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On the penetration of Alfven waves from the chromosphere into the corona

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Abstract. Within the framework of the two–layer model the expression for the reflection coefficients of Alfven (torsion) waves propagated from the chromosphere into the corona have been obtained. As a result of reflection the energetic losses of waves with a period less than several tens of seconds are about 70%. This shows evidence in favor of the essential contribution of Alfven waves with a period of 10–40 s to coronal heating of the Sun.

Keywords. Sun: corona, chromosphere, waves, oscillations

There are many indications that Alfven waves excited in the lower atmosphere can be responsible for the high temperature of the solar corona. However the reflection of Alfven waves between the chromosphere and corona must be quite strong. Therefore the aim of this work is to consider the penetration of Alfven waves from the chromosphere into the corona on the basis of the two–layer model.

The linearized MHD equations described the propagation of Alfven waves (torsion modes) along the axis Z of the magnetic flux tube can be written as (Hollweg 1984)

$$\rho\frac{\partial\delta v_\varphi}{\partial t} = \frac{B}{4\pi}\frac{\partial\delta B_\varphi}{\partial z}, \quad \frac{\partial\delta B_\varphi}{\partial t} = B\frac{\partial\delta v_\varphi}{\partial z}, \tag{1}$$

where δB_φ and δv_φ are disturbances of the velocity and the magnetic field, respectively. Combining equations (1), we obtain the wave equation

$$\frac{\partial^2\delta v_\varphi}{\partial t^2} = v_A^2(z)\frac{\partial^2\delta v_\varphi}{\partial z^2}, \tag{2}$$

where $v_A(z) = B/\sqrt{4\pi\rho(z)}$ is the Alfven velocity.

In case where $v_A \propto \exp(z/2H)$ and $\delta v, \delta B \propto \exp(i\omega t)$ equation (2) has the following solution

$$\delta v_\varphi = [C_1 H_0^{(1)}(\eta) + C_2 H_0^{(2)}(\eta)]e^{i\omega t}. \tag{3}$$

where C_1 and C_2 are constants, $\eta = 2H\omega/v_A$, $H_0^{(1)}$ and $H_0^{(2)}$ are the Hankel functions.

Disturbances of velocities of the incident (δv_h), reflected ($\delta v_h'$), and transmitted (δv_c) waves are proportional to $H_0^{(1)}(\eta)$, $H_0^{(2)}(\eta)$, and e^{-ikz}, respectively. Consequently, using the matching conditions at $z = 0$, $\delta v_h + \delta v_h' = \delta v_c$, $\delta B_h + \delta B_h' = \delta B_c$, and (1), we find

$$\frac{\delta v_h'}{\delta v_h} = -\frac{1 - i\omega/(kv_{A_h})H_1^{(1)}(\eta)/H_0^{(1)}(\eta)}{1 - i\omega/(kv_{A_h})H_1^{(2)}(\eta)/H_0^{(2)}(\eta)}. \tag{4}$$

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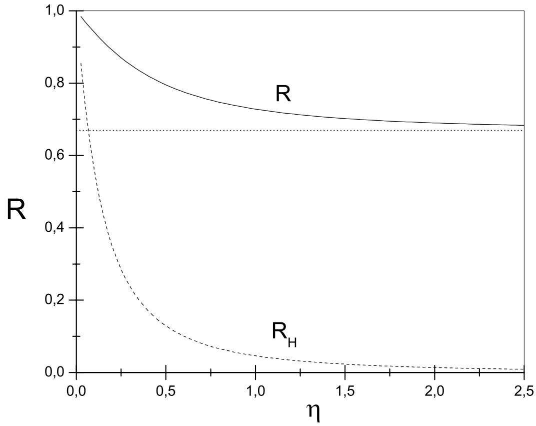

Figure 1. Plots of the reflection coefficients R and R_H versus η at $\rho_h/\rho_c = 10^2$.

It should be pointed out that equation (4) does not coincide with the appropriate formula (15) obtained by Hollweg (1984) (see also Leer *et al.* 1982). The main distinguish is connected with the ratio $\omega/(kv_{A_h})$. Hollweg (1984) adopted $\omega/(kv_{A_h}) = 1$ while as follows from our consideration $\omega/(kv_{A_h}) = \sqrt{\rho_h/\rho_c}$. It seems to us, equation (4) is more adequate since at $H \to \infty$ it is reduced to the well known expression, $\delta v_h'/\delta v_h = (v_{A_c} - v_{A_h})/(v_{A_c} + v_{A_h})$ (formula (15) gives $\delta v_h'/\delta v_h = 0$).

According to equation (4) the reflection coefficient is

$$R = \left|\frac{\delta v_h'}{\delta v_h}\right|^2 = \frac{J_0(\eta)^2 + N_0(\eta)^2 + (\omega/kv_{A_h})^2(N_1(\eta)^2 + J_1(\eta)^2) - (\omega/kv_{A_h})4/(\pi\eta)}{J_0(\eta)^2 + N_0(\eta)^2 + (\omega/kv_{A_h})^2(N_1(\eta)^2 + J_1(\eta)^2) + (\omega/kv_{A_h})4/(\pi\eta)},$$

where J_n and N_n are the Bessel and Macdonald functions, respectively. On the other side, Hollweg (1984) obtained

$$R_H = \frac{J_0(\eta)^2 + N_0(\eta)^2 + N_1(\eta)^2 + J_1(\eta)^2 - 4/(\pi\eta)}{J_0(\eta)^2 + N_0(\eta)^2 + N_1(\eta)^2 + J_1(\eta)^2 + 4/(\pi\eta)}.$$

Plots of $R(\eta)$ and $R_H(\eta)$ are shown in Fig. 1. It is seen that at $\eta > \eta_0 \approx 1$ the reflection coefficient $R \approx 0.7$ is not significantly changed. Therefore the transmission coefficient can be evaluated as $T = 1 - R \approx 0.3$. Taking $v_{A_h} = 3 \times 10^7$ cm/s, we obtain the characteristic period $T_p = 4\pi H/(\eta_0 V_{A_h}) \approx 21$ s. Such oscillations have been observed both in microwave and in optical ranges (e.g. Gelfreikh *et al.* 2004). Note especially that Alfven waves with $T_p < 10$ s are strongly damped in the partially ionized plasma of the solar chromosphere (De Pontieu *et al.* 2001).

Thus, for reasons given above we can suggest that the short–period Alfven waves with $T_p = 10$–40 s may play essential role in coronal heating.

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