THE STRUCTURE AND EMISSION OF A NON-RADIATIVE SHOCK

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Faint filaments are observed a few arcmin outside the bright optical filaments of the Cygnus Loop. They show nearly pure Balmer line emission spectra, and they are interpreted as emission from non-radiative shocks (1). Each neutral H atom passing through the shock front emits on average about 0.1 Hα photon before it is ionized. Since this radiation arises very close to the shock front, rather than in an extended post-shock cooling zone (2), it can be used to study the physics of the shock front itself. The structure of a shock poses several important questions (3). There may be an electron thermal conduction precursor ahead of the shock and there may be plasma turbulence. The shock thermalizes 3/4 of the bulk velocity of the incoming particles, so the ions initially have nearly all of the thermal energy. The electron and ion temperatures can reach equilibrium on the Coulomb collision time scale, but plasma turbulence may bring them into equilibrium much more rapidly. The Coulomb equilibration time scale is similar to the hydrogen ionization time, so that the hydrogen line emission will depend on the nature of the equilibration. The interpretation of the Hα line profile in terms of the shock velocity also depends on this equilibration, so this question is important for comparison of shock models with X-ray spectra.

Models have been computed with the assumptions that the electrons and ions each have Maxwellian distributions (possibly with different temperatures) and that 90% of the pre-shock hydrogen is neutral. Energy losses due to ionization and excitation of hydrogen and helium were included, and great care was taken in the selection of atomic rate coefficients. The assumption of Maxwellian velocity distributions is questionable, but the available data do not yet justify the great complexity of models which drop this assumption.

The observations available for detailed comparison with these models are an IUE SWP spectrum, a blue spectrum, and an Hα profile of a filament 5 arcmin outside the bright northeast portion of the Cygnus Loop (4). The line profile gives a shock velocity of 170 km s^{-1} if

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the electron and ion temperatures equilibrate instantly or about 150 km s^{-1} if the equilibration is more gradual. The observed relative intensities in the UV and optical are compared with models using these two assumptions in Table 1.

TABLE 1

Observed and Theoretical
Relative Intensities

	Observed	$T_e = T_i$	$T_e \neq T_i$
N V λ1240	1.0	1.0	1.0
C IV λ1550	.73	.78	.43
He II λ1640	.64	.12	.03
2-photon	11.	2.9	1.1
Hβ (Broad)	1.0	1.0	1.0
O III λ5007	.29	.04	.13
O II λ3727	.54	.002	.02
Ne V λ3420	.89	.13	2.1

Comparison of the models with the observations shows that the assumption of Coulomb equilibration of T_e and T_i gives much better fits to the optical forbidden line intensities, though the predicted [O II] intensity is still far too small. The He II λ1640 intensity predicted by either model is too small. This can be qualitatively explained by the conversion of He II λ256 photons into λ1640 and λ304 photons as the λ256 photons are scattered by He^+ in the emission region. The optical depth for resonant scattering of λ256 photons is about 1 at line center, and conversion of λ256 photons could enhance the intensity of λ1640 by a factor of three or four. A detailed radiative transfer calculation is required for more precise comparison of this line with the models.

The $T_e = T_i$ model predicts C IV and He II intensities relative to the N V lines in agreement with the observations. The two-photon continuum seems brighter than predicted, but the uncertainty in this measurement might be as large as a factor of three. All these aspects of the UV spectrum are more poorly accounted for by the slow equilibration model. On the other hand the absolute intensities of the C IV and N V lines are straining the limits of the $T_e = T_i$ model, and resonant scattering of these lines (5) presents a possible problem. These difficulties are less severe by a factor of four in the Coulomb equilibration model.

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In conclusion, the present models do not fully account for the observations, and they do not answer the equilibration question. The filament observed is atypical both in its brightness and in the strength of its optical forbidden lines, so the more normal non-radiative shocks may be more amenable to modelling. The approximately equal intensities of the broad and narrow components of the Hα line show that any thermal conduction precursor present is not extensive enough to ionize much of the pre-shock hydrogen.

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REFERENCES

1. Raymond, J.C., Davis, M., Gull, T.R., and Parker, R.A.R 1980, Ap. J., 238, L21.
2. Chevalier, R.A., and Raymond, J.C. 1978, Ap. J., 225, L27.
3. McKee, C.F., and Hollenbach, D.J. 1980, Ann. Revs. Ast. and Ap., 18, 219.
4. Raymond, J.C., Fesen, R., and Gull, T.R. 1981, B.A.A.S., 13, 887.
5. Raymond, J.C., Black, J.H., Dupree, A.K., Hartmann, L., and Wolff, R.S. 1980b, Ap. J., 246, 100.