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Pressure broadening and shift of the potassium D_1 transition by the noble gases and N_2, H_2, HD, D_2, CH_4, C_2H_6, C_3H_8, and n-C_4H_{10} with comparison to other alkali rates

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ABSTRACT

The pressure broadening and shift rates for the potassium $D_1(4^2P_{1/2} \leftarrow 4^2S_{1/2})$ transition with the noble gases and ^{3}He, H_2, HD, D_2, N_2, CH_4, C_2H_6, C_3H_8, and n-C_4H_{10} were obtained for pressures up to 80 Torr and at a temperature of 55 °C by means of laser absorption spectroscopy. The collisional broadening rate, γ_L, for He, ^{3}He, Ne, Ar, Kr, Xe, H_2, HD, D_2, N_2, CH_4, C_2H_6, C_3H_8, and n-C_4H_{10} are 13.08, 17.46, 6.14, 19.45, 16.64, 20.02, 22.15, 19.36, 17.47, 17.78, 29.35, 26.63, 27.27, and 27.85 MHz/Torr, respectively. The uncertainty in the broadening rates is typically less than 1.6%. The corresponding pressure induced shift rates, δ, are 1.63, 6.82, −1.27, −6.44, −5.42, −6.54, −5.34, −5.10, −4.70, −6.80, −7.41, −8.32, −8.59, and −8.80 MHz/Torr with a uncertainty of less than 2.4%. A comparison with the other alkali D_1 broadening cross-sections is presented.

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1. Introduction

The lineshape, broadening, and shift of the atomic hyperfine profiles due to collisions with other atoms or molecules have been studied thoroughly, with numerous reviews available [1–3]. In particular, the collisional broadening and shift of the alkali atoms by various buffer gases have been the subject of multiple experimental and theoretical treatises [4–21]. In recent years there has been a resurgence of interest as to the value and magnitude of these interactions due to the recent incarnation of the diode pumped alkali laser (DPAL). This novel three level laser system was presented by Krupke and Beach in 2003 [22]. Unlike the first alkali optical maser proposed by Schawlow and Townes in 1958, the DPAL system leverages recent advances in diode technology to directly pump the alkali's outer shell valence electron from the ground state ($^2S_{1/2}$) along the D_2 transition to the excited state ($^2P_{3/2}$) [23]. Collisional mixing with an additive buffer gas transfers the excited state population from the $^2P_{3/2}$ to the $^2P_{1/2}$ state, where it lases on the D_1 transition back to the ground state [24,25]. The efficiency of these systems relies on the amount of overlap between the diode emission bandwidth and the absorption linewidth of the alkali. High fidelity measurements of the D_2 broadening and shift rates are necessary to accurately model these laser systems and are used to predict how efficiently pump radiation is absorbed by the alkali. In addition, the broadening and shift rates of the D_1 transition will be used to compare the output beam's frequency profile with the known atmospheric absorption lines to determine how it will interact with those species as it is

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propagated through the air. These broadening and shift rates are necessary for potassium as it lies between two O_2 ($b,^1\Sigma$) rotational lines [26].

The pressure effects on the $^2S_{1/2}\rightarrow{}^2P_{1/2,3/2}$ transitions of potassium have been investigated by several groups, with the most recent study being completed in the late-seventies by Lwin [19]. Broadband absorption spectroscopy using a quartz halogen lamp as the optical source in conjunction with a 4.5 m plane diffraction grating spectrometer was used to measure the broadening and shift of potassium by the noble gases. At pressures above 300 Torr asymmetries were observed [19].

A compilation of the reported rates appears to present some discrepancies. For example, there is a discrepancy of nearly a factor of two for the broadening rate of potassium by helium [19–21]. The other noble gases show similar discrepancies with Demtroder reporting values on average of 58% less than Lwin [19,20]. The shift rates have similar variations. In the case of neon, Kielkopf has theoretically modeled a blue shift while Lwin has measured a red shift [19,21].

A reinvestigation of these values appears prudent in order to improve current DPAL system models and further the understanding of the alkali-buffer gas interaction. In addition, these prior rates are limited to noble gases and nitrogen. Currently high pressure ($>$ 760 Torr) potassium DPAL systems are being developed that only use rare-gas collision partners, but low pressure systems ($<$ 760) utilize the hydrocarbons to collisionally mix the two excited states [27,28]. The broadening and shift rates for the hydrocarbons have not been measured to date and additionally ^{3}He is of interest due to its smaller mass and the enhanced mixing of the K fine-structure levels [28,29].

2. Experimental details

The experiment utilized a diode laser (Sacher) tuned to 770 nm and scanned over 15 GHz. The laser has a line width around 1 MHz with a power less than 1 W. This beam was greatly attenuated ($<$ 1 μW) before reaching the test cell to avoid any saturation broadening and to stay within the Beer's law regime of absorption. The output beam was coupled into a 1×4 fiber splitter box (Gould fiber optics). This box was designed to propagate

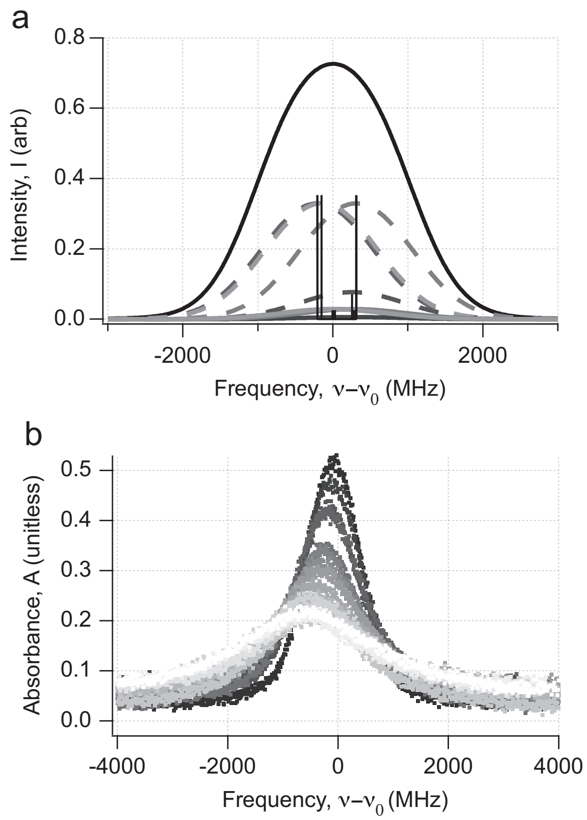

Fig. 2. A modeled D_1 hyperfine profile of potassium with each hyperfine component [its (- - -) Voigt profile and a bar for its zero pressure location and relative amplitude] (a) and a set of experimental spectrum of potassium as it is broadened by methane (b) from 5 to 80 Torr.

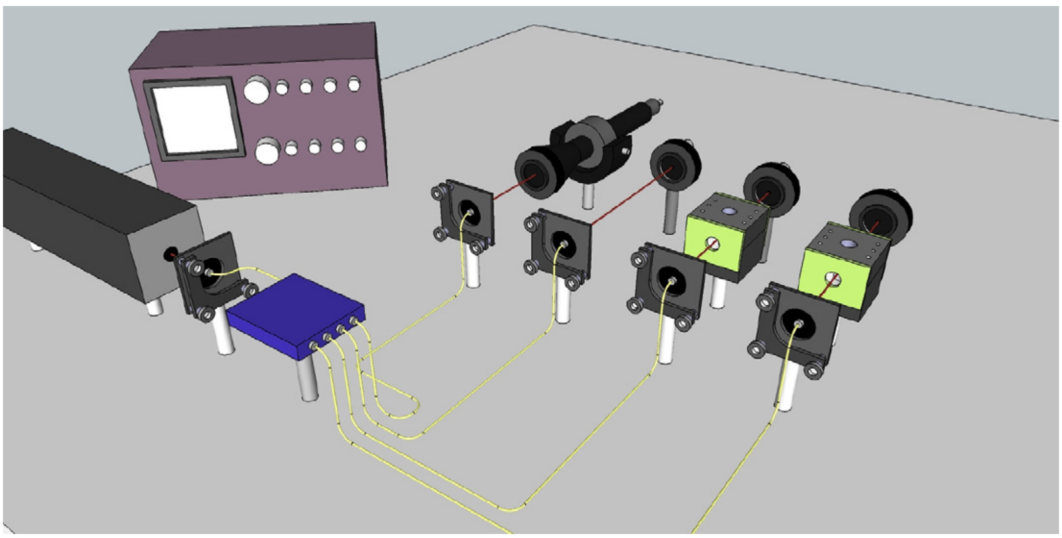

Fig. 1. Experimental apparatus for laser absorption spectroscopy.