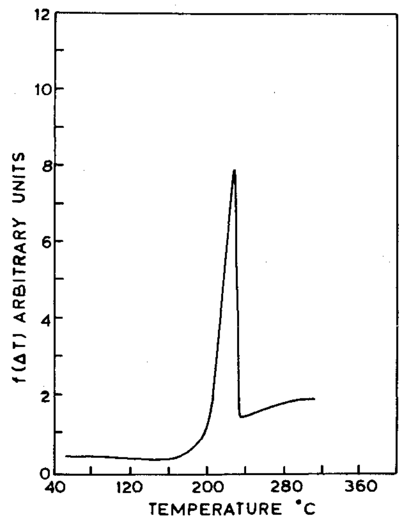

Fig. 1 DTA trace of polyethylenimine perchlorate.

about 50°C in the ignition temperatures of the two poly (vinyl pyridine) salts. The most plausible explanation is that there is some sort of hydrogen bonding between the vinyl→C–H and O of the ClO_4 group in the case of poly (2-vinyl pyridine) perchlorate due to the proximity of the two groups. This given an additional stability for this compound which ignites at a higher temperature than poly (4-vinyl pyridine) perchlorate. Such a trend is noticed again in the case of ortho and para poly (amino styrene) perchlorates. The assumption of hydrogen bonding in these compounds finds support from the recent theoretical[12] and experimental[13] studies on hydrogen bonding where the hydrogen is attached to a carbon atom.

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Relaxation Distance and Equilibrium Electron Density Measurements in Hydrogen-Helium Plasmas

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Introduction

THE physical properties of shock-heated hydrogen-helium plasmas which surround an entry probe during outer planet entry present a challenging area for theoretical and experimental investigation. In the present Note, electron density measurements are reported for 84.17% H_2–15.83% He for a wide range of shock velocities (26km/sec to 46 km/sec at an initial pressure of 1 torr). Two completely independent diagnostic techniques, namely, pulsed laser interferometry and high-resolution spectral measurements of the Stark-broadened H_β line profile from the transient plasma are used. The flow behind the incident shock wave within the shock tube simulates the flow behind the bow shock wave of an outer planet entry probe. The radiative emission of this shock-heated, hydrogen-helium plasma and consequent heat flux at an entry probe heat shield is directly related to the electron temperature and density.

Holographic Interferometry Measurements

The shock wave is produced in the annular arc accelerator (ANAA) shock tube[1] which consists of a cold gas driver, an expansion section, high-voltage electrode sections, and the shock tube test section (see Fig. 1). The shock speed is monitored by fast-rise photo-multiplier tubes at nine stations along the test section so that any shock attenuation can be measured accurately. Good quality flow with various shock velocities is achieved. The holographic interferometer consists of a pulsed ruby[4] laser system, a beam splitter, a scene beam expander, two spherical collimating mirrors, a reference beam expander, and the hologram film holder. All of these components are mounted about the ANAA shock tube on tables or optical stands with the optical axis of the scene beam in a horizontal plane 1.5 m above the floor. The scene beam passes through the test section which is composed of a 15.3-cm inside diameter tube. The fringe shift from the first exposure with a neutral 84.17% H_2–15.83% He gas in the test section to the second exposure with the shock heated plasma in view is the integral $\int(\mu\text{-}1)d\ell/\lambda$ where the refractive index μ is a function of the particle species encountered along a ray of length ℓ and the laser wavelength λ. Each species of molecule, atom, ion, or electron has a different refractive index. Through the previous integral, they all contribute to the total fringe shift. The free electrons cause a fringe shift of opposite sign and are more than 40 times more effective in changing laser phase than the neutral species. These properties allow us to interpret the hologram for electron density with a minimun of uncertainty.

Spectroscopic Measurements

In constrast to stationary plasmas where spectroscopic measurements can be made with little time limitation so that one can scan across a line profile at a large number of wave-

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Index categores: Radiatively Coupled Flows and Heat Transfer; Shock Waves and Detonations; Supersonic and Hypersonic Flow.

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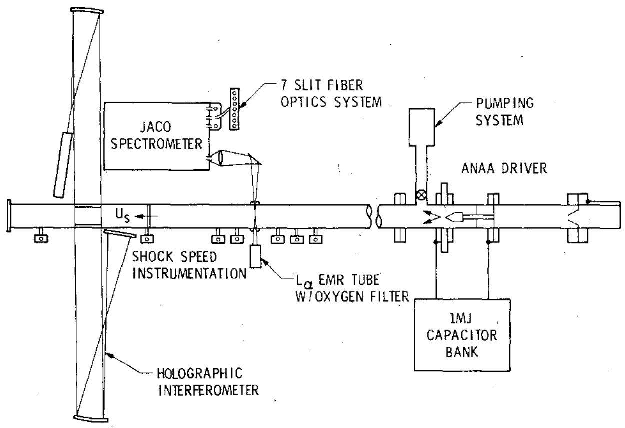

Fig. 1 Annular arc accelerator shock tube and optical instrumentation.

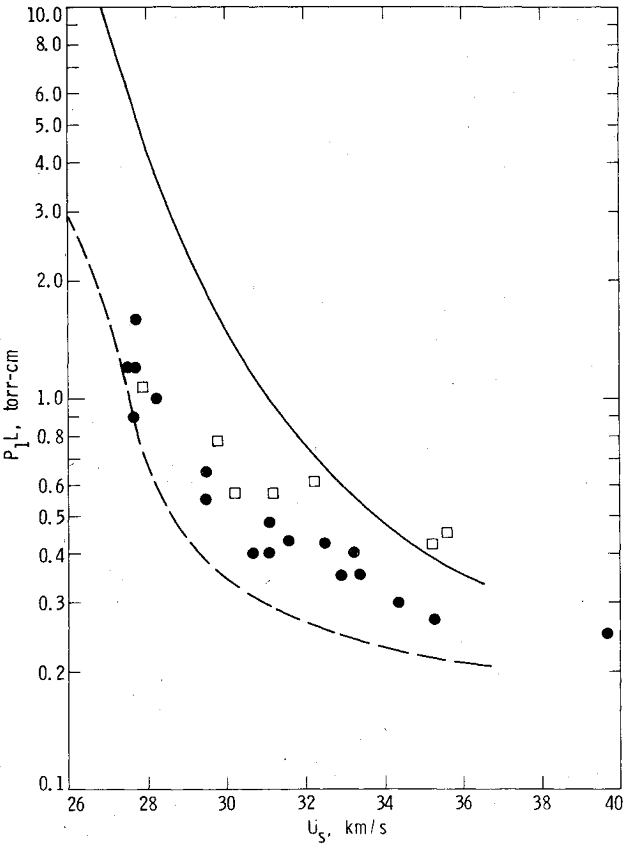

Fig. 2 Nonequilibrium relaxation length obtained from holographic measurements (●) and spectroscopic measurements (□)[3] of H_α line in 84.17% H_2-15.83% He.

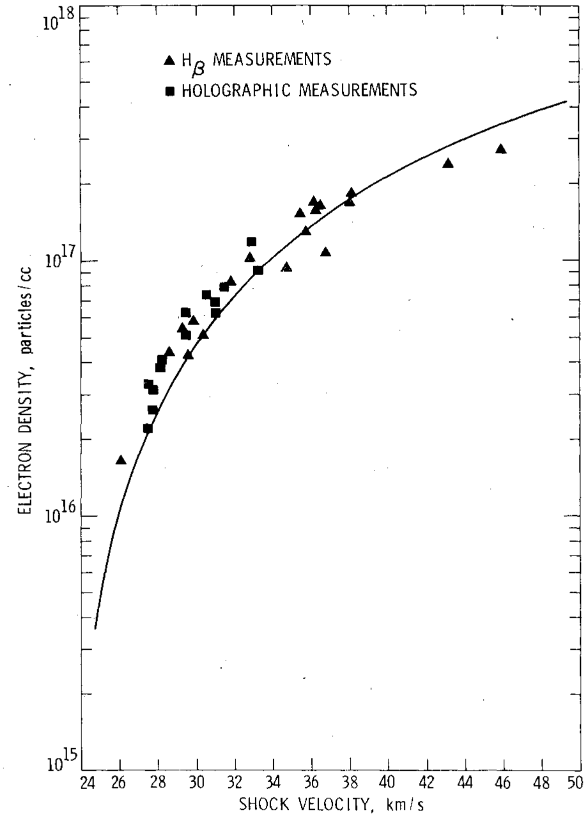

Fig. 3 Equilibrium electron density measured behind normal shock wave in 84.17% H_2-15.83% He.

lengths with a high-resolution spectrograph, the transient plasma slug exists for only a few microseconds. Furthermore, in order to obtain meaningful time-resolved data, the spectral measurements at various wavelengths must be made simultaneously with a time resolution of the order of 0.05 μsec. This is made possible by using a fiber optics slit system[2] placed at the exit plane of a Jarrel Ash Model 75-000 plane grating spectrograph (f/6.3, 0.75 m focal length). The radiation from the plasma after being dispersed in the spectrograph, becomes incident on each of seven slits and is transmitted through bundles of optical fibers to seven fast-rise photomultiplier tubes, enabling continuum as well as line intensity measurements to be made. Doppler broadening of the H_β line is calculated to be less than 0.4 Å for the plasma and is completely negligible. The equilibrium electron density is inferred from the measured Stark-broadened H_β profiles.

Experimental Results

Relaxation Distance Measurements

From a series of experiments, a pattern of ionization relaxation distance has been established, somewhat less than that measured with radiometers. It was measured by holographic interferometry as a function of shock velocity. Both the present holographic measurements and radiometer measurements from Ref. 3 indicate a relaxation distance diminishing with shock velocity up to the maximum velocity observed, as shown in Fig. 2. The present holographic measured relaxation distance is about 50% longer than that computed in Ref. 3 (broken line), based on reaction rates obtained from experimental radiometer measurements of helium rich mixtures, and about 50% lower than that computed in Ref. 4 (solid line). In our present work, we have found the radiometers to have a time response that is a factor of 5 slower than the 20 ns ruby laser pulse; therefore, the relaxation distance measured by the holographic system is thought to be more realistic than the radiometric measurements.

Holographic Interferometry Measurements of Electron Density

The equilibrium electron density in the shock-heated plasma is determined from the total fringe shift from the region immediately ahead of the quasi-uniform ionized region behind the gasdynamic shock wave. Immediately behind the shock wave, a compression and dissociation of the 84.17% H_2-15.83% He gas occurs resulting in a positive fringe shift of about 0.3 compared to a calculated fringe shift of 0.45 for a completely dissociated gas without electrons. With ionization of the hydrogen and helium atoms, the free electrons cause a decrease in the refractivity of the gas, resulting in a negative shift in the interferogram fringes. The total fringe shift caused by the formation of electrons behind the shock wave is converted to electron density which is plotted in Fig. 3. Incidentally, this is the electron density measured on the centerline of the shock tube–some variation with vertical position was observed. Along with these data in Fig. 3 is a line representing the JPL thermochemical calculation of expected electron density. Generally, the present holographic measurements indicate an electron density 30% more than the calculation.

Spectroscopic Measurements of Electron Density

The path length across the diameter of the shock tube is quite long (15.3 cm) and reabsorption becomes appreciable for electron density of the order 10^{16} cm^{-3} or higher. The half-intensity width must be corrected for reabsorption; otherwise errors of 25% or more in the determination of the electron density may be incurred. The spectroscopic measurements reported here complement the previous effort described in Ref. 2 with the additional aspect that, besides covering new shock conditions simulating outer planet entry for a realistic hydrogen-helium composition, we take into account the influence of reabsorption on the line profile, which was neglected previously. Furthermore, our analysis is based on the improved Kepple-Griem[5] treatment on Stark broadening instead of an earlier version by Griem et al.[6] The measured electron densitied for 84.17% H_2–15.83% He with initial pressure 1 torr from H_β profiles corrected for reabsorption are shown in Fig. 3, where measurements by holographic interferometry are also shown.

Conclusions

Experimental determination of the ionization relaxtion distances and electron density has been made by means of holographic interferometry and spectroscopic measurements over a wide range of shock conditions (26–46 km/sec at an initial pressure of 1 torr) for a realistic composition (84.17% H_2–15.83% He simulating outer planet entry. As the shock velocity increases, the electron density increases while the relaxation distance decreases, as expected. There is good agreement between the results obtained from the holographic interferometry measurements and the spectroscopic measurements, which are two completely independent diagnostic techniques. In general, the equilibrium electron density determined from the experimental measurements is about 30% more than that predicted by the JPL thermochemistry code at shock speed from 26–33 km/sec. The extent of the nonequilibrium ionization zone measured with the holographic interferometer agrees qualitatively with H_α line emission measurements made by previous investigators at this laboratory over the shock speed range duplicated by each instrument. The range of test conditions covered by this work gives more realistic simulation of the entry conditions into Saturn nominal and Jupiter nominal atmospheres than previous experimental investigations.

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Analytical Comparison of the Performance of Different Base-Burning Modes

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Introduction

THE notion of "base burning" in an attempt to reduce the drag, or even provide thrust, on supersonic projectiles has been of interest for a number of years. In recent times, suggestions for locating the heat release zone adjacent to, but outside of, the viscous base flow have been presented[2] with a view toward improving performance. One also can envision combined systems where part of the energy is released in the base flow region and part to the outside. Unfortunately, there have been no direct experimental or analytical comparisons of these various schemes in terms of performance.

Earlier, we presented a simplified treatment of pure base-burning cases,[2] and it is the purpose of this Note to report on an extension of that work such that cases with all external burning or combined schemes can also be treated. Finally, a direct comparison of performance for a specific example is given.

Analysis

The original base-burning analysis[2] has been extended to include external burning processes using the flow model shown in Fig. 1. Transverse fuel injection is assumed to produce an oblique shock which turns the flow from the body axis to angle α. External burning turns it back to the horizontal, and α is proportional to $h_f f_s$, the product of the heating value of the fuel and its stoichiometric fuel-air ratio. It is assumed implicitly here that the injection process is tailored to $h_f f_s$ so as to produce a uniform, horizontal, but compressed flow external to the base region. This process then can be coupled to the base-burning analysis.

We may write the pressure change due to heat release as[3]

$$C_p = \frac{(\gamma-1)\, q}{\rho_1 u_1 (\gamma R T_1)(M_1{}^2-1)^{1/2}} \frac{\sin\mu}{\sin(\mu+\alpha)} \qquad (1)$$

where μ is the local Mach angle, γ the ratio of specific heats, ρ_1, u_1, T_1, and M_1 are the density, velocity, temperature and Mach number behind the injection shock, respectively, and q is a heat rate per unit time and area, assumed uniform in space. This last assumption can be easily removed. It remains now to calculate the heat release that results from the combustion with air entrained into the fuel-rich external mixing zone. This entrainment rate can be estimated as for the base mixing region[2] noting that there are two sides to the mixing region here. Thus

$$\mathrm{d}\dot{m}/\mathrm{d}x = 2k\ \rho_1 u_1 [1-(\rho u/\rho_1 u_1)] \simeq 2k\ \rho_1 u_1 \qquad (2)$$

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