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I. Introduction

Shock front excitation and relaxation processes of diatomic molecules determine to a large extent the flow and radiation field around hypersonic re-entry vehicles. The study of these processes is therefore quite important. For sufficiently strong shock waves, the instantaneous translational temperature just behind the shock is higher than the equilibrium temperature. The approach to equilibrium is then governed by the rates of vibrational relaxation, dissociation and ionization. During this relaxation process, electronic excitation rates can proceed sufficiently fast and are capable of producing radiation overshoots.[1] The purpose of the present work was to examine this shock front radiation in a shock tube and to develop a spectroscopic method for measuring temperatures in the relaxation zone.

One of the most interesting shock front regimes for making temperature measurements is the nonequilibrium region. Temperature measurements in this region are difficult to interpret because of the nonequilibrium nature of the gas. At any given point in the relaxation region, different temperatures can be used to describe the state of the translational, rotational, vibrational and electronic degrees of freedom. One must assume, of course, that the distribution of energy over each degree of freedom is Boltzmann-like. In a nonequilibrium gas sample, the temperature of a thermometric molecule may not be the same as that of the gas. For this reason, one of the

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constituent molecular radiators of the gas was used to make meaningful nonequilibrium temperature measurements.

Qualitatively, the method used for making nonequilibrium temperature measurements on incident shocks in this study was to examine how the molecular band structure of the radiation varied working backward in laboratory time from the equilibrium region into the nonequilibrium region, after assuming an equilibrium temperature based on the shock conditions.

2. Experimental

a) Shock Tube

These measurements were made in an electric arc-driven six-inch shock tube. The operation of this shock tube has been thoroughly described in the literature.[2] Measurements were made on incident nitrogen shocks viewed through copper knife edges mounted in the test section, which was located 20 feet downstream from the driver. The speed was measured the usual way, using photomultipliers which located the arrival of the shock wave at equally-spaced locations over the last 10 feet of the tube.

b) Monochromator

The instrument used in these measurements was a Jarrel-Ash triple channel monochromator. The optical system was collimated by a combination of entrance slit and stop size, producing a spatial resolution of $0.1\,\mu$sec. The entrance slit of the monochromator was imaged on the axis of the shock tube, using the usual optical train reported in the literature for making this type of measurement.[3,4] Wavelength calibration to within approximately 0.5 Å was achieved by a mercury lamp and the effective wavelength resolution on each channel was 5 Å. Although intensity calibration was not necessary for making the nonequilibrium temperature measurements, it was used to obtain a photometric survey which served to investigate impurity effects as well as to obtain an independent measurement of the f number for the $N_2^+(1-)$ system of .035.

A monitor channel was also used which employed an S1 surface photomultiplier with a cut-off filter at 5500 Å.

c. Temperature Measurements

Shock tube spectra show the $N_2^+(1-)$ radiation to be the prominent radiator from the nonequilibrium and equilibrium regions of incident nitrogen shock between 3500 and 4500 Å, and at temperatures in the vicinity of 7000°K. The $N_2^+(1-)\ \Delta v = +1$ sequence in the vicinity of 4200 Å was used for inferring the rotational and vibrational temperature because the spectra showed this region to be clear of impurity radiation from CN, a commonly found impurity in the $N_2^+(1-)\ \Delta v = 0$ sequence.[5]

The three channels of the monochromator were so spaced that the red and middle channel could be used to measure the rotational temperature of the 0, 1 $N_2^+(1-)$ transition, while the red and blue channel could be used to measure the vibrational temperature from observing the 0, 1 and 2, 3 vibrational $N_2^+(1-)$ transitions. The monitor channel was used to view essentially only the $N_2(1+)$ band system and was identical to that used by Allen et al[3] to observe the $N_2(1+)$ radiation in measuring N_2 recombination rates. This channel was used to measure the electronic temperature history.

Measured temperature histories for a typical run in pure nitrogen are shown in Fig. 1.

REFERENCES

1. Allen, R.A., Rose, P.H. and Camm, J.C., "Non-equilibrium and Equilibrium Radiation at Super-Satellite Re-Entry Velocities," Avco-Everett Research Laboratory Research Report 156, September 1962.
2. Camm, J.C. and Rose, P.H., "Electric Shock Tube for High Velocity Simulation," Avco-Everett Research Laboratory Research Report 136, July 1962.
3. Allen, R.A., Keck, J.C. and Camm, J.C., "Non-equilibrium Radiation from Shock Heated Nitrogen and a Determination of the Recombination Rate," Avco-Everett Research Laboratory Research Report 110, June 1961.
4. Allen, R.A., Camm, J.C. and Keck, J.C., "Radiation from Hot Nitrogen," J. Quant. Spect. Rad. Transf. 1, 269-277 (1961).
5. Keck, J.C., Camm, J.C., Kivel, B. and Wentink, T. Jr., "Radiation from Hot Air, Part II," Annals of Physics 7, 1-38 (1959).

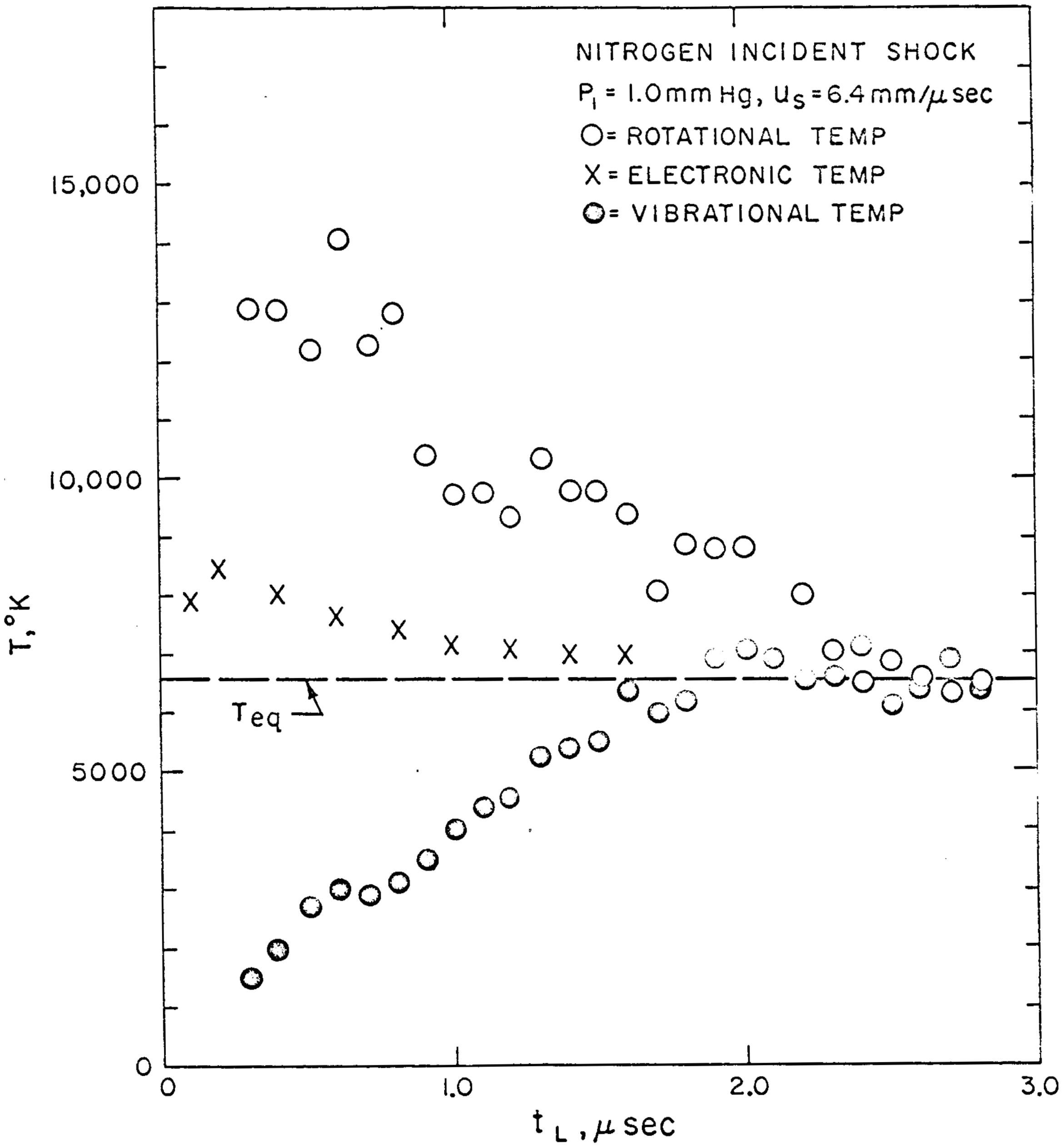

Fig. 1 Measured rotational, vibrational and electronic temperature histories for an incident nitrogen shock. The rotational and vibrational temperatures are those of the excited $N_2^+(B)$ molecule and the electronic temperature is based on the relative populations of the $N_2(X)$ and $N_2(B)$ states.