CURRENT SHEETS AS THE SOURCE OF HEATING FOR SOLAR ACTIVE REGIONS

B. V. SOMOV and S. I. SYROVATSKII
P. N. Lebedev Physical Institute of the Academy of Sciences, Moscow, U.S.S.R.

(Received 28 June, 1977)

Abstract. Observational data and theoretical arguments suggest that the heating source for an active region is the quasi-steady dissipation of magnetic field in current sheets. Effects in the solar atmosphere which are due to the presence of current sheets are considered. The most important of them is the heating of the chromosphere by the strong ultraviolet radiation of the current sheet. This can give rise to the brightening of an active region in optical emission. The energy flux from the current sheet in different ranges of the ultraviolet spectrum and the depths (column densities) into the chromosphere where this energy is absorbed are estimated.

1. Introduction

Active regions are known to be a result of the emergence of a new magnetic flux into the solar atmosphere (cf. Švestka, 1976a). This process is accompanied by the observed quasi-steady increase of radio, ultraviolet and soft X-ray emission as well as by a non-steady energy release in flares (for review, see Švestka, 1976b). The latter prevails in the active regions which have the phase of a more rapid (days) development and more complicated types of magnetic configurations ($\beta_y, \delta$) and motions (rotation, shear, collision) of magnetic spots (e.g. Tanaka, 1976).

From a theoretical point of view the appearance in the solar atmosphere of a new magnetic field necessarily leads to the formation of one or several current sheets where the magnetic field reconnection and dissipation take place (Syrovatskii, 1969, 1975). The reconnection of magnetic field lines in an active region in the corona has been proved by direct observations of spatial structures in ultraviolet and soft X-ray lines (Sheeley et al., 1975; Nolte et al., 1977). One can judge the presence of the reconnection in the chromosphere, for example, from the observed motion of fibrils and filaments (Tanaka, 1976).

Thus, a magnetic field dissipation in an active region may proceed in two main forms, quasi-steady and in flares. Here we discuss the possibility suggested by Somov and Syrovatskii (1976a) that the quasi-steady energy release in current sheets is the main source of heating of an active region.

2. The Quasi-Steady Current Sheet as the Energy Source for an Active Region

Parameters that characterize a quasi-steady current sheet in the solar atmosphere can be expressed in terms of the ambient plasma density $n_0$, the strength of the external (see below) electric field $E_0$ and the external magnetic field gradient $h_0$ in the
vicinity of the neutral line (Syrovatskii, 1976). According to Syrovatskii (1976), a steady current sheet in an active region can produce the power up to the value

$$P_\sigma = \sigma E_0^2 \alpha \beta l = 10^{28} \text{ erg s}^{-1}. \quad (1)$$

Here $\sigma$ is an electric conductivity in the sheet (it is taken as a Coulomb one: $\sigma = \sigma_0 T^{3/2}, \sigma_0 = 1.4 \times 10^8 \text{ A}^{-1} \text{ s}^{-1} \text{ grad}^{-3/2}, \lambda$ is the Coulomb logarithm), $E_0$ is the strength of the electric field induced by the changes of the magnetic field sources (e.g. by the emergence of a new magnetic field). The quantities $a$, $b$ and $l$ are half-depth, half-width and length of the current sheet, respectively. They can be expressed through the abovementioned initial parameters $n_0$, $E_0$ and $h_0$. In (1) $E_0 = 4 \times 10^{-4}$ CGSE, $T = 8 \times 10^4$ K, $a = 10$ cm, $b = 7 \times 10^8$ cm, $l = 10^{10}$ cm, which is the case when $n_0 = 5 \times 10^8$ cm and $h_0 = 5 \times 10^{-7}$ G cm$^{-1}$.

This power is obviously small as compared to the power of energy release up to $P_{\text{max}} = 3 \times 10^{29}$ erg s$^{-1}$, which can be reached during the flash phase of a large flare (at a current sheet disruption (Syrovatskii, 1975)). It is known however that such a powerful phase lasts $10^2-10^3$ s only. In this period the energy up to $3 \times 10^{31}-3 \times 10^{32}$ erg is delivered. On the contrary, a quasi-steady current sheet in an active region may exist tens of hours and even days. According to Tanaka (1976), the characteristic time of a more rapid development of an active region before a flare takes from 1 up to 3 days. The same value is true for the characteristic time of repetition of large flares in the same active region, when its rapid development is prolonged (about 10 days). For this time the total energy released by the quasi-steady current sheet in an active region can reach $(1-3) \times 10^{33}$ erg. It should also be emphasized that in a rapidly developing active region there can be several current sheets.

Thus, a quasi-steady magnetic field dissipation in current sheets is a powerful energy source for the active region.

### 3. Basic Forms of Energy Release in a Quasi-Steady Current Sheet

In a quasi-steady phase of current sheet development the particle acceleration is not essential. The energy transported by plasma motion and by heat conduction is also of a secondary role (Syrovatskii, 1976). As is shown by Syrovatskii (1976), Heyvaerts and Priest (1976), the cooling of the current sheet by radiation is essential, since it balances the Joule heating of the current sheet. This balance is possible only for the temperatures that do not exceed $T_\sigma = 8 \times 10^4$ K. (At higher temperatures the radiative cooling cannot compensate the Joule heating of the sheet). Therefore the main channel of energy release in a quasi-steady current sheet is ultraviolet radiation. The emission measure of a current sheet can reach the values

$$EM = n_\sigma^2 4 \alpha \beta l = 10^{49} \text{ cm}^{-3}, \quad (2)$$

where the estimate is given for the abovementioned sheet parameters before a very powerful flare.