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TITLE: THE SIMULATION OF PLASMA DOUBLE-LAYER STRUCTURES

AUTHOR(S): J. E. Borovsky and G. Joyce

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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THE SIMULATION OF PLASMA DOUBLE-LAYER STRUCTURES

Joseph E. Borovsky
Los Alamos National Laboratory
Los Alamos, NM 87545 USA

and

Glenn Joyce
Naval Research Laboratory
Washington, D.C. 20375 USA

Electrostatic plasma double layers are numerically simulated by means of a magnetized 2 1/2-dimensional particle-in-cell method. The investigation of planar double layers indicates that these one- dimensional potential structruces are susceptible to periodic disruption by instabilities in the low-potential plasmas. Only a slight increase in the double-layer thickness with an increase in its obliqueness to the magnetic field is observed. Weak magnetization results in the double-layer electric-field alignment of accelerated particles and strong magnetization results in their magnetic-field alignment. The numerical simulations of spatially periodic two-dimensional double layers also exhibit cyclical instability. A morphological invariance in two-dimensional double layers with respect to the degree of magnetization implies that the potential structures scale with Debye lengths rather than with gyroradii. Electron-beam excited electrostatic electron-cyclotron waves and (ion-beam driven) solitary waves are present in the plasmas adjacent to the double layers.

Uniformly magnetized plasma double layers are simulated on a two-dimensional grid, periodic in one direction and bounded by reservoirs of Maxwellian plasma in the other, an extension of previous numerics (Joyce and Hubbard, 1978). Poisson's equation is solved by means of a Fourier transform in the periodic coordinate and a cubic spline in the other. Fixing the elctrostatic potential on the boundary-reservoirs in various configurations allows the simulation of either planar or two-dimensional structures.

The structures of planar double layers oblique to externally generated magnetic fields are found to be nearly identical with the structures of field-aligned or unmagnetized double layers, an oblique double layer being slightly thicker than a corresponding unmagnetized double layer. The thicknesses of the simulated oblique double layers are not related to any particle gyroradii. This is corroborated with solutions to Poisson's equation for variously magnetized plasmas (Borovsky, 1982) which yield oblique double-layer scale sizes in terms of Debye lengths.

In certain instances planar double layers are observed to be susceptible to periodic disruption by an instability in the adjacent low-potential plasmas. As viewed in Figure 1, the disruption of an oblique ($\theta=60^{\circ}$) double layer is preceeded by the appearance of large amplitude two-dimensional solitary pulses, the pulses always propagating in the direction of the electron drift, against the ion beam. These pulses form, and the double layers are disrupted, only if the low-potential plasmas are of sufficient spatial extent. (Prior to disruption, the low-potential plasma may be crowded with large amplitude solitary pulses, a point measurement of the potential appearing to be an observation of low-frequency electrostatic turbulence.) This same disruption phenomenon also effects two-dimensional double layers, as will be discussed. In the high-potential plasmas adjacent to the oblique double layers electron-beam driven electrostatic electron cyclotron waves with amplitudes of 3-5 k_BT/e are observed.

When strongly magnetized particles are accelerated through an oblique double layer they obtain large velocity vectors parallel to the magnetic field and become field-aligned beams. On the other hand, if the particles are weakly magnetized, upon accelaration they obtain large velocity vectors nearly parallel to the internal electric field of the double layer to become double-layer-aligned beams. Thus there exists the posibility of producing beams of magnetic-field-aligned electrons and beams of non-magnetic-field-aligned ions emanating from opposite sides of an oblique double layer. This may have implications on the satellite detection of particles in the auroral magnetosphere (Borovsky and Joyce, 1982a).

The equipotential contours of a magnetized and an unmagnetized two-dimensional double layer may be viewed in Figure 2. Two-dimensional double layers are found to be U-shaped structures, the shapes being nearly independent of the strength of the external magnetic field, and the thicknesses of the segments oblique to the magnetic field being approximately equal to the thicknesses of segments which are field-aligned, both being approximately equal to the thicknesses of planar double layers of the same potential jump. These facts again indicate Debye-length scaling for magnetized structures. This may be anticipated since planar double layers were found to scale in terms of Debye lengths. Although two-dimensional structures with the high- potential plasma on the concave side (positive structure) appear to be much the same as structures with the low-potential plasma on the concave side (negative structure), they behave quite differently when two structures are brought close together--the adjacent positive structures will merge while the negative structures will not (Borovsky and Joyce, 1982b).

As was stated above, two-dimensional double layers are subject to periodic disruption as are planar double layers, the instability again being preceeded by the appearance of large amplitude solitary pulses in the low-potential plasmas adjacent to the structures. This disruption leads to a sudden increase in the flux of accelerated electrons emanating from the double layer; such an enhancement should be detectable in the auroral zone (Borovsky and Joyce, 1982a). Langmuir waves are observed in the high-potential plasmas adjacent to the structures, for high-potential plasmas of small spatial extent, the waves being confined to the region containing the electron sheet beam.

As in the case of planar double layers, if particles are strongly magnetized they are accelerated to become field aligned and if they are weakley magnetized they are accelerated to obtain pitch angles nearly equal to the obliqueness of the part of the two-dimensional double layer which they traverse. In the auroral zone this may mean field-aligned sheet beams of down-going electrons and non-field- aligned beams of up-going ions, the latitudinal extents of these ion beams being too narrow for proper resolution by present satellites (Borovsky and Joyce, 1982a).

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FIGURES

FIGURE 1. The electrostatic potential along a cut through a planar oblique double layer prior to disruption, the cut intersecting a solitary pulse in the low-potential plasma. (Mass ratio=16)

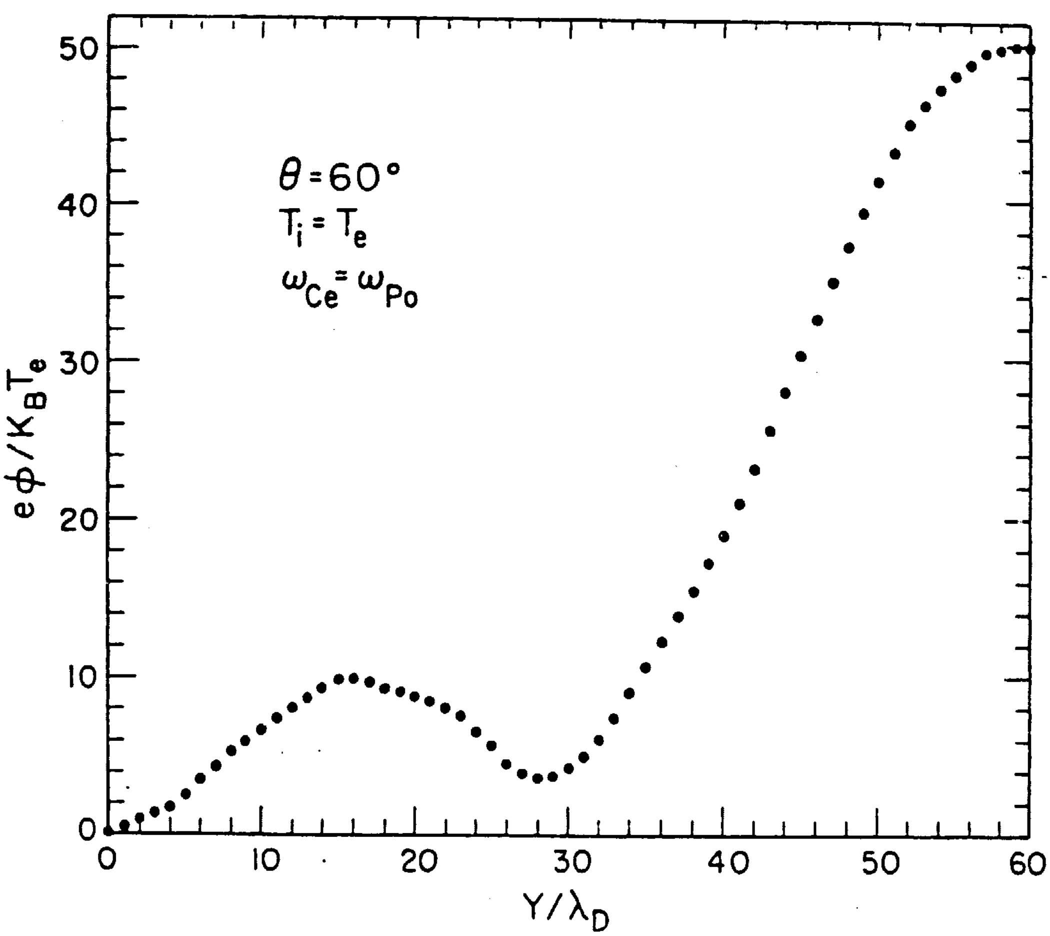

FIGURE 2. The equipotential contours of an unmagnetized (a) and a magnetized (b) two-dimensional double layer simulation, the only parameter differing being the magnetic field strength. In Figure (b) parallel and perpendicular are relative to the magnetic-field direction, which is vertical. (Mass ratio=16)