Hydrogen Boltzmann Analysis

Introduction

In this model the Boltzmann equation in the two-term approximation is solved for a background gas of molecular and atomic hydrogen. This type of study is normally done to obtain macroscopic transport parameters and source terms that can be used in fluid-type models. Here, the results are only analyzed to test if the computed electron energy distribution function (EEDF), transport parameters, and source terms have reasonable values. The outcome of the analysis allows us to have confidence in the cross-section data.

Model Definition

The Boltzmann equation in the two-term approximation can be written as the divergence of the electron flux in the energy space

$$\frac{\sqrt{\varepsilon}}{N}\frac{\partial F_0}{\partial t} + \frac{\partial}{\partial \varepsilon}\left(WF_0 - D\frac{\partial F_0}{\partial \varepsilon}\right) = S$$

with a convection part given by

$$W = -\gamma\varepsilon^2\sigma_\varepsilon - 3a\left(\frac{n_e}{N_n}\right)A_1 \tag{1}$$

and a diffusive part with a diffusive coefficient given by

$$D = \frac{\gamma}{3}\left(\frac{E}{N_n}\right)^2\left(\frac{\varepsilon}{Q}\right) + \frac{\gamma k_b T}{q}\varepsilon^2\sigma_\varepsilon + 2a\left(\frac{n_e}{N_n}\right)(A_2 + \varepsilon^{3/2}A_3) \tag{2}$$

Here, F_0 is the electron energy distribution function (EEDF) ($eV^{-3/2}$).

For definitions of the quantities in Equation 1 and Equation 2, see the chapter *The Boltzmann Equation, Two-Term Approximation Interface* in the *Plasma Module User's Guide*. Ref. 1 is a good reference to learn about solving the Boltzmann equation for cold plasma applications.

When the Boltzmann equation has been solved, different macroscopic quantities can be computed by suitable integration of electron impact cross sections over the EEDFs.

Typically, the Boltzmann equation in the two-term approximation is solved in the DC or HF limits. In both these limits, the Boltzmann equation is stationary. In the HF limit it is assumed that the EEDF experiences only the time-averaged electric field.

The DC limit occurs when the collision frequency for energy transfer is much larger than the reduced excitation frequency so that the EEDF can follow the electric field instantaneously. The HF limit occurs when the collision frequency for energy transfer is much smaller than the reduced excitation frequency so that the electrons only experience an averaged electric field.

For the conditions explored in this work we are between the DC and HF limits, and in these cases the time-dependent Boltzmann equation needs to be solved. As shown in this work, this can be done. However, when coupling with a fluid model it is not practical. This topic is discussed in Ref. 2 and the practical approach of using the HF limit is justified by the results that the time-averaged EEDFs are similar to the ones obtained in the HF limit. This approach should be used with caution, since computing macroscopic quantities with a time-averaged EEDF is not necessary equal to time-averaged macroscopic quantities.

The electron collisions are characterized by cross sections that need to be provided by the user. In this model, the background gas is atomic and molecular hydrogen. The electron impact collisions considered, listed in Table 1, are from Ref. 3 and retrieved from Ref. 4.

TABLE 1: HYDROGEN ELECTRON IMPACT COLLISIONS.

Reaction	Formula	Type	$\Delta\varepsilon$ (eV)
1	e+H2=>e+H2	Elastic	-
2	e+H2=>e+H2	Vibrational excitation	0.516–1.5
3	e+H2=>e+H2	Excitation	7.93–14.6
4	e+H2=>e+H(1s)+ H(2p,2s,3,4,5)	Excitation	14.68–17.53
5	e+H2=>2e+H2+	Ionization	15.4
6	e+H2=>2e+H+H+	Ionization	19
7	e+H2=>2e+H2+	Ionization	15.4
8	e+H2=>2e+H+H+	Ionization	19
9	e+H=>e+H	Elastic	–
10	e+H=>e+H(2p,2s,3, 4,5)	Excitation	10.2043–13.0615
11	e+H=>2e+H+	Ionization	13.6057

Results and Discussion

Figure 1 shows an EEDF computed in the HF limit and a time-averaged EEDF together with EEDFs for time instants corresponding to the most depleted and populated tails. The time-dependent EEDF clearly has a low-energy region that changes little in time (close to the HF limit) and a high-energy tail that is modulated in time (close to the DC limit). This is because around 10 eV an important set of electron impact reactions have thresholds, and the frequency for electron energy transfer is much larger than in the low-energy region. This plot clearly shows that for the current operation conditions we are between the DC and HF limits. Figure 1 also shows that the time-averaged EEDF is similar to the one obtained in the HF limit, as discussed in Ref. 2.

Figure 2 through Figure 5 present results for the solution of the Boltzmann equation in the two-term approximation in the HF limit for values of reduced fields between 10 to 500 Td. All results have expected values and trends, which gives us confidence to use this cross-section data in fluid models. To be absolutely sure of the quality of cross-section data, it should be compared with swarm experiments. In practice, this means comparing quantities as electron drift velocity and characteristic energy, as was done by the authors in Ref. 2 and Ref. 4.

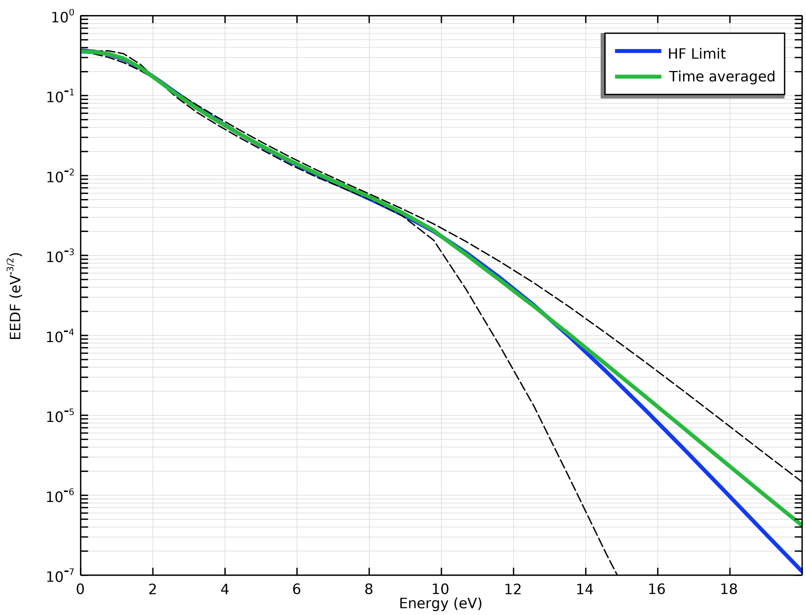

Figure 1: Computed EEDF in the HF limit and time averaged. Also shown (dashed) are the EEDFs for time instants corresponding to the most depleted and populated tail.

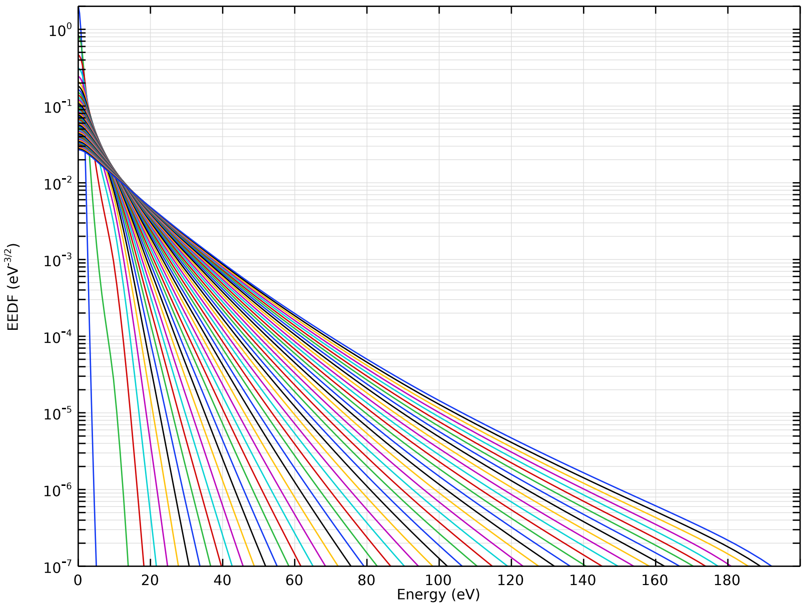

Figure 2: EEDFs for the for values between 10 and 500 Td in steps of 10 Td.

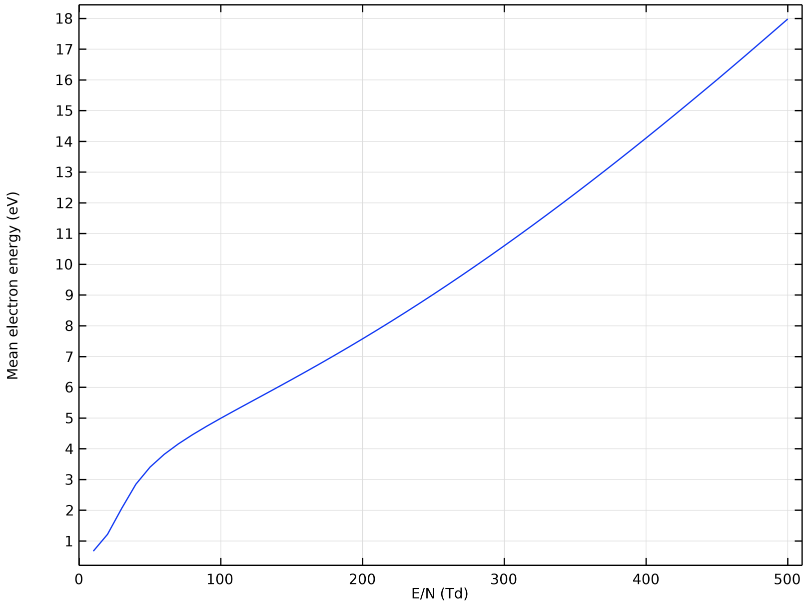

Figure 3: Mean electron energy as a function of the reduced electric field.

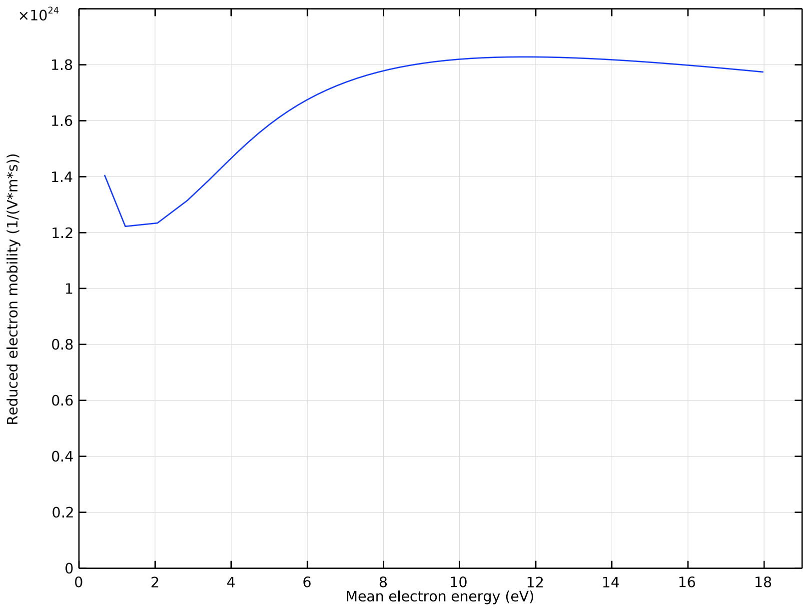

Figure 4: Reduced electron mobility as a function of the mean electron energy.

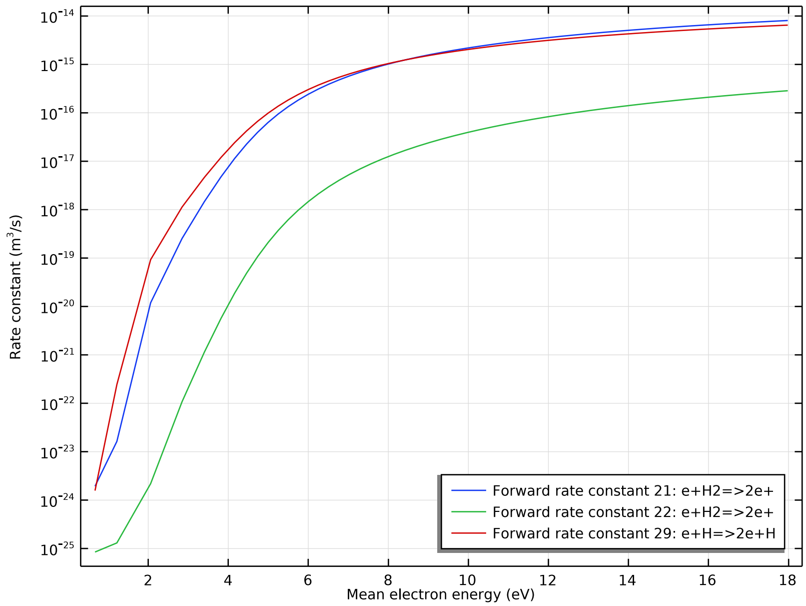

Figure 5: Ionization rate constants as function of the mean electron energy.

References

1. G.J.M. Hagelaar and L.C. Pitchford, "Solving the Boltzmann Equation to Obtain Electron Transport Coefficients and Rate Coefficients for Fluid Models," *Plasma Sources Sci. Technol.*, vol. 14, pp. 722–733, 2005.

2. K. Hassouni, A. Gicquel, M. Capitelli, and J. Loureiro, "Chemical Kinetics and Energy Transfer in Moderate Pressure H_2 Plasmas Used in Diamond MPACVD Processes," *Plasma Sources Sci. Technol.*, vol. 8, pp. 494–512, 1999.

3. L. Marques, J. Jolly, and L.L. Alves, "Capacitively Coupled Radio-Frequency Hydrogen Discharges: The Role of Kinetics," *J. Appl. Phys.*, vol. 102, p. 063305, 2007.

4. IST-Lisbon database, www.lxcat.net, retrieved 2023.

Application Library path: `Plasma_Module/Two-Term_Boltzmann_Equation/boltzmann_hydrogen`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **0D**.

2 In the **Select Physics** tree, select **Plasma>Boltzmann Equation, Two-Term Approximation (be)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Reduced Electric Fields**.

6 Click **Done**.

Add parameters for the gas number density, reduced angular frequency, and reduced electric field.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
Tgas	300[K]	300 K	Gas temperature
p0	25000[Pa]	25000 Pa	Gas pressure
Ngas	p0/(k_B_const*Tgas)	6.0358E24 1/m³	Gas density
f0	2.45[GHz]	2.45E9 Hz	Excitation frequency
w0	2*pi*f0	1.5394E10 Hz	Angular frequency
wsN	w0/Ngas	2.5504E-15 m³/s	Reduced angular frequency
EN	50[Td]	5E-20 V·m²	Reduced electric field

Solve the Boltzmann equation in the two-term approximation in the HF limit and import electron-electron impact cross sections for H2 and H.

BOLTZMANN EQUATION, TWO-TERM APPROXIMATION (BE)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Boltzmann Equation, Two-Term Approximation (be)**.

2 In the **Settings** window for **Boltzmann Equation, Two-Term Approximation**, locate the **Electron Energy Distribution Function Settings** section.

3 From the **Electron energy distribution function** list, choose **Boltzmann equation, two-term approximation (linear)**.

4 Select the **Oscillating field** check box.

5 In the ω/N text field, type `wsN`.

6 In the ε_{max} text field, type `200[V]`.

Cross Section Import 1

1 In the **Physics** toolbar, click **Global** and choose **Cross Section Import**.

2 In the **Settings** window for **Cross Section Import**, locate the **Cross Section Import** section.

3 Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `H2_marques_xsecs.txt`.

5 Click **Import**.

Cross Section Import 2

1 In the **Physics** toolbar, click **Global** and choose **Cross Section Import**.

2 In the **Settings** window for **Cross Section Import**, locate the **Cross Section Import** section.

3 Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `H_marques_xsecs.txt`.

5 Click **Import**.

Set input conditions like the gas temperature and mole fraction for H2 and H.

Boltzmann Model 1

1 In the **Model Builder** window, click **Boltzmann Model 1**.

2 In the **Settings** window for **Boltzmann Model**, locate the **Boltzmann Settings** section.

3 In the T_g text field, type `Tgas`.

4 Locate the **Mole Fraction Settings** section. In the table, enter the following settings:

Species	Mole fraction (1)
H2	`0.5`
H	`0.5`

5 Locate the **Results** section. Find the **Generate the following default plots** subsection. Clear the **Rate coefficients** check box.

6 Clear the **Transport properties** check box.

7 Clear the **Mean electron energy** check box.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the ε_0 text field, type `3[V]`.

4 In the E/N_0 text field, type `35[Td]`.

The first study solves for two reduced electric fields: One at 50 Td that is used as the initial solution for the time-dependent study, and the other at 35.355 Td, which is the rms value of the first field and is used to compare with the time-averaged EEDF.

HF LIMIT STATIONARY

1 In the **Model Builder** window, click **Study 1**.

2 In the **Settings** window for **Study**, type `HF Limit Stationary` in the **Label** text field.

3 Locate the **Study Settings** section. Clear the **Generate default plots** check box.

Step 1: Reduced Electric Fields

1 In the **Model Builder** window, under **HF Limit Stationary** click **Step 1: Reduced Electric Fields**.

2 In the **Settings** window for **Reduced Electric Fields**, locate the **Study Settings** section.

3 In the **Reduced electric fields** text field, type `35.355[Td] 50[Td]`.

4 In the **Home** toolbar, click **Compute**.

Create a plot for the EEDF in the HF limit.

RESULTS

EEDF HF Limit vs. Time Averaged

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type EEDF HF Limit vs. Time Averaged in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **None**.

Line Graph 1

1 Right-click **EEDF HF Limit vs. Time Averaged** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **HF Limit Stationary/Solution 1 (sol1)**.

4 From the **Parameter selection (freq)** list, choose **From list**.

5 In the **Parameter values (freq (V*m^2))** list, select **3.5355E-20**.

6 Locate the **Selection** section. From the **Selection** list, choose **All domains**.

7 Locate the **y-Axis Data** section. In the **Expression** text field, type be.f.

8 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

9 In the **Expression** text field, type xe_be*root.comp1.be.emax.

10 Click to expand the **Legends** section. Select the **Show legends** check box.

11 From the **Legends** list, choose **Manual**.

12 In the table, enter the following settings:

Legends
HF Limit

13 Click to expand the **Coloring and Style** section. From the **Width** list, choose **3**.

EEDF HF Limit vs. Time Averaged

1 In the **Model Builder** window, click **EEDF HF Limit vs. Time Averaged**.

2 In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.

3 Select the **x-axis label** check box. In the associated text field, type Energy (eV).

4 Select the **y-axis label** check box. In the associated text field, type EEDF (eV^{-3/2}).

5 Locate the **Axis** section. Select the **y-axis log scale** check box.

6 Select the **Manual axis limits** check box.

7 In the **x minimum** text field, type 0.

8 In the **x maximum** text field, type 20.

9 In the **y minimum** text field, type 1e-7.

10 In the **y maximum** text field, type 1.

11 In the **EEDF HF Limit vs. Time Averaged** toolbar, click **Plot**.

The next step is to solve for the temporal evolution of the EEDF. Add a Time Dependent study and choose to solve the time-dependent EEDF.

ADD STUDY

1. In the **Home** toolbar, click **Add Study** to open the **Add Study** window.
2. Go to the **Add Study** window.
3. Find the **Studies** subsection. In the **Select Study** tree, select **General Studies> Time Dependent**.
4. Click **Add Study** in the window toolbar.
5. In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2

Step 1: Time Dependent

1. In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
2. In the **Output times** text field, type `range(0,(5/f0-0)/4,5/f0) range(5/f0,(6/f0-(5/f0))/24,6/f0)`.
3. Click to expand the **Values of Dependent Variables** section. Find the **Initial values of variables solved for** subsection. From the **Settings** list, choose **User controlled**.
4. From the **Method** list, choose **Solution**.
5. From the **Study** list, choose **HF Limit Stationary, Reduced Electric Fields**.
6. From the **Parameter value (freq (V*m^2))** list, choose **From list**.
7. In the **Parameter value (freq (V*m^2))** list, select **5E-20 V*m^2**.
8. In the **Model Builder** window, click **Study 2**.
9. In the **Settings** window for **Study**, locate the **Study Settings** section.
10. Clear the **Generate default plots** check box.

BOLTZMANN EQUATION, TWO-TERM APPROXIMATION (BE)

1. In the **Model Builder** window, under **Component 1 (comp1)** click **Boltzmann Equation, Two-Term Approximation (be)**.
2. In the **Settings** window for **Boltzmann Equation, Two-Term Approximation**, locate the **Electron Energy Distribution Function Settings** section.
3. From the **Temporal behavior** list, choose **Time dependent EEDF**.

Boltzmann Model 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Boltzmann Equation, Two-Term Approximation (be)** click **Boltzmann Model 1**.

2 In the **Settings** window for **Boltzmann Model**, locate the **Boltzmann Settings** section.

3 In the p_A text field, type `p0`.

4 In the E/N text field, type `EN*cos(2*pi*f0*t)`.

Plot the EEDFs at the instants where the tail is at its maximum and minimum values. Also, plot the time-averaged EEDF.

TIME DEPENDENT

1 In the **Home** toolbar, click **Compute**.

2 In the **Model Builder** window, click **Study 2**.

3 In the **Settings** window for **Study**, type `Time Dependent` in the **Label** text field.

RESULTS

Line Graph 2

1 In the **Model Builder** window, right-click **EEDF HF Limit vs. Time Averaged** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Time Dependent/Solution 2 (sol2)**.

4 From the **Time selection** list, choose **From list**.

5 In the **Times (s)** list, choose **2.0578E-9** and **2.1599E-9**.

6 Locate the **Selection** section. From the **Selection** list, choose **All domains**.

7 Locate the **y-Axis Data** section. In the **Expression** text field, type `be.f`.

8 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

9 In the **Expression** text field, type `xe_be*root.comp1.be.emax`.

10 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.

11 From the **Color** list, choose **Black**.

12 In the **EEDF HF Limit vs. Time Averaged** toolbar, click **Plot**.

Line Graph 3

1 Right-click **EEDF HF Limit vs. Time Averaged** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Time Dependent/Solution 2 (sol2)**.

4 From the **Time selection** list, choose **Last**.

5 Locate the **Selection** section. From the **Selection** list, choose **All domains**.

6 Locate the **y-Axis Data** section. In the **Expression** text field, type `timeavg(5/f0, 6/f0, be.f)`.

7 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

8 In the **Expression** text field, type `xe_be*root.comp1.be.emax`.

9 Locate the **Coloring and Style** section. From the **Width** list, choose **3**.

10 Locate the **Legends** section. Select the **Show legends** check box.

11 From the **Legends** list, choose **Manual**.

12 In the table, enter the following settings:

Legends
`Time averaged`

13 In the **EEDF HF Limit vs. Time Averaged** toolbar, click **Plot**.

Add one last study to parameterize over the reduced field and obtain transport parameters and rate coefficients as functions of the electron mean energy.

BOLTZMANN EQUATION, TWO-TERM APPROXIMATION (BE)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Boltzmann Equation, Two-Term Approximation (be)**.

2 In the **Settings** window for **Boltzmann Equation, Two-Term Approximation**, locate the **Electron Energy Distribution Function Settings** section.

3 From the **Temporal behavior** list, choose **Stationary EEDF**.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Reduced Electric Fields**.

4 Click **Add Study** in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 3

Step 1: Reduced Electric Fields

1 In the **Settings** window for **Reduced Electric Fields**, locate the **Study Settings** section.

2 In the **Reduced electric fields** text field, type range(10,10,500)[Td].

3 In the **Model Builder** window, click **Study 3**.

4 In the **Settings** window for **Study**, locate the **Study Settings** section.

5 Clear the **Generate default plots** check box.

6 In the **Label** text field, type HF Limit parameterization.

7 In the **Home** toolbar, click **Compute**.

RESULTS

EEDFs

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type EEDFs in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **HF Limit parameterization/ Solution 3 (sol3)**.

Line Graph 1

1 Right-click **EEDFs** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **All domains**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type be.f.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type xe_be*root.comp1.be.emax.

EEDFs

1 In the **Model Builder** window, click **EEDFs**.

2 In the **Settings** window for **1D Plot Group**, locate the **Title** section.

3 From the **Title type** list, choose **None**.

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** check box. In the associated text field, type Energy (eV).

6 Select the **y-axis label** check box. In the associated text field, type EEDF (eV^{-3/2}).

7 Locate the **Axis** section. Select the **y-axis log scale** check box.

8 Select the **Manual axis limits** check box.

9 In the **x minimum** text field, type `0`.

10 In the **x maximum** text field, type `200`.

11 In the **y minimum** text field, type `1e-7`.

12 In the **y maximum** text field, type `2`.

13 Locate the **Legend** section. Clear the **Show legends** check box.

14 In the **EEDFs** toolbar, click **Plot**.

Electron Mean Energy vs. E/N

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Electron Mean Energy vs. E/N` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **HF Limit parameterization/ Solution 3 (sol3)**.

Global 1

1 Right-click **Electron Mean Energy vs. E/N** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`be.ebar`	`V`	`Mean electron energy`

4 Locate the **x-Axis Data** section. From the **Unit** list, choose **Td**.

Electron Mean Energy vs. E/N

1 In the **Model Builder** window, click **Electron Mean Energy vs. E/N**.

2 In the **Settings** window for **1D Plot Group**, locate the **Title** section.

3 From the **Title type** list, choose **None**.

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** check box. In the associated text field, type `E/N (Td)`.

6 Select the **y-axis label** check box. In the associated text field, type `Mean electron energy (eV)`.

7 In the **Electron Mean Energy vs. E/N** toolbar, click **Plot**.

8 Locate the **Legend** section. Clear the **Show legends** check box.

Electron Mobility vs. Electron Mean Energy

1. In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2. In the **Settings** window for **1D Plot Group**, type `Electron Mobility vs. Electron Mean Energy` in the **Label** text field.
3. Locate the **Data** section. From the **Dataset** list, choose **HF Limit parameterization/ Solution 3 (sol3)**.
4. Locate the **Title** section. From the **Title type** list, choose **None**.

Global 1

1. Right-click **Electron Mobility vs. Electron Mean Energy** and choose **Global**.
2. In the **Settings** window for **Global**, locate the **y-Axis Data** section.
3. In the table, enter the following settings:

Expression	Unit	Description
`be.muN`	`1/(V*m*s)`	`Reduced electron mobility`

4. Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
5. In the **Expression** text field, type `be.ebar`.

Electron Mobility vs. Electron Mean Energy

1. In the **Model Builder** window, click **Electron Mobility vs. Electron Mean Energy**.
2. In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.
3. Select the **x-axis label** check box. In the associated text field, type `Mean electron energy (eV)`.
4. Locate the **Axis** section. Select the **Manual axis limits** check box.
5. In the **x minimum** text field, type `0`.
6. In the **x maximum** text field, type `19`.
7. In the **y minimum** text field, type `0`.
8. In the **y maximum** text field, type `2e24`.
9. Locate the **Legend** section. Clear the **Show legends** check box.
10. In the **Electron Mobility vs. Electron Mean Energy** toolbar, click **Plot**.

Ionization Rate Constants vs. Electron Mean Energy

1. In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2. In the **Settings** window for **1D Plot Group**, type `Ionization Rate Constants vs. Electron Mean Energy` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **HF Limit parameterization/ Solution 3 (sol3)**.

4 Locate the **Title** section. From the **Title type** list, choose **None**.

Global 1

1 Right-click **Ionization Rate Constants vs. Electron Mean Energy** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
be.k_21	m^3/s	Forward rate constant 21: e+H2=>2e+H2+
be.k_22	m^3/s	Forward rate constant 22: e+H2=>2e+H+H+
be.k_29	m^3/s	Forward rate constant 29: e+H=>2e+H+

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

5 In the **Expression** text field, type be.ebar.

6 Click to expand the **Legends** section. In the **Ionization Rate Constants vs. Electron Mean Energy** toolbar, click  **Plot**.

Ionization Rate Constants vs. Electron Mean Energy

1 In the **Model Builder** window, click **Ionization Rate Constants vs. Electron Mean Energy**.

2 In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.

3 Select the **x-axis label** check box. In the associated text field, type Mean electron energy (eV).

4 Select the **y-axis label** check box. In the associated text field, type Rate constant (m³/s).

5 Locate the **Axis** section. Select the **y-axis log scale** check box.

6 Locate the **Legend** section. From the **Position** list, choose **Lower right**.