WEDNESDAY MORNING, 8 JUNE 1994
9:45 AM—OTOWI

Oral Session 5C: Basic Phenomena in Partially Ionized Gases II

Chair: R. Piejak

5C1-2 *Invited*

Quasi-neutral Particle Simulations of Magnetized Low Pressure Discharges, Wallace Manheimer, Martin Lampe, Glen Joyce and Steven Slinker, Plasma Physics Division, NRL

Particle simulations of bulk discharges are constrained by the Debye length scale, which is orders of magnitude less than any other scale length of interest in the bulk plasma. While artificial scaling of the parameters, and nonuniform grid spacing can somewhat alleviate the problem, it still represents a serious constraint. Quasi-neutral fluid and hybrid simulations are routinely done; however in many plasmas on the kinetic nature of both the electrons and ions play important roles. We report progress on the development of a quasi-neutral particle simulation for an ECR discharge. The quasi-neutral nature of the plasma means that the algorithms for advancing the ions, electrons and for calculating the electric field are very non standard. The ions are initially advanced in three dimensions. However very fast time scale, short scale length electrostatic electric fields impose average quasi-neutrality perpendicular to the field. The ion motion in the simulation is slightly corrected to reflect this. Along the field line, quasi-neutrality is maintained by very fast electron oscillations. The electron motion is also slightly corrected to insure quasi-neutrality. Once the particles are convected, the electric field is calculated from the electron momentum equation. Simulations of ion acoustic waves in one dimensional plasmas, and of simple ECR reactors in two dimensional plasmas have been done. This work was supported by ONR.

5C3-4 *Invited*

REVIEW ON LASER-INDUCED FLUORESCENCE METHODS FOR MEASURING RF- AND MICROWAVE ELECTRIC FIELDS IN DISCHARGES

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Development of methods for measuring rf- or μ-wave electric fields $\mathbf{E}(t)=\mathbf{E}_0\cos\omega t$ in discharge plasmas is of a great practical importance. First, these are fields used for producing rf- or μ-wave discharges. Second, the fields $\mathbf{E}(t)$ may represent electromagnetic waves penetrating into a plasma from the outside. This paper reviews methods for diagnostics of the fields $\mathbf{E}(t)$ in low temperature plasmas based on Laser-Induced Fluorescence (LIF). Compared to emission (passive) methods, LIF-methods have a higher sensitivity as well as higher spatial and temporal resolutions. Underlying physical effects may be highlighted by an example of LIF of hydrogen atoms in a plasma, the fluorescence being induced by a laser field $\mathbf{E}_L(t)=\mathbf{E}_{0L}\cos(\omega_L+\phi_L)$ resonant to a transition between an upper 2 and a lower 1 atomic levels:

$$\omega_L=\omega_{21}+q\omega-\mu_0,\quad q=0,\pm1,\pm2,\ldots;\quad |\mu_0|<<\omega<<\omega_L. \qquad (1)$$

In conditions of the resonance (1), a population of the level 2 is increased leading to a fluorescence signal at the transition 2→1. Its intensity I_{f1} depends in an entangled way on parameters of both the laser field and the field $\mathbf{E}(t)$ to be measured:

$$I_{f1}\propto ND_{12}^2E_{oL}^2\tau_{12}/(W_{21}f_k), \qquad (2)$$

$$f_k\equiv1+\mu^2\tau_{12}^2+D_{12}^2E_{0L}^2\tau_{12}\hbar^{-2}W_{21}^{-1},\quad D_{12}\equiv d_{12}J_q(v),$$

$$\mu\equiv\mu_0-d_{12}^2E_{0L}^2\sum_{r=1}^{\infty}[J_{q-r}^2(v)-J_{q+r}^2(v)]/(2\hbar^2r\omega), \qquad (3)$$

where $v\equiv(d_{11}-d_{22})E_0/(\hbar\omega)$, W_{21} and τ_{12}^{-1} - rates of longitudinal and transverse relaxations respectively, $d_{\alpha\beta}$ - dipole matrix element between states α and β, N - atomic density, $J_k(v)$ - Bessel functions. Relations (1),(2) illustrate the following basic phenomena employed by contemporary LIF methods for diagnosing the fields $\mathbf{E}(t)$: 1) dependence of I_{f1} on number of quanta q of the field $\mathbf{E}(t)$ involved into the resonance (1); 2) dependence of an effective dipole matrix element D_{12} on parameters of the field $\mathbf{E}(t)$; 3) dependence of a dynamic Stark shift (the second term in (3)) on parameters of the field $\mathbf{E}(t)$.

After a presentation of the underlying physical principles, the review focuses on key experiments where these principles were implemented for measurements of rf- and μ-wave electric fields in various discharges.

5C5

Theory of the plasma–sheath transition and the Bohm criterion

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In typical boundary layer problems a quasineutral plasma is shielded from a negative absorbing wall by a positive space charge region ("sheath") with a characteristic extension of several electron Debye lengths λ_D. In the usual case $\lambda_D \ll L$ —where L is the smallest competing characteristic length relevant for the boundary layer — the formation of a positive space charge is impeded by ion wall losses, and a positive sheath can exist only if the Bohm criterion [1,2] is fulfilled. In its simplest form it requires that the ions enter the sheath region with a velocity exceeding the the ion sound velocity. Consequently, the ions must be preaccelerated by a non-shielded residual field in the quasineutral "presheath" region with an extension $L \gg \lambda_D$. Apart from field and inertia, the presheath ion acceleration is necessarily governed by (at least) one of the following processes:

(a) geometric current concentration (L =curvature radius)
(b) collisional ion friction (L = ion mean free path)
(c) ionization (L = plasma extension)
(d) magnetic deflection of the ion orbits (L = ion gyro radius)

The "sheath edge" separating the sheath and presheath regions in the limiting case $\lambda_D/L \to 0$ is (usually) defined by a field singularity. This singularity is related to the marginal (equality) form of the Bohm criterion and may be interpreted in terms of the ion acoustic sound barrier [2,3]. The simple picture of the plasma-sheath transition sketched so far must be supplemented or modified in many cases for the following reasons:

(1) The usual sheath edge singularity requires to consider an intermediate region between sheath and presheath.
(2) There are exceptions from the general rule that the sheath edge can be defined by a singularity and by the marginal form of Bohm's criterion [3].
(3) There are cases where the kinetic and hydrodynamic analyses of the sheath edge lead to contradictory results [3].
(4) The mechanism of a presheath (d) governed by magnetic ion orbit deflection is not sufficiently understood [4].
(5) Since the Bohm criterion refers to stationary problems, its application to RF sheaths is not trivial [5].
(6) The Bohm criterion must be modified for emitting and/or reflecting walls.

These and realated probems concerning the plasma-sheath transition are discussed coherntly on the basis of a general review [2] and of recent reults (e.g. [3-5]).

[1] D. Bohm, in *The Character. of Electr. Disch. in Magn. Fields*, eds. A. Guthry and R.K. Wakerling (Mc Graw-Hill, 1949), p. 77
[2] K.-U. Riemann, J. Phys. D: Appl. Phys. **24**, 493 (1991)
[3] K.-U. Riemann, Phys. Fluids B **3**, 3331 (1991)
[4] K.-U. Riemann, Phys. Plasmas (in press)
[5] K.-U. Riemann, Phys. Fluids B **4**, 2693 (1992)

5C6

Two-dimensional Model of Stationary Plasma Thruster*

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A stationary plasma thruster (SPT) is an electromagnetic thruster design which has been developed primarily in the Former Soviet Union and which has properties which make it especially suitable for applications such as satellite station-keeping. The device geometry is cylindrical with a central dielectric rod and dielectric walls. A voltage (a few 100 V) is maintained between the anode (at one end of the cylinder) and the cathode (usually a hollow cathode or a filament slightly past the other end of the cylinder), and the current flowing through the device is on the order of several amps. Gas (usually xenon) flows in from the anode and is ionized by the electrons which are emitted from the cathode. An external magnetic field is applied primarily in the radial direction with a magnetic strength (on the order of 100 Gauss) such that the electron gyroradius is much less than the device dimension but that the ion gyroradius is larger than the device dimensions. The SPT is a particular type of closed-drift thruster where ions are electrostatically accelerated in the thrust direction, with the accelerating electric field established by an electron current interacting with a transverse magnetic field. In such a configuration, an ion flux is produced with a high efficiency.

We have developed a two-dimensional model (in the radial and axial directions) for the purpose of elucidating the physical phenomena controlling the device performance and eventually developing scaling laws to guide the optimization of SPT's. The model consists of fluid equations for the electrons (drift-diffusion) and ions (free fall) coupled to Poisson's equation for the self-consistent electric field. The description of ion transport can be improved if necessary by solving the Vlasov equation with a particle method. Electron diffusion across the magnetic field is an important aspect of closed-drift thruster operation. Classical $1/B^2$ diffusion is too small to account for the measured conductivity and the assumption of $1/B$ anomalous diffusion is more consistent with experimental observations. However it is not yet clear whether this enhanced conductivity is due to plasma oscillations and fluctuations or to electron collisions with the walls or both. The electron diffusion has been taken as a parameter in the model.

We will present the results of our calculations of the self-consistent fields and the charged particle density distributions under discharge conditions similar to SPT's.

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5C7

Non-Maxwellian Bounded Plasma Model with Charge Exchange Ion Collisions

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A bounded plasma model in which ion motion is controlled by ion inertia and charge exchange collisions has been developed for a non-Maxwellian electron energy distribution functions (EEDF) of functional form: $\exp(\varepsilon/\alpha)^k$ with k = 0.5, 1 and 2. These three types of EEDF are frequently encountered in gas discharge plasmas and correspond to bi-Maxwellian-like, Maxwellian and Druyvesteyn distributions. The spatial distribution of the plasma density and the effective electron temperature are found numerically for these three types of EEDF in the non-local regime of ion and electron kinetics.