Abstract. Following previous order of magnitude estimates (Poletto, 1980), the possibility that hot downflowing motions in the solar transition region could be ascribed to spicular matter returning to the chromosphere after being heated by compression, is more thoroughly investigated. The equations describing the one-dimensional non stationary motion of the spicular plasma during the heating process are analytically solved, and the temporal profiles of temperature, density and velocity are given for a set of representative situations. The results are finally compared with available data.

1. Introduction

The characteristics of the mass motions in the solar transition zone are still not completely defined, even if Skylab, OSO-8, and rocket observations have provided a great deal of data. At present we know that, at UV wavelengths, transition zone motions are confined above the supergranular boundaries in areas of dark Hα mottles, are mostly directed downward, and are best seen in ions such as C IV and Si IV. Their visibility diminishes both in ions formed at higher and lower temperatures (Brueckner et al., 1977), and independent observations agree in giving 20 km s⁻¹ as a typical downflow velocity (Athay et al., 1980; Brueckner, 1980; Bonnet, 1978).

The brightness of the C IV λ 1548 resonance line, where most of the observations have been made, is at least a factor of 20 higher in dark mottle areas than outside (Brueckner, 1980). However if the emitting elements really are as small as it has been estimated - 1.3 × 10⁷ cm or even less - the operating instruments had not the capability of resolving individual structures, so that far greater intensities can be anticipated (Nicolas et al., 1979). The temporal behaviour of these motions is not precisely known; the flare like brightenings, sometimes referred to as bursts, or explosive events, which occur more frequently near active than in quiet regions last from less than a minute to several minutes (Brueckner, 1980; Athay et al., 1980), but steady flows lasting for hours with somewhat slower velocities (2–5 km s⁻¹) have also been reported (Priest, 1980). Electron densities in downflowing motions have seldom been measured; a particle flux, averaged over the whole sun of 1.6 × 10¹⁵–1.6 × 10¹⁶ cm⁻² s⁻¹, and electron densities higher than 3 × 10¹² cm⁻³ have been estimated by Brueckner and co-workers from rocket observations (Brueckner et al., 1977; Brueckner, 1980).

Simultaneous observations in several UV lines, temporal behaviour of non explosive downflows, and a better definition of the spatial and temporal correlation with Hα mottles, Hα flares or, possibly, surges and prominences, would provide a
more complete scenario for the downflows, and will greatly help in the problem of explaining the origin of the observed mass motions.

Up to now a few possibilities have been advanced, and none of them has received more than a qualitative description. Bruner and Lites (1979) propose a shock wave mechanism, where the waves propagate down magnetic flux loops, while Athay et al. (1980) interpret the bursts as prominence material moving through the field of view of the spectrometer. More recently, following previous suggestions (Pneuman and Kopp, 1977) it has been proposed that UV motions are due to the cool material of the spicules, which returns to the chromosphere after being heated by compression (Poletto, 1980). Order of magnitude estimates have shown that the required temperature rise can be obtained in the correct time scale.

Should this interpretation be correct, the association of UV downflows with dark Hα mottles, known to be the location of spicules, would be explained, together with the problem of the spicular outflowing mass which is known to exceed both the downflowing mass in Hα spicules, which are less numerous than the outward moving ones, and the solar wind mass.

Purpose of this paper is to give a quantitative description of the non-stationary motion of spicules in the solar gravitational field, and to derive temperature, density and velocity vs time profiles of the moving plasma. Even if a detailed comparison with experimental results would be, at present, premature, the proposed mechanism leads to velocities, temperatures and densities consistent with the available data.

The details of the physical process and its mathematical formulation are described in Section 2; in Sections 3 and 4 sample temperature, density and velocity models are discussed and compared with observational results. An Appendix gives details of the more lengthy mathematical computations.

2. Basic Process and Mathematical Formulation

The essentials of the heating mechanism, already outlined in Poletto (1980), will be recalled here, to better clarify, before starting the mathematical procedure, the process and the underlying hypothesis.

No assumption is made about the origin of the optical spicule, whose physical parameters representing initial conditions for our problem, will be assumed according to the usually adopted values. Its motion, in the earlier stage not dealt with at present, is assumed to be a ballistic one, representative of the spicule velocity throughout an unspecified time interval of the order of a few minutes during which the cool spicule is developing. At a time \( t = 0 \), we will assume that the mass ejection into the spicule body is going on with a base velocity \( u_0 \), constant or linearly decreasing with time, which is representative, at time \( t = 0 \), only of what happens at the level \( x = 0 \), while the conditions at higher levels will be determined by the physics of the process.

According to optical observations, the spicule diameter is constant throughout the whole spicule extent. This indicates that no apparent funneling of the magnetic field