DYNAMICAL ASPECTS OF ELECTROSTATIC DOUBLE LAYERS*

MICHAEL A. RAADU

Department of Plasma Physics, The Royal Institute of Technology, Stockholm, Sweden

and

J. JUUL RASMUSSEN

Association Euratom – Riso National Laboratory, Physics Department, Roskilde, Denmark

(Received 30 September, 1987)

Abstract. Electrostatic double layers have been proposed as an acceleration mechanism in solar flares and other astrophysical objects. They have been extensively studied in the laboratory and by means of computer simulations. The theory of steady-state double layers implies several existence criteria, in particular the Bohm criteria, restricting the conditions under which double layers may form. In the present paper several already published theoretical models of different types of double layers are discussed. It is shown that the existence conditions often imply current-driven instabilities in the ambient plasma, at least for strong double layers, and it is argued that such conditions must be used with care when applied to real plasmas. Laboratory double layers, and by implication those arising in astrophysical plasmas, often produce instabilities in the surrounding plasma and are generally time-dependent structures. Naturally occuring double layers should, therefore, be far more common than the restrictions deduced from idealised time-independent models would imply. In particular it is necessary to understand more fully the time-dependent behaviour of double layers. In the present paper the dynamics of weak double layers is discussed. Also a model for a moving strong double layer, where an associated potential minimum plays a significant role, is presented.

1. Introduction

A double layer (DL) is a local region in a plasma which can sustain a potential difference. Essentially it consists of two adjacent layers with equal and opposite net charge. The layer as a whole is globally neutral but has an internal electric field. The structure is determined in a self-consistent manner by the particle dynamics in the electric field set up by the net charge distribution produced by the particles. This is indicated schematically in Figure 1 (see also Figure 3). In general a DL requires both free and reflected ion and electron components. The free particles carry current through the layer and lead to emerging beams of accelerated particles. The hatched areas in Figure 1 denote regimes of ion and electron acceleration. The potential across the DL must in general be maintained by external sources which are the source of energy for the particle acceleration.

Double layers are of interest in astrophysics as a direct means of accelerating particles (Alfvén, 1981, 1986). They can sustain a local region of parallel electric field leading to the magnetohydrodynamic relaxation of a large-scale magnetic field. The globally stored magnetic energy is then released both as accelerated particles and in the mass motions

* Paper dedicated to Professor Hannes Alfvén on the occasion of his 80th birthday, 30 May 1988.

set up by the untwisting motions of the magnetised plasma (Raadu, 1984). The power supplied to accelerated particles is simply the product of the current crossing the double layer and the potential across it. The formation of a DL in a current carrying loop in the solar corona has been proposed as a mechanism for energy release in a solar flare (Jacobsen and Carlqvist, 1964; Alfvén and Carlqvist, 1967; Hasan and ter Haar, 1978). Carlqvist (1979) has also argued that the associated motions in the coronal loop can explain the occurrence of solar surges. For suitable conditions the released magnetic energy can go predominantly to the surge mass ejection rather than particle acceleration at the DL. Hénoux (1986) argues that multiple DLs can explain the high rate of energy release observed in solar flares.

In the magnetosphere the first indications of parallel electric fields leading to electrostatic acceleration of particles were provided by electron measurements in a rocket experiment (McIlwain, 1960). Further evidence was provided by the discovery of the inverted-V structures and associated electric field patterns (Frank and Ackerson, 1971; Gurnett and Frank, 1973). There is evidently a close relationship between parallel electric fields and the aurora (e.g., Mozer et al., 1980, 1985; Chiu et al., 1983,