ON HEATING OF SOLAR CORONA THROUGH MAGNETIC FIELDS

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Abstract

In this article the heating of solar corona by magnetic fields, with particular emphasis to the work done by authors has been presented. It is found that the heating of active regions by twisting of magnetic fields (Tucker, 1973) does not seem feasible in view of very high twisting velocities predicted for the magenetic field. Further the heating by reconnection (Levine, 1974) seems interesting and needs further quantitative investigation.

1. Investigation

In recent years there have been several detailed and excellent reviews on the heating of the solar corona (e.g. Withbroe & Noyes, 1977; Kuperus et al, 1981). Here we wish to highlight the work done by us on heating of solar corona through magnetic fields.

2. Theoretical Details

Magnetic heating results from dissipation of currents or magnetic field annihilation. The magnetic field configurations are calculated on the basis of the assumption that the coronal fields are either potential (current free) or force free i.e.

$$\vec{\nabla} \times \vec{B} = \alpha \vec{B} \tag{1}$$

where α is a constant. On the basis of comparison of calculated and observed coronal structures, Neupert, Nakagawa & Rust (1975), Levine (1976), Krieger, de Fieter & Vaiana (1976) and others have concluded that the magnetic field configurations in some active regions require the presence of currents of sufficiently large magnitude to force the magnetic field structures to depart significantly from a potential configuration. Coronal heating is thought to result from the dissipation of these currents.

Two methods of releasing the energy stored in non-potential magnetic fields are well known, viz. Joule dissipation (Tucker, 1973; Somov & Syrovatskii, 1977; Rosner et al. 1978; Nolte et al. 1979; Hinata, 1979, 1980) and field reconnection (Levine, 1974; Parker, 1975; Heyvaerts & Priest, 1984). In Joule dissipation no topological changes in the magnetic flux surfaces of the magnetic structure occur whereas in reconnection such topological changes occur with Joule heating and strong convective flows (Spicer & Brown, 1980).

A. Heating by Current Dissipation

Tucker (1973) suggests that active region loops exist in a quasi-steady state where new currents are generated by twisting of magnetic fields through photospheric motions. In this case the rate of generation of magnetic energy is given by

$$\dot{W}_m = B^2 v_\phi A/8\pi \qquad (2)$$

where v_ϕ is the effective velocity with which the magnetic field is twisted and A is the effective area of cross section in which twisting is taking place.

Associated with a force-free non-potential field is a current

$$\vec{J} = \frac{c}{4\pi}(\vec{\nabla}\times\vec{B}) \quad , \qquad (3)$$

which gives rise to heating at a rate

$$\dot{W}_m \approx j^2 \eta V \quad , \qquad (4)$$

where V is the volume of the heat producing region, and η the resistivity. Classical resistivity, due to Coulomb collisions between electrons and ions, is too small to be important in the corona. However, the turbulent resistivity is important and is approximately given by

$$\eta_t = 0.1\ F/\omega_p \quad , \qquad (5)$$

where ω_p is the electron plasma frequency and F is a numerical factor which ranges from about unity for weak turbulence to about 100 for strong turbulence (Tucker, 1973 and references therein). Here electrons interact with elements of current driven plasma turbulence and give rise to significant heating.

Kumar and Narain (1985) have examined Tucker's proposal using the data of Newkirk (1967). They calculate twisting velocity for the magnetic field using the equation

$$v_\phi = c^2 \eta_t h/2\pi\lambda^2 \quad , \qquad (6)$$

where c is the velocity of light in vacuum, h, the height of the active region and λ, the radius of the current sheet.

The results are presented in Table I. The expected value of v_ϕ is $\sim 10^4$ cm s^{-1}. Our calculations (Table I) show that v_ϕ is $\sim 10^{14}$ cm s^{-1} which is too high.

Rosner et al. (1978) proposed that active region loops are heated by anomalous current dissipation. The heat generation rate per unit volume is obtained from

$$U_H = \vec{E}.\vec{J} = 1.1\times10^{-18}\ n_e^{1.5}\ T \ , \qquad (7)$$

Where $\vec{E}$ is the induced electric field and $\vec{J}$ the current density.

Using the data of Parkinson (1973), Narain and Kumar (1985a) have investigated anomalous heating along loops assuming line dipole geometry (Antiochos & Sturrock, 1976). Ionson (1982) shows that for coronal loops anomalous current dissipation is not important contrary to this we find substantial amount of heating (Figure 1).

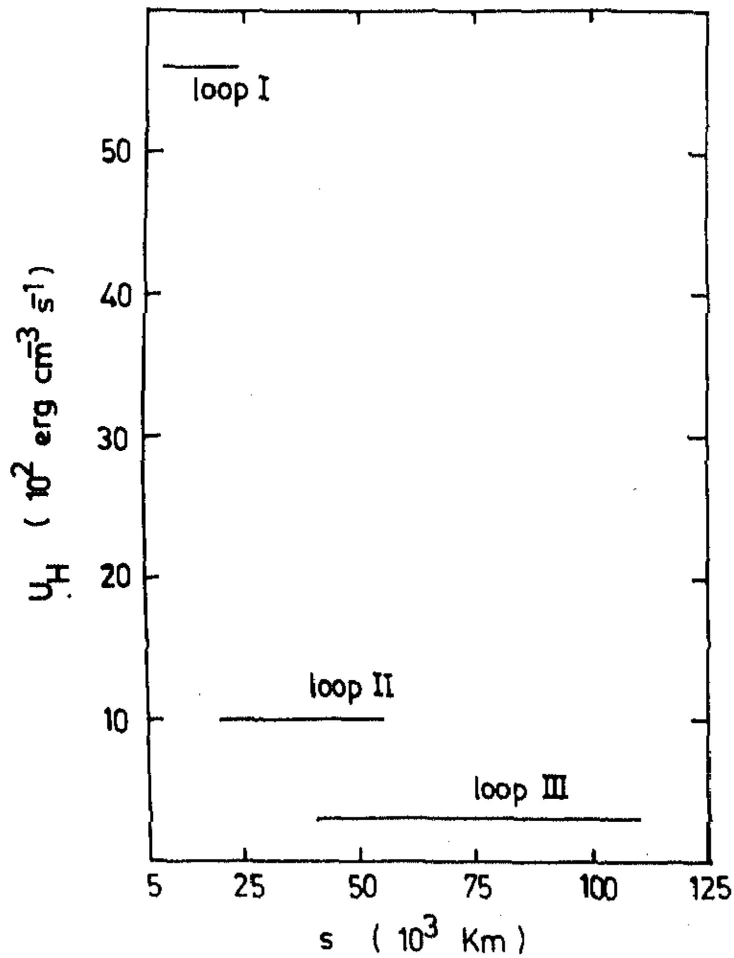
loop I
loop II
loop III
50
40
30
20
10
5
25
50
75
100
125
s (10^3 Km)
U_H (10^2 erg cm^-3 s^-1)

Fig.1.

Table I

Twisted velocity and connected parameter*

Feature	h (cm)	n_e (cm^{-3})	T (K)	η_t (s)	B (gauss)	λ (cm)	v_ϕ ($cm\ s^{-1}$)
Active region enhancement	2.10 (10)[a]	8.0 (8)	1.5 (6)	7.1F (-11)	2.9	1109	1.6F (14)
			2.0 (6)		3.3	1110	
Permanent condensation	8.0 (9)	5.0 (9)	2.0 (6)	2.8F (-11)	8.3	442	1.7F (14)
		7.0 (9)	2.5 (6)	2.4F (-11)	1.2(1)	377	1.9F (14)

[a] The numbers in the bracket are the powers of ten: e.g. 2.0(10) = 2.0×10^{10}

* Taken from Kumar and Narain (1985)

B. Heating by Reconnection

Levine (1974) proposes that the entire corona is interspersed with magnetic neutral sheets which reconnect and accelerate particles to a few times their thermal velocity. The areas in which acceleration of particles takes place are called magnetic accelerating regions. The accelerated particles (mostly protons) from these regions travel through the corona and lose their increased energy through Coulomb collisions. It is shown that this mechanism can provide the energy needed to heat the corona and that such acceleration can account for regions of enhanced (e.g. active regions, bright points, etc.) and decreased (e.g. coronal holes, quiet regions at solar minimum) heating in the corona. The distribution of the magnetic accelerating regions could vary with solar cycle to produce necessary changes in coronal heating.

In order to explain the apparent spatial smoothness and lack of rapid time variability of coronal structures the netural sheets must be finely distributed through the large scale coronal structures, at a scale small compared to the resolution of ground-based observations or instruments of space. While dynamic microstructure in the field with continual formation of magnetic neutral sheets is not ruled out by observations but it seems hard to reconcile with the observed rather simple structure of the field on observable spatial scales (Withbroe and Noyes, 1977).

Narain and Kumar (1985b) have investigated energy balance using the solar maximum inhomogeneous temperatures of Brandt et al. (1965) and the solar maximum electron densities of Allen (1973). They calculate the heating rate (erg s^{-1}) using the equation (Levine, 1974)

$$P_h = (\delta f L^3 \alpha / t_B D^2) \sum_{\text{layers}} n_e T \quad , \tag{8}$$

where L is the characteristic dimension of the magnetic region and t_B its characteristic collapse time. D is the distance between two layers of magnetic accelerating regions and f an uncertainty factor. α stands for $(E_f-E_0)/E_0$, in which E_f is the energy of the particle after accleration and E_0 the mean thermal energy. δ is a numerical factor having the value 1.5×10^7.

It is found that heating by magnetic reconnection balances the losses only when the dimension of the magnetic accelerating regions varies with radial distance measured from the centre of the sun (Narain and Kumar, 1985b). The dimension of these magnetic accelerating regions comes out to be $\sim10^4$ km. which is of the same order as that of current sheets (Svestka, 1976).

Conclusions

1. Steady state heating by force free currents, as proposed by Tucker (1973), is unsatisfactory because it predicts unacceptably high values of the twisting velocity for the magnetic field.

2. Active region loops may be heated through anomalous current dissipation (Rosner et al, 1978), contrary to apprehension of Ionson (1982).

3. Heating by reconnection, proposed by Levine (1974), seems quite interesting and needs further quantitative investigations.

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