Low-Temperature Plasmas, Plasma Applications, Plasma Sources, Sheaths

THE PHYSICS OF FLUIDS VOLUME 2, NUMBER 2 MARCH-APRIL, 1959

Theory of Electrostatic Probes in a Low-Density Plasma

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(Received November 12, 1958)

The theory of sperical and cylindrical probes immersed in plasmas of such low density that collisions can be neglected is formulated. The appropriate Boltzmann equation is solved, yielding the particle density and flux as functionals of the electrostatic potential, the situation in the body of the plasma, and the properties of the probe. This information when inserted in Poisson's equation serves to determine the potential, and hence the probe characteristic. No *a priori* separation into sheath and plasma regions is required. Though amenable to a determination of the full probe characteristic, the method is applied in detail and numerical results are presented only for the collection of monoenergetic ions, for the case of negligible electron current. These results indicate that the potential is not so insensitive to ion energy as has been believed, and that if the probe radius is sufficiently small, there enters the possibility of a class of ions which are trapped near the probe in troughs of the effective radial potential energy. The population of these trapped ions is determined by collisions, however infrequent. It is difficult to calculate, and conceivably can have a marked effect on the local potential.

Phys. Fluids **2**, 112 (1959)

THE PHYSICS OF FLUIDS VOLUME 2, NUMBER 6 NOVEMBER-DECEMBER, 1959

Thermal and Electrical Properties of an Argon Plasma

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(Received May 1, 1959; revised manuscript received September 8, 1959)

Temperatures ranging from 10 000 to 25 000°K have been measured spectroscopically in thermal plasmas of atmospheric pressure argon arcs at currents in the range of 200 to 800 amp. Electrical properties of the plasmas have been derived from measured radial temperature distributions using Spitzer's theory for the temperature dependence of electrical conductivity of a completely ionized gas. Existence of local thermal equilibrium has been demonstrated by the agreement between excitation temperatures determined from both atomic and ionic spectral line intensities. Agreement between values of electrical quantities obtained by direct measurement and those derived from measured temperatures based on the assumption of thermal equilibrium demonstrates the internal consistency of the experimental and analytical methods.

Phys. Fluids **2**, 614 (1959)

Performance of a Hydromagnetic Plasma Gun

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(Received September 21, 1959)

THE gun discussed here accelerates several liters of hydrogen plasma, containing altogether about 5×10^{19} protons, to a velocity of approximately 1.5×10^{7} cm/sec, and deposits more than 40% of the electrical input energy at its terminals into kinetic energy of the jet. The familiar coaxial tube geometry[1-5] is used, but with the difference that, (1) the tubes or electrodes are longer (30 to 100 cm) than usual, (2) no auxiliary magnetic field is employed, and, (3) the gas to be accelerated is admitted as a puff into the previously evacuated space between the tubes.

Phys. Fluids **3**, 134 (1960)

THE PHYSICS OF FLUIDS VOLUME 3, NUMBER 4 JULY-AUGUST, 1960

Diffusion Processes in a Plasma Column in a Longitudinal Magnetic Field

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(Received March 18, 1960)

Earlier results, by Lehnert, on the diffusion processes in the positive column in a longitudinal magnetic field have been confirmed in a new series of measurements over a wide range of data. Experiments with helium, argon, krypton, nitrogen, and hydrogen are described. In the case of helium good agreement is obtained between the collision diffusion theory and the experiment up to a certain critical magnetic field. For stronger fields the potential drop along the column indicates a much higher diffusion rate across the magnetic field than that expected from the binary collision theory. Account is taken, in the theory, of the presence of molecular ions and of charge exchange collisions. Abnormal voltage characteristics indicating an increased diffusion rate above a certain magnetic field strength have also been investigated in argon, krypton, nitrogen, and hydrogen. The transition from the normal to the abnormal branch of the characteristics seems to depend neither on the length of the discharge tube nor on the length of the magnetic field, provided that these lengths exceed some fifty tube diameters. On the other hand, the transition depends upon the gas density, the nature of the gas, the tube radius, and, also slightly, upon the discharge current. The transition is also indicated by an increasing noise level above the transition point. Finally, the product of the magnetic field strength and the tube radius seems to be constant at this point.

Phys. Fluids **3**, 600 (1960)

THE PHYSICS OF FLUIDS VOLUME 6, NUMBER 9 SEPTEMBER 1963

Plasma Sheath Formation by Radio-Frequency Fields

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(Received 19 June 1962; revised manuscript received 3 April 1963)

It has been observed experimentally that the application of a radio-frequency voltage (10 kc/sec–50 Mc/sec) to any one of several electrode configurations around the outside of a plasma discharge tube results in a constriction of the luminous portion of the plasma away from the inner walls of the glass tube. This investigation has established that the phenomenon is basically a radio-frequency rectification effect, leading to the formation of thick ion sheath. The interaction is described mathematically in terms of a differential equation which has an approximate solution that fits qualitatively all the observed characteristics of the phenomenon. The differential equation, in its most general form, has also been solved numerically and the solution is shown to quantitatively fit our experimental observations for both radio-frequency sine and square wave signals. An application of this phenomenon as a possible external diagnostic probe technique is proposed.

Phys. Fluids **6**, 1346 (1963)

THE PHYSICS OF FLUIDS VOLUME 6, NUMBER 10 OCTOBER 1963

Continuum Theory of Spherical Electrostatic Probes

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(Received 2 January 1963)

A continuum theory for spherical electrostatic probes in a slightly ionized plasma is developed. The density of the plasma is taken to be sufficiently high such that both ions and electrons suffer numerous collisions with the neutrals before being collected by an absorbing probe. A general discussion of probes at an arbitrary potential is given. It is found that for very negative probe potentials the sheath thickness can be comparable to the probe radius. Two explicit forms of current–voltage characteristics are given; one for very negative probes, the other for probes at nearly plasma potential. Both of these are based on the assumption that the probe radius is large compared with the Debye length. Numerical computation is also given for negative probes of a wider range of probe sizes.

Phys. Fluids **6**, 1479 (1963)

THE PHYSICS OF FLUIDS VOLUME 6, NUMBER 12 DECEMBER 1963

Exact Solution of the Collisionless Plasma-Sheath Equation

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(Received 4 March 1963; revised manuscript received 22 July 1963)

The plasma-sheath problem for the low-pressure discharge in plane geometry is treated exactly, that is, with no arbitrary division into plasma and sheath regions. Numerical solutions are presented for various values of the parameter α, which is of the order of the ratio of the Debye length to the discharge width for $10^{-3} \leq \alpha \leq 10^{-1}$; and for three assumptions regarding the ion generation rate, namely generation uniform, proportional to electron density, and proportional to the square of electron density.

For the higher values of α, corresponding to weak laboratory discharges, there is a smooth transition from a quasi-neutral plasma region to a thick sheath. At the smaller values of α, the conventional model of a quasi-neutral plasma region passing rather abruptly into a narrow sheath region is substantiated. In all cases, accurate values for the potential profile throughout the plasma and sheath regions are given and compared with the separate asymptotic plasma and sheath solutions for $\alpha = 0$. The ion current density, wall potential, space-charge density, mean ion energy, and sheath thickness are discussed.

Phys. Fluids **6**, 1762 (1963)

THE PHYSICS OF FLUIDS VOLUME 8, NUMBER 1 JANUARY 1965

Unified Theory for the Langmuir Probe in a Collisionless Plasma

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(Received 2 June 1964; final manuscript received 3 September 1964)

An asymptotic analysis is presented of the Langmuir-probe problem in a quiescent, collisionless plasma in the limit of large body dimension to Debye length ratio. The structures of the electric potential distribution about spheres and cylinders are analyzed and discussed in detail. It is shown that when the probe potential is smaller than a certain well defined value, there exists no sheath adjacent to the solid surface. At large body potentials, for which a sheath is present, the electric potential distribution is given in terms of several universal functions. Master current-voltage characteristic diagrams are given which exhibit clearly the effects of all the pertinent parameters in the problem. An explicit trapped-ion criterion is presented. The general problem with an arbitrary body dimension to Debye length ratio is qualitatively discussed.

Phys. Fluids **8**, 73 (1965)

THE PHYSICS OF FLUIDS VOLUME 11, NUMBER 4 APRIL 1968

Measurement of Low Plasma Densities in a Magnetic Field

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(Received 19 September 1967)

Absolute measurements of plasma density in the range 8×10^8 to 3×10^{11} cm^{-3} were made in a potassium plasma by four methods: (1) Langmuir probes, (2) microwave cavity, (3) microwave interferometry, and (4) propagation of electrostatic waves. Agreement to $\approx 25\%$ between the probe and microwave measurements was achieved by careful application of probe theory. By contrast, indiscriminate use of probe theory would lead to an error of 600% at low densities. The fourth method, though less accurate, was found to be a useful independent check.

Phys. Fluids **11**, 811 (1968)

Electric sheath and presheath in a collisionless, finite ion temperature plasma

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The plasma-sheath equation for a collisionless plasma with arbitrary ion temperature in plane geometry is formulated. Outside the sheath, this equation is approximated by the plasma equation, for which an analytic solution for the electrostatic potential is obtained. In addition, the ion distribution function, the wall potential, and the ion energy and particle flux into the sheath are explicitly calculated. The plasma-sheath equation is also solved numerically with no approximation of the Debye length. The numerical results compare well with the analytical results when the Debye length is small.

Phys. Fluids **23**, 803 (1980)

Plasma–wall transition in an oblique magnetic field

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(Received 16 October 1981; accepted 6 May 1982)

The effect of a magnetic field on the transition layer between a plasma and an absorbing wall is studied. A numerical model is used which simulates the motion of plasma particles in the electric and magnetic fields for a prescribed particle influx at the plasma boundary. Bohm's condition for the existence of a monotonic profile of the layer is generalized. The transition layer proves to have a double structure comprising a quasineutral magnetic presheath preceding the electrostatic Debye sheath. The magnetic presheath scales with the ion gyroradius at the sound speed and with the angle of the magnetic field. The total electric potential drop between plasma and wall proves to be fairly insensitive to the magnitude and angle of the magnetic field.

Phys. Fluids **25**, 1628 (1982)

A fluid theory of ion collection by probes in strong magnetic fields with plasma flow

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(Received 24 November 1986; accepted 3 September 1987)

A one-dimensional fluid theory of Langmuir probe operation in strong magnetic fields is presented. Cross-field diffusion of ions both into and out of the the collection region is consistently accounted for, in effect taking momentum and particle diffusivity to be equal. The results differ by significant factors from previous analyses, which did not account for outward diffusion but in effect set momentum diffusivity to zero. The differences are especially large when parallel flow of the external plasma is present. It is thus clear that the value assumed for the momentum diffusivity strongly affects the interpretation of recent probe measurements. It is argued that the present results offer a more reliable basis for this interpretation.

Phys. Fluids **30**, 3777 (1987)

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Plasma flow and plasma–wall transition in Hall thruster channel

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In this paper a model of the quasineutral plasma and the transition between the plasma and the dielectric wall in a Hall thruster channel is developed. The plasma is considered using a two-dimensional hydrodynamic approximation while the sheath in front of the dielectric surface is considered to be one dimensional and collisionless. The dielectric wall effect is taken into account by introducing an effective coefficient of the secondary electron emission (SEE), s. In order to develop a self-consistent model, the boundary parameters at the sheath edge (ion velocity and electric field) are obtained from the two-dimensional plasma bulk model. In the considered condition, i.e., ion temperature much smaller than that of electrons and significant ion acceleration in the axial direction, the presheath scale length becomes comparable to the channel width so that the plasma channel becomes an effective presheath. It is found that the radial ion velocity component at the plasma–sheath interface varies along the thruster channel from about $0.5C_s$ (C_s is the Bohm velocity) near the anode up to the Bohm velocity near the exit plane dependent on the SEE coefficient. In addition, the secondary electron emission significantly affects the electron temperature distribution along the channel. For instance in the case of $s=0.95$, the electron temperature peaks at about 16 eV, while in the case of $s=0.8$ it peaks at about 30 eV. The predicted electron temperature is close to that measured experimentally. The model predictions of the dependence of the current–voltage characteristic of the $E\times B$ discharge on the SEE coefficient are found to be consistent with experiment. [DOI: 10.1063/1.1421370]

Phys. Plasmas **8**, 5315 (2001)

