THE FORMATION OF Mg I 4571 Å IN THE
SOLAR ATMOSPHERE

V. The Multi-Dimensional Structure of the Photosphere and Low Chromosphere

RICHARD C. ALTROCK
Sacramento Peak Observatory, Air Force Cambridge Research Laboratories,
Sunspot, N.M. 88349, U.S.A.

and

C. J. CANNON*
Institut d'Astrophysique, 98 bis, Boul. Arago, Paris 75014, France

(Received 4 December, 1974; in final form 17 March, 1975)

Abstract. The two-dimensional equation of transfer is solved for the case of locally-controlled source function (LTE) and radiationally-controlled ionization. Horizontal fluctuations in electron temperature and macroscopic velocity fields are superposed on the basic one-dimensional model (cf. Altrock and Cannon, 1972). Output intensities are compared with observed rms intensity fluctuations and spatially-averaged intensities in Mg I 4571 Å. We find that at least one model (with a height-independent temperature fluctuation \( \Delta T/T = \pm 0.02 \) in the range \( 0 \leq h \leq 450 \) km) can predict the magnitude of the intensity fluctuations in both the continuum and \( \lambda 4571 \) Å. The asymmetry of the line can be explained by adding a height-independent, temperature-correlated flow of amplitude 1 to 2 km s\(^{-1}\). The relationship between these results and other multi-dimensional analyses is discussed.

1. Introduction

In previous papers (Altrock and Cannon, 1972, 'Paper I'; 1973a, 'Paper II'; 1973b, 'Paper III') we discussed setting up a one-dimensional model analysis program for absorption profiles of Mg I 4571 Å. Paper I outlined the assumed atomic parameters, source function, elemental abundance, ionization equilibrium and microturbulent velocity field. A final one-dimensional atmospheric model was obtained that provided a 'best fit' to the observed profiles. This model required minor changes to the Harvard-Smithsonian Reference Atmosphere ('HSRA'-Gingerich \textit{et al.}, 1971).

Paper II investigated the observed asymmetry in the line. To the final model of Paper I we added a depth-varying one-dimensional flow velocity and found that this model generated profiles with asymmetries very close to those observed.

Obviously, the actual situation on the Sun is much more complex than the situation presented in Papers I and II, and the aim of the present paper is to extend these studies to a multi-dimensional model with horizontal variations in the parameters discussed above. The results so obtained can then be used to infer the more realistic multi-dimensional structure of the region of the temperature minimum and, together with similar analyses of the photosphere (Wilson, 1969; Canfield and Mehltretter, * On leave from Department of Applied Mathematics, University of Sydney, Sydney, Australia.

\textit{Solar Physics} 42 (1975) 289–302. All Rights Reserved
Copyright © 1975 by D. Reidel Publishing Company, Dordrecht-Holland
1973) and low chromosphere (Cannon, 1971a, b), therefore enable some insight to be gained into the dominating mechanisms giving rise to the observed radiation at these depths.

2. Method of Analysis

We begin with the one-dimensional model of Paper I and consider fluctuations on that model. In order to simplify the problem we consider only a two-dimensional atmosphere (cf. Avery et al., 1969). We consider in the final model fluctuations in electron temperature and macroturbulent or flow velocities. We also include fluctuations in density, although this parameter has little effect on the formation of such a temperature-sensitive line. The preliminary ideas and formulation of the mathematics for this study were based on a series of papers by C. J. Cannon and P. R. Wilson (see Cannon, 1971a, for a list of references).

The two-dimensional transfer equation may be written as

$$\sin \theta \frac{\partial I_v(x, z)}{\partial x} + \cos \theta \frac{\partial I_v(x, z)}{\partial z} = -\kappa_v(x, z) [I_v(x, z) - S_v(x, z)], \quad (1)$$

where we have used a standard polar coordinate system with $z$ positive upwards on the Sun. Following Paper II we have oriented our coordinate system so that $\varphi = 0$. The absorption coefficient is given by

$$\kappa_v(x, z) = N_L(x, z) n_0(x, z) H(a, v(x, z)), \quad (2)$$

where $N_L$ and $n_0$ have been defined in Paper II, and $H(a, v)$ has been defined by Equations (3) through (6) of Paper II. In this case, however, the flow velocity, $V$, is a function of both $x$ and $z$.

In order to solve Equation (1) we employ the method of characteristics. If we consider the intensity $I_v$ to be a function of $x$ and $z$ then we note that

$$dI_v = \frac{\partial I_v}{\partial x} dx + \frac{\partial I_v}{\partial z} dz, \quad (3)$$

and if we introduce the condition

$$dx = \tan \theta \, dz, \quad (4)$$

we obtain

$$\mu \frac{dI_v}{dz} = \sin \theta \frac{\partial I_v}{\partial x} + \cos \theta \frac{\partial I_v}{\partial z}, \quad (5)$$

where $\mu = \cos \theta$. Combining Equations (1) and (5) we obtain

$$\mu \frac{dI_v}{dz} = -\kappa_v [I_v - S_v], \quad (6)$$

which is just the one-dimensional transfer equation, but where $I_v$, $\kappa_v$ and $S_v$ are