# Streamer propagation in cold plasma

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## Electric Field isolines

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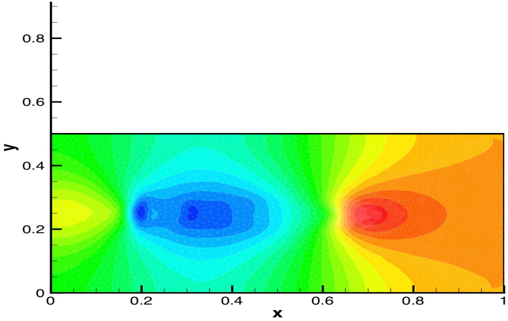

## Adaptive mesh

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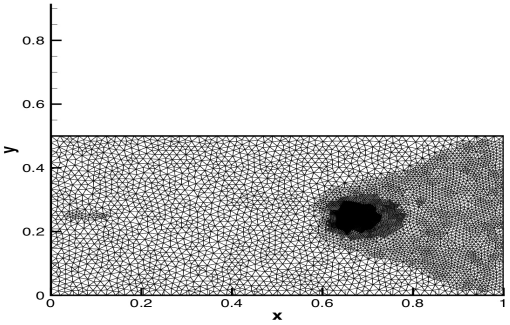

Electric Field 1D view

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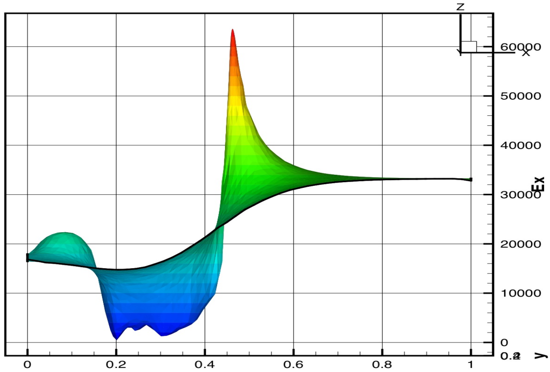

**General form of streamer equation**

The is general form of the streamer equations writes:

$$\begin{aligned} \frac{\partial n_e}{\partial t} + div(n_e \overrightarrow{v_e} - De \overrightarrow{\nabla} n_e) &= S_e, \\ \frac{\partial n_i}{\partial t} &= S_e, \\ \triangle V &= k \cdot (n_e - n_i), \end{aligned} \tag{1}$$

where unknowns have following meanings: $n_e$ - electron density, $n_i$ - ion density, $v_e$ - electron drift velocity, $De$ - diffusion coefficient, $S_e$ - source term, $V$ - electric potential, $k = \frac{e}{\epsilon_0}$ is constant with $e$ - elementary charge, $\epsilon_0$ - permittivity of vacuum. The system of equation (1) is closed by following formulas (equations).

Intensity of electric field $E$ is computed as minus gradient of electric potential

$$\vec{E} = -grad(V). \tag{2}$$

The electron drift velocity is a function of the intensity of electric field and we've got different formulas for four intervals of elctric field

$$\text{for} \quad \frac{\|\vec{E}\|}{n} > 2 \cdot 10^{-15}, \quad v_e = -\left[7.4 \cdot 10^{21} \cdot \frac{\|\vec{E}\|}{n} + 7.1 \cdot 10^{6}\right] \cdot$$

$$\text{for} \quad 10^{-16} < \frac{\|\vec{E}\|}{n} \leq 2 \cdot 10^{-15}, \quad v_e = -\left[1.03 \cdot 10^{22} \cdot \frac{\|\vec{E}\|}{n} + 1.3 \cdot 10^{6}\right]$$

$$\text{for} \quad 2.6 \cdot 10^{-17} < \frac{\|\vec{E}\|}{n} \leq 10^{-16}, \quad v_e = -\left[7.2973 \cdot 10^{21} \cdot \frac{\|\vec{E}\|}{n} + 1.63 \cdot 10\right.$$

$$\text{for} \quad \frac{\|\vec{E}\|}{n} \leq 2.6 \cdot 10^{-17}, \quad v_e = -\left[6.87 \cdot 10^{22} \cdot \frac{\|\vec{E}\|}{n} + 3.38 \cdot 10^{4}\right]$$

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with $n = 2.5 \cdot 10^{19}\ cm^{-3}$. The diffusion coefficient $De$ is a function of the electron drift velocity $v_e$ and the intensity of electric field $E$

$$De = \left[ 0.3341 \cdot 10^{9} \cdot \left( \frac{\|\vec{E}\|}{n} \right)^{0.54069} \right] \cdot \frac{\|\overrightarrow{v_e}\|}{\|\vec{E}\|}. \tag{4}$$

The source term $S_e$ depends on the drif velocity $v_e$ and the electron density $n_e$

$$S_e = \frac{\alpha}{n} \cdot \|\overrightarrow{v_e}\| \cdot n_e \cdot n, \tag{5}$$

where $\frac{\alpha}{n}$ is computed by following formula

$$\text{if} \quad \frac{\|\vec{E}\|}{n} > 1.5 \cdot 10^{-15}, \quad \frac{\alpha}{n} = 2 \cdot 10^{-16} \cdot exp\left(\frac{-7.248 \cdot 10^{-15}}{\|\vec{E}\|/n}\right), \quad (6)$$

$$\text{else}, \quad \frac{\alpha}{n} = 6.619 \cdot 10^{-17} \cdot exp\left(\frac{-5.593 \cdot 10^{-15}}{\|\vec{E}\|/n}\right).$$