JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
29: S339 ~ S340, 1996

RESPONSES OF THE TRANSITION REGION TO DOWNWARD AND UPWARD FLOWS

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ABSTRACT

In the present study we examine physical characteristics of a thin and rigid magnetic flux tube with a steady flow inside, which is embedded vertically upward in the solar atmosphere. We found from this study that (1) The downward material flow gives rise to a dominant heating in the flux tube which works with the conductive heating in the same direction. However, the upflow flow creates a dominant cooling which works against the conductive heating, resulting in a steeper temperature gradient with a shallower transition region. (2) Since the thickness of the transition region determines the material content in the transition region, a broader transition region of the downflow tube produces a larger differential measure.

Key Words : hydrodynamics—Sun:atmospheric motions—Sun:transition region

I. INTRODUCTION

The flow of mass and energy from the chromosphere to the corona and vis.-a-via. has been a difficult and unsolved problem. The source of energy for the corona must obviously originate in the lower solar atmosphere. But there is also a flow from the hot corona to the cool chromosphere. An important part of this is the material flow in both directions. While the solar wind indicates that there is a significant outward flow of material from the sun, observations of transition region lines, such as C IV, show a predominant downflow of material.

In this paper we present the results of new computer modeling of the mass and energy flow from the chromosphere to the corona. These models include the effects of material flow, conduction, non-LTE radiative transfer in H and He, and partial ionization.

II. THEORETICAL FORMULATION

We have solved a set of steady flow equations numerically, assuming a thin flux tube with a constant cross section which is embedded vertically upward in the solar upper atmosphere. We also assume that the magnetic field in the tube dominates to the extent that the gas motions do not perturb the magnetic structure so that the flow can be described in one dimension along the flux tube. The temperature and density at each point along the tube are treated as the average horizontal value as described in Kuin and Poland(1991). The conductive energy transport is assumed to be directed only along the tube axis, and the flux tube is completely insulated conductively from the surrounding medium.

The velocity at the upper boundary at $T = 10^5$ K is set to be about 7 km/s, which is a typical value of downward velocity observed in C IV 1548 line(e.g., Dere et al. 1984). Following the result of Fontenla et al.(1991), two values of pressure, 0.4 dynes cm^{-2} and 1.2 dynes cm^{-2} are chosen as a typical set of values at $T = 10^5$ K, representing bright network and active region, respectively. At the lower boundary at T=8,000K a small value of the conductive flux is set.

III. RESULTS AND DISCUSSION

Figure 1 presents the temperature structure for a typical downflow model and upflow model. As seen from the figure, a marked difference exists in their physical structure between the two models, particularly, in the temperature gradient and spatial extent of the transition zone. Since this extent determines the material content in the transition region, the downflow region should appear much brighter than the upflow region. This feature is consistent with earlier studies(e.g.,Mariska,1988; McClymont1989).

Why does the downflow region have a thicker transition zone than the upflow region? The key to the answer lies in the fact that the material downflow gives rise to a dominant heating, which works with the conductive heating in the same direction. However, in the upflow case the material flow gives rise to a dominant cooling, which works against the conductive heating from the corona. This steepens the temperature gradient in order to compensate, within an extremely short distance, a large amount of the convective energy loss with the energy transported by conduction from the corona.

This can be readily understood as we note that (1) the convective energy associated with the local energy balance in the transition zone mostly comes from enthalpy and (2) the local convective cooling rate(upflow) or heating rate(downflow) by enthalpy energy is given

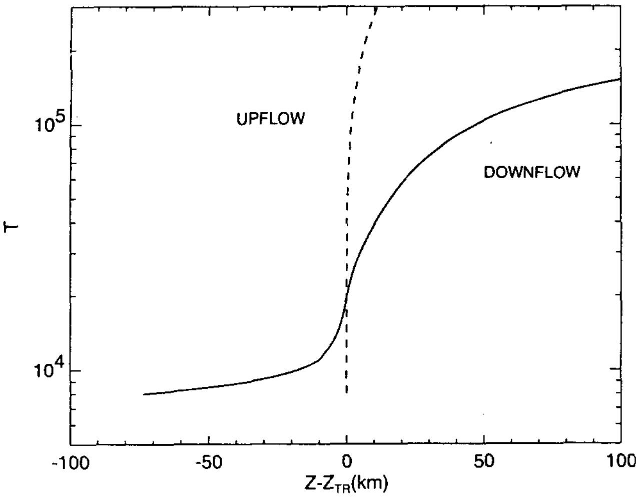

Fig. 1.

by

$$H_{ent} = -\frac{5}{2}pv\frac{d\ln T}{dz} \tag{1}$$

under constant pressure. As can be seen from equation(1), the amount of enthalpy energy carried by per unit volume of plasma is inversely proportional to the thickness Δz of the transition region, while the corresponding conductive energy is inversely proportional to the square of the thickness Δz^2. Accordingly, the enthalpy heated downflow model has a broader transition region than the conduction heated upflow model.

Our result strongly suggests that observed brightness of UV and EUV transition lines should have a positive correlation with the mangitude of the downflow velocity.

ACKNOWLEDGEMENTS

This work is in part supported by the Basic Science Research Institute Program, Ministry of Education, ROK. 1996(BSRI-96-5408).

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