Abstract. It is proposed that the solar flare phenomenon can be understood as a manifestation of the electrodynamic coupling process of the photosphere-chromosphere-corona system as a whole. The system is coupled by electric currents, flowing along (both upward and downward) and across the magnetic field lines, powered by the dynamo process driven by the neutral wind in the photosphere and the lower chromosphere. A self-consistent formulation of the proposed coupling system is given. It is shown in particular that the coupling system can generate and dissipate the power of $10^{29}$ erg s$^{-1}$ and the total energy of $10^{32}$ erg during a typical life time (10$^3$ s) of solar flares. The energy consumptions include Joule heat production, acceleration of current-carrying particles along field lines, magnetic energy storage and kinetic energy of plasma convection. The particle acceleration arises from the development of field-aligned potential drops of $10^{-150}$ kV due to the loss-cone constriction effect along the upward field-aligned currents, causing optical, X-ray and radio emissions. The total number of precipitating electrons during a flare is shown to be of order $10^{37}$-$10^{38}$.

1. Introduction

Most of the modern flare theories have been developed on the basis that the magnetic energy stored in the solar atmosphere is suddenly released by magnetic field reconnection or by current interruption; for a recent review of solar flare models, see Sturrock (1980). However, there has been little discussion of how the stored magnetic energy is generated. Regardless of any specific models of solar flares, it is important to treat the flare phenomenon in the context of an energy generation-dissipation system as a whole. The purpose of this paper is to propose a dynamo theory of solar flares. The reason for emphasizing the dynamo process is two fold. The first is to propose that temporal variations of energy dissipated during a flare follow closely those of the dynamo power which can supply the required power of $10^{29}$ erg s$^{-1}$ and total energy of $10^{32}$ erg. This is in contrast to the prevailing view that the energy for solar flares should be stored in the coronal magnetic field prior to flare onset. The second is to formulate the electrodynamic coupling of the photosphere-chromosphere-corona system, powered by the dynamo process, in which solar flares are a consequence of enhanced dynamo power output. Thus, we emphasize both energy generation and energy dissipation associated with solar flares.

The idea of powering solar flares by the dynamo process in the partially ionized chromosphere-photosphere region has been discussed earlier by several workers, including Sen and White (1972), Heyvaerts (1974), Obayashi (1975), Akasofu (1979). Certain aspects of these models are briefly reviewed here. Sen and White (1972) suggested that the dynamo-induced Hall current leads to Joule heating in the photosphere and that the electric field is anti-parallel to the convection velocity in the photospheric dynamo region. They suggested that a two-stream instability (Farley,
1963) can occur in the Hall current to trigger a flare in the photosphere. Heyvaerts (1974) presented a photospheric dynamo model in which the coronal currents are entirely field-aligned and are driven by horizontal photospheric motions. Following Alfvén and Carlqvist (1967), Heyvaerts (1974) assumed that the coronal field-aligned currents can be interrupted by an instability (unspecified) and thereby release the stored magnetic energy to produce flares. Obayashi (1975) proposed a flare model similar to Heyvaerts (1974) except the suggestion that the release of the stored coronal energy is initiated by a collapse in the magnetic field and the formation of an X-type reconnection line in the corona. Recently, Akasofu (1979) emphasized that the dynamo process in the photosphere can supply the required power ($10^{29}$ erg s$^{-1}$) and the total energy ($10^{32}$ erg) and suggested that disruption of coronal field-aligned currents driven by the photospheric dynamo can lead to an electric potential structure which accelerates the current-carrying electrons to produce flares.

The proposed solar flare process to be developed in the present paper has evolved from the above-mentioned dynamo flare models (Sen and White, 1972; Heyvaerts, 1974; Obayashi, 1975; Akasofu, 1979). The important differences between the proposed model and those earlier models lie in (i) solar flares are treated self-consistently and quantitatively as a consequence of the electrodynamic coupling of the photosphere-chromosphere-corona system and (ii) the onset of flares is quantitatively identified as a result of the development of field-aligned potential drops due to the loss-cone constriction effect (Knight, 1973) on enhanced upward field-aligned currents, independent of any instabilities.

2. Flares Driven Directly by Photosphere-Chromosphere Dynamo

Consider the photosphere-chromosphere-corona coupling system which is magnetically connected by arch-like (two-dimensional) field lines anchored in the photosphere, as schematically illustrated in Figure 1. A horizontal motion of the neutral gas in the photosphere and the lower chromosphere across the feet of the arch-like field lines constitutes a dynamo process. For simplicity, the dynamo region is assumed to consist of a shear flow of horizontal neutral wind $V_n$ as indicated in Figure 1. The corona is located in the upper part of the arch and is primarily a reactive load (capacitive and inductive). The conjugate chromosphere-photosphere region is primarily a resistive load (hereafter referred to as the conjugate region).

As the suggested horizontal wind blows in the photosphere and the lower chromosphere (hereafter referred to as the dynamo region), dynamo currents are generated and flow through the whole system (the photosphere-chromosphere-corona), both along and across magnetic field lines. The power generated by the dynamo consists of power dissipated in the dynamo region and power output to the load. The output power delivered to the load is partially dissipated in the conjugate region; the remaining power is in part consumed to accelerate current-carrying particles along magnetic field lines and in part stored in the corona.

Suppose that the velocity of the wind in the dynamo region increases from a very low