A DOUBLE LAYER REVIEW*

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Abstract. A review is given of the main results on electrostatic double layers (sometimes called 'space charge layers' or 'sheaths') obtained from theory and laboratory and space experiments up to the spring of 1977.

The paper begins with a definition of double layers in terms of potential drop, electric field, and charge separation. Then a review is made of the theoretical results obtained so far. This covers, among other things, necessary criteria for existence and stability, quantitative estimates of charge separation and thickness, and some probable cause of DL-formation in terms of an instability.

Next, experimental results obtained in the laboratory are compared with the theoretical results. Due to recent progress in experimental technique, the interior of a double layer can now be studied in much more detail than was possible before.

By means of barium jets and satellite probes, double layers have now been found at the altitudes that were previously predicted theoretically. The general potential distribution above the auroral zone, suggested by inverted V-events and electric field reversals, is corroborated.

1. Introduction

Elementary electrodynamics tells us that charged particles can never be accelerated by magnetic fields. Electric fields are required, either electrostatic or induced by time-varying magnetic fields.

Since energetic electrons and ions are often observed in plasmas, it is important to understand the mechanisms that can create and maintain electric fields in plasmas. Several such mechanisms have been discussed by Block and Fälthammar (1976). One of these is the double layer mechanism, which is of electrostatic nature, since in a double layer the electric field is sandwiched between two opposite space charge layers. If a magnetic field B is present, it may in principle be arbitrarily directed, but the simpler case with E||B is most commonly discussed.

Our understanding of double layers is far from complete, in spite of the fact that they have been studied in laboratories for several decades. However, progress has been made in recent years, both theoretically and experimentally and through observations in space. The present paper represents an attempt to summarize the state of the art, with special emphasis on properties of importance in space plasmas.

2. Definition of a Double Layer

The meaning of the term 'double layer' seems sometimes to have been confused. In this paper, as in the author’s previous publications on the subject, a double layer

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is defined as consisting of two equal but oppositely charged, essentially parallel but not necessarily plane, space charge layers (see Figure 1). The potential, electric field and space charge density vary qualitatively within the layer, as shown in Figure 2. If the potential would not vary monotonically through the entire layer but would contain a few maxima and minima (as, for example, in Figure 3), we may still call it a double layer (provided the conditions below are fulfilled) although, strictly speaking, it consists of more than one double layer.

The following three conditions must be fulfilled:

(i) The potential drop $\phi_0$ through the layer must obey the relation

$$|\phi_0| \geq kT/e,$$

where $T$ is the temperature of the coldest plasma bordering the layer, and $k$ and $e$ have their usual meanings.

(ii) The electric field is much stronger inside the double layer than outside, so the integrated positive and negative charges nearly cancel each other.

(iii) Quasi-neutrality is locally violated in both space charge layers.

In addition, a typical but not strictly necessary condition is that the collisional mean free path is much longer than the double layer thickness. Experimental as well as theoretical evidence indicate that as long as collisions play an appreciable role a double layer will not be formed.

It may be pointed out, in order to prevent some common misunderstandings, that the definition neither includes some particular type of instability or wave, causing or maintaining the layer, nor some minimum current density through the layer.

In the remainder of the paper double layers will be abbreviated as DL.

Fig. 1. Schematic picture of a double layer.