FLAME TEMPERATURES FROM VIBRATIONAL RAMAN SCATTERING

by

Marshall Lapp

General Electric Corporate Research and Development
Schenectady, New York 12301

ABSTRACT

Raman scattering signatures are functionally dependent upon temperature, and are therefore useful as diagnostic probes. Various Raman scattering techniques for the measurement of temperature are outlined here. Those methods based upon rotational molecular structure are then briefly discussed in order to compare and contrast them with the ones based upon vibrational structure. For flame gases, the elevated temperatures and the multicomponent, variable composition make the vibrational scattering techniques appear to be more useful than those based upon pure rotational scattering. Temperature measurements based upon vibrational Raman scattering are described next, with an emphasis on the vibrational techniques developed in this laboratory. These techniques are based upon the spectral structure of the fundamental Stokes vibrational band series, which consists of the ground state band (initial → final molecular vibrational levels: \( v = 0 \rightarrow v = 1 \)) and the upper state or "hot" bands (\( 1 \rightarrow 2, 2 \rightarrow 3, \text{etc.} \)).

I. INTRODUCTION

This work is directed toward the development and implementation of a method for temperature measurement in gases, both in thermal equilibrium and non-thermal equilibrium conditions. The method is based upon observation of Raman scattering vibration-rotation signatures, and is sensitive to the vibrational and rotational degrees of freedom of the molecular species probed.

*The work reported here has been supported in part by Project SQUID, Office of Naval Research, and by the U. S. Air Force Aerospace Research Laboratories.
The measurement of temperature is often desired, of course, for the determination of the thermal properties of the system under investigation. For example, we may wish to calculate the population of some excited state of the molecular species in question based upon Raman scattering temperature data, or perhaps we may wish to make some heat transfer estimates from temperature profiles based upon thermal equilibrium considerations. However, an estimate of the temperature is also necessary for implementation of Raman scattering density measurement schemes. This fact arises because the scattering signature is temperature-sensitive, as is the integrated scattering intensity for conditions such that excited vibrational states become appreciably populated. The temperature dependence of Raman profiles has been introduced at this meeting by Prof. Gaufres and Dr. Leonard; in this presentation we will discuss the changes in scattering profiles with temperature in a detailed fashion. The general advantages and disadvantages of Raman scattering techniques for diagnostics of combustion gases have been discussed elsewhere in this Proceedings, including the Introduction.

In the experimental work described here, we concentrate upon evaluation of the temperature from the structure of the fundamental vibrational Q-branch band series, which consists of the ground state band (i.e., scattering from the ground vibrational level to the first excited vibrational level) and the upper state or "hot" bands (i.e., scattering from excited vibrational levels to the next higher vibrational levels). (See Refs. 1-4 for further details of the vibrational Raman scattering thermal equilibrium work from our laboratory that is described here, as well as a discussion of the physical basis from which the Raman scattering profiles arise.)

II. COMPARISON OF SCATTERING TECHNIQUES

In order to illustrate the rough spectral positions and shapes of rotational and vibrational Raman scattering from a multi-component system, we show, in Figure 1, approximate rotational and vibrational spectra for N₂ and O₂ at room temperature (300°K) and at an elevated temperature (1100°K). This figure depicts the effective "spreading" of intensity with increase of temperature, and shows, for comparative purposes, the corresponding Rayleigh scattering. From this figure, we can obtain relative estimates of the strengths of the various scattering processes. These strengths can be indicated in a quantitative fashion by differential scattering cross sections. For example, the approximate magnitudes of the differential cross sections for N₂ are, for 488.0 nm excitation:

- Rayleigh: $10^{-27}$ cm$^2$/sr
- Rotational Raman (all lines): $10^{-29}$
- Rotational Raman (strong line, including fractional population factor at room temperature): $6 \times 10^{-31}$
- Vibrational Raman (Stokes Q-branch): $5 \times 10^{-31}$