SOCIETY OF PHYSICS STUDENTS
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SPS Chapter Research Award Interim Report

Project Title	Collisional Processes in Alkali-Buffer Gas Systems for Alkali Laser Development
Name of School	United States Air Force Academy
SPS Chapter Number	7502
Total Amount Awarded	$1535
Project Leader	Jeremiah Wells

Abstract

The research project to be performed by the United States Air Force Academy SPS chapter aims at measuring collisional excitation transfer and quenching cross-sections in rubidium-methane and rubidium-deuterated methane systems. This study is relevant for alkali laser development and for understanding collisional processes in alkali-buffer gas systems.

Statement of Activity

Interim Assessment

- **Research question –** The proposed research project aims at studying collisional processes in rubidium-buffer gas systems subjected to laser radiation. Specifically, the goal of the proposed research project is to determine collisional excitation transfer and quenching cross-sections in rubidium-methane (Rb-CH_4) and rubidium-deuterated methane (Rb-CD_4) systems.
- **Brief description of project –** When a rubidium atom is excited from the ground state to the $5P_{3/2}$ state by a 780 nm photon in the presence of a buffer gas, several processes can occur: (1) spontaneous (radiative) decay to the ground state and emission of a 780 nm photon, (2) collisional quenching (non-radiative decay) and (3) collisional excitation transfer (mixing) to the $5P_{1/2}$ state followed by emission of a 795 nm photon. The third process is at the heart of the operation of an alkali laser, a laser whose active medium is an alkali vapor such as rubidium, cesium or potassium. The first two processes act as losses in the laser gain medium. While the radiative decay is a natural process with rates that are well known, the other two processes depend on the alkali-buffer gas combination and are not well understood.
- **Progress on research goals –** So far we have measured the collisional excitation transfer and quenching cross-sections in the rubidium-methane system. A manuscript is in preparation for submission to Physical Review A describing our research findings.
- **Any changes in the scope of project –** There are no changes as of right now.

- **Personnel** – Cadet First Class Jeremiah Wells was the leader of the proposed research project. Jeremiah is a senior physics major with a concentration in "Lasers and Optics" and an SPS National member. Cadet First Class Jared Wesemann and Cadet Fourth Class Philip Rich were also involved in the research project. Jared is a senior physics major with a concentration in "Nuclear Physics", president of the USAFA SPS chapter and SPS National member. Philip is a freshman physics major and a member of the USAFA SPS chapter.
- **SPS connection** – The proposed project has provided hands-on experience to three undergraduate physics students. This is particularly important at an undergraduate institution such as USAFA, as our cadets become officers in the US Air Force immediately upon graduation and are often posted to technical positions where a scientific background is extremely useful. Providing undergraduates with meaningful research experience is one of the SPS objectives that our chapter fully embraces.

Updated Background for Proposed Project

Ref [1] describes measurements of the collisional excitation transfer cross-section in the Rb-methane system with a 12% uncertainty. No measurements of the quenching cross-sections were performed. Ref [2] describes measurements of the quenching cross-sections in Rb-methane, but due to limitations in their experimental setup and method, only an upper bound is reported ($\leq 1.9\times10^{-18}$ cm^2).

Description of Research - Methods, Design, and Procedures

In our experiment, a self-mode-locking Ti:Sapphire laser creates ultrafast laser pulses at 780 nm which excite Rb atoms to the $5P_{3/2}$ state. The Rb atoms collide with methane buffer gas at a given pressure. The buffer gas facilitates a transition from the $5P_{3/2}$ state to the $5P_{1/2}$ state and the resulting photons (795 nm) are detected by a photomultiplier tube. These fluorescence photons are recorded as a function of time by a time-to-digital converter.

The time evolution of the $5P_{3/2}$ state population after termination of the laser pulse is described by the following rate equation:

$$\frac{dn_2}{dt} = -(\gamma_2 + R_{21} + Q_2)n_2 + R_{12}n_1$$

where n_2 is the population of the $5P_{3/2}$ state, n_1 is the population of the $5P_{1/2}$ state, γ_2 is the spontaneous decay rate of the $5P_{3/2}$ state, R_{21} is the collisional transfer rate from the $5P_{3/2}$ state to the $5P_{1/2}$ state, R_{12} is the collisional transfer rate from the $5P_{1/2}$ state to the $5P_{3/2}$ state, and Q_2 is the collisional quenching rate of the $5P_{3/2}$ state. The $5P_{1/2}$ state population is modeled by a similar rate equation. Solving the coupled differential equations gives a solution in the form of a double exponential:

$$n_1(t) = Ae^{s_+t} + Be^{s_-t}$$

where A, B, s_+ and s_- are coefficients depending on γ, R, and Q. By fitting the data we collected to the above functional form and knowing γ, we can then determine R and Q at that particular pressure.

Initial Results

Figure 1 shows the resulting fluorescence photons as a function of time for 25 Torr of methane. The rising portion of the curve is due to collisional excitation transfer (mixing), while the decay portion is due to quenching and spontaneous decay. Figure 2 shows the collisional excitation transfer rate as a function of the methane pressure. The slope of the line in Fig. 2 yields a cross section of $(3.57 \pm 0.07)\times10^{-15}$cm^2. This value is in agreement with previous measurements [1], while having a 2% uncertainty.

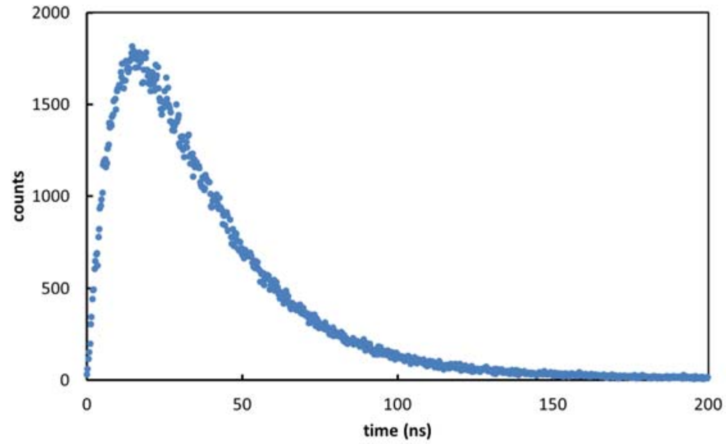

Fig. 1. Fluorescence vs time

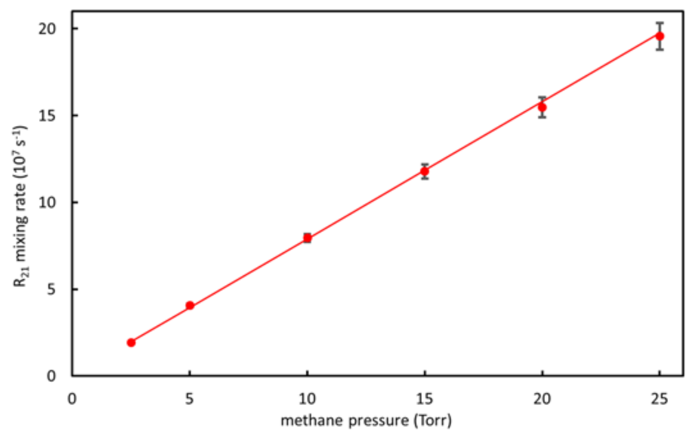

Fig. 2. Mixing rate vs methane pressure

The decay portion of the fluorescence curve in Fig. 1 is used to determine the quenching rate at that particular pressure. A plot of the quenching rate as a function of the methane pressure similar to that shown in Fig. 2 is used to determine the quenching cross-section. The slope of the line yields a numerical value of 7.28×10^{-19} cm^2, which is in agreement with the upper bound reported in Ref. [2]. We are currently working on estimating the systematic errors in our experiment and determine the uncertainty associated with our measured quenching cross-section for the rubidium-methane system.

Statement of Next Steps

Plan for Carrying Out Remainder of Project (including Timeline)

Key milestones

- Mid-August 2017 – manuscript submitted for publication describing the rubidium-methane study
- October 27-28, 2017 - results disseminated at the Annual Meeting of the Four Corners of the APS in Fort Collins, CO
- Mid-December 2017 – rubidium-deuterated methane study completed
- December 31, 2017 - final report submitted to SPS National
- Mid-March 2018 - manuscript submitted for publication describing the deuterated methane study
- June 2018 – results disseminated at the Annual Meeting of the Division of Atomic, Molecular and Optical Physics of the American Physical Society in Fort Lauderdale, FL

Personnel – Cadet Third Class Phillip Rich will become the new leader of the project. We expect to recruit at least another physics major and SPS member to join the project in the fall.

Bibliography

[1] M. D. Rotondaro and G. P. Perram, "Role of rotational energy defect in collisional transfer between the Rb $^2P_{1/2,3/2}$ levels in rubidium," Phys. Rev. A **57**, 4045 (1998)

[2] N. D. Zameroski, W. Rudolph, G. D. Hager, and D. A Hostutler, "A study of collisional quenching and radiation-trapping kinetics for Rb(5p) in the presence of methane and ethane using time-resolved fluorescence," J. Phys. B **42**, 245401 (2009)