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Radiative Interaction Between Driver and Driven Gases in an Arc-Driven Shock Tube

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Summary

An electric-arc driven shock tube was operated with hydrogen as the driven gas and either hydrogen or helium as the driver gas. Electron density was measured behind the primary shock wave spectroscopically from the width of the Beta line of hydrogen. The measured electron density values were many times greater than the values calculated by the Rankine-Hugoniot relations. By accounting for the radiative transfer from the driver gas to the driven gas, the measured electron density values were numerically recreated.

Introduction

One well known method of producing a strong shock wave in a shock tube is to use an electrically-heated driver (see, e.g., Ref. 1). At NASA Ames Research Center, one such shock tube, with a driven-section internal diameter of 10 cm, is in operation. The driver section, also of 10 cm internal diameter and 75 cm length, is filled either with hydrogen or helium. An arc is initiated in the driver by exploding a tungsten wire. The mass of the tungsten wire used is approximately equal to that of the driver gas.

Tests were made in this shock tube with the intention of studying the radiation phenomenon occurring in the shock layer over the Galileo Probe vehicle which entered the atmosphere of the planet Jupiter in 1995. The tests were motivated by the fact that the surface recession of its heatshield was different from the prediction.[2] It was hoped that the shock layer condition for the Galileo Probe would be simulated by the flow behind the primary shock wave in the shock tube.

Method of Measurement and Analysis

Spectroscopic observation was made through a window in the driven section of the shock tube. A 0.25 meter focal length McPherson Model 238 grating spectrograph, equipped with a CCD array at its exit plane, and two narrow band-pass monochromators were used. Spatially-resolved, time-frozen spectral snap-shots were obtained with the spectrograph, and time-resolved monochromatic intensities were obtained at 486.13 and 488.69 nm using the two monochromators. Initially, using the well-known theory of Stark broadening of hydrogen lines, a chart was constructed which relates the ratio of intensities at the two wavelengths with the width of the hydrogen Beta line at 486.13 nm. By comparing the

measured intensity ratio at these two wavelengths with the chart. the width of the Beta line was deduced. Electron density was then deduced from the width of the line.
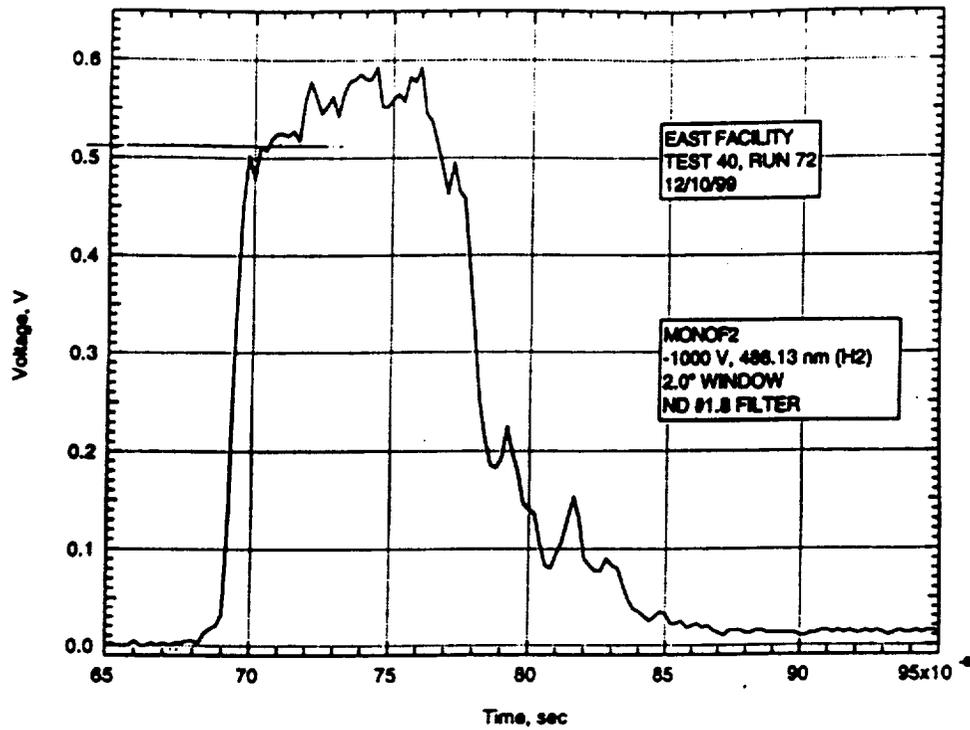

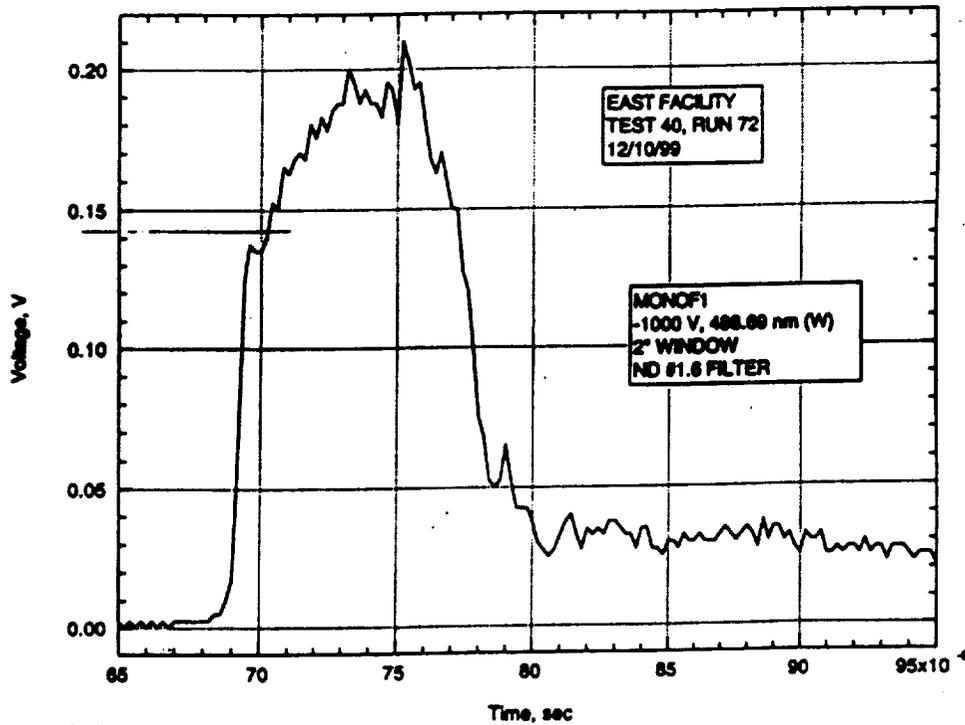Figure 1. Monochromator output, Us = 22 km/s, p1 = 1 Torr. (a) 486.13 nm.

Figure 1. (b) 488.69 nm.

A numerical computation was made to determine the state of the driven gas accounting for the radiative transfer from the driver gas. The driver gas was assumed to emit a black body radiation at an arbitrarily assigned temperature. Regardless of whether hydrogen or helium is used as the driver gas, the main radiator in the driver section is likely to be metallic tungsten. Tungsten has a large number of lines, and therefore the spectrum of the radiation emitted by the driver gas is believed to be nearly that of a black body. The one-dimensional radiative transfer phenomenon was calculated assuming the gas to be inviscid and in equilibrium. The spectrum of hydrogen is represented at 400 wavelength points.

Time after shock passage of station E, microsec
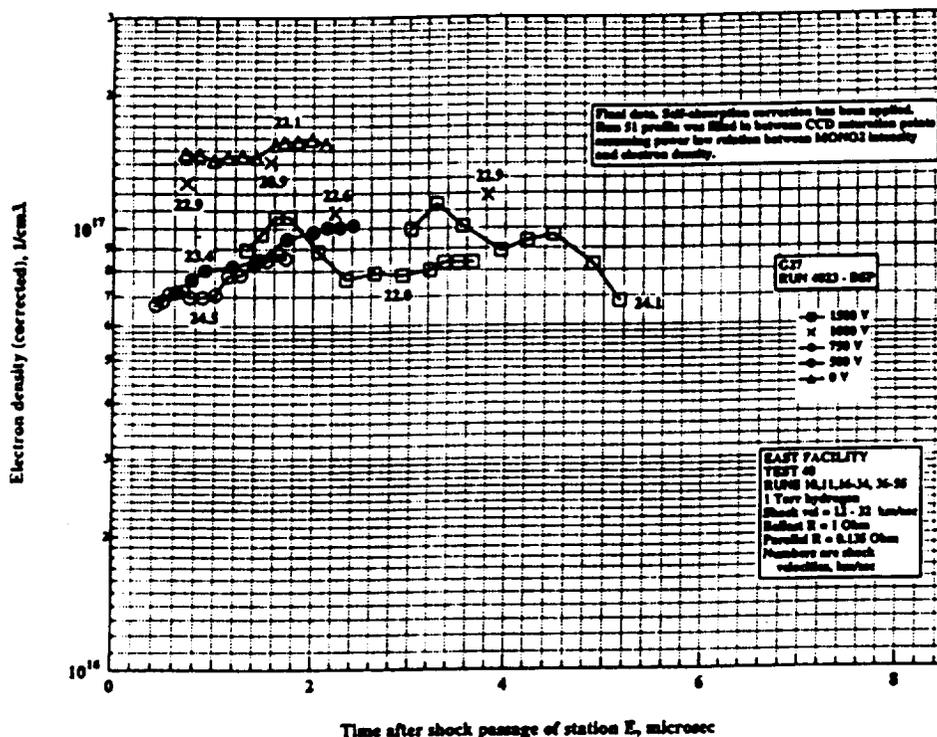
Results

In Figures 1(a) and (b), typical outputs from the monochromators are shown. The electron density values determined are presented in Figure 2. The figure shows a considerable degree of scatter. The equilibrium temperature corresponding to the measured electron density is in the range between 10,000 and 12,000 K.

Figure 3 shows the wavelength resolution of the spectrum used in the radiative transfer calculation. As shown that the spectrum is represented by the present method in sufficient detail.

In the calculation of radiative transfer, the black-body temperature of the driver gas was varied arbitrarily until the calculation agreed with the measurement. In Figure 4, the electron density values so calculated are compared with the measured values. As indicated in the figure, the calculated values are for the black body temperature of 18,000 K. The
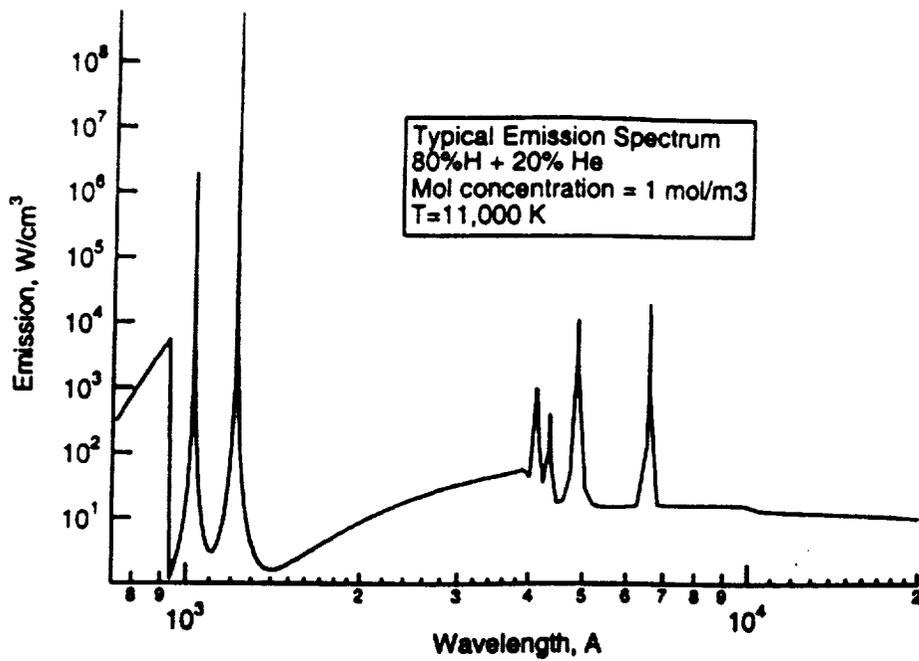
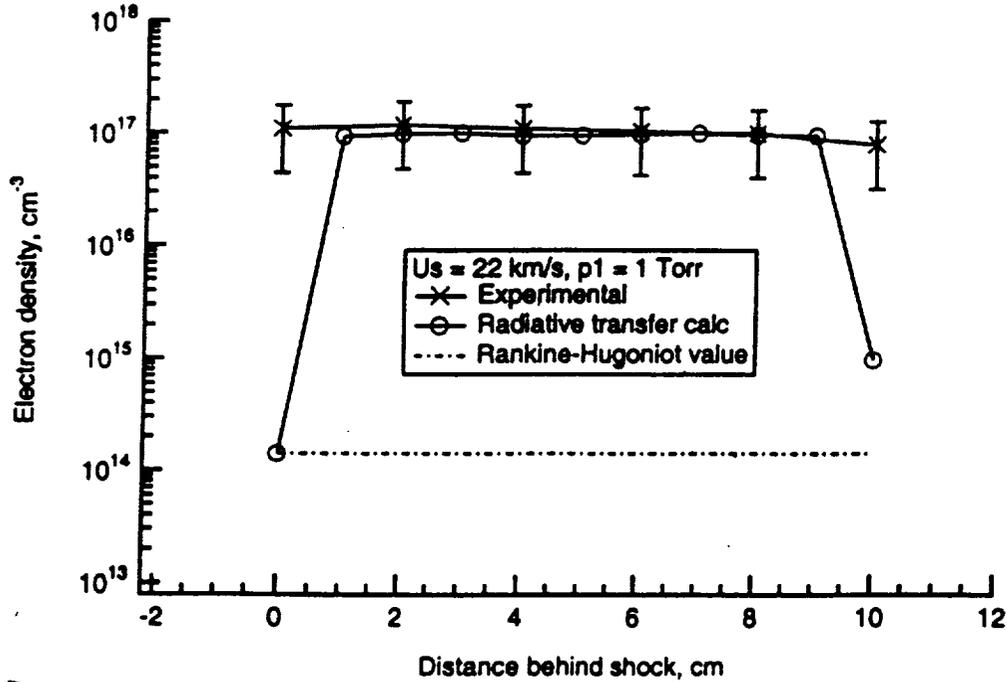Figure 3. Typical spectrum of hydrogen used in radiative transfer calculation.

Figure 4. Comparison between the measured and the calculated electron densities. Assumed driver black body tempeature = 18,000 K.

Rankine-Hugoniot value is shown also for comparison. As seen in the figure, the calculated values agree with the measured values. However, the Rankine-Hugoniot value is three orders of magnitude smaller than the measured value. The static enthalpy of the flow with black-body radiation is 550 MJ/kg while that determined by the Rankine-Hugoniot relation is only 135 MJ/kg.

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The relatively large scatter in Fig. 2 can be attributed to the fluctuation in the radiation intensity emitted by the driver gas.

The radiation absorbed by the driven gas is calculated to be of the order of 1/100 of the total radiation emitted by the driver.

Conclusions

When the driver is heated by electric arc discharge, the radiation emitted by the driver gas can heat the driven gas to a great extent, thereby increasing the enthalpy of the driven gas greatly.

Acknowledgement

References

1. Sharma, S. P., and Park, C., "Operating Characteristics of 60-cm and 10-cm Electric Arc-Driven Shock Tubes, Part 1: The Driver" Journal of Thermophysics and Heat Transfer, Vol. 4, No. 3, July 1990, pp. 259-265.

2. Milos, F. S., "Galileo Probe Heat Shield Ablation Experiment," Journal of Thermophysics and Heat Transfer, Vol. 34, No. 6, November-December 1997, pp. 705-713.