SOME COMMENTS ON THE PROPAGATION OF ALFVEN WAVES IN AN ATMOSPHERE.

B. LEROY
Observatoire de Paris, Département d'Astrophysique Fondamentale, 92190 Meudon,France.

The transverse character of Alfvén waves makes them virtually undetectable. This, however, is no reason why they should not contribute to the energy balance of the solar chromosphere and corona. Now, when astronomers refer to Alfvén waves in the solar atmosphere, they very often (if not always) fail to take into account the density stratification of the atmosphere. The reason for this is of technical order: under the assumption of a uniform medium the propagation of Alfvén waves is in many respects comparable with that of sound waves. In this short communication we wish to point out the effects of the density stratification on the propagation of Alfvén waves.

In the case of a uniform magnetic field being at an arbitrary angle to the (vertical) uniform gravity field, the equations of motion are coupled to each other; thus thus describing complicated interactions between the different types of waves susceptible of existence in an atmosphere in hydrostatic equilibrium permeated by a magnetic field (Leroy and Bel,1979). Under certain conditions Alfvén waves decouple from the magneto-acoustic-gravity waves (Leroy, 1980a). One case is when the magnetic field is aligned with the gravity field and that only vertical propagation is considered; in teh following, we limit our study to this particular situation.

For the sake of mathematical simplicity the solar atmosphere is assumed to be plan-parallel. The photosphere and low chromosphere are represented by an isothermal layer comprised within the altitudes z=0 (top of the convection zone) and z=2000 km. At this altitude lies the transition region, which is represented by a density discontinuity. Above the transition zone there is another isothermal layer, representing the corona. The parameters necessary for the description of the photosphere and low chromosphere on the one hand, and of the corona of the other, are determined from the HSRA model and the "average" corona as given by Athay (1976),respectively.

In a real atmosphere the magnetic field is not constant and the density does not decrease exponentially with height. As a result, for a fixed value of the wave period, there exists a height above which the stratified medium behaves as if non-stratified. Roughly speaking, the effect of stratification is to induce reflection of the waves. This is easily understood if one regards the stratified medium as a pile of slabs of constant density, with a density discontinuity between two neighbouring slabs. In the case of the solar atmosphere, it can be shown that the waves whose period is less than, say, 10^5s "see" the part of the corona located above $z=3\ R_\odot$ as a non-stratified medium (Leroy, 1980b); in other words, once arrived in this part of the corona, the waves suffer no further reflection.

The question we wish to answer is the following: under the assumption of the Alfvén waves being generated by the motions in the convection zone, how much energy flux will be recorded in the form of Alfvén waves at heights $z \gtrsim 3R_\odot$?

The equation governing the propagation of Alfvén waves in the solar atmosphere is (assuming a time dependence $\exp(i\omega t)$):

$$d^2a/dz^2+(4\pi\rho(z)\omega^2/B^2)a = 0, \qquad (1)$$

where a is the wave amplitude. If convection is thought of as some driving mechanism shaking the field lines, and thereby generating Alfvén waves, a reasonable boundary condition to be imposed on Eq.(1) is that the velocity amplitude be given at the base of the photosphere. A second boundary condition is that no Alfvén wave (in the range of period of interest) shall come into the corona from above $z= 3R_\odot$.

Having solved Eq.(1) with these boundary conditions one can determine the transmissivity of the solar atmosphere with respect to Alfvén waves as a function of the wave period. The result is plotted on Fig.1. For extremely short periods (not shown on the figure) the media lying on either side of the transition zone are "seen" by the waves as non-stratified media; as a consequence, the transmissivity is constant and assumes its eikonal value, which is here of about 25%. For extremely long periods, the transmissivity turns out to be also constant, assuming a rather low value of about 10^{-7}. Between these two limits the most striking feature of the transmissivity is its resonant behaviour at certain discrete values of the wave period. We have been able to show that these values correspond to resonances in the layer representing the corona. They are not due, as claimed by Hollweg (1972,1978), to the discontinuity in scale height at the transition zone.

It is worth mentioning that, except for the resonant peaks, the actual values

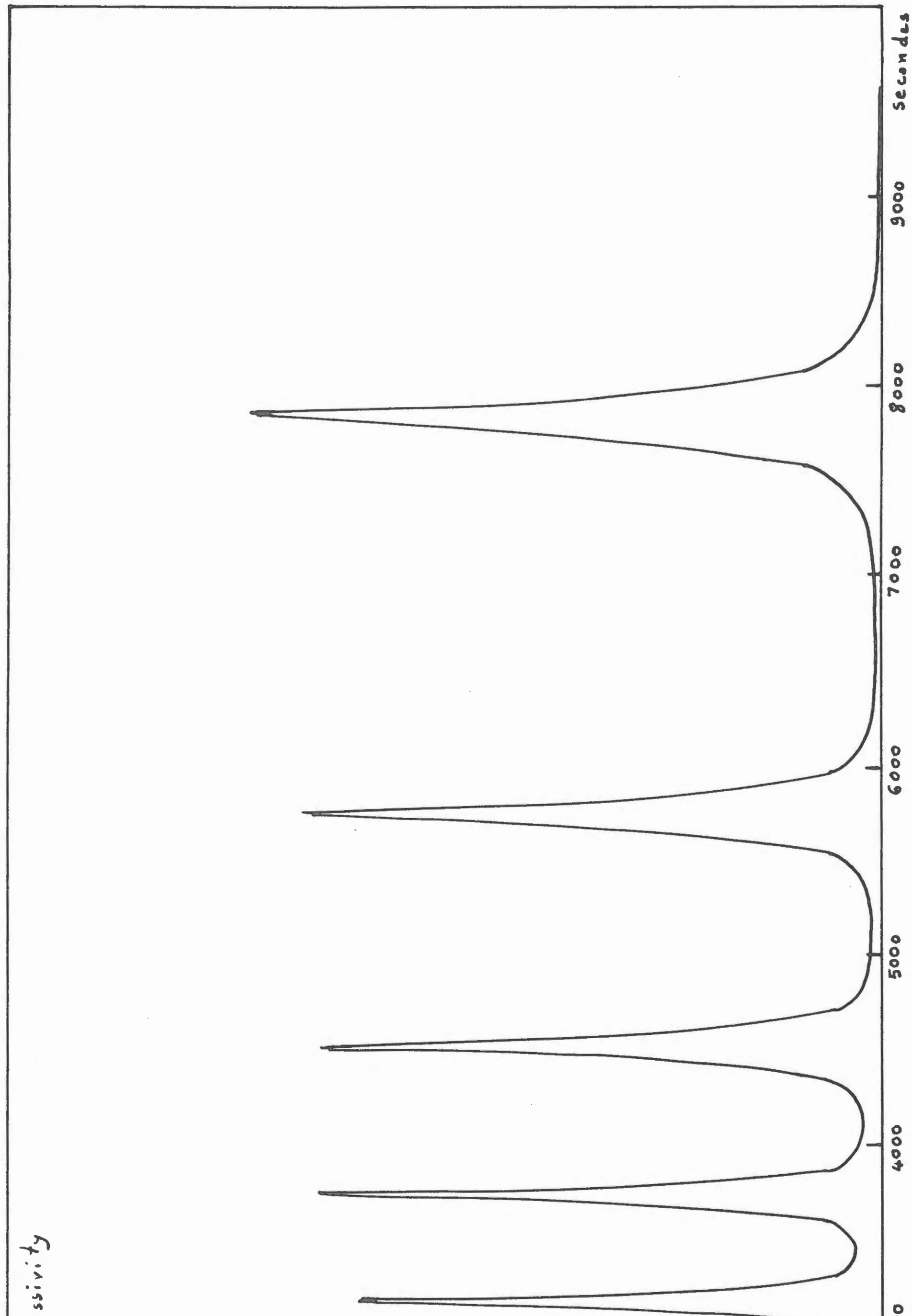

Fig.1 : Transmissivity vs. Wave period.

of the transmissivity always lie below the eikonal value. This implies that the energy flux recorded at $z \gtrsim 3R_{\odot}$ will generally be less than its eikonal value. As a consequence, one can say that the solar atmosphere is rather opaque to Alfvén waves, except at certain discrete frequencies.

Expressions for the relative velocity amplitude and the relative magnetic fluctuations as a function of the wave period can be derived. A numerical anlysis of these expressions reveals that both are oscillating functions and that both display a resonant behaviour. However, whereas the relative velocity amplitude all in all assumes rather low values in the photosphere and low chromosphere, less than 10^{-2}, it increases more rapidly than $\rho^{-1/4}$ (as the eikonal approximation would require) to values of the order of 10 at $z= 3R_{\odot}$. As a consequence, non linearities (e.g., shocks) are likely to develop at lower altitudes than is usually believed on the basis of the eikonal approximation. The magnetic fluctuations as a function of period are much alike the velocity amplitude. However, their dependence on height is rather insignificant, and they assume extremely small values, typically less than 10^{-5}. Finally, let us mention that an increase in the magnetic field just shifts the curve on Fig.1 as a whole towards the short periods. As a result, the solar atmosphere is still more opaque to Alfvén waves. Heating of the upper chromosphere and corona by Alfvén waves therefore appears to be very difficult.

Without going into details, let us mention another consequence of this study. When one computes the energy flux recorded at $z= 3R_{\odot}$, and not only the transmissivity, one finds a function which display still much more resonant peaks (at any rate, far more than in Hollweg's work); this implies, following the same line of reasoning as Hollweg's, that Alfvén waves detected in the solar wind are not generated in the convection zone.

References:

Athay, R. G.:1976, The Solar Chromosphere and Corona: Quiet Sun, Reidel, p.330.

Hollweg, J.V.:1972, Cosmic Electrodyn. 2, 423.

1978, Solar Physics 56, 305.

Leroy, B.: 1980a, Astron. Astrophys. (in preparation).

1980b, Astron. Astrophys. (in press).

Leroy, B. and Bel, N.: 1979, Astron. Astrophys. 78, 129.