INTRODUCTION TO

Electric Discharge Module

6.4

COMSOL

Introduction to the Electric Discharge Module

Version: COMSOL 6.4

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Introduction

Engineers and scientists working in the fields of electrical engineering and applied physics use the Electric Discharge Module to model and analyze a wide variety of electric discharge phenomena. Electric discharges occur in diverse environments and materials, ranging from atmospheric gas discharges and liquid breakdown in transformer oils to microscale events in MEMS devices. The high costs associated with experimental testing and prototyping in these areas make simulation tools essential for understanding and optimizing designs. The Electric Discharge Module is a specialized tool for exploring these phenomena, particularly when dealing with the multiphysics effects that often accompany discharges, making COMSOL Multiphysics an ideal platform for such investigations.

The Electric Discharge Module includes predefined interfaces for simulating breakdown thresholds and surface charge dynamics. These capabilities are crucial for designing effective insulation and understanding phase interfaces, particularly the gas-solid interface. Users can simulate and analyze discharge processes, predicting the effects of lightning-induced electromagnetic pulses and electrostatic discharges on electronic systems. This is especially useful for EMC/EMI design in electronic devices, ensuring compliance with regulatory standards and enhancing product reliability.

Built-in transport models facilitate the modeling of discharge phenomena, while the module also allows for the integration of user-defined electric discharge chemistries, providing the flexibility needed for accurate analysis and innovative design. You can easily incorporate these customizations using the intuitive COMSOL Desktop interface, without the need for scripting or complex programming.

To set up a simulation, users define the geometry, select appropriate materials, and configure the Electric Discharge interfaces. Initial and boundary conditions are specified, followed by mesh generation and solver selection. The module then uses advanced solvers to handle the coupled partial differential equations that describe the electric potential and discharge dynamics. Once a solution is obtained, you can leverage a wide range of visualization and analysis tools to interpret the results and optimize your designs.

The Electric Discharge Module supports simulations in one, two, and three space dimensions, providing versatility across various applications. Whether analyzing the electric field, charge densities, or induced electromagnetic effects, you have access to predefined and user-defined expressions for a comprehensive evaluation of the simulated phenomena. This empowers researchers and engineers to gain critical insights into discharge mechanisms, enabling the development of safer, more efficient, and more innovative electrical systems.

The Electric Discharge Module Physics Interface Guide

Each COMSOL Multiphysics physics interface (for example, the Electric Discharge interface or the Arc Discharge interface) expresses the relevant physical phenomena in the form of sets of partial or ordinary differential equations, together with appropriate boundary and initial conditions. Each feature added to the physics interface represents a term or condition in the underlying equation set. These features are usually associated with a geometric entity within the model, such as a domain, boundary, edge, or point.

Figure 1 uses the application library example *Negative Surface Discharge at Gas–Solid Interface* to show the Model Builder tree structure and the Settings window for the selected Gas 1 feature node. This node adds electrostatics and charge transport equations to the simulation within the domains selected. In the Transport Properties section, the Settings window indicates that the electron mobility and ion mobility are inherited from the material properties assigned to the domain. The material properties can be set up as functions of other dependent variables in the model, for example, the temperature and gas pressure. The Solid 1 feature is also added to model solid dielectrics. Charge transport dynamics at the Gas–Solid interface is modeled with the built-in boundary features.

The Electric Discharge interface is the starting point for most simulations. The Electric Discharge Module also includes physics interfaces to enable modeling of different physical situations encountered in electric discharges. When a new model is started, these physics interfaces are selected from the Model Wizard.

Figure 2 shows the physics interfaces included with the Electric Discharge Module. Some physics interfaces such as the Electrostatics are shared with other add-on products.

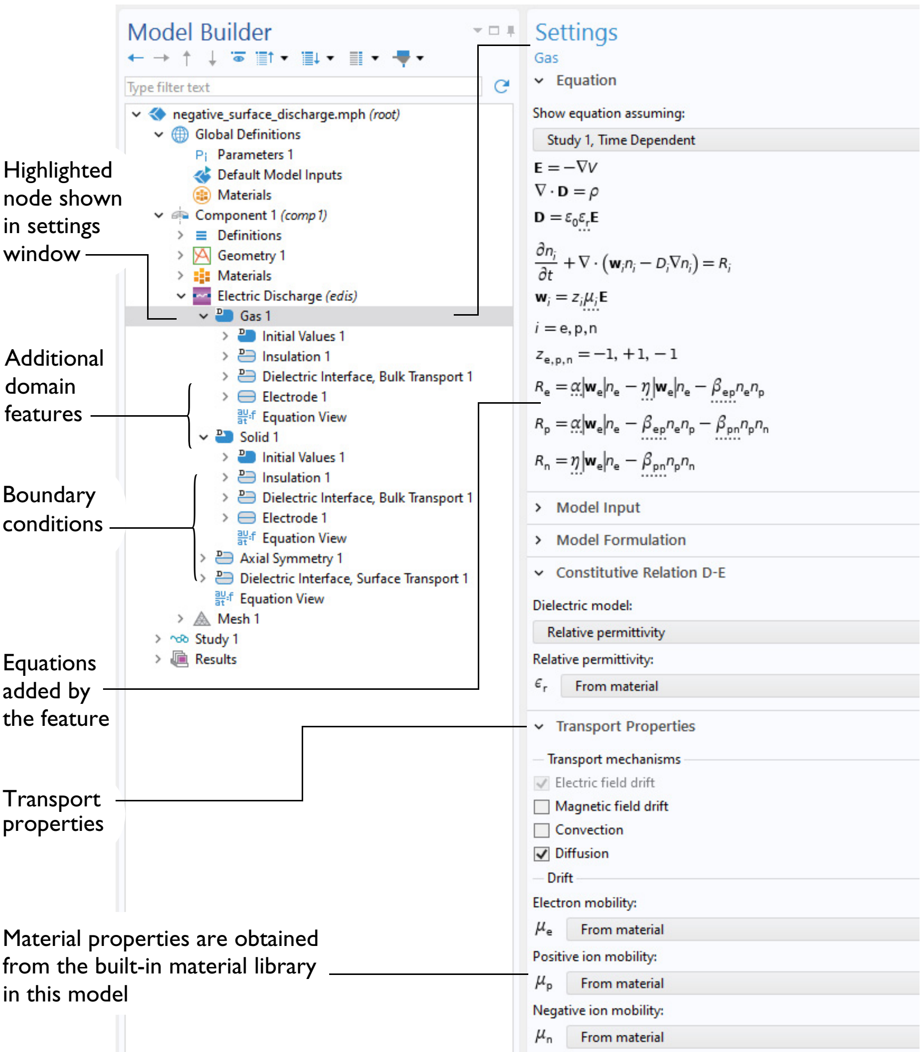

Figure 1: The Model Builder (to the left), and the Settings window for the selected feature node (to the right). The Equation section in the Settings window shows the model equations.

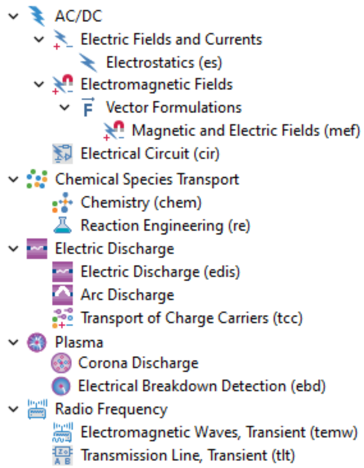

Figure 2: The Electric Discharge Module interfaces as displayed in the Model Wizard for a 3D model.

Also see Physics Interface Guide by Space Dimension and Study Type. Below, a brief overview of each of the Electric Discharge Module physics interfaces is given.

Electrostatics

The Electrostatics interface ( ), found under the AC/DC branch in the Model Wizard, solves for the electric potential given the charge distribution in the domain and the voltages applied to boundaries. It is used to model electrostatic devices under static or quasistatic conditions, that is, at frequencies sufficiently low that wave propagation effects can be neglected. The Electrostatic interface is often used together with the Transport of Charge Carriers interface. Note that the Electric Discharge interface has the built-in electrostatics solver and transport equation solver.

Magnetic and Electric Fields

The Magnetic and Electric Fields interface ( ), found under the AC/DC branch in the Model Wizard, is used to model magnetostatics and magnetodynamics. It solves Ampère's law for the magnetic vector potential together with a current conservation equation for the electric potential. This interface is often used to solve electromagnetics in electric arc discharges that are formulated in magnetohydrodynamics equations.

Electrical Circuit

The Electrical Circuit interface ( ), found under the AC/DC branch in the Model Wizard, has the equations to model electrical circuits with or without connections to a distributed fields model. The interface solves for the voltages, currents, and charges associated with the circuit elements. Circuit models can contain passive elements like resistors, capacitors, and inductors as well as active elements such as diodes and transistors. Circuits can be imported from an existing SPICE net list. The interface can be connected to the Electric Discharge interface to model discharge phenomenon triggered in a circuit.

The Reaction Engineering interface

The Reaction Engineering interface ( ) includes all of the tools required to simulate chemical reaction kinetics in well-defined environments. It sets up simulations of reversible, equilibrium, and irreversible reactions in volumes or on surfaces. You can study the evolution of species concentrations and temperature in controlled environments described by batch, continuous stirred-tank, semibatch, and plug flow reactors. Using the Parameter Estimation Study, multiple objectives may be optimized, and with the Optimization Module, additional methods become available.

Chemistry

The Chemistry interface ( ) provides libraries of chemical reactions for use by other physics interfaces. It also provides kinetic expressions for reaction rates, reaction heat sources, and species transport properties to other interfaces. This interface is always created when a Reaction Engineering model is exported to a space-dependent model. As such, it serves as a reaction kinetics and material property provider to the space-dependent transport interfaces, such as Transport of Diluted Species.

Electric Discharge

The Electric Discharge interface ( ) is used to simulate electric discharges and predict electrical breakdown in gas, liquid, and solid dielectrics. It contains built-in charge transport models that solve the drift-diffusion equations of electrons, holes, positive and negative ions fully coupled with Poisson's equation. In addition, it can also model the surface charge accumulation and relaxation effect at dielectric interfaces. Typical modeling applications are streamer discharges, corona discharges, electrostatic discharges, and dielectric barriers discharges. The effect of a background magnetic field and/or a flow field can be easily considered by coupling to another physics interface.

Arc Discharge

The Arc Discharge multiphysics interface ( ) is used to study electric arc discharges (fully ionized) in a magnetohydrodynamics (MHD) framework. This multiphysics interface adds three single physics interfaces: Magnetic and Electric Fields, Heat Transfer in Fluids, and Laminar Flow, together with several multiphysics coupling features. The multiphysics couplings add the MHD coupling between the Magnetic and Electric Fields and the Laminar Flow interfaces. The multiphysics couplings also add heating and cooling of the equilibrium plasma by enthalpy transport, Joule heating and radiation loss.

Transport of Charge Carriers

The Transport of Charge Carriers interface ( ) is used to solve the number density of one or multiple charge carriers. The charge carriers can be charged species such as electrons, ions, and neutral species like molecules and their excited states. Transport and reactions of charge carriers can be handled with this interface. The driving forces for transport can be drift when coupled to an electromagnetic field, convection when coupled to a flow field, and diffusion.

Corona Discharge

The Corona Discharge interface employs a simplified charge transport model combined with electrostatics to approximate the charge density and electrostatic field in stationary corona discharges. This model does not include the ionization layer of corona discharges, instead utilizing an approximate boundary condition. Additionally, electron dynamics are not solved in this approach. It is generally recommended to use the Electric Discharge interface which is more general.

electrical breakdown detection

The Electrical Breakdown Detection interfaces uses an approximate method to determine if electrical breakdown will occur in a given design by integrating Townsend growth coefficients along electric field lines. It is generally recommended to use the Electric Discharge interface which is more general.

Electromagnetic waves, Transient

The Electromagnetic Waves, Transient interface ( ) solves a time-domain wave equation for the electric field. The sources can be in the form of point dipoles, line currents, or incident fields on boundaries or domains. It is used primarily to model electromagnetic wave propagation in different media and structures when a time-domain solution is required — for example, nonsinusoidal waveforms or nonlinear media. Typical applications involve the propagation of electromagnetic pulses and the generation of harmonics in nonlinear optical media.

Transmission Line, Transient

The Transmission Line, Transient interface ( ) is used to study propagation of waves in time domain along one-dimensional transmission lines. The physics interface solves the time-domain transmission line equation for the electric potential.

Physics Interface Guide by Space Dimension and Study Type

The table below lists the physics interfaces available specifically with this module in addition to the COMSOL Multiphysics basic license.

PHYSICS INTERFACE	ICON	TAG	SPACE DIMENSION	AVAILABLE STUDY TYPE
AC/DC				
Electrical Circuit		cir	Not space dependent	stationary; frequency domain; time dependent; frequency domain; eigenfrequency
Electrostatics		es	all dimensions	stationary; time dependent; stationary source sweep; eigenfrequency; frequency domain; small signal analysis, frequency domain
Magnetic and Electric Fields		mef	3D, 2D, 2D axisymmetric	stationary; time dependent
Chemical Species Transport				
Chemistry		chem	all dimensions	stationary; time dependent
Reaction Engineering		re	0D	time dependent; stationary plug flow
Electric Discharge				
Electric Discharge		edis	all dimensions	time dependent; stationary; frequency domain perturbation
Arc Discharge		—	all dimensions	time dependent; stationary; frequency–transient; frequency–stationary

PHYSICS INTERFACE	ICON	TAG	SPACE DIMENSION	AVAILABLE STUDY TYPE
Transport of Charge Carriers		tcc	all dimensions	time dependent; stationary; frequency domain perturbation
Plasma				
Corona Discharge		—	all dimensions	stationary
Electrical Breakdown Detection		ebd	3D, 2D, 2D axisymmetric	time dependent
Radio Frequency				
Electromagnetic Waves, Transient		temw	3D, 2D, 2D axisymmetric	eigenfrequency; time dependent; time dependent, modal; time dependent with FFT
Transmission Line, Transient		tlt	3D, 2D, 1D	time dependent