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Oscillator Strengths and Predissociation Widths for Rydberg Transitions in Carbon Monoxide

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ABSTRACT

CO is used as a probe of astronomical environments ranging from planetary atmospheres and comets to interstellar clouds and the envelopes surrounding stars near the end of their lives. One of the processes controlling the CO abundance and the ratio of its isotopomers is photodissociation. Accurate oscillator strengths for Rydberg transitions are needed for modeling this process. We present results of recent analyses on absorption from the $E - X$ (1-0), $B - X$ (6-0), $K - X$ (0-0), $L' - X$ (1-0), $L - X$ (0-0), and $W - X$ ($\nu'-0$, $\nu' = 0$ to 3) bands acquired at the high resolution ($R \approx 30,000$) SU5 beam line at the Super-ACO Synchrotron (Orsay, France). Spectra were obtained for the $^{12}\text{C}^{16}\text{O}$, $^{13}\text{C}^{16}\text{O}$, and $^{13}\text{C}^{18}\text{O}$ isotopomers. Absorption bands were analyzed by synthesizing the profiles with codes developed independently in Meudon and Toledo. Each synthetic spectrum was adjusted to match the experimental one in a non-linear least-squares fitting procedure with the band oscillator strength, the line width (instrumental and predissociation),

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and the wavelength offset as free parameters. In order to perform the synthesis, the CO column density was required. Because a differentially pumped cell was used, the measured CO pressure had to be corrected to determine the CO column density. This was accomplished by fitting absorption obtained at the same pressure from the $E - X$ (0-0) band, whose oscillator strength is well known. For the $K - X$, $L' - X$, and $L - X$ bands, the substantial amount of mixing among the upper states was considered in detail. Predissociation widths determined for the $B - X$ band varied widely among isotopomers. For the $W - X$ bands, when possible, J -dependent widths and widths for both e and f parities were extracted from the data. Our results are compared with earlier determinations.

1. Introduction

The interstellar distribution of CO is determined by the interaction of the molecule and the prevailing radiation field. Both photodissociation and self shielding depend on the strength of Rydberg transitions below 1200 Å. Therefore, precise oscillator strengths (f -values) are required for correct modeling of the molecule's distribution in space. Furthermore, the possibility exists that f -values and predissociation widths for Rydberg bands vary among CO isotopomers. The focus of our recent laboratory measurements are on the three species, $^{12}\text{C}^{16}\text{O}$, $^{13}\text{C}^{16}\text{O}$, and $^{13}\text{C}^{18}\text{O}$; the results are described here.

It has been almost 20 years since the first laboratory measurements were available for theoretical models of interstellar CO (Letzelter et al. 1987; Eidelsberg et al. 1991). Later on it became apparent that many f -values of Rydberg bands were underestimated and required renewed laboratory effort (Federman et al. 2001), as well as input from the astronomical front, such as *FUSE* observations (Sheffer et al. 2003). Here we report on the combined effort by our two teams (Toledo and Meudon) to measure a consistent set of f -values, and predissociation widths when possible, for Rydberg bands that will help to improve theoretical predictions (e.g., van Dishoeck & Black 1988; Warin et al. 1996) of the distribution of CO in astronomical environments, such as diffuse clouds. These data will lead to better agreement between measured CO abundances and predictions (Sheffer et al. 2002).

2. Measurements

All our data were collected at the LURE Super-ACO synchrotron ring in Orsay, France, using the SU5 beam line in its high-resolution spectral mode (R in the range 25,000 to 60,000). This is high enough to resolve individual rotational lines in most bands, as well as to assure successful deblending of superposed bands. Our VUV spectra include a selection of Rydberg bands between 925 Å and 1051 Å: $W(3)$, $W(2)$, $W(1)$, $E(6)$, $L(0)$, $L'(1)$, $K(0)$,

$W(0)$, $B(6)$, and $E(1)$, where we use the upper state solely to designate a transition from the ground state, $X(0)$. Each band was observed multiple times under different CO pressures, together with the primary calibrating band $E(0)$ at 1076 Å, which has a well-determined f -value: 0.068(7) according to Federman et al. (2001).

Two independent fitting routines (one in Toledo and one in Meudon) were used to model the data, yielding consistent results at the level of 1% to 2% agreement. We successfully deblended a cluster of 4 Rydberg bands around 968 to 970 Å from the mutually interacting states $K(0)$, $L'(1)$, $L(0)$, and $E(6)$, and determined new f -values for them (Eidelsberg et al. 2004). The results for the other bands were recently submitted for publication (Eidelsberg et al. 2006). The analysis involves the determination of f -values and predissociation widths. The latter allows us to derive predissociation rates for the upper level. For the W states and the $B(6)$ state, the line width is broad enough to be treated as a free parameter in our simulations of the laboratory spectra.

3. Discussion

Our f -values are usually larger than those determined in the earliest studies for $E(1)$, $K(0)$, $L'(1)$, and $L(0)$, but the agreement improves for the more recent laboratory and astronomical results (Chan et al. 1993; Yoshino et al. 1995; Zhong et al. 1997; Sheffer et al. 2003). We attribute the global trend of higher f -values compared to Eidelsberg et al. (1991) to a better treatment of optical depth effects in our simulations. The same may apply to the results of Stark et al. (1991, 1992, 1993). The improved treatment for mixing among the upper levels involved with the $K(0)$, $L'(1)$, $L(0)$, and $E(6)$ transitions (Eidelsberg et al. 2004) is the reason for the remaining differences with Eidelsberg et al. (1991).

For the other bands, the agreement among results is much better. Since the intrinsic line widths for the W and $B(6)$ bands are much broader (faster predissociation rates), optical depths are always small and do not impact the earlier results. As a result, these bands are likely to play a less important role in selective isotope photodissociation. Our suite of f -values and predissociation widths represent the most complete set currently available. When incorporated into theoretical models for CO in astronomical environments, the larger f -values are expected to yield higher photodissociation rates for all isotopomers, as well as increased levels of self shielding for CO whenever it is sufficiently abundant. The increased number of measured predissociation widths will also lead to improved models.

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