ENERGY BALANCE IN COOL QUIESCENT PROMINENCES

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Abstract. The energy balance for cool quiescent prominences is examined using a 6000 km, 6000 K isothermal slab model prominence with a density gradient dictated by a modified Kippenhahn-Schlüter model. The model is irradiated from both sides by the coronal, chromospheric, and photospheric radiation fields. The radiative transfer problem is solved in detail for the Lyman continuum and Hα to determine the net radiative energy loss for hydrogen. An estimate of the energy loss for Ca II H and K indicates that this source of energy loss is unimportant when compared with the hydrogen radiation. The radiative energy loss is easily balanced by the conductive energy gain from the corona.

The only difficulty with our model is that the total hydrogen density must be of the order of 3 × 10^{12}/cm^3 to match the n=2 population density of 5 × 10^{15}/cm^3 obtained from observation. To support a prominence of this density and a thickness of 6000 km against gravity requires magnetic fields of the order of 20 G which is much higher than the average magnetic field in quiescent prominences deduced from limb observations. Two possible explanations for this discrepancy are given.

1. Introduction

The energy balance for quiescent prominences is a complicated problem since there is energy flowing into the prominence in the forms of radiation from the photosphere, chromosphere, and corona and conduction from the hot coronal surroundings. All of this energy must be radiated out of the prominence for a steady state to exist, and we know that this must be the case since many prominences remain quite stationary for long periods of time.

Since hydrogen is the dominant element in the Sun and since the lines and continua of hydrogen are dominant features in prominence spectra, we expect that most of the radiative energy transfer would be determined by hydrogen. The problem of radiative energy transfer in prominences for the hydrogen atom has been treated by Jefferies and Orrall (1961), Yakovkin and Zel’dina (1964), Kawaguchi (1964), Hirayama (1964), Giovanelli (1967), and Poland et al. (1971). All of the above authors have assumed isodensity, isothermal models for prominences, and only Poland et al. have solved the radiative transfer problem for hydrogen in prominences in detail.

In this work we use a magneto-hydrostatic equilibrium model slab similar to the model proposed by Kippenhahn and Schlüter (1957). We solve the radiative energy transfer problem for the Lyman continuum and Hα and calculate the radiative energy losses and gains through these transitions. We also estimate the energy loss occurring through Ca II H and K. We calculate the energy gain due to thermal conduction from

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the corona into the prominence for different values of both the temperature and the length scale for various temperature changes. We show that for a reasonable combination of these two parameters we can establish an energy balance in quiescent prominences between the gain through thermal conduction and the net radiative loss. Therefore we can construct a model of a quiescent prominence for which a steady state exists, once a prominence is formed.

2. The Prominence Model

We approximate a quiescent prominence by a thin slab of matter standing vertically on the Sun. For further discussion we introduce the following coordinate system: x-direction perpendicular to the prominence, y-direction horizontal and along the prominence, z-direction vertical. To describe the prominence we use the MHD approximation in which the equation of motion is given by:

\[
\frac{dV}{dt} = -\text{grad} P + \frac{1}{4\pi} \text{curl} \mathbf{B} \times \mathbf{B} - q \text{ grad } \phi
\]  

(1)

where all of the symbols have their standard meaning. We assume that the prominence is in static equilibrium and that all physical quantities are independent of y and z. The second approximation is inadequate if one were interested in the fine structure of prominences, but for the discussion of the average behavior of physical quantities it is a reasonable approach.

The components of Equation (1) with these assumptions are:

\[
-\frac{dP}{dx} - \frac{1}{4\pi} \left( B_x \frac{dB_z}{dx} + B_y \frac{dB_y}{dx} \right) = 0
\]  

(2)

\[
\frac{1}{4\pi} B_x \frac{dB_y}{dx} = 0
\]  

(3)

\[
-\rho g + \frac{1}{4\pi} B_x \frac{dB_x}{dx} = 0.
\]  

(4)

Equation (3) together with the solenoidal condition \( \nabla \cdot B = dB_z/dx = 0 \), show that our model only allows for a constant x- and y-component of the magnetic field. Then the integral of Equation (2) gives \( p + B_z^2/8\pi = \text{const} = (1/8\pi) B_0^2 \) where \( B_z \rightarrow B_0 \) and \( P \rightarrow 0 \) for \( x \rightarrow \infty \).

We also have the equation of state:

\[
P = \frac{R}{\mu} \rho T
\]  

(5)

where \( \mu \) and \( T \) are functions of \( x \), and should be calculated in such a way as to be consistent with the solution of the radiative transfer and heat conduction problems. Kippenhahn and Schlüter (1957) solved the equation for magnetohydrostatic equili-