RESISTIVE EFFECTS IN THE TURBULENT PHOTOSPHERE
AND CHROMOSPHERE

I. LERCHÉ*

Enrico Fermi Institute and Dept. of Physics, University of Chicago, Chicago, Ill., U.S.A.

(Received 29 September, 1970)

Abstract. We have investigated the role of finite resistivity effects in the photosphere and chromosphere. We demonstrate that turbulence in the photospheric conductivity gives rise to a resistive instability, as does the gradient in resistivity between the chromospheric layer of the Sun and the photospheric layer, which latter unstable mode is the well known tearing mode of Furth, Killeen and Rosenbluth. In both cases the calculations indicate time scales of the order of seconds or minutes, and we therefore believe that solar flares and spicules can be produced by finite conductivity instabilities. We also demonstrate that the finite resistive diffusion makes it difficult to maintain an initially force-free flux tube in the chromosphere unless the Alfvén speed is sufficiently high and/or the flux tube is sufficiently thick. We also demonstrate that the magnetic fields in the turbulent photosphere becomes ‘trapped’ by high conductivity regions and this leads to enhancement of the resistive instabilities.

Our analysis does not explain the origin of the high-energy particles in solar flares – for this the problem of dynamical acceleration must be investigated.

1. Introduction

In recent years calculations of the conductivity of the photospheric layers of the Sun have demonstrated that partial ionization drastically lowers the conductivity from that obtaining for a fully ionized gas by about three orders of magnitude (Nagasawa, 1955; Kopecký, 1957, 1958; Stepanov and Petrova, 1959; Schröter, 1966; Kiepenheuer, 1966; Oster, 1968). Specifically the conductivity, $\sigma$, in the chromosphere is about $10^{12}$ esu while in the underlying photosphere $\sigma \sim 10^9$ esu. The transition from the photospheric value to the chromospheric value occurs over a thickness estimated to be in the range $10^5$–$10^6$ cm. (Severny, 1958, 1959; Jaggi, 1963; Sweet, 1969). It has also been suggested (Gold, 1963) that the photosphere is a turbulent medium in which the Alfvén speed is negligible compared to diffusion velocities, while in the chromosphere the Alfvén speed dominates the diffusion (due both to the increased conductivity and the conservation of flux linking the photosphere to the chromosphere). And tubes of flux in the chromosphere are considered to be essentially force-free. This has led to several models for solar flares (see Sweet, 1969 for a review of current ideas).

The purpose of the present paper is to present some simple calculations relating to resistive instabilities in the turbulent photosphere, and to compare and contrast the associated instabilities rates with the resistive instability calculations of Furth, Killeen and Rosenbluth (1963) as applied by Jaggi (1963) and Sturrock (1963) to models of

* Alfred P. Sloan Foundation Fellow.

Astrophysics and Space Science 10 (1971) 486–499. All Rights Reserved
Copyright © 1971 by D. Reidel Publishing Company, Dordrecht-Holland
solar flare phenomena. In particular our main comparison will be with the ‘tearing mode’ which appears to be dominant for the photosphere-chromosphere transition layer. We shall also present some simple calculations bearing on the existence and stability of cylindrical configurations of force-free magnetic fields in a turbulent medium.

We have done the calculations in order to illustrate some of the basic physical effects associated with turbulent resistive media in general, and the Sun’s photosphere and chromosphere in particular. We believe that the simple situations discussed here enable a more complete understanding to obtain of physical processes occurring in the atmosphere of the Sun.

The outline of the paper is as follows. In Section 2 we first give the instability rate, and range of validity, of the FKR tearing mode as applied to the Sun. We then demonstrate by several illustrative examples that both a turbulent, and a laminar, photosphere give rise to resistive instabilities.

In Section 3 we discuss the possibility of obtaining force-free tubes of flux in the chromosphere under the assumption that it is a turbulent medium and we demonstrate that it is possible to maintain any such tubes of flux only under very specific conditions.

In Section 4 we illustrate how applications of our results can lead to a better understanding of the observed solar atmospheric structure.

2. Resistive Instabilities

A. THE TEARING MODE OF FURTH, KILLEEN AND ROSENBLUTH

For an infinite plane current layer, of thickness $d$, embedded in a medium of conductivity $\sigma$ and density $\rho$, FKR found that perturbations with real wave numbers, $k$, parallel to the current sheet are unstable with a growth rate $\tau^{-1}$ given by

$$\tau_R^{-1} = \alpha^{-2/5} S^{2/5}, \quad \text{in } S^{-1/4} \lesssim \alpha \lesssim 1,$$

where

$$\tau_A S = \tau_R, \quad \alpha = kd, \quad e^2 \tau_R = 4\pi d^2 \sigma, \quad \tau_A V_A = d, \quad \text{and } 4\pi \rho V_A^2 = B^2.$$

Equation (1) gives the smallest $\tau$ (and hence the fastest growth rate) when $\alpha \approx S^{-1/4}$ and then

$$\tau \approx \tau_R S^{-1/2}, \quad kd \approx S^{-1/4}. $$

With $V_A \approx 10^8$ cm sec$^{-1}$, then $S \approx 10^2$ so that the e-folding time is about 10% of the resistive time scale $\tau_R$, and $3dk \approx 1$. Jaggi (1963) has given an extensive table of e-folding time for the tearing mode as a function of the relevant parameters. In general, for the case of the chromosphere-photosphere boundary he obtains time scales of the order of seconds to minutes depending on the relevant numerical parameters assumed. So the tearing mode instability is a prime candidate for indicating the behaviour of solar granulation and solar flares. And the calculations of FKR were carried through under the assumption that the conductivity in both the photo-