Measurements of the Hβ Line Shape Using a Fiber Optics Slit System

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Theme

THE electron density of a transient plasma is measured by monitoring the emission of the hydrogen $H\beta$ line. A fiber optics slit system, coupled with electronic phototubes, is used to measure the spectral shape and abolute magnitude of the $H\beta$ emission with a time resolution of 0.1 μ sec.

Contents

The presence of electrons and ions in a plasma has a large effect on the discrete or line emission from bound-bound atomic transitions. Stark broadening of the lines, due to electron and ion collisions, is the dominant broadening mechanism in singly ionized plasmas (10,000–20,000°K); such broadening is strongly dependent on the electron density and nearly independent of the temperature. Thus it is an excellent monitor of the electron density.

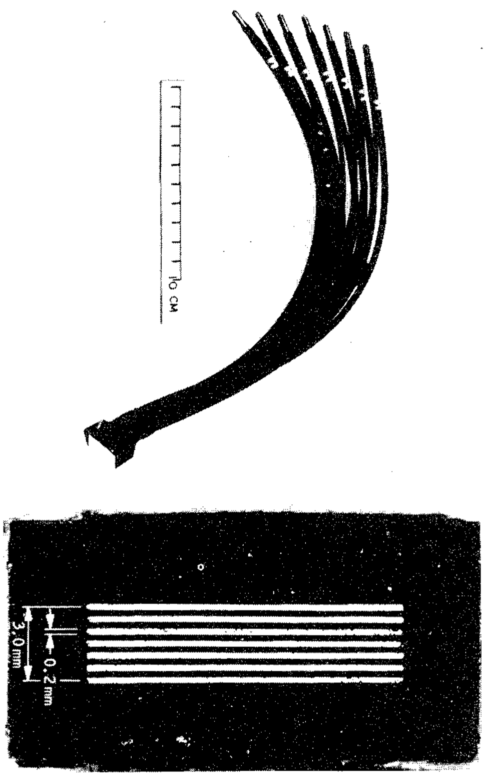

Fig. 1 Fiber optics slit system.

Stark broadened line profiles for hydrogen have been computed by Griem, Kolb, and Shen[1] and are tabulated by Griem.[2] An estimate of the theoretical accuracy is placed at 15%. However, a later experiment by Hill and Gerardo[3] suggests that the profile for the $H\beta$ line may be much better. Their measured profiles agree to within $\pm 2\%$ of the calculated profiles.

The wavelength resolution required to measure the spectral intensity of the $H\beta$ line in a shock tube plasma was obtained by constructing the fiber optics slit system[4] shown in Fig. 1a (a similar technique is described in Ref. 6). The slit system consists of seven slits 0.2 mm wide and spaced every 0.5 mm, as shown in Fig. 1b. The slits are filled with three rows of quartz fibers approximately 75 μm in diameter and 30 cm long. The fibers from each slit are individually bundled and optically connected to separate phototubes (RCA 1P28). These slits were placed in the focal plane of a Jarrel Ash Model 75-000 Plane Grating Spectrograph (*f*/6.3, 0.75 m focal length). The grating has a reciprocal linear dispersion of approximately 9 Å/mm (at 4861 Å). The slit spacing is therefore 4.5 Å, with each slit viewing a spectral bandpass of 1.8 Å. This configuration gives sufficient resolution to resolve the $H\beta$ profile in plasmas with electron densities of from 10^{16} to 10^{17} electrons/cm^3.

The spectrograph was focused on the center of the JPL electric-arc-driven shock tube, and viewed the shock heated gas along a line perpendicular to the length of the tube. The fiber optics slit system was positioned to monitor the radiative

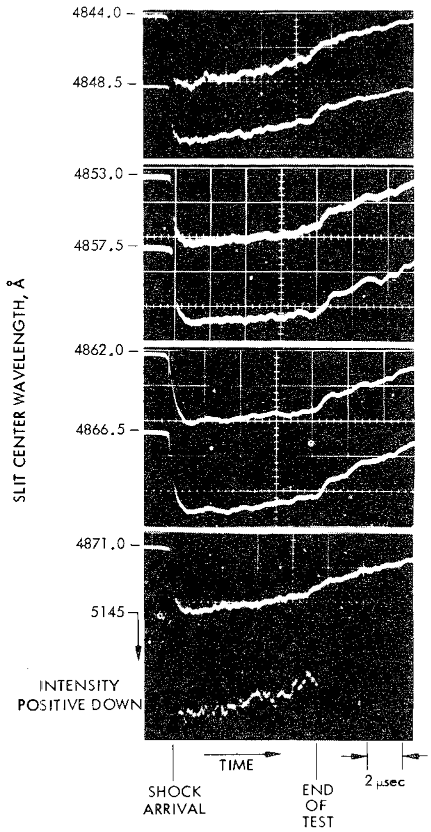

Fig. 2 Oscillograms of H_β spectral intensity measurements behind an incident shock, $P_1 = 1.0$ mmHg, $V_s = 19.5$ km/sec.

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Index categories: Atomic, Molecular and Plasma Properties; Research Facilities and Instrumentation.

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Table 1 Summary of shock tube runs

RUN No.	CONFIG.	P_1, N/m^2 (mm hg)	V_s, km/s	T, K	Ne/Ne ideal	RMS Error
245	RS	33.3 (0.25)	14.0	13,825	0.992	3.9 %
252	RS	33.3 (0.25)	12.0	12,265	0.935	6.2
253	RS	33.3 (0.25)	12.5	12,610	0.790	10.5
257	RS	66.6 (0.50)	11.0	12,050	0.827	17.2
259	RS	66.6 (0.50)	12.9	13,425	0.881	19.8
283	IS	133.3 (1.0)	17.0	11,870	1.138	9.3
284	IS	133.3 (1.0)	18.05	12,540	0.935	5.0
285	IS	133.3 (1.0)	18.8	13,000	0.842	5.7
286	IS	133.3 (1.0)	18.3	12,690	1.013	5.0
287	IS	133.3 (1.0)	18.3	12,690	0.841	3.0
288	IS	133.3 (1.0)	20.0	13,710	0.779	6.2
290	IS	33.3 (0.25)	21.8	13,690	1.19	6.6
291	IS	33.3 (0.25)	21.4	13,460	0.947	8.8
292	IS	33.3 (0.25)	24.4	15,630	0.880	7.0
RS = REFLECTED SHOCK IS = INCIDENT SHOCK						

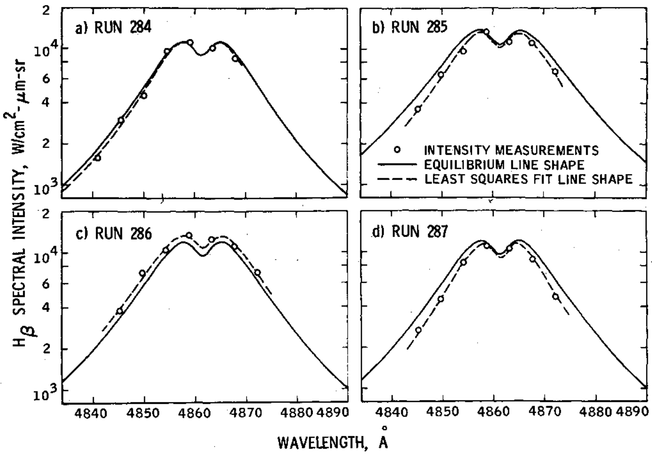

Fig. 3 H_β spectral intensity data compared with equilibrium line profile.

intensity emitted by the plasma behind the shock wave at seven points across the Hβ line. Within the limits of the phototube response time, which is approximately 0.10 μsec, the system measures a time resolved, seven point profile of Hβ. This represents at least a factor of 10 increase in time resolution over previously used techniques.[3,5]

Shown in Fig. 2 is a representative set of phototube output oscillograms. The radiative intensity of each slit is displayed (positive is down) as a function of time along with the output of a phototube viewing the continuum at 5145 Å (10 Å band pass). The intensity is seen to rise as the shock heated plasma comes into view and then remain relatively constant until the arrival of the driver gas. The line radiation decreases upon arrival of the helium driver gas, whereas the continuum channel radiation increases due to the impurity radiation at this wavelength.

For the present experimental conditions, the plasma test slug should reach equilibrium in less than 1 μsec after the passage of the shock wave and remain in equilibrium throughout the test slug. The plasma properties behind the incident shock and the reflected shock should correspond to the conditions predicted by the conservation equations and equilibrium thermodynamics.

Presented in Fig. 3 are some results of the Hβ line intensity distribution measurements. In each case the data are compared with the computed line intensity using the equilibrium plasma conditions corresponding to the measured shock speed and initial pressure of the run (the solid line). The dashed curves are least squares fit profiles which were determined by varying the electron density until the profile best matched the measured intensity.

Presented in Table 1 is a summary of 14 shock tube runs. The column Ne/Ne_{ideal} is a ratio of the best-fit measured electron density to the computed value and on the average is about 10% low. In all cases, the data represented the measured intensity immediately behind the shock. In the last column is the rms error between the measured intensities and the least squares fit profile for the particular run. For most of the runs this error was less than 10% but did approach 20% on one run (259). The shape of the line, and consequently the electron density, is felt to be specified to approximately this level of accuracy.

Some runs experienced a decrease in measured intensity through the test slug, as can be seen in Fig. 2. In this run, channels 1 and 2 located in the line wings (4844.0 and 4848.5 Å) demonstrate a larger drop in intensity than the other channels, indicating that the line is narrowing. The corresponding decrease in electron density, though it is small, compares with the predicted decrease due to radiative cooling of the gas.

References

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