more precise than the previous measurements of Kasdan et al. by fixed-frequency laser photoelectron spectrometry [5], Thorgensen et al. by tunable laser photodetachment spectroscopy [6] and Scheer et al. by the same improved method [3].

In order to eliminate the uncertain Doppler angle between the laser beam and the ion beam, we achieve a double-pass scheme of the laser beam onto the ion beam nearly at right angle, with tight focusing both at the forth and back crossings. The double-pass configuration is chosen so as to separate enough the two electron images. Analysing the two different electron pictures and taking into account the bending of the ion beam by the electric field give a way to determine the electron affinity A without any absolute measurement of the intersection angle, the only required measurement being the distance between the forth and back interaction zones.

The provisional ^{28}Si electron affinity measured value A=11207.255(20) cm^{-1}, which is consistent with the previous most precise value A=11207.24(15) cm^{-1} [3], has an accuracy improved by one order of magnitude. This new determination shows the interest of our technique that makes use of the sensitivity of the electron interference pattern to measure the detachment energies.

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