

# **K-shell photoexcitation of carbon ions: lifetime of a K-shell vacancy**

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## **INTRODUCTION**

Carbon is ubiquitous in nature and is the building block of life. The carbon atom in its various states of ionization has a small number of electrons, and is thus amenable to theoretical study. Given the importance of the carbon atom, it is surprising that there are few detailed measurements of inner-shell photoionization or photoexcitation processes, and that the lifetime of a K-shell vacancy in a free carbon atom is not experimentally known. The major difficulty is that free carbon atoms cannot readily be produced. In the present investigation we have measured photoexcitation of a  $C^+$  ion rather than photoionization of a neutral carbon atom, producing the same state of  $C^+$  as would be produced by direct photoionization of a neutral carbon atom. Photoexcitation of  $C^{2+}$  and  $C^{3+}$  has also been studied, both experimentally and theoretically.

## **LIFETIME OF A K-SHELL VACANCY**

The lifetime of a K-shell vacancy in a free carbon ion ( $C^+$ ) has been measured as part of a study of photoexcitation of K-shell electrons in carbon ions. The lifetime is determined by measuring the energy width of the resonance created by photoexcitation of a K-shell electron in the  $C^+$  ion: the innermost 1s electron is promoted to the 2p shell, resulting in production of the  $1s2s^22p^2\ ^2,^4P$ ,  $^2S$ ,  $^2D$  autoionizing states. The excited state of the  $C^+$  ion produced in this experiment is identical to that produced by direct K-shell photoionization of the neutral carbon atom. Knowledge of such lifetimes is important for comparative studies of the autoionization widths for a K-shell vacancy in hydrocarbons and other carbon-containing molecules, where the molecular properties are known to affect the charge distribution and therefore the core-hole lifetimes and autoionization rates.

## **PHOTON-ION MERGED-BEAMS EXPERIMENT**

A photon beam on beamline 10 is merged with a well-collimated energy- and charge-state-selected ion beam from a small accelerator [1]. The ion beam is charge-state analyzed after the interaction region: the primary ion beam is collected by a Faraday cup, while ions whose charge state has increased are detected and counted. The photon beam is time modulated to subtract ions which have changed their charge state in collision with background gas. All experimental parameters can be measured for determination of absolute cross sections; however, only relative cross sections have been measured in the present experiment.

## RESULTS: ELECTRON SCREENING

Photon energy was scanned over the energy range where resonances are predicted by theory. Relative cross sections for photoexcitation of an admixture of ground-state and metastable  $C^+$ ,  $C^{2+}$ , and  $C^{3+}$  beams are presented in Fig. 1. The insets show small peaks which would not be visible on the scale of the larger resonances. Experimental energies have been corrected for the Doppler-shift of the moving ions, and the energy scale has been determined relative to photoabsorption in CO. The large energy shift in the resonances with increasing charge state of the incident ion seen in Fig 1 is due to electron screening: there are fewer electrons on an ion in a higher charge state to pass between the nucleus and the K-shell electrons which reduce the nuclear charge felt by the K-shell electrons. Theoretical calculations using state-of-the-art techniques are in good agreement with the measurements. This comparison is valuable for benchmarking theory and for interpreting x-ray satellite data.

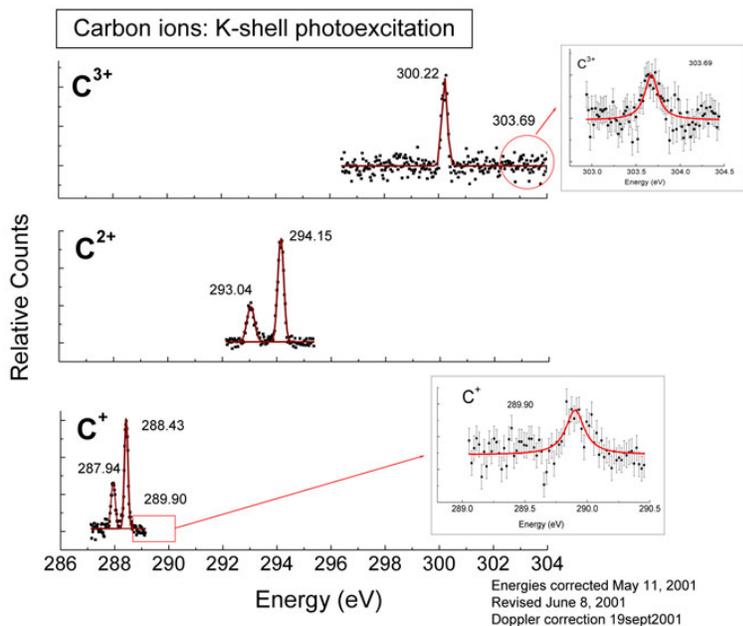


Figure 1. Experimental K-shell photoexcitation cross sections for  $C^+$ ,  $C^{2+}$ , and  $C^{3+}$  ions. Relative cross sections are shown, for an admixture of ground-state and excited-state ions.

Natural linewidth can be measured in some cases by varying the spectral resolution of the incident photon beam, accomplished by changing the width of the entrance and exit slits of the monochromator. Data have been obtained for photoexcitation of  $C^+$  ions with three different nominal spectral resolutions: 200 meV, 100 meV, and 50 meV. The resonance peaks were fit with a Voigt profile, which is a convolution of a Gaussian and a Lorentzian profile. The Gaussian width is instrumental, while the Lorentzian width is the natural lifetime width of the resonance. The fit was done on the two larger peaks, constrained to have the same Gaussian width for the same nominal resolving power. Results are shown in Fig. 2. The same value of lifetime linewidth was obtained for all three nominal spectral resolution values, providing confidence in the validity of the fitting process. The result is a width of  $54 \pm 4$  meV for the higher-energy peak and  $102 \pm 10$  meV for the lower-energy peak. It is interesting to note that the actual spectral resolution determined by the Gaussian width is better than the nominal resolution for relatively wide slits, but approaches the nominal width for the narrowest slits. This is because the undulator beam does not fill the entrance slit of the monochromator except for narrow settings of the entrance slit—which is the case for high spectral resolution.

The linewidth of a carbon-atom K-shell vacancy in a molecule is known to be greater than the theoretical linewidth of a free carbon atom due to molecular properties, e.g., charge distribution in the molecule. Coville and Thomas [2] and Carroll et al [3] list both theoretical and experimental values for a wide variety of carbon-containing molecules. A notable absence is that of an experimental value for a free carbon atom. (N.b., a carbon atom with a K-shell vacancy is, of course, a  $C^+$  ion.) Two features are apparent from their work: the significant disagreement between experiment and theory; and the linewidth of a carbon K vacancy in all molecular species studied is significantly greater than the theoretical linewidth of a free carbon atom. The theoretical linewidth of a K-shell vacancy produced in a free carbon atom (thus in a  $C^+$  ion) is 56 meV [2]. However, until now there have been no measurements of this linewidth. Furthermore, measurements of linewidths by photoionization of a molecular species are often complicated by post-collision interactions and other factors. The experimental method reported here, the production of the K-vacancy state of an atom by photoexcitation of the ion, does not have PCI, as there are no slow electrons to influence the lineshape. The lifetime of a K-shell vacancy is shorter in all molecules (the linewidth is greater) than in an isolated carbon atom. The present results are therefore significant in understanding vacancy-filling mechanisms in molecules. The measured lifetime agrees well with theory.

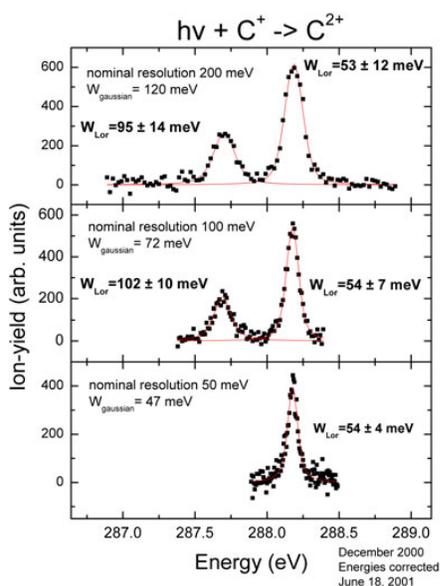


Figure 2. Experimental relative cross section for photoexcitation of  $C^+$  ions, for three different values of nominal spectral resolution. The Gaussian width is the experimental resolution, the Lorentzian width is the lifetime width of each peak.

## REFERENCES

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- [3] Carroll et al, Phys. Rev. A **59**, 3386 (1999).

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