KINK INSTABILITY OF SOLAR CORONAL LOOPS AS THE CAUSE OF SOLAR FLARES

A. W. HOOD and E. R. PRIEST

Applied Mathematics Department, The University, St. Andrews, Scotland

(Received 8 January; in final form 12 July, 1979)

Abstract. Solar coronal loops are observed to be remarkably stable structures. A magnetohydrodynamic stability analysis of a model loop by the energy method suggests that the main reason for stability is the fact that the ends of the loop are anchored in the dense photosphere. In addition to such line-tying, the effect of a radial pressure gradient is incorporated in the analysis.

Two-ribbon flares follow the eruption of an active region filament, which may lie along a magnetic flux tube. It is suggested that the eruption is caused by the kink instability, which sets in when the amount of magnetic twist in the flux tube exceeds a critical value. This value depends on the aspect ratio of the loop, the ratio of the plasma to magnetic pressure and the detailed transverse magnetic structure. For a force-free field of uniform twist the critical twist is 3.3π, and for other fields it is typically between 2π and 6π. Occasionally active region loops may become unstable and give rise to small loop flares, which may also be a result of the kink instability.

1. Introduction

Recent X-ray and EUV observations have shown that the solar corona consists of a vast number of loop structures, which probably outline the local magnetic field. These loops can be divided into five different types, depending on their temperature, density and length (see Priest, 1978; Hood and Priest, 1979a). Hood and Priest (1979a) investigated the thermal equilibrium of loops and the purpose of this paper is to study their magnetohydrodynamic stability. Coronal loops appear remarkably stable most of the time and we are able to show that the dominant stabilizing feature is probably line-tying at the ends of a loop in the dense photosphere.

There are basically two types of solar flare, namely *small compact loop flares* and *large two-ribbon flares* (see, e.g., Priest, 1976a). One explanation for flares has been put forward as the *emerging flux model* (Priest, 1976a, b; Heyvaerts *et al.*, 1977; Tur and Priest, 1976, 1978), which considers the current sheet that forms at the boundary between new and old magnetic flux. The flare is triggered when the sheet reaches a critical height for the onset of turbulence and the type of flare depends on the nature of the ambient field in which the newly emerging flux finds itself. In this paper an alternative explanation for flares is considered. We suggest that small loop flares are due to an instability produced by a 'kink' perturbation, possibly resistive in nature, though we limit ourselves to the ideal dissipationless case here. Gibson (1977), for instance, has interpreted observations of limb flares in X-rays as examples of the kink instability. He suggested that eight flares, which involved large scale deformations of their structure, had, in fact, become unstable to magnetohydrodynamic kinks.

Solar Physics **64** (1979) 303–321. 0038–0938/79/0642–0303$02.85.

Two-ribbon flares follow the eruption of an active region filament and we suggest that the filament follows a magnetic flux tube, whose eruption is again caused by the kink instability. The twisting up of the footpoints probably occurs very slowly and so would be extremely difficult to detect at the photosphere. The hypothesis that erupting filaments are an example of kink instability has previously been put forward by, for example, Sakurai (1976), who gave an elegant nonlinear treatment without line-tying.

Kruskal *et al.* (1958) and Shafranov (1957) independently considered the stability of a cylindrical magnetic flux tube with magnetic field components $(0, B_\theta, B_z)$ in terms of cylindrical polar coordinates r, θ, z. They found that an infinitely long tube is unstable to a *helical kink perturbation*

$$\boldsymbol{\xi} = \boldsymbol{\xi}(r)\, e^{i(\theta + kz)}$$

when

$$B_\theta / r + kB_z \geq 0 .$$

At equality, the wave number vector $(0, r^{-1}, k)$ is perpendicular to the equilibrium magnetic field. In other words the crests and troughs of the perturbation follow the field as it spirals around the axis.

If the flux tube represents a coronal loop of length $2L$ a useful parameter is the amount Φ by which a field line is twisted about the tube axis in going from one end of the tube to the other. In terms of the magnetic field components, the twist Φ may be written as

$$\Phi(r) = \frac{2LB_\theta}{rB_z} . \tag{1.1}$$

Then the Kruskal–Shafranov result applied to a solar coronal flux loop states that, *for any twist Φ*, the loop is locally unstable to a helical kink perturbation above with wavenumber k greater than

$$k = -\Phi/(2L) .$$

Furthermore, for a given wavenumber k, instability occurs when the twist is given by

$$\Phi = -2Lk .$$

(For the particular case of a torus of length $2L$, one needs $-k$ to be a multiple of π/L since two points that are located an axial distance $2L$ apart refer to the same location on the torus. For $-k = \pi/L$, the above criterion gives instability when $\Phi = 2\pi$ at some radius.) However the Kruskal–Shafranov analysis for a coronal loop does not take into consideration the stabilizing effect of the photosphere, which effectively anchors the ends of the magnetic field lines and so forces the perturbations to vanish at the ends of the loop. The helical kink perturbation above does not vanish at any location z along the loop for all values of θ.