Kinetics of Glow Discharges.

Direct Current Discharges for Aerospace Applications

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Outline

• Improved DCD computing model: prediction of electronic temperature
• Improved DCD computing model: vibrationally excited gas (N₂)
• New DCD drift-diffusion computing model: flow of neutral particles through a glow discharge with magnetic field
• Quasineutral drift-diffusion model: hypersonic flow through plane channel
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Hierarchy of the DCD models

Boltzmann equation for weakly ionized gases in electric and magnetic fields

- **Kinetic approach**
  - Integral-Differential equations
  - Monte-Carlo methods
  - PIC/DSMC approach

- **Multi-fluid/multi-temperature MHD models**

- **Quasi-neutral (Ambipolar) models**

The **Maxwell** equations for prediction E&B fields.
The **Poisson** equation: In the simplest physical case

Current density continuity equation: for prediction E

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Hierarchy of the DCD models

1. Physical kinetics approach:
   Integral-Differential equations for excited particles

2. Multi-fluid/multi-temperature models:
   Chemical kinetics approach.


The Poisson equation for prediction of electric field.
Multi-fluid/multi-temperature model of DCD in chemical active gas

- This model is the **Modified Diffusion-Drift model** of a DCD
- This model takes into account near electrodes regions of space charge
- This theory allows predict “Large-scale” experimentally observed parameters of DCD
- This theory allows predict Chemical processes in DCD
The theory and numerical simulations have demonstrated influences:

- gas pressure,
- Emf. of power supply,
- magnetic field induction,
- geometry of gas discharge gap,
- coefficient of secondary electronic emission,
- vibrational excitation of neutrals particles
- heating effects on electrodynamics’ structure of the glow discharges.
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**Multi-fluid/two-temperature model of DCD with chemical kinetics**

\[
\frac{\partial n_e}{\partial t} + \frac{\partial \Gamma_{e,x}}{\partial x} + \frac{\partial \Gamma_{e,y}}{\partial y} = \alpha(E) |\Gamma_e| - \beta e n_e n_e
\]

\[
\frac{\partial n_+}{\partial t} + \frac{\partial \Gamma_{+,x}}{\partial x} + \frac{\partial \Gamma_{+,y}}{\partial y} = \alpha(E) |\Gamma_+| - \beta_+ n_+ n_e
\]

\[
\rho c_p \frac{\partial T}{\partial r} = \frac{\partial}{\partial x} \left( \lambda \frac{\partial T}{\partial x} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r \lambda \frac{\partial T}{\partial r} \right) + Q
\]

\[
\rho \frac{\partial Y_k}{\partial t} + \frac{\partial}{\partial x} J_{k,x} + \frac{1}{r} \frac{\partial}{\partial r} r J_{k,r} = W_k, k = 0...m
\]

\[
\Delta \varphi + 4\pi e \sum_i Z_i n_i = 0, \ E = -\nabla \varphi
\]

\[
m_e << M_+ : \quad \frac{M_{N_+}^2}{m_e} = 28. \times \frac{M_p}{m_e} = 28. \times 1836 = 5.1408 \times 10^4
\]

\[
\Gamma_e = n_+ u_e = -\mu_e n_e E - \cdot \nabla n_e
\]

\[
\Gamma_+ = n_+ u_+ = +\mu_+ n_e E - \cdot \nabla n_+
\]

\[
M_k^2 \sum_{j \neq k} \frac{Y_j J_k - Y_k J_j}{M_k M_j D_{kj}} = \nabla M_k Y_k, k = 1...m
\]

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Constitutive relationships

\[ \mu_e(p) = \frac{4.2 \cdot 10^5}{p}, \text{ cm}^2/(\text{V}\cdot\text{s}) \]

\[ \mu_i(p) = \frac{2280}{p}, \text{ cm}^2/(\text{V}\cdot\text{s}) \]

\[ c_p = 8.314 \frac{7}{2 M_\Sigma}, \text{ J/(g}\cdot\text{K}) \]

\[ \lambda = \frac{8.334 \cdot 10^{-4}}{\sigma^2 \Omega^{(2.2)^*}} \sqrt{\frac{T}{M_\Sigma}} \left( 0.115 + 0.354 \frac{c_p M_\Sigma}{R} \right) \]

\[ \Omega^{(2.2)^*} = \frac{1.157}{(T^*)^{0.1472}}, T^* = \frac{T}{(\varepsilon/k)}, \]

\[ (\varepsilon/k) = 71.4 \text{K}, \sigma = 3.68 \text{Å} \]
Constitutive relationships

Ionization coefficient:

$$\frac{\alpha}{p} = A \exp \left[ -\frac{B}{(E/p)} \right]$$

$$A_{N_2} = 12 , \text{1/(cm\times torr)}$$

$$B_{N_2} = 342 , \text{V/(cm\times torr)}$$

Analysis of experimental data obtained by Townsend and Bailey [Townsend J.S., Bailey V.A. Philos. Mag., 1921, v.42, p.874.] allows suggest the following empirical relation for determination of electronic temperature:

$$\frac{T_e}{T} = 29.96 \ln \left( \frac{E}{p} \right) + 24.64$$

$T_e$ is the electron temperature, K,
$T$ is the gas temperature, K,
$E/p$ is the discharge parameter, V/(cm*torr).
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Theoretical analysis of the empirical relation:

\[
\frac{T_e}{T} = 29.96 \ln \left( \frac{E}{p} \right) + 24.64
\]

The mobility of electrons is

\[
\mu_e = \frac{e}{m_e v_{en}}
\]

and

\[
V_{dr,e} = \mu_e E
\]

Electron diffusion coefficient is defined as:

\[
D_e \approx \frac{1}{3} l_e \bar{V}_e = \left\{ l_e = \frac{\bar{V}}{v_{en}} \right\} = \frac{1}{3} \frac{\bar{V}_e^2}{v_{en}} = \frac{2}{3} \frac{\bar{\epsilon}_e}{m_e v_{en}} = \frac{2}{3} \frac{\bar{\epsilon}_e}{m_e v_{en}} \mu_e
\]
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Theoretical analysis of the empirical relation:

\[
\frac{T_e}{T} = 29.96 \ln \left( \frac{E}{p} \right) + 24.64
\]

So,

\[
D_e \approx \frac{2}{3} \frac{\bar{e}_e}{e} \mu_e
\]

where

\[
\bar{e}_e = \frac{m_e \bar{V}_e^2}{2}
\]

From the kinetic theory

\[
\bar{e}_e = \frac{3}{2} kT_e
\]

therefore

\[
\frac{D_e}{\mu_e} = \frac{kT_e}{e} \quad \text{or} \quad D_e = \mu_e T_e, [eV]
\]
Theoretical analysis of the empirical relation:

\[
\frac{D_e}{\mu_e} = \frac{kT_e}{e} \quad \bar{\varepsilon}_e = \frac{3}{2} kT_e \quad \Rightarrow \quad \bar{\varepsilon}_e = \frac{3}{2} e \frac{D_e}{\mu_e}
\]

Experimentally, electronic temperature is measured by determining the spreading, due to diffusion, of electron drifting in the field E.

At a distance \(x = V_{dr,e} t\) from the point where electrons start, the beam has spread in the transverse direction to a radius

\[
r \approx \sqrt{D_e t} = \sqrt{D_e \frac{x}{V_{dr}}} = \sqrt{D_e \frac{x}{\mu_e E}}
\]
Vibrational kinetics

\[ N_2 + e \rightarrow N_2(w) + e, \quad w = 1 \ldots 10 \]

\[ K_{el}^{v,v+w} = K_{el}^{0,1} \exp(-0.7w) \]

\[ N_2(v+1) + N_2(w) \rightleftharpoons N_2(v) + N_2(w+1) \quad v, w = 0 \ldots 49 \]

\[ K_{v+1,v}^{w,w+1} = (v+1)(w+1)K_{1,0}^{0,1}Z \left( \frac{3}{2} - \frac{Z}{2} \right) \exp \left( \frac{h\nu k}{kT} \frac{w-v}{kT} \right) \quad Z = \exp \left( -\sqrt{\frac{T_0}{T}}(w-v) \right) \quad K_{1,0}^{0,1} = A_1 T^{-3/2} \]

\[ N_2(v) + N_2 \rightarrow N_2(v-1) + N_2 \]

\[ K_{VT}^{v+1,v} = K_{VT}^{1,0} (v+1) \exp \left( \sqrt{\frac{T_0}{T}} + \frac{h\nu k}{kT} \right) \quad K_{VT}^{v+1,v} = A_2 \exp \left( B_2 T^{-1/3} \right) \]
Initial data

\[ R_c = 2 \text{ cm} \]
\[ H_c = 2 \text{ cm} \]
\[ p = 5 \text{ Torr} \]
\[ E = 2 \text{ kVolt} \]
\[ R_o = 1000 \text{ Ohm} \]
\[ \gamma = 0.05 \]

1) \( T_e = 1 \text{eV} \)  
2) \( T_e = \text{var} \)
Boundary conditions

\[ r = 0 : \frac{\partial n_e}{\partial r} = \frac{\partial n_i}{\partial r} = \frac{\partial \varphi}{\partial r} = 0; \]

\[ r = R_c : \frac{\partial n_e}{\partial r} = \frac{\partial n_i}{\partial r} = \frac{\partial \varphi}{\partial r} = 0; \]

\[ x = H_c : n_i = 0, \quad \frac{\partial n_e}{\partial x} = 0, \quad \varphi = V; \]

\[ x = 0 : \frac{\partial n_i}{\partial x} = 0, \quad \Gamma_e = \gamma \Gamma_i, \quad \varphi = 0; \]
Numerical simulation results: $T_e=\text{var}$

**Graph 1:**

- $10^{-9}n_e, \text{ cm}^{-3}$
- $X, \text{ cm}$
- $R, \text{ cm}$
- $n_e, n_+: p=5 \text{ Torr}, E=2 \text{ kV}$

**Graph 2:**

- $10^{-9}n_e, \text{ cm}^{-3}$
- $X, \text{ cm}$
- $R, \text{ cm}$

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Numerical simulation results: \( T_e = \text{var} \)

Temperature of gas at the xor plane, K

Electronic temperature in gas discharge gap, eV

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Numerical simulation results

Current density distributions at the cathode (2,4) and anode (1,3): 1, 2 - $T_e = \text{var}$; 3, 4 - $T_e = 1 \text{ eV}$
Numerical simulation results

Axial distribution (at $r = 0$) of electrons (dotted line) and ions (solid line) concentrations; $1, 2 - T_e = \text{var}; 3, 4 - T_e = 1 \text{ eV}$
Numerical simulation results: **Vibration relaxation**

Mass fraction distribution of $N_2$ in ground state; $x$, $r$ in cm
Numerical simulation results: Vibratiotion relaxation

Mass fraction distribution of the N₂(1) level; x, r in cm

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Numerical simulation results: **Vibration relaxation**

Mass fraction distribution of the $\text{N}_2(20)$ level; $x$, $r$ in cm
Numerical simulation results: \textit{Vibratiation relaxation}

Mass fraction distribution of the $N_2(50)$ level; $x, r$ in cm
Conclusions:

- Two-dimensional numerical simulation model of direct current discharge (glow discharge) is presented and numerically analyzed.

- The model takes into account processes of collisional ionization of neutral gas, ion-electron recombination, secondary ion-electronic emission of electrons from cathode surface, heating of neutral gas and electrons, and vibrational kinetics of molecular nitrogen.

- It is shown that presented numerical simulation model allows predict parameters of normal glow discharge and distribution of molecular nitrogen on vibrationally excited energy levels which are do not contradict to known experimental data and previous theoretical analysis.
Part 2

DCD drift-diffusion computing model: flow of neutral particles through a glow discharge with magnetic field
Hierarchy of the DCD models

Boltzmann equation for weakly ionized gases in electric and magnetic fields

Kinetic approach
- Integral-Differential equations
- Monte-Carlo methods
- PIC/DSMC approach

Multi-fluid/multi-temperature MHD models
- CFD approach

Quasi-neutral (Ambipolar) models
- CFD approach

The Maxwell equations for prediction E&B fields.
The Poisson equation: In the simplest physical case

Current density continuity equation: for prediction E
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**Multi-fluid/multi-temperature MHD models.**

**Typical formulation (“fluid” dynamics):**

\[
m_e n_e \frac{\partial u_e}{\partial t} + m_e n_e (u_e \cdot \nabla) u_e = -\nabla p_e + \frac{M_e n_e F_e}{m_e} - \tau_e - en_e \left( E + \frac{1}{c} [u_e, B] \right) - m_e n_e \sum_n v_{en} (u_e - u_n) - m_e n_e \sum_i v_{e+} (u_e - u_+) - m_e n_e \sum_i v_{e-} (u_e - u_-)
\]

\[
M_{i+} n_{i+} \frac{\partial u_{i+}}{\partial t} + M_{i+} n_{i+} (u_{i+} \cdot \nabla) u_{i+} = -\nabla p_{i+} + \frac{M_{i+} n_{i+} F_{i+}}{m_{i+}} - \tau_{i+} + en_{i+} \left( E + \frac{1}{c} [u_{i+}, B] \right) - M_{i+} n_{i+} \sum_n v_{i+n} (u_{i+} - u_n) - M_{i+} n_{i+} \sum_i v_{i+,i} (u_+ - u_+) - M_{i+} n_{i+} \sum_j v_{i+,j} (u_{i+} - u_{j+}), \ i_+ = 1, 2, ..., N_+
\]

\[
M_{i-} n_{i-} \frac{\partial u_{i-}}{\partial t} + M_{i-} n_{i-} (u_{i-} \cdot \nabla) u_{i-} = -\nabla p_{i-} + \frac{M_{i-} n_{i-} F_{i-}}{m_{i-}} - \tau_{i-} - en_{i-} \left( E + \frac{1}{c} [u_{i-}, B] \right) - M_{i-} n_{i-} \sum_n v_{i-n} (u_{i-} - u_n) - M_{i-} n_{i-} \sum_i v_{i-,i} (u_- - u_+) - M_{i-} n_{i-} \sum_j v_{i-,j} (u_{i-} - u_{j+}), \ i_- = 1, 2, ..., N_-
\]

\[
[\nabla \times H] = J + \frac{dD}{dt}, \quad [\nabla \times E] = -\frac{dB}{dt}, \quad \Delta E = 4\pi e (\sum n_+ + n_e - \sum n_{n+}), \quad \Delta B = 0, \quad D = eE, \quad B = \mu_0 H
\]

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Two-fluid/two-temperature MHD models.

Simplified equations \((n_e, n_+)\):

\[
m_e \ll M_+ : \quad \frac{M_{N_2}^+}{m_e} = 28. \times \frac{M_p}{m_e} = 28. \times 1836 = 5.1408 \times 10^4
\]

\[
\frac{\partial n_e}{\partial t} + \frac{\partial \Gamma_{e,x}}{\partial x} + \frac{\partial \Gamma_{e,y}}{\partial y} = \alpha(E)|\Gamma_e| - \beta_e n_+ n_e
\]

\[
\frac{\partial n_+}{\partial t} + \frac{\partial \Gamma_{+,x}}{\partial x} + \frac{\partial \Gamma_{+,y}}{\partial y} = \alpha(E)|\Gamma_e| - \beta_e n_+ n_e
\]

\[
\Gamma_e = n_e u_e = -\mu_e n_e E - D_e \nabla n_e
\]

\[
\Gamma_+ = n_+ u_+ = +\mu_+ n_+ E - D_+ \nabla n_+
\]

\[
\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 4\pi e(n_e - n_+)
\]

\[
E = -\text{grad} \varphi
\]

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DCD in magnetic field: Governing equations

\[ m_e n_e \frac{\partial u_e}{\partial t} + m_e n_e (u_e \cdot \nabla) u_e = -\nabla p_e + \frac{M_e n_e F_e}{m_e} - \tau_e - en_e \left( E + \frac{1}{c} [u_e B] \right) - m_e n_e \nu_{en} (u_e - u_n) - m_e n_e \nu_{e+} (u_e - u_+) - m_e n_e \nu_{e-} (u_e - u_-) \]

\[ M_+ n_+ \frac{\partial u_+}{\partial t} + M_+ n_+ (u_+ \cdot \nabla) u_+ = -\nabla p_+ + \frac{M_+ n_+ F_+}{m_+} - \tau_+ + en_+ \left( E + \frac{1}{c} [u_+ B] \right) - M_+ n_+ \nu_{+e} (u_+ - u_e) - M_+ n_+ \nu_{+n} (u_+ - u_n) - M_+ n_+ \nu_{+-} (u_+ - u_-) \]
DCD in magnetic field: Governing equations

The first general assumption of the model

\[ n_n \gg (n_+, n_e) \]

Typical glow discharge in air:
- \( p = 5 \) Torr,
- Emf. of power supply \( E = 1 \) kVolt,
- \( n_n \sim 10^{17} \) cm\(^{-3}\),
- \( n_e \sim n_+ \sim 10^{11} \) cm\(^{-3}\).
DCD in magnetic field: Governing equations

Estimations of significant physical times:

\[ \nu_{e^+} = 5.5 \cdot T_e^{-3/2} n_\ast \ln \left( 220 \frac{T_e}{n_\ast^{1/3}} \right) \]

\[ \nu_{+n} = \frac{2\sqrt{2}}{3} \pi a^2 \sqrt{\frac{8kT}{m_e \pi}} n_n \quad n_\ast = (n_e, n_+) \]

Half-empirical relations:

\[ \nu_{eN_2} = 2.5 \times 10^{-11} n_{N_2} T_e \left( 1 + 9.3 \times 10^{-3} \sqrt{T_e} \right) \]

\[ \nu_{eO_2} = 1.5 \times 10^{-10} n_{O_2} \sqrt{T_e} \left( 1 + 4.2 \times 10^{-2} \sqrt{T_e} \right) \]

\[ \nu_{eO} = 2.8 \times 10^{-10} n_O \sqrt{T_e} \]
DCD in magnetic field: Governing equations

The second general assumption of the model

\[ t \gg \max \{ \tau_{en}, \tau_{e+}, \tau_{e-} \} \]

\[
\mu_e = \frac{e}{m_e v_{en}} \\
\mu_+ = \frac{e}{M_+ v_+} \\
\mu_- = \frac{e}{M_- v_-}
\]

\[
D_e = \frac{kT_e}{m_e v_{en}} = \left( \frac{kT_e}{e} \right) \left( \frac{e}{m_e v_{en}} \right) = T_{e[\text{eV}]} \mu_e
\]

\[
D_+ = \frac{kT}{M_+ v_+} = \left( \frac{kT}{e} \right) \left( \frac{e}{M_+ v_+} \right) = T_{e[\text{eV}]} \mu_+
\]

\[
D_- = \frac{kT}{M_- v_-} = \left( \frac{kT}{e} \right) \left( \frac{e}{M_- v_-} \right) = T_{e[\text{eV}]} \mu_-
\]
DCD in magnetic field: Governing equations

\[
\frac{\partial n_e}{\partial t} + \frac{\partial \Gamma_{e,x}}{\partial x} + \frac{\partial \Gamma_{e,y}}{\partial y} = \alpha(E)|\Gamma_e| - \beta e n_+ n_e
\]

\[
\frac{\partial n_+}{\partial t} + \frac{\partial \Gamma_{+,x}}{\partial x} + \frac{\partial \Gamma_{+,y}}{\partial y} = \alpha(E)|\Gamma_e| - \beta e n_+ n_e
\]

\[
\Gamma_{e,x} = n_e u_{e,x} = -\mu_e n_e E_{e,x} - \frac{1}{1 + b_e^2} D_e \frac{\partial n_e}{\partial x} + \frac{b_e}{1 + b_e^2} D_e \frac{\partial n_e}{\partial y}
\]

\[
\Gamma_{e,y} = n_e u_{e,y} = -\mu_e n_e E_{e,y} - \frac{1}{1 + b_e^2} D_e \frac{\partial n_e}{\partial y} - \frac{b_e}{1 + b_e^2} D_e \frac{\partial n_e}{\partial x}
\]

\[
\Gamma_{+,x} = n_+ u_{+,x} = +\mu_+ n_+ E_{+,x} - \frac{D_+}{1 + b_+^2} \frac{\partial n_+}{\partial x} - \frac{b_+}{1 + b_+^2} D_+ \frac{\partial n_+}{\partial y}
\]

\[
\Gamma_{+,y} = n_+ u_{+,y} = +\mu_+ n_+ E_{+,y} - \frac{D_+}{1 + b_+^2} \frac{\partial n_+}{\partial y} + \frac{b_+}{1 + b_+^2} D_+ \frac{\partial n_+}{\partial x}
\]
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DCD in magnetic field: Governing equations

\[ b_e = \frac{\mu_e B_z}{c} = \frac{\omega_{B,e}}{v_e} \]
\[ E_{e,x} = \frac{E_x - b_e E_y}{1 + b_e^2} \]
\[ E_{e,y} = \frac{E_y - b_e E_x}{1 + b_e^2} \]

\[ b_+ = \frac{\mu_+ B_z}{c} = \frac{\omega_{B,+}}{v_+ n} \]
\[ E_{+,x} = \frac{E_x + b_+ E_y}{1 + b_+^2} \]
\[ E_{+,y} = \frac{E_y - b_+ E_x}{1 + b_+^2} \]
DCD in magnetic field: Governing equations

\[
\frac{\partial n_e}{\partial t} + \frac{\partial}{\partial x}\left(-\mu_e n_e E_{e,x} - \frac{D_e}{1 + b_e^2} \frac{\partial n_e}{\partial x}\right) + \frac{\partial}{\partial y}\left(-\mu_e n_e E_{e,y} - \frac{D_e}{1 + b_e^2} \frac{\partial n_e}{\partial y}\right) = \alpha(E)|\Gamma_e| - \beta_e n_e n_e
\]

\[
\frac{\partial n_+}{\partial t} + \frac{\partial}{\partial x}\left(+\mu_+ n_+ E_{+,x} - \frac{D_+}{1 + b_+^2} \frac{\partial n_+}{\partial x}\right) + \frac{\partial}{\partial y}\left(+\mu_+ n_+ E_{+,y} - \frac{D_+}{1 + b_+^2} \frac{\partial n_+}{\partial y}\right) = \alpha(E)|\Gamma_e| - \beta_e n_e n_e
\]

\[
\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 4\pi e(n_e - n_+) \quad \mathbf{E} = -\nabla \varphi
\]
DCD in magnetic field: Neutral particles flow
DCD in magnetic field: Neutral particles flow

\[
\frac{\partial n_e}{\partial t} + \frac{\partial}{\partial x} \left( -n_e \mu_e E_{e,x,\text{eff}} - \frac{D_e}{1 + b_e^2} \frac{\partial n_e}{\partial x} \right) + \frac{\partial}{\partial y} \left( -n_e \mu_e E_{e,y,\text{eff}} - \frac{D_e}{1 + b_e^2} \frac{\partial n_e}{\partial y} \right) = \alpha \Gamma_e - \beta n_e n_i
\]

\[
\frac{\partial n_i}{\partial t} + \frac{\partial}{\partial x} \left( u_{n,x} + b_i u_{n,y} - \frac{D_i}{1 + b_i^2} \frac{\partial n_i}{\partial x} \right) + \frac{\partial}{\partial y} \left( u_{n,y} - b_i u_{n,x} - \frac{D_i}{1 + b_i^2} \frac{\partial n_i}{\partial y} \right) = \alpha \Gamma_e - \beta n_e n_i
\]

\[
E_{e,x,\text{eff}} = \frac{E_x - b_e E_y}{1 + b_e^2} \quad E_{e,y,\text{eff}} = \frac{E_y + b_e E_x}{1 + b_e^2} \quad E_{i,x,\text{eff}} = \frac{E_x + b_i E_y}{1 + b_i^2} \quad E_{i,y,\text{eff}} = \frac{E_y - b_i E_x}{1 + b_i^2}
\]

\[
\nu = V_0 \left( 1 - \left( \frac{z}{h} \right)^m \right) \quad \text{where } m=2 \text{ or } 6
\]
DCD in magnetic field: Neutral particles flow

Numerical simulation results

\[
\nu = V_0 \left( 1 - \left( \frac{z}{h} \right)^m \right)
\]

where \( m = 2 \) or 6
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✓ Initial conditions: Plane channel, $E = 2000$ V, $p = 5$ Torr, $T_e = \text{var}$, $V_0 = 100$ m/s

$V_0 = 100$ m/s

$t = 120$ mcs

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Initial conditions: Plane channel, $E = 2000$ V, $p = 5$ Torr, $T_e = \text{var}$, $V_0 = 1000$ m/s

$V_0 = 1000$ m/s

$t = 20$ mcs

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Initial conditions: Plane channel, \( E = 2000 \) V, \( p = 5 \) Torr, \( T_e = \text{var} \), \( V_0 = 100 \) m/s, \( B_z = -0.05 \) T

\[ V_0 = 100 \text{ m/s} \]

\[ t = 60 \text{ mcs} \]

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Conclusion (Part 2)

Two-dimensional model and computing code for prediction parameters of glow discharge in the presence of a gas stream and a cross magnetic field is created.

A study of dynamics of a glow discharge in the presence of magnetic field and a cross gas stream has been performed with use of the developed model.

Obtained numerical simulations show the following peculiarities of the glow discharge in neutral gas flow:
1) The glow discharge is involved in the movement of neutral gas with velocity, which differs from the velocity of neutral gas movement,
2) It is possible to select specific magnetic field induction (and its direction) in order that to accelerate or to slow down movement of the glow discharge in gas flow.

External magnetic field can be used as external parameter for control gas discharge movement in neutral gas flow.