R.R. Haar, T.J. Kvale, D.G. Ellis,
I. Martinson and L.J. Curtis

Lifetime measurements of core excited quintet levels in carbon I

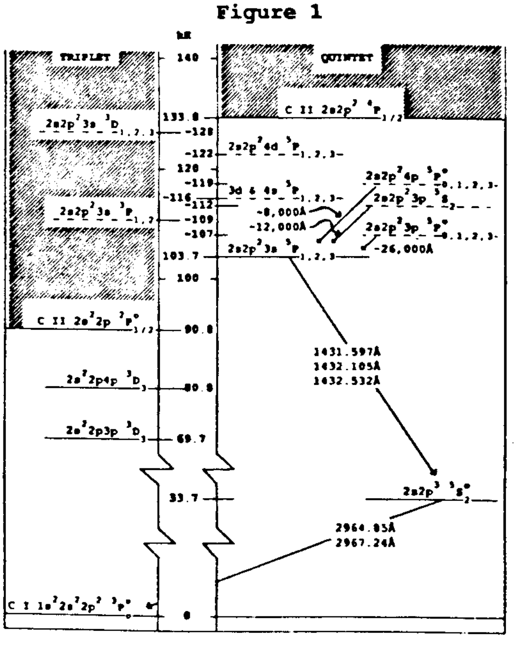
ABSTRACT

J dependent lifetimes for the $2s2p^2 3s\ ^5P$ levels in C I have been studied by beam foil measurements and by multiconfiguration relativistic Hartree-Fock calculations. The experimental lifetimes $\tau(J=3)=2.5(5)$ ns and $\tau(J=1,2)=0.3(1)$ ns indicate the presence of differential autoionisation channels.

INTRODUCTION

Although the singlet and triplet spectra of C I have been comprehensively studied, only the $2s2p^3\ ^5S$ and $2s2p^2 3s\ ^5P$ terms have been established for the core-excited quintet

Figure 1



system (Edlén 1947, Shenstone 1947). As shown in Fig.1, the ^5P levels lie above the first (doublet) ionisation limit, but well below its parent (quartet) ionisation limit. Thus autoionisation to the triplet continuum is energetically possible, but forbidden to Coulomb interactions in LS coupling by the $\Delta S=0$ selection rule. Intermediate coupling opens autoionisation channels through triplet-quintet mixing and leads to lifetimes that are strongly J-dependent. In order to investigate these radiative and autoionisation effects, we have performed a combined theoretical and experimental study of the lifetimes of the individual fine structure levels of the $2s2p^2 3s\ ^5P$ term. The experimental portion was carried out by beam foil excitation methods, and the theoretical calculations were made using the multiconfiguration Hartree-Fock program of Cowan, which includes both radiation and autoionisation.

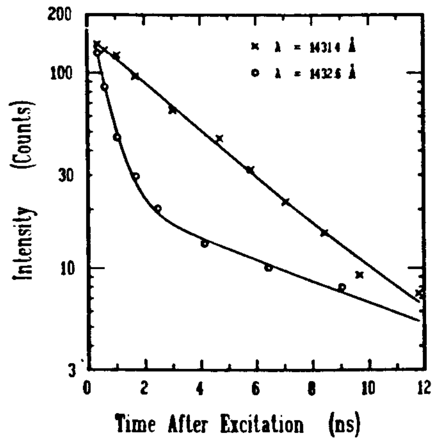
EXPERIMENT

Time resolved carbon spectra were obtained by directing beams of 100-200 keV C^+ ions from the University of Toledo 330 kV Danfysik heavy ion accelerator through a translatable 2 $\mu g/cm^2$ carbon foil. At these energies the beam loses approximately 3.5 keV in traversing the foil. The wavelength range 1150-1800 Å was studied, using an Acton 1 m normal incidence vacuum monochromator equipped with a solar blind EMI photomultiplier at the exit slit. The wavelength resolution used was 0.8 Å and the time window was set at 0.3 ns, values chosen to optimise the necessary compromises between resolution and signal intensity that are inherent in the beam-foil light source. Lifetimes were measured by recording the intensity of the spectral lines as a function of the distance from the foil. Many known lines from C I and C II were identified, and their relative intensities were used to select a beam energy that is well suited to the study of C I. Lifetime measurements of many of the singlet and triplet levels were also made. The results agreed well with earlier work, and served as an additional check of the determination of beam energy and energy loss in the foil.

TIME RESOLVED DEBLENDING

The wavelength separations of the lines are about 0.5 Å, which creates special problems. While the beam foil source copiously populates these excited core states, its inherent Doppler broadening precludes them from being completely resolved spectroscopically. However, since these lines were found to be relatively free of cascades, blends, and backgrounds, it was possible to determine the lifetimes of the individual fine structure levels by performing a three dimensional array of intensity vs wavelength vs time measurements. Fig.2 shows a sample decay curve, indicating

Figure 2



the distinct variation in lifetime content over the unresolved multiplet profile. The experimental lifetimes show a strong J-dependence with $\tau(J=3)=2.5(5)$ns and $\tau(J=1,2)=0.3(1)$ns. The radiative branch for each of these decays was measured in emission by Boldt (1963) using an intensity calibrated wall stablised arc. Assuming statistical populations, these measurements indicate that the radiative rates are essentially J independent . Combining the lifetime and emission measurements permits experimental determination of the J-dependent autoionisation rates.

THEORETICAL CALCULATIONS

In order to provide a theoretical comparison, the Cowan suite of programs RCN-RCG (Cowan 1981) was used to compute the autoionisation rates of the ^5P levels. The calculation included interactions among eight even and seven odd parity configurations. The autoionisation transition $2s2p^2 3s \rightarrow 2s^2 2p\varepsilon p$ was calculated using an outgoing electron energy of 0.116 Ry, computed from the observed position of the $2s2p^2 3s\ ^5P$ term and the ionisation potential. The autoionisation rate is J-dependent because the spin-orbit mixing with nearby triplet levels is J-dependent. This mixing is determined by the spin-orbit interaction strength and by the energy intervals between the ^5P and the other $2s2p^2 3s$ terms.
The former can be determined empirically from the ^5P fine structure; the latter cannot because the energies of the other terms are not known.

In order to investigate the possibility of cascade repopulation from higher lying $2s2p^2 n\ell$ quintet levels, approximate calculations of some of these levels and their decay rates were made. These are indicated on Fig.1, but it should be emphasised that these are only order of magnitude estimates, and not of spectroscopic accuracy. The results indicated that, although $2s2p^2 3p$ quintet levels which have infrared transitions to the levels of interest do exist, they have very low ($<10^7$/s) radiative transition rates. Thus these theoretical results lend considerable support to our interpretation of the source of the J-dependent meanlives.

ACKNOWLEDGEMENTS

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AUTHORS' ADDRESS

Department of Physics and Astronomy, University of Toledo, Toledo Ohio 43606 USA