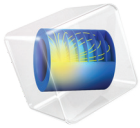

COMSOL Multiphysics

Physics Builder Manual

6.4

COMSOL

Physics Builder Manual

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1

Introduction

This guide describes the Physics Builder, a set of tools for creating custom physics interfaces directly in the COMSOL Desktop®.

In this chapter:

- About the Physics Builder
- Overview of the Manual

About the Physics Builder

In this section:

- What Can You Do With the Physics Builder?
- Where Do I Access the Documentation and Application Libraries?

What Can You Do With the Physics Builder?

The Physics Builder is a graphical programming environment where application experts can design tailored physics interfaces through an interactive desktop environment and without the need for coding.

With the Physics Builder you can deploy the tailored physics interfaces to create your own products and custom physics interfaces for specific applications.

The workflow for creating new physics interfaces is similar to creating a multiphysics model except that the result is a new user interface rather than a new model.

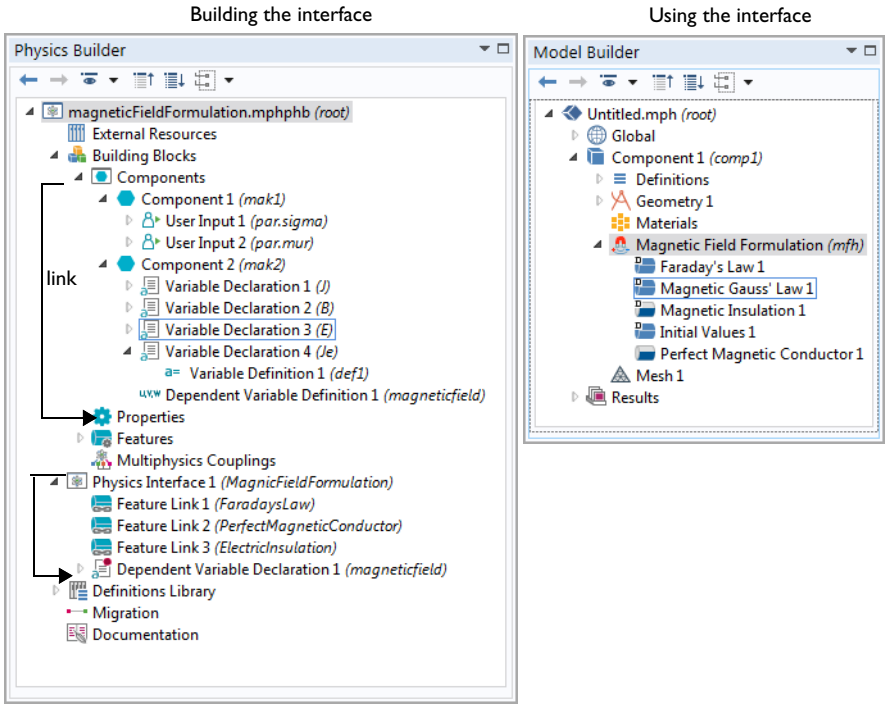

Figure 1-1: The definition of a new physics interface "Magnetic Field Formulation": in the Physics Builder (left) and the result in the Model Builder (right).

The Physics Builder window contains a tree that represents a physics interface design project. Such a project can define anything from a single physics interface to an entire product with a collection of physics interfaces.

Custom physics interfaces created using the Physics Builder can be included in applications created using the Application Builder and compiled using the COMSOL Compiler™.

The following chapters describe the tools that you use in the Physics Builder and provide detailed examples of how to create custom physics.

Where Do I Access the Documentation and Application Libraries?

A number of online resources have more information about COMSOL, including licensing and technical information. The electronic documentation, topic-based (or context-based) help, and the Application Libraries are all accessed through the COMSOL Desktop.

If you are reading the documentation as a PDF file on your computer, the blue links do not work to open an application or content referenced in a different guide. However, if you are using the Help system in COMSOL Multiphysics, these links work to open other modules, application examples, and documentation sets.

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Events	www.comsol.com/events
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COMSOL Video Gallery	www.comsol.com/videos
Learning Center	www.comsol.com/support/learning-center
Support Knowledge Base	www.comsol.com/support/knowledgebase

Overview of the Manual

This *Physics Builder Manual* contains information that helps you to get started with creating custom physics using the Physics Builder in the COMSOL Multiphysics product. The information in this guide is specific to this functionality. Instructions on how to use COMSOL in general are included with the *COMSOL Multiphysics Reference Manual*.

As detailed in the section Where Do I Access the Documentation and Application Libraries?, this information can also be searched from the COMSOL Multiphysics software **Help** system.

TABLE OF CONTENTS AND INDEX

To help you navigate through this guide, see the Contents and Index.

DESIGN

The Physics Builder Design chapter has an overview of the tools available and includes information about Designing the GUI Layout, Entering Names and Expressions, Using Coordinate Systems, Specifying Selections, and The Physics Builder Manager.

TOOLS

The Physics Builder Tools chapter has a description of each of the tools in the Physics Builder that allow you to create custom physics interfaces for specific application.

EXAMPLE

The Examples of Custom Physics chapter provide two examples to show how to create custom physics interfaces: The Thermoelectric Effect and The Schrödinger Equation.

2

Physics Builder Design

The information in this chapter is useful at various stages of the design of the physics interfaces.

In this chapter:

- Overview of the Physics Builder
- Designing the GUI Layout
- Entering Names and Expressions
- Using Coordinate Systems
- The Physics Builder Manager

Overview of the Physics Builder

The Physics Builder is a graphical programming environment where you can design custom physics interfaces using an interactive desktop environment without the need for coding.

In this section:

- Creating a New Physics Builder File
- The Physics Builder Window
- Saving and Opening Custom Physics Interfaces
- The Physics Builder Manager

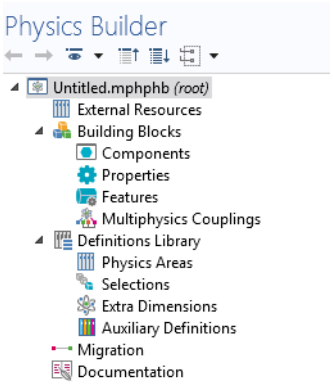
This manual is a companion to the *COMSOL Multiphysics Reference Manual*, where extensive information is available for some of the concepts and features used in the Physics Builder. See Where Do I Access the Documentation and Application Libraries? to learn how to use topic-based help in COMSOL Multiphysics®.

Creating a New Physics Builder File

1. Open COMSOL.
2. Open the **Preferences** window. Select it from **File** > **Preferences** (Windows users) or **Options** > **Preferences** (Mac and Linux users).
3. Click **Physics Builder** and select the **Enable Physics Builder** checkbox. Click **OK**.
4. Select **New** from the **File** menu.
5. On the **New** page under **Physics**, click the **Physics Builder** button ( ) to open the Physics Builder.

   The COMSOL Desktop then contains a **Physics Builder** window with a tree similar to the **Model Builder**.

   From the main Physics Builder toolbar or from the **Windows** menu (Linux and Mac), you can open The Physics Builder Manager where you can administer testing of Physics Builder files and deployment of entire Physics Builder packages.



The **Physics Builder** window displays the tree containing the sequence of all physics and building blocks within a file.

- To add new functionality, right-click a node in the tree and choose a functionality from the context menu or click a corresponding button in the Physics Builder toolbars.
- It is only possible to add new physics interfaces to the root of the tree. Each new node represents a new physics interface that can be chosen from the Model Wizard when the interface is complete.

THE PHYSICS BUILDER BRANCHES AND SUBBRANCHES

External Resources

The External Resources branch is useful to avoid reimplementing features, properties, or components. Import previously created items stored in a different builder file. All items that you implement under the Building Blocks branch in a builder file can be used by any other builder file that imports it.

Building Blocks

Use the Building Blocks branch to create a library of Components, Properties, Features, and Multiphysics Couplings that you can build physics interfaces (including multiphysics interfaces). The Physics Builder Tools chapter describes the features and subfeatures available in detail.

Definitions Library

The Definitions Library contains definitions of material property groups, physical quantities, and other definitions that are used by but are not part of a physics interface. There are these subbranches: **Physics Areas**, **Selections**, **Extra Dimensions**, and **Auxiliary Definitions**.

Migration

Migration, or backward compatibility, has to be considered in situations when you make changes to your physics interface design but still want users of the interface to use COMSOL model files created in the old Version of the interface.

The Physics Builder Manager

Use The Physics Builder Manager to manage testing, compilation, version control and history, and comparison of your Physics Builder files.

To open this window, click **Physics Builder Manager** ( ) in the main toolbar (Windows) or, from the main menu, select **Windows** > **Physics Builder Manager** (Linux, Mac). In the toolbar, click again to close the window.

Saving and Opening Custom Physics Interfaces

Saving Physics Builder files works in the same way as ordinary model files (`*.mph`) except that it has the extension `mphphb`. Opening a file is also similar to opening `MPH`-files, but select **Physics Builder File (*.mphphb)** from the list of file types in the **Open** dialog.

- See The Physics Builder Manager for more information about organizing development files.
- Saving COMSOL Files in the *COMSOL Multiphysics Reference Manual*

Designing the GUI Layout

The design of the GUI layout of a feature or a property is an important and sometimes complex task. You often have to compromise between a simple layout and flexibility in the functionality. Each User Input node often represent a GUI component (or *widget*), for example fields, combo boxes, and tables. Based on the declaration of a user input, there is often only one possible choice of GUI component. In situations where there are several possible choices, you have the option to choose. You always find such choices under the **GUI Options** section of a **User Input** node.

In contrast to user inputs, which controls what GUI components you see, the User Input Group node controls when and where to display the GUI components. As an example, the user input group can list the user inputs you want to see under a specific section. This is an option in the **GUI Options** section of a **User Input Group**.

In this section:

- User Inputs and GUI Components
- User Input Group GUI Options

Use this section in combination with the features described in the Inputs section.

User Inputs and GUI Components

The settings under the **Declaration** section often determines what GUI component you see when the user input is visible.

Use this section in combination with the features described in the Inputs section.

SINGLE-ARRAY INPUTS

The table below summarizes the behavior for single-array inputs (option **Array type** set to **Single**).

DIMENSION	ALLOWED VALUES	GUI COMPONENT
Scalar or 1x1	**Any**	field (text box)
Scalar or 1x1	**From list**	Combo box
Vector (3x1)	Not applicable	Table with 1–3 rows, depending on the option **Vector component to display**.
Matrix (3x3)	Not applicable	Table with 1–3 rows and 1–3 columns, depending on the option **Matrix component to display**. You also get a combo box for matrix symmetry.
Boolean	Not applicable	Checkbox. Note that there is a special node for creating Boolean inputs.
Custom	Not applicable	Table with rows and columns representing the specified dimension. If it represents a square matrix, you can specify a symmetry with the option **Matrix symmetry for square matrix**.
Changeable	Not applicable	Single column table with the possibility to add rows.

Depending on the dimension of the input, you get different options in the **GUI Options** section. You find the available options below:

- **Hide user input in GUI when inactive**. The logic controlling the user input determines that it is inactive, the input's GUI component disappears from the layout. This is not necessary if the user input is a member of a user input group that can disappear.
- **Show no description**. Removes the label above the GUI component.
- **Show no symbol**. Removes the symbol to the left of the GUI component.
- **Add divider above the user input**. Places a horizontal line above the GUI component, possibly with a descriptive text.
- **Show no coordinate labels**. For spatial vectors, by default you get the coordinate labels in the leftmost column. Selecting this option removes that column.
- **Vector components to display**. Controls what components of a spatial vector you want to display in non-3D geometries. You can choose between **All**, **In-plane**, and **Out-of-plane**.
- **Matrix components to display**. Same as above but for spatial matrices.
- **Matrix symmetry for square matrix**. For nonspatial, square matrices you can force a matrix symmetry with this option. The choices are **Diagonal**, **Symmetric**, **Anisotropic**,

and **Symmetric, fixed diagonal**, and they control the cells that the user can edit. For **Symmetric, fixed diagonal**, the diagonal is fixed to the default values, and the user can only edit the off-diagonal elements.

DOUBLE-ARRAY INPUTS

Double-array inputs are far more complex to design GUI components for, and some combinations are not supported. The table below summarizes the behavior for the supported double-array inputs (option **Array type** set to **Double**).

OUTER DIM.	INNER DIM.	ALLOWED VALUES	GUI COMPONENT
Vector (3x1)	**Scalar** or 1x1	**Any**	Behaves as a single-array vector
Vector (3x1)	**Scalar** or 1x1	**From list**	Several combo boxes when the input is a member to a special input group, see User Input Group GUI Options. Otherwise, behaves as a single-array vector with restrictions what you can enter in the table cells.
Matrix (3x3)	**Scalar** or 1x1	**Any**	Behaves as a single-array matrix
Vector (3x1)	**Boolean**	Not applicable	Several checkboxes when the input is a member to a special input group, see User Input Group GUI Options. Otherwise, behaves as a single-array vector with restrictions what you can enter in the table cells.

For double-array inputs, you might get an error when you try to use an unsupported combination. In other situations, especially when the inner dimension is a scalar, you can get a component, but with an unpractical behavior. For example, when the outer dimension is fixed but nonscalar, the inner dimension is scalar, and **Allowed values** is set to **From list**. Then the input behaves as the single-array version, but with restrictions on what you can enter in the table cells.

There are fewer GUI options for double-array inputs, but those supported are identical to the options for single-array inputs.

User Input

User Input Group GUI Options

You can use the User Input Group for two main purposes: controlling GUI layout and putting the same activation conditions on several user inputs. The latter is usually a consequence when implementing the first. Grouping of user inputs also makes it possible to define the section name and to create help contents for the section. The **GUI layout** option under the **GUI Options** section controls the behavior of a user input group. The available layouts are **Group members below each other** (the default), **Group members placed in a stack**, **Create a widget for each vector component**, **Radio buttons from first user input, others interleaved**, **Group members define columns in table**, or **Group members define a section**.

Use this section in combination with the features described in the User Input Group section.

GROUP MEMBERS BELOW EACH OTHER

The GUI components that each group member represents appear below each other. The member can be another group, so the entire layout of that group gets a spot in this sequence. The figure below shows a schematic drawing of this layout.

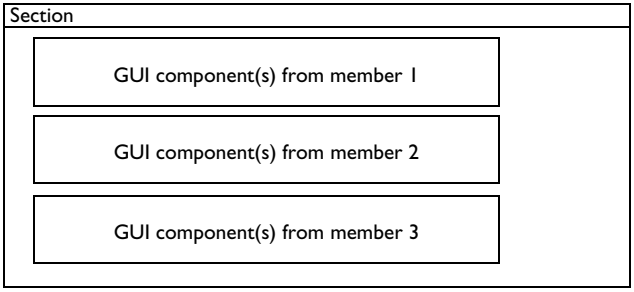


Figure 2-1: A schematic of the layout of the option "Group members below each other".

If any of the user inputs or user input groups has the option **Hide user input in GUI when inactive** selected, it gets hidden when inactive. It is still present, and its presence can be noted because it occupies a small empty space in the layout. If you only have one hidden member like this, you hardly notice it, but if there are several such hidden members in a row, you get a clearly visible empty space. You should then use the option **Group members placed in a stack** (see below).

GROUP MEMBERS PLACED IN A STACK

The GUI components of each member are placed in separate sublayouts, called cards. Each card can appear and disappear as a unit, giving the effect that a part of the layout changes instantly. The activation condition on each member controls when its card appears or disappears. Each card can contain several GUI components and other cards depending on the type of member it corresponds to. In this way, you can create an advanced nested dynamic GUI. See below for a schematic drawing of this type of layout.

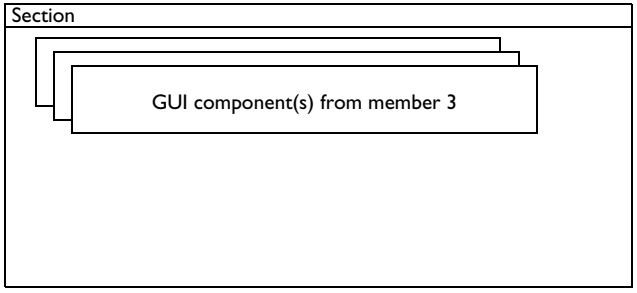


Figure 2-2: A schematic of the layout of the option "Group members placed in a stack".

GROUP MEMBERS DEFINE A SECTION

The simplest and one of the most important GUI layouts is the section layout. You use it when you want specify what members that belong to a certain section. You specify the title of the section in the **Description** field.

The recommended way of creating a section is to use the **Section** node instead of the **User Input Group** node.

If you do not specify a section, there is a default section that can be good enough for simple layouts. There are several situations when the default section is never generated:

- When you want more than one section, you must specify all sections.
- When you have at least one Constraint node in your feature. The constraint usually adds a special section for weak constraints and constraint type selection, so you must specify all other sections as a section group.

As rule of thumb, always add a section if you do not see the user inputs you expect.

The section that constraint nodes usually adds is not always shown. You must show advanced physics options to see it.

CREATE A WIDGET FOR EACH VECTOR COMPONENT

You can use this layout if you want to place a GUI component sequentially for each component of a vector-valued user input. The user input can either be a single-array vector or a double-array vector with a scalar or Boolean inner type.

A typical example is if you want to activate each vector component value with a checkbox. Then you create one double-array user input with the outer dimension set to vector and the inner dimension set to Boolean, and one single-array user input as a vector. Put both these user inputs as member to a group using this layout, and you get a layout like the screenshot below.

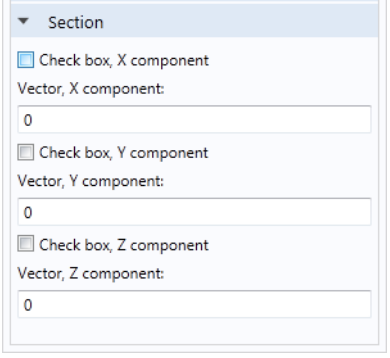


Figure 2-3: A window created with the layout option "Create a widget for each vector component".

RADIO BUTTONS FROM FIRST USER INPUT, OTHERS INTERLEAVED

Use this option when you want two or more radio buttons (option buttons) that control the visibility of other user inputs or groups. The first user input must have a set of valid values, each one representing one radio button. The number of group members except the first one has to be equal to the number of allowed values in the first user input. Similar to the previous GUI layout, you get the GUI components of a group member after each radio button. It is also common that you activate the group members depending on the value of the radio-button input. See Figure 2-4 that displays an example with two radio buttons. It needs three user inputs, where the first one has two allowed values.

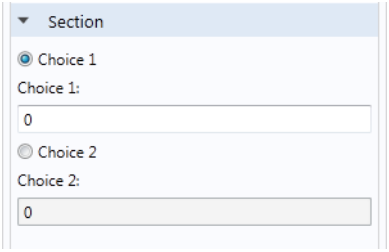


Figure 2-4: A window created with the layout option "Radio buttons from first user input, others interleaved".

GROUP MEMBERS DEFINE COLUMNS IN A TABLE

Use this option when you want to combine several user inputs into a table GUI component, where each user input represents a column in the table. This requires that the user inputs are vectors and have the same dimension. In the **Table height** field you set the height of the table in pixels. You can control the behavior of the table through the checkboxes listed in the table below:

CHECKBOX	DESCRIPTION
Automatically add new rows	Select if you always want an empty row below the entered ones.
Rows can be added	Select to enable adding of rows.
Rows can be deleted	Select to enable deleting of rows.
Rows can be moved up and down	Select to enable row content to be movable.

CHECKBOX	DESCRIPTION
Table data can be saved to file and loaded	Select to add toolbar buttons for saving and loading table content.
Table can be cleared	Select to add a **Clear** button under a table to clear all data in that table.

The table columns get their headers from each user input if the **Table headers** list has the option **Use user input descriptions**. Choose **Specify** to enter them manually in the table that pops up below the list. The last table controls the settings for each column, where you specify the column settings in the corresponding row. The table below summarizes the available options.

OPTION	DESCRIPTION
Widths	The initial width of the column.
Editable	Selected means that the user can edit the column.
Variable	The column must represent unique and valid variable names.
Expression	The values must be an expression without syntax errors.
Synchronized	You get fields below the table for easier typing.
New row	Control the default value for new rows, either when automatically added or when added through a toolbar button, The default array contains the initial values that the table is populated with when a feature is created. The value in the **New row** column is only used as default for new rows (representing new array elements in the user inputs).

ATTACH ACTIVATION ON GROUP MEMBERS

Selecting this option means that all activation conditions under this group will be attached to the list of activation conditions for all members. The attachment will be done when using the interface in the Model Builder and can be used to do modifications of existing user input activations that you either cannot access or want to do selectively for a certain feature sharing a component with other features.

User Input Group

Entering Names and Expressions

In this section:

- Entering Names
- Using Customized Names and Descriptions
- Entering Names of Operators and Functions
- Adding a Delimiter to a String
- Tensor Operators and Other Operators
- Using Ctrl+Space to Access Expressions

Use this section in combination with the features described in the Physics Builder Tools chapter.

Entering Names

All variable names that you write in an expression are first assumed to be a variable defined by the physics interface, which means that it has a physics interface scope. If no variable is found with that scope, it checks the component scope and finally the root scope. If you want to access a variable in the root scope, but you are unsure if it exists in any other scope, enter the variable fully scoped, for example, `root.lambda` to access the eigenvalues from the solver.

You might also want to access the value of a user input in your equations without adding it as a variable. The syntax for this is to add `par.` before the input parameter name. For example, to access the input parameter `sigma` in an expression, type `par.sigma`. The `par` prefix is part of a name generation syntax that the builder interprets. This syntax is built up by a sequence of dot-separated items, where each position has a special meaning. The full syntax description can be defined by the following rule

```
[<prefix>].<identifier>.[<input>]*.[<integer>]*
```

All items within brackets mean that you do not have to specify them, and in some cases a default is used instead. An asterisk (`*`) means that you can write zero or several items. The `par` prefix in the mentioned above, is an example when the identifier position is a user input, and the value of that user input replaces the entire sequence. There are

other similar reserved prefixes for accessing different scopes and specifying operators. You find the complete list in the following table:

PREFIX	DESCRIPTION	EXAMPLE
`phys`	Replaced by the physics interface scope. Under a coupling feature the `phys` prefix can be appended with a coupling type; see Generic Multiphysics Coupling	`phys.A => root.comp1.es.A`
`comp`	Replaced by the model component scope.	`comp.u => root.comp1.u`
`root`	Used as is to define root scope.	`root.h => root.h`
`coord`	Identifies the coordinate and is used together with number-dot. Can be prefixed by `s`, `m`, `g`, or `M` corresponding to the coordinate in the spatial, material, geometry, or mesh frame, respectively.	`coord.1 => X` `g.coord.2 => Yg`
`item`	Replaced by a scope that represents the full path to the feature or property.	`item.V0 => root.comp1.es.gnd1.V0`
`parent`	Replaced by a scope that represents the full path of the parent to the feature or property.	`parent.V0 => root.comp1.es.V0`
`dep`	The subsequent identifier is a dependent variable, and the true name replaces the entire sequence.	`dep.u => root.comp1.u2`
`order`	The subsequent identifier is a dependent variable, and shape order of the variable replaces the entire sequence.	`order.u => 2`
`par`	The subsequent identifier is an input, and the value of that input replaces the entire sequence.	`par.sigma => 12[S/m]`
`mat`	The subsequent identifier is a material property, and the material property value, either from the material or the user defined, replaces the sequence.	`mat.rho => root.comp1.mat2.def.rho(root.comp1.T)`
`arg`	The subsequent identifier is a component parameter. The parser substitutes the argument with the parsed result of the value.	`arg.C => phys.C2 => root.comp1.ht.C2`

PREFIX	DESCRIPTION	EXAMPLE
`map`	The subsequent identifier is an extrusion operator of a pair or a periodic condition. `map.nsign` is a variable for the normal sign, defined as 1 on all boundaries. To change the normal direction on some boundaries, redefine this variable to be -1 to flip the normal direction.	`map.src2dst(c1) => root.comp1.src2dst_p1(c1)`
`rot`	The subsequent identifier defines a rotation of a vector or matrix variable in a periodic condition.	`rot.src2dst(A) => {cos(30)*Ax+sin(30)*Ay,sin(30)*Ax-cos(30)*Ay`
`minput`	The subsequent identifier is a valid model input variable name, and the value of the model input parameter replaces the entire sequence.	`minput.T => root.comp1.ht.T`
`entity`	The subsequent identifier is a valid get method from the current feature or property. Valid methods are only those without arguments and that return a string value.	`entity.tag => init1` `entity.name => Initial value 1`
`loop`	Modifies the variable name so it represents a unique name for the current pass in a loop.	`loop.D => root.comp1.di.D_c1`
`dev`	Replaced by the current device scope.	`dev.v => root.comp1.cir.R1_v`
`sys`	Usually replaced with the scope of the coordinate system currently selected in the **Coordinate system list** in the Settings window of the feature instance. In other cases it can represent more complex expressions; see The Input Base Vector System for more details.	`sys.T => sys2.T`

If the prefix is left out, it is assumed to be `phys` for variable names, but not for dependent variables, operators, and functions (see below). After the identifier there can be a trailing sequence of integers. This sequence represents indices of a tensor element. Assume that there is a 3-by-3 tensor A with physics interface scope, and that it is used in a 2D axisymmetric model where the coordinate names are `r`, `phi`, and `z`. If you type

```
A.1.2
```

in a builder expression, it becomes

```
Arphi
```

in the 2D axisymmetric model. The standard naming convention for components of a vector or matrix is a base name concatenated with the coordinate names. You can override this naming convention using the Component Settings node.

Dependent variables are treated differently. Firstly, they always have component scope, so unscoped names get this scope. Secondly, the user can change their names, so you always specify them by their default name. The physics scope lookup has precedence over the default-name lookup of dependent variables, so if you want to use a dependent variable that has the same default name as the name of a variable, you must use the `dep` prefix.

SCOPE OPERATORS

The scope prefixes `phys`, `item`, and `comp` are also available as operators that complement the scope prefixes used in the tensor parser of the Physics Builder (see Tensor Operators and Other Operators). The following table summarizes a few examples for these prefixes and their corresponding operator (assuming a physics with the name `abc` and a feature with the name `feat`):

TABLE 2-1: SCOPE OPERATOR SYNTAX

PREFIX	VARIABLE USE	RESULT	OPERATOR USE	RESULT
`phys`	`phys.A`	`root.comp1.abc.A`	`phys(str.append ('A_', arg.suffix))`	`root.comp1. abc.A_suffix`
`item`	`item.A`	`root.comp1.abc. feat.A`	`item(par.B)`	`root.comp1. abc.feat.DOF`
`comp`	`comp.A`	`root.comp1.A`	`item(par.B)`	`root.comp1. DOF`

For the operator use in the table, `arg.suffix = 'suffix'` and `par.b = DOF`.

Using Customized Names and Descriptions

In the Component Settings node, you can define custom names and descriptions by selecting different options in the **Create components by** list. The first option, **Appending coordinates to the name**, is the default behavior for spatial tensors that concatenate the tensor name with the coordinate name for each tensor component:

```
Axy
```

The option **Appending indices to the name**, concatenate the tensor name with the tensor index:

```
A12
```

This is the default for nonspatial tensors. Use the option **Specifying a template**, if you have a certain naming convention for the *i*th component. For example, assume that you want to the use following names and descriptions for a velocity vector:

NAME	DESCRIPTION
x_vel	x-velocity
y_vel	y-velocity
z_vel	z-velocity

Then you specify the following template for the variable name

```
str.append(coord.i,_vel)
```

and for the description

```
#coord.i#-velocity
```

If you have a tensor with up to 4-indices, use the identifiers `j`, `m`, and `n` to access the other indices.

It is also possible to concatenate parts with `str.append` operator. The operator appends all its argument to generate the final component name. Assume that a feature has a user input called `Port` that has the value `2`. The following template

```
str.append(phys.R,par.Port,par.Port)
```

then generates the following component name (`root.comp1.ph` is the physics scope)

```
root.comp1.ph.R22
```

The final option is **Specifying each component separately**. Here you type the name and description for each component in the table below the list. You can use the dot (`.`) and

hash (#) symbols to use the coordinate names. You can implement the example above with the following component settings:

COMPONENT NAMES	COMPONENT DESCRIPTIONS
`str.append(coord.1,_vel)`	`#coord.1#-velocity`
`str.append(coord.2,_vel)`	`#coord.2#-velocity`
`str.append(coord.3,_vel)`	`#coord.3#-velocity`

Components

Entering Names of Operators and Functions

When you want to enter a name to an operator or function almost the same rules apply as for variable names. The only difference is the default scope. For variable names, the default scope is always the physics scope, represented by the `phys` prefix. When you declare a new operator or function, the default prefix is also `phys`, but not when you use the operator or function in an expression. Then the default is the `comp` prefix, which is interpreted as component scope. The reason is simply that it is most common that you declare new operators with physics scope, but not when you use a function. Then you often refer to functions that are unscoped (for example, `sin`, `cos`, `exp`, `gradient`, and `normalize`). In the Model Builder, all unscoped names are first interpreted using component scope, then root scope, so it is possible to change the meaning of the function name `sin` if you want.

Operators and Functions

Adding a Delimiter to a String

The `str.delimited` operator creates a string by concatenating the arguments separated by the delimiter. You can use this operator in expressions in Variable Definitions, Components Settings, and so on. The delimiter can be any string, while the arguments can be string literals, variables, user inputs, or other commands (such as `entity.tag`). In the case of vector or matrix variables, each component is considered as a separate argument. The `str.delimited` operator has the following syntax:

`str.delimited(<delimiter>, <arguments>...)`

Use this section in combination with the features described in the Physics Builder Tools chapter.

Tensor Operators and Other Operators

All **Expression** fields supports tensor variables and operators for tensors. If you, for example, want the cross product between two vectors, simply type

$$A \times B$$

directly in the **Expression** field. The symbol for the cross product is among the standard mathematical symbols defined by the Unicode standard. Other special symbols used by expressions are the (inner) dot product, $A \cdot B$, and the nabla operator, ∇A. The system font must support the special symbols to display them properly; otherwise, the expression might not look correct. It is always possible to copy-paste them from an editor that supports Unicode input or directly from a Unicode character map.

There are also some functions that you can use to perform tensor operations — for example, the transpose of a matrix or the inverse of a matrix.

Use this section in combination with the features described in the Physics Builder Tools chapter.

The following table lists the operator symbols and operations that the tensor parser supports.

OPERATION	PRECEDENCE	EXAMPLE
Cross product	Same as multiply	$a \times b$ or `cross(a,b)`
Inner dot product	Same as multiply	$a \cdot b$ or `dot(a,b)`
Double dot product	Same as multiply	$a : b$
Gradient	Function	∇a or `gradient(a)`
Tangential gradient	Function	`gradientT(a)`

OPERATION	PRECEDENCE	EXAMPLE
Divergence	Function	$\nabla \cdot a$ or `divergence(a)`
Curl	Function	$\nabla \times a$ or `curl(a)`
Tangential curl	Function	`curlT(a)`
Identity matrix	Function	`identity(4)`, `identity('3x5')`, `identity({3,4})`, or `identity(size(par.in1))`
Inverse of a matrix	Function	`inverse(a)`
Determinant of a matrix	Function	`determinant(a)`
Transpose of a matrix	Function	a^{T} or `transpose(a)`
Normalize a vector	Function	`normalize(a)`
Norm of a vector	Function	`norm(a)`
Sum over last index	Function	`sum(a)`
Deviatoric part of a tensor	Function	`deviatoric(a)`
Maximum element in a vector	Function	`maxElem(a)`
Minimum element in a vector	Function	`minElem(a)`
Fill with variable to size	Function	`array(a,{2,2}) = {{a,a},{a,a}}` `array(a,"3x1") = {a,a,a}`
Specify elements of vector	Variable name	`{1,2,3,4,5}`
Specify elements of matrix	Variable name	`{{11,12},{21,22}}`

Expand elements to list of arguments	Variable name	Let `r = {x,y,z}`
		`f(r.1..n)` becomes `f(x,y,z)`
		`g(r.1..2)` becomes `g(x,y)`

OPERATION	PRECEDENCE	EXAMPLE
Force symmetry in matrix	Function	Let `M` be a matrix that is symmetric, `M = {{u*u, u*v, u*w}, {v*u, v*v, v*w}, {w*u, w*v, w*w}}`. Symmetry cannot be detected because `v*u` is different than `u*v` by string comparison. The `symmetric` operator forces symmetry: `symmetric(M) = {{u*u, u*v, u*w}, {u*v, v*v, v*w}, {u*w, v*w, w*w}}`
Zero out in-plane components of a spatial vector	Function	Let `r = {r,phi,z}` in 2D axial symmetry `zeroInPlane(r) = {0,phi,0}`
Zero out out-of-plane components of a spatial vector	Function	Let `r = {r,phi,z}` in 2D axial symmetry `zeroOutOfPlane(r) = {r,0,z}`
Multiply by volume integration factor	Function	`integrand(a+b)` becomes `(a+b)*2*pi*r` in 2D axial symmetry `(a+b)*ie1.detInvT` for an infinite element domain
Evaluate physical constants, global parameters, and units to numerical values. You can use this operator with conditional expressions to check if a parameter is larger than a certain value, for example.	Function	Let `T0` be a global parameter set to 300K, `evalConst(k_B_const*T0/e_const)` becomes `0.025851997154882865` `evalConst(1[μm])` becomes `1e-6` if the base unit is meter.
commaDerivative	Function	Let `u` be a vector-valued dependent variable with components `u`, `v`, and `w` and the coordinate names `x`, `y`, and `z`. Then `commaDerivative(u) = {{ux,uy,uz}, {vx,vy,vz}, {wx,wy,wz}}`

The *double dot product* is a summation over two indices:

$$\mathbf{a}:\mathbf{b} = a_{ij}b^{ij}$$

Unfortunately, there are two definitions of the double dot product, and the above is referred to the *Frobenius inner product* or the *colon product*. The other definition has flipped order for the indices in the second factor

$$\mathbf{a}:\mathbf{b} = a_{ij}b^{ji}$$

The former definition is used by the tensor parser.

The *gradient operator* can be suffixed with `s`, `m`, `g`, or `M` to specify in regard to which coordinate variables (spatial, material, geometry, or mesh frame, respectively) it should take its derivatives. Example `∇.m.u` is the gradient of the variable u in the material frame.

The *eval operator* makes it possible to control the evaluation context locally in an expression. The operator must be preceded by one of the frame prefixes: `M` (mesh), `g` (geometry), `m` (material), and `s` (spatial). The `eval` operator can, for example, be used in the subnode definition of a variable declaration to provide an automatic transform for all frames but one. Assume that you have a declaration on all frames for a variable named `A`. The definition subnode of this declaration has the expression `m.eval(A)`, which means that the evaluation context is locally changed to the material frame. The evaluation in that frame will always pick up the declaration in the material frame, `[AX, AY, AZ]` and then transform it to the frame of the evaluation context of the definition. This results in three definitions for each of the declarations, where the definitions for geometry and spatial will have an automatic transform using the material variable. The definition of the material variable, on the other hand, will have a circular reference to itself. This last definition has to be replaced with a separate **Variable Definition** node on the same selection with an explicit definition (for example, a shape definition).

To create an identity matrix, the *identity operator* can take a single positive integer argument N for a square N-by-N identity matrix. You can also use a string of the form `'`*N*`x`*M*`'`, or a size array of two positive integers (for example, produced by the `size` operator). All nonsquare matrices are cropped to the desired size; for example, for 2-by-3: {1, 0, 0; 0, 1 0}.

SUBSTITUTION OPERATOR FOR REPLACING MODEL INPUTS

The *subst operator*, `mat.subst` can replace model inputs inside expressions of material properties. The syntax is as follows:

```
mat.subst(<material_property>, <model_input_1>, <replacement_1>,
..., <model_input_N>, <replacement_N>)
```

The first argument must be the name of a material property with or without the `mat` prefix. If the prefix is missing, it will be automatically added to the given name. The model input arguments are either variable names or field names of model inputs (for example, `T` or `temperature`) with or without the `minput` prefix. Again, the prefix will be added if missing. The replacements arguments are parsed as ordinary expressions and must match the tensor size of the model input argument it belongs to.

An example of the use of this operator:

Assume that the material property for density, `rho`, has the expression `rho(T, pA)`. The statement

```
mat.subst(rho,T,300[K],electricfield,{1,0,0}[V/m])
```

will result in the final expression

```
rho(300[K],comp1.id.id1.minput_pressure)
```

where the last argument is the internal model input variable name for pressure. The temperature has been replaced, and the electric field is ignored.

FRAME OPERATORS

The following operators are available for checking variables with respect to frames:

- The `hasSameFrame(var1, var2, ..., varN)` operator returns 1 (`true`) if all variables (names or expressions) are defined on equivalent frames (that is, the same frame or different frames if there is no transformation between them). Otherwise, it returns 0 (`false`).
- The `hasMovingFrame(var)` operator returns 1 (`true`) if `var` has been declared in a moving frame (such as a frame driven by an ALE method). Otherwise, it returns 0 (`false`).

Using Ctrl+Space to Access Expressions

Press Ctrl+Space in text fields for expressions to get access to lists of special operators, variables, prefixes, functions, and other expressions that the Physics Builder parser supports. The following list are available:

- **Operators**: Supported special mathematical operators.
- **Functions**: Various mathematical and logical functions supported by the Physics Builder.
- **Special Prefixes**: Special prefixes that can be used in the Physics Builder.

- **Coordinate Access**: Variables that are used to access coordinates.
- **Source Destination Access**: Functions and variables used in the context of a pair feature or periodic feature.
- **Entity Access**: Variables that access properties of the current model entity.
- **Coordinate System Access**: Variables that access the selected coordinate system.
- **Custom Physics Builder Functions**: Any tensor-valued functions declared under the **Auxiliary Definitions** branch also show up under the **Custom Physics Builder Functions** menu.

Using Coordinate Systems

When creating a feature or property, you can define two coordinate systems: the Base Vector System and the Input Base Vector System.

In this section:

- The Base Vector System
- The Input Base Vector System
- Transformation Between Coordinate Systems

Use this section in combination with the features described in the Physics Builder Tools chapter.

The Base Vector System

This is the system a feature declare its variables in. Typically, this only has an effect if the variable is a spatial tensor (for example, a vector with length 3). It also has an effect for weak form equations, where the base vector system can define the volume factor for the weak form integration. The most common choice is to use the coordinate system represented by the current frame used by the feature. In the **Base vector system** lists, this is the option **Frame system compatible with material type**.

About Frames in the *COMSOL Multiphysics Reference Manual*

The table below summarizes all possible options for the Base vector system list.

OPTION	DESCRIPTION
Frame system compatible with material type	Uses a coordinate system that represents the frame compatible with the selected material type for the feature.
Selected input coordinate system	This options activates a coordinate system selection list for a feature, where the user can choose between user-defined systems and a global system that corresponds to the feature's frame.
Spatial frame system	Uses the coordinate system for the spatial frame no matter what the feature's frame is.

OPTION	DESCRIPTION
Material frame system	Uses the coordinate system for the material frame.
Mesh frame system	Uses the coordinate system for the rarely used mesh frame.
Geometry frame system	Uses the coordinate system for the geometry frame.

The feature determines its frame from the **Frame type** list, which has the options **Material**, **Spatial**, **From physics**. or **Selectable by user**. The **Material** option corresponds to the material frame, and the **Spatial** (typically fluids) option corresponds to the spatial frame. Select **From physics** to use the frame specified by the physics interface. For the **Selectable by user** option, the frame type depends on user choice or material setting during a Model Builder session.

When you select the base vector system for a feature, it acts as a default for all variables, user inputs, weak form equations, and constraints declared by the feature. If necessary, it is possible to override this default by changing the setting in the **Base vector system** list under the **Advanced** section of any of these nodes. Under the same **Advanced** section for variables, you can also set the tensor type, individual base vector system, and base vector type for each tensor index. In the **Tensor type** list, choose the type of vector: a **Normal tensor**, a **Tensor density**, or a **Tensor capacity**. Tensor densities and capacities are affected by the scaling of the unit volume during a change of base vector system. For nonscalar quantities, use the **Base vector system** column in the table to set individual base vector systems for each tensor index. In the **Type of base vector** column, set the type to **Covariant** or **Contravariant** for each index.

By default, all tensor indices are contravariant, and this setting is only important for nonscalar, spatial tensors in nonorthonormal coordinate systems.

The Input Base Vector System

This is the system used by all spatial (length 3) vector-valued and tensor-valued user inputs. The options in the **Input base vector system** list are the same as The Base Vector System list. When the settings differ between these two lists, everything a user enters for a user input, is automatically transformed to the system defined by the **Base vector system** list. The transformation matrices used by the transformation can be accessed through a special scope syntax, `sys.<variable>.` There are six variables defined by a

coordinate system that you can access using this scope. These are summarized in the table below:

VARIABLE	SYMBOL	DESCRIPTION	BASE VECTOR SYSTEM
`T`	T_i^j	Transformation matrix from public system to global system for contravariant tensors	i: public system j: global system
`invT`	$(T^{-1})_i^j$	Transformation matrix from global system to public system for contravariant tensors	i: global system j: public system
`gSup`	g^{ij}	Contravariant metric tensor for public system with respect to global system	i, j: public system
`gSub`	g_{ij}	Covariant metric tensor for public system with respect to global system	i, j: public system
`detT`	$\left\|T_i^j\right\|$	Determinant of `T`, and also the volume of a unit cube in the public system measured in the global system	Not applicable
`detInvT`	$\frac{1}{\left\|T_i^j\right\|}$	Determinant of `invT`, and also the volume of a unit cube in the global system measured in the public system	Not applicable

The public system of a coordinate system is the base vector system it defines and the global system is the base vector system the public system is defined with respect to. A global system is almost always also a frame system, whose base vectors represents the coordinates of a frame. For example, a rotated system performs a rotation of the base vectors of the global system to get the base vectors of the public system.

In some special situations, the global system of the selected coordinate system can differ from the global system of the base vector system used by the feature or property. In those cases, the transformation matrices include an extra transformation between the different global systems. Because the global systems also are frame systems, these extra transformations are usually called frame transformations. A frame transformation between the material frame and the spatial frame is given by the differentiation of the spatial coordinate with respect to the material coordinates or vice versa.

Transformation Between Coordinate Systems

All spatial vectors and matrices can transform as tensors, when an operation involves two such objects defined in different coordinate systems.

Consider the example of the normal component of a flux,

$$q = \mathbf{n} \cdot \mathbf{D}$$

where **D** is the flux vector. Using the Einstein summation convention,

$$q = n_i D^i$$

where subscripts indicate *covariant* indices and superscripts indicate *contravariant* indices. The type of index determines how the components of a tensor transform between different coordinate systems. A nonorthonormal coordinate system has, among other, two sets of basis vectors known as the covariant and contravariant bases. Covariant tensor components refer to the contravariant basis vectors and contravariant tensor components refer to the covariant base vectors. For all orthonormal systems, these two sets of basis vectors, and these two sets of components, are identical. Now assume that D^i is given in a different coordinate system than n_i. To compute q properly, D^i first has to be transformed as a contravariant (first order) tensor

$$D^{i,\,\mathrm{x}} = \frac{\partial x^i}{\partial u^j} D^{j,\,\mathrm{u}}$$

where x^i is the ith coordinate in the desired system, and u^i is the ith coordinate in the original system. To separate tensor indices in different systems, they also include the coordinate name. If the tensor instead was covariant originally, the transformation would become

$$D_{i,\,\mathrm{x}} = \frac{\partial u^j}{\partial x^i} D_{j,\,\mathrm{u}}$$

These transformations are used whenever there exists several systems in an expression or variable assignment. The most common example is when you use an input coordinate system for your user inputs that differs from the base vector system in which the variables are stored. A material tensor from the material library can, for example, undergo a rotation to align its z-axis with the y-axis of the system where the tensor variables that are used in the model are defined.

Another situation when a variable might undergo an automatic conversion is if you try to perform a scalar dot product between two tensors of the same type — for example, two covariant tensors. The expression parser then performs a raise-index operation on D_j before taking the dot product

$$q = n_i (g^{ij} D_j)$$

This is essentially a multiplication with the contravariant metric tensor, g^{ij}. The metric tensor is the identity matrix for all orthonormal systems, where the covariant and contravariant components are identical.

REFERENCE

1. G.B. Arfken and H.J. Weber, *Mathematical Methods for Physicists*, Academic Press, 1995.

Specifying Selections

Selection Section Settings

Specifying the selection where a certain variable definition is valid works in the same way for all types of definitions throughout the Physics Builder. You find these settings under the **Selection** section of all nodes that support a selection.

It is not possible to give an absolute selection, because you do not know enough about the geometry that the physics interface is used in. Instead, set up the selection relative to selections that are known in the Model Builder.

In the **Selection** list specify what selection to start from. The bullets below explain the list options, assuming that the selection belongs to a variable, but this is also valid for all other types of nodes that support selections.

- **From parent**. The selection becomes identical to the selection of the feature. If the variable belongs to a property or a physics interfaces, the selection becomes identical to the selection of the physics interface.
- **From selection input**. The selection is taken from the selection input.
- **Global**. The variable gets a global selection. This option can disable other settings, like shape selection, for example. A shape selection does not make sense for global selections because the only valid degree of freedom is an ODE variable.
- **From physics interface**. Only available for selection components. The selection is taken from the physics interface.
- **Source**. Only available for periodic condition features and pair features. The selection is identical to the source selection of the periodic condition or pair.
- **Destination**. Only available for periodic condition features and pair features. The selection is identical to the destination selection of the periodic condition or pair.
- **Operation**. Performs an operation between several selection components defined under the **Building Blocks** branch ( ). The supported operations are the same as for selections in the Model Builder; see Visualization and Selection Tools in the *COMSOL Multiphysics Reference Manual*.
- **From external resource**. Use this option to select a link to a selection definition from an external resource. To define the selection, choose an **Imported file** and a **Link**. The **Imported file** list is the list of **Import** nodes that has been defined and imported from the external resource.

- **From built-in**. Use this option to define a link to a built-in Java maker, which you defined using the **Package**, **Link**, and **Output entities** lists.
- **Top level entities applicable to parent**. The selection become the top level entities applicable to the parent node (domains or boundaries, for example).
- **Operations on sibling-feature selections**. Searches for sibling features with a specific type in the list containing the current feature, or if the current entity is a property or physics interface, it searches the feature list under the physics interface. Then performs the selected operation on the selections of the found features. With this option in a Selection node, you can select the **Use condition on sibling** checkbox. When this checkbox is selected, a **Condition** field becomes available. Here you can enter a conditional expression that is evaluated for all siblings that match the criteria. The condition must evaluate to 0 (false) or 1 (true). You can also press Ctrl+space to get a list of supported operators, prefixes, and functions. Only when the condition evaluates to 1 (or true) the selection of the sibling feature will be included in the total selection operation.
- **From definitions library**. The selection refers to a selection component under the **Building Blocks** branch that defines the selection; see Selection.
- **From moving domains**. The selection is taken from the moving domains.

For all options except **Global**, you can also choose the output entity from the **Output entities** list. This list has the following options:

- **Selected entities**. Use the same selected entities as the selection you start from.
- **Adjacent boundaries**. The variable's selection contains the adjacent boundaries to the selection, which typically is a domain selection. If the selection is a boundary selection, this option returns the boundaries adjacent to the selection.
- **Adjacent domains**. The variable's selection contains the adjacent domains to the selection.
- **Adjacent edges**. The variable's selection contains the adjacent edges to the selection.
- **Adjacent points**. The variable's selection contains the adjacent points to the selection.
- **Mesh boundaries**. Specifies that the selection is of a special kind where the entities represents the boundaries of each mesh element in a domain selection.
- **Restricted to geometric entity types**. The selected entities undergo a filtering only including the entity types selected in the **Allowed entity types list**, such as **Exterior**, **Interior**, or **Symmetry axis** (in axial symmetry). See Selection Terminology for more details.

- **Restricted to frame type**. Restrict the use of the selected entities to the frame type selected from the **Frame type** list. A frame type can vary across the selected entities of a feature when the **Frame type** list of a feature uses the option **Selectable by user**; see Using Coordinate Systems.
- **Base selection of extra dimension**. With this option, the output selection only contains the base selection.
- **Attached extra dimension**. The output selection contains only the extra dimension that was attached to the production selection.
- **Selected entities and propagate extra dimension to lower dimensions**. For a product selection, this option includes all lower dimensions for the selection in the extra dimension.

Except for **Adjacent points** and **Mesh boundaries**, there is a **Propagate to lower dimensions** checkbox. When selected, the output selection also contains all adjacent entities in all the lower dimensions of the output selection. For the **Selected entities and propagate extra dimension to lower dimensions** option, that checkbox is labeled **Propagate base dimension to lower dimension** to make it more clear what part of a product selection it controls.

For the option **Adjacent boundaries** you get another option to restrict the output boundaries to certain conditions. Some restrictions only make sense if the original selection (determined by the **Selection** list) is a domain selection. In the **Restrict to** list, you can choose among the following options:

- **All adjacent boundaries**. This option returns all adjacent boundaries, and this is the only option that makes sense for nondomain original selections.
- **Exterior boundaries to the domain selection**. All boundaries that only has one of the upside domain or downside domain belonging to the domain selection.
- **Interior boundaries to the domain selection**. The boundaries where the upside domain and downside domain both belong to the domain selection.

- **Exterior boundaries whose upside is in the domain selection**. Include exterior boundaries that has the upside domain in the domain selection.
- **Exterior boundaries whose downside is in the domain selection**. Include exterior boundaries that has the downside domain in the domain selection.

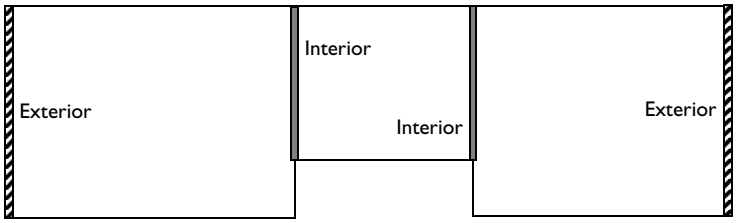


Figure 2-5: A schematic of a domain selection with highlighted exterior and interior boundaries. Note that some exterior boundaries are not highlighted.

Selection Terminology

A selection represents a set of entities on an entity dimension or geometric entity level. A boundary selection is a selection with the geometric entity level boundary. For a boundary selection in 3D the set of entities is face numbers and the entity dimension is 2. In 2D, a boundary selection has a set of edge numbers and the entity dimension is 1. There are no edge selection in 2D and 1D, and no point selection in 1D, because there are redundant with the boundary selection. The table below summarizes the geometric entity levels and their entity dimensions.

LEVEL	DIMENSION 3D	DIMENSION 2D, 2D AXISYMMETRIC	DIMENSION 1D, 1D AXISYMMETRIC	DIMENSION 0D OR GLOBAL
Domain	3	2	1	N/A
Boundary	2	1	0	N/A
Edge	1	N/A	N/A	N/A
Point	0	0	N/A	N/A
Global	-1	-1	-1	-1

The geometric entity type, or just entity type, is a category in which each entity in a set belongs. Usually, the physics interface selection defines in what entity types an entity

in a set belongs. Below is a short summary of all entity types available for features and selections.

ENTITY TYPE	APPLIES TO LEVEL(S)	DESCRIPTION
Active	All levels	Entities where the physics interface is active.
Inactive	All levels	Entities where the physics interface is inactive.
Geometry	All levels	Same as Active.
Exterior	Boundary	Entities that are exterior to the physics interface selection.
Interior	Boundary	Entities that are interior to the physics interface selection.
Symmetry axis	Boundary, Edge, Point	Only for axial symmetry. The entities that lies on the symmetry axis (z-axis).
Pair	Boundary, Edge, Point	Not used by entities. For a Feature it means that the program creates an automatic version for pairs.
Source or destination	All levels	Not used by entities. For a Feature it means it only applies as a fallback feature for pairs.
Exterior, neither source nor destination	Boundary	Not used by entities. For a Feature it means that it is excluded from the list of fallback features for pairs.
Neither source nor destination	Domain, Edge, Point	Same as the previous row for domains, edges, and points.
Identity pair	All levels	Entities that are identity pairs.
Contact pair	All levels	Entities that are contact pairs.
Perfectly matched layer	Domain	Domains that are perfectly matched layers,
Infinite element domain	Domain	Domains that are infinite elements domains.
Absorbing layer	Domain	Domains that are absorbing layers.
Scaled systems	Domain	Domains that are scaled systems.
Voids	Domain	Domains that are finite voids or an infinite void.
Infinite void	Domain	Domain that is an infinite void.
Finite voids	Domain	Domains that are finite voids.

Only a subset of these makes sense for a selection, and some are not used at all by the Physics Builder.

Comparing Physics Builder Features

To help troubleshooting a physics interface developed using the Physics Builder, it can be helpful to compare different versions of some Physics Builder features to help pinpoint possible changes that may affect the behavior and results.

Comparing Versions

You can compare two different version of a Physics Builder file. The comparison result appears in the **Comparison Result** window. Click the **Comparison Result** ( ) button in the **Home** toolbar to toggle this window on and off.

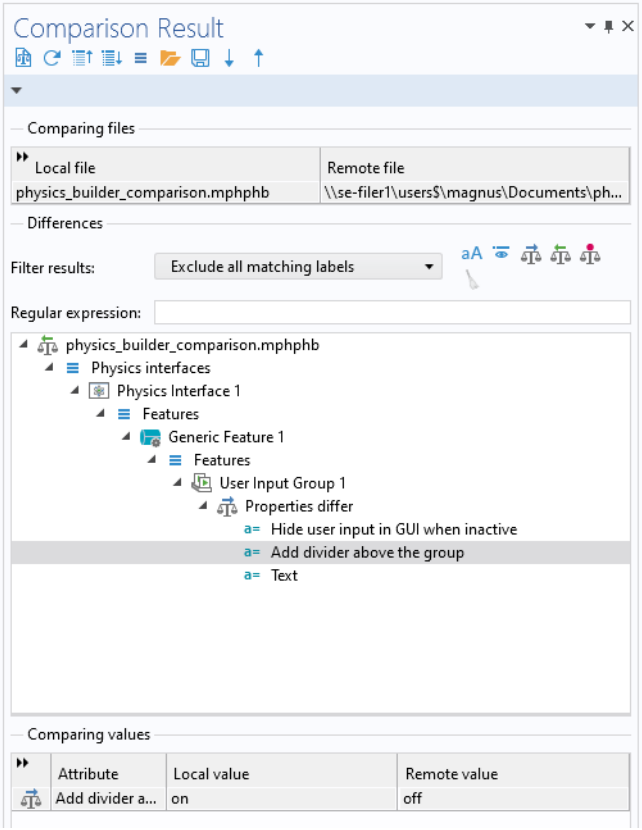


Figure 2-6: The Comparison Result window, displaying differences between two Physics Builder files.

At the top of the **Comparison Result** window there is a toolbar with the following buttons:

- **New Comparison** ( ), to make a new comparison. A **New Comparison** dialog opens. Select the **Use open file** checkbox to use the currently active file. Clear it to specify

another **Local file**. Specify a **Remote file** and then click **OK** to perform a new comparison.

- **Update** ( ), to update the comparison.
- **Collapse All** ( ) and **Expand All** ( ), to collapse or expand all branches in the comparison tree.
- **Show Table View** ( ), to toggle between the view with the comparisons in a tree and a view with a list of the differences.
- **Load Comparison from File** ( ), to load the results from another comparison from an XML-file.
- **Save Comparison to File** ( ), to save the results from the current comparison to an XML-file.
- **Show Next Difference** ( ), to move to the next difference in the tree with nodes that differ under **Differences**.
- **Show Previous Difference** ( ), to move to the previous difference in the tree with nodes that differ under **Differences**.

Under **Comparing files**, you find the file paths to the local model and the remote model. The local model is typically the model open in the COMSOL Desktop, and it can have been modified after the last save. The left column is called **Local file (Open application)** when the local model is the opened model or application. When the local model is a new model that has not yet been saved, the left column is called **Open application**.

Under **Differences**, you can use the **Filter results** list to control filtering with the options **No filter**, **Exclude all matching labels** (the default), and **Include all matching labels**. The entries in the **Regular expression** field define what node labels to filter. You can make the filtering case sensitive by selecting the **Case Sensitive** button (aA) box next to the list. The filter matching is done with regular expressions, and any label that contains a matching text will be either included or excluded. Filtering can be disabled by choosing **No filter** from the **Filter results** list. Click the **Show Only Active** button ( ) next to the list to exclude inactive settings from the comparison.

For nodes that correspond to a node in the Physics Builder tree, double-click the node (or right-click and choose **Go to Source**) in the tree of nodes with differences to display the corresponding node in the tree in the local file. When applicable, you can also right-click a node and choose **Go to Remote Source** to display the corresponding node in the Physics Builder tree in the remote file. You can also right-click a node and choose **Override Difference in Local File** ( ) or **Override Difference in Remote File** ( ) to remove that difference in either the local file or the remote file.

Selecting a node in the tree will update the table under **Comparing values** below the tree. This table shows the attributes of the selected node, both in the local model (**Local value** column) and the remote model (**Remote value** column). This table is particularly interesting for the nodes labeled **Attributes differ** because they show the values that differ. Parent nodes can also show the same differences but typically with a larger number of attributes that have the same local and remote values. For differences that contain long entries or large arrays, there is an option to show a more detailed difference in a separate window for a selected table. Either double-click the table row or click the **Detailed Comparison of Selected Attribute** button ( ) below the table to open the **Compare Attribute** window.

Copying and Pasting Physics Builder Nodes

Using copy and paste operations, you can copy, paste, and duplicate Physics Builder nodes within a session and also, via the system clipboard, between Physics Builder sessions. To copy a Physics Builder node, right-click it and choose **Copy** ( ). To paste a node, right-click the parent node under which you want to add it, and choose, for example, **Paste Domain Condition** ( ). You can also right-click a Physics Builder node and choose **Duplicate** ( ) to duplicate it (or press Ctrl+Shift+D).

There are some rules that control how the COMSOL Multiphysics software deals with conflicts and unresolved references when pasting nodes. These rules applies in the given order:

1. If the reference points to an object that is also among the copied objects, use that object as reference.
2. If the reference points to an object that exists but is not among the copied objects, use that object as target with a notification in the **Messages from Paste** dialog. No notification is added when pasting to the same file and the reference target is the same as in the original node.
3. If there is no reference in the original but a default reference is used in the target, keep it but add a notification in the **Messages from Paste** dialog.
4. If there was a valid reference in the original but no suitable reference could be found in the target, the default reference (either undefined or first available node) is used and a notification is added to the **Messages from Paste** dialog. For arrays of references, the invalid reference is removed from the array.
5. If the copied node links to an **External Resource** node, the external resource will automatically be included among the copied objects and pasted to the target if there is not already an external resource present referring to the same file.

The Physics Builder Manager

With the **Physics Builder Manager** window ( ) you manage testing, compilation, and comparison of your Physics Builder files. Testing is when you temporarily register one or more development files (`*.mphphb`) in your COMSOL session to fully test their physics interfaces in a real modeling environment. When you are satisfied with a collection of builder files, you can compile them into a builder archive.

To open this window, click **Physics Builder Manager** ( ) in the main toolbar (Windows) or, from the main menu, select **Windows** > **Physics Builder Manager** (Linux, Mac). In the toolbar, click again to close the window.

In this section:

- The Development Files
- Compiling an Archive
- Working with Builder Archives
- Searching in Archives
- Version Control and Version History

Testing Custom Physics Interfaces

Physics Builder files can contain several physics declarations that you can access from the Model Wizard. These physics interfaces are identical to *built-in* physics interfaces (the physics interfaces shipped with COMSOL Multiphysics), with the difference that their functionality is specified by your Physics Builder file.

The COMSOL Multiphysics software searches and uses the Physics Builder files that are located under the **Development Files** branch ( ).

1 Click the **Physics Builder Manager** button ( ) in the main Physics Builder toolbar, or (on Linux and Mac) select **Windows** > **Physics Builder Manager** ( ) to open the window.

2 Under **Archive Browser**, right-click the **Development Files** node to add new Physics Builder files to the list.

To remove a builder file from the list, select it and then right-click it and choose **Remove Selected** ( ) from the context menu.

COMSOL loads all physics interfaces listed in the **Development Files** node when a new session is started. If a Physics Builder file is added during a session, COMSOL loads it and updates the list of physics interfaces.

If the Physics Builder file is changed on the file system by another session, you have to manually reload it to activate these changes.

3 Click the **Register Development Files** toolbar button ( ) in the **Physics Builder Manager** window to reload all physics interfaces listed in the **Development Files** branch ( ).

The Development Files

The files listed are included in your COMSOL session. This means that your interfaces appear in the Model Wizard, so you can add them to your model and work with them like any other physics interface. You can also save model files (`*.mph`) that use your new interface. To add a development file, right-click the **Development Files** node ( ) and choose **Add Builder File**. If you right-click any added development file, you can choose to remove it from the list or to open it. There is also an option to compact the archive. The compact operation removes all unnecessary data in the file to save space and simplify textual comparisons between different versions of a file.

Whenever you make changes to a builder file listed as a development files, you must click the **Register Development Files** toolbar button ( ) to reread all files into the current session.

	If you save a model file (`*.mph`) that uses one of your new physics interfaces, you must make sure that the same physics interface is available when you open the file again.

	Adding files to **Development Files** in the **Physics Builder Manager** does not work when running on a cluster. To test a physics interface on a cluster, an archive have to be compiled first (see Compiling an Archive and Working with Builder Archives).

Compiling an Archive

When your interface is finalized and you are ready to distribute it to others, you can compile all development files into a builder archive. Right-click the **Development Files** branch and choose **Compile to Archive Folder**. Either choose an empty folder or create a new one. When the compilation is finished, the new archive folder can be found as a new branch under the **Archives** branch. The archive is a folder containing your source builder files, the compiled builder files, all files the builder files refer to (icons for example), the necessary Java® code, and a set of language files for translation. The language files are ordinary text files where you can add a translation to all descriptions displayed for your interfaces. A language file has the following format:

```
##
# German language file
#
# Original description = Auto current calculation
deployment1.phys1.description = Automatische Stromberechnung
# Original description = Current domain
deployment1.phys1.feat1.description = Stromführender Bereich
```

All lines starting with a hash symbol (`#`) are comments. All files use the original description string by default, but you replace them when translating. The original description is always in the comment above the translation for reference. Do not change the tag on the left side of the equal sign. This is used by the COMSOL Multiphysics software to identify the description. The tag is a path to an entity within a builder file with the localization tag set to `deployment1` in the above example. You can change this tag in the **Root** window of the root node of a builder file. Enter the new tag in the **Localization tag** field, located in the **Physics Builder** section. You can also select the type of localization tang from the **Localization tag** list: **Individual resources for all descriptions** (the default), **Re-use identical resources**, or **Use built-in COMSOL resources**. For the last option, the **Localization tag** field is not used.

If you recompile an archive into to an existing archive, the compilation replaces all files except the language files. The compilation tries to merge the language files, by adding

new descriptions, removing unused descriptions, and leave translated descriptions untouched. Unused or unreferenced files are kept in the archive.

	Do not open a builder file from the **Compiled builder files** folder in an archive or add it to the development files. These files might contain file references that only work in a compressed archive (`*.jar`). Furthermore, they might also contain encrypted expressions that you cannot read or change.

SAVING MPHPHB SOURCES DURING COMPILATIONS

When you select the **Save all MPHPHB sources during compile** checkbox in the **Compilation** section, then all compiled source files will also be saved.

PERFORMING ARGUMENT CONVERSION DURING COMPILE

When you select the **Perform argument conversion during compile** checkbox in the **Compilation** section, then the COMSOL software performs an argument conversion while compiling. See Component for more information about argument conversion.

Working with Builder Archives

Under the **Archives** node ( ) you find your compiled archives. You can add and remove archives manually from this list, but a compilation always adds the compiled archive. This list has several purposes: exporting archive as a plug-in, recompiling archives, and open the source files for editing. Once you have compiled the development files to a new archive, you should work with the source builder files in that archive, which are copies of the ones that you added to the development files. You find them under the **Source Builder Files** folder under the archive node. You can right-click any file under the **Source Builder Files** node and click **Open Selected** to edit the file.

Right-click the archive node and choose **Compile Archive** to recompile the entire archive. This replaces all builder files under the **Compiled Builder Files**, adds new or replaces existing icons, and updates the language files as described in the previous section. To compile an individual file in an archive, right-click the node of that file and choose **Compile File**. Compiling individual files is a bit limited and sometimes it is necessary to do a full compilation of the archive to update everything properly. Here is a list of changes that require a full update:

- Adding a new **Physics Interface** node.

- Adding a new file that other files link to through the **External Resources** branch.
- Changing icons of a physics interface, adding or changing menus and menu items of a physics interface, and other changes that alters the `plugin.xml` of the archive.
- To fully update the language resources for translation.

The two latter issues are often not required to do simple testing of the functionality of the physics interface, so it is probably safe to compile a single file although you might not see the correct icon, for example.

Choose the option **Compact Archive** to reduce the file size of the builder files in the archive by removing unnecessary data. Note that this operation does change the files under the **Source Builder Files** node. A compacted file always undergoes a compact operation before future save operations. To turn this off, open the file and select the root node of the file. In the **Physics Builder** section of the **Root** window, clear the **Compact file during save** checkbox.

Compare the entire archive against an SVN repository by choosing **Compare with Repository**. A **Connect to SVN Repository** dialog appears where you fill in the connection settings. In the **URL** field you enter the location in the SVN repository that contains the checked in archive (folder) with the same name as the selected archive. Also fill in the user credentials in the **Username** and **Password** fields. You can perform other comparisons between builder files in the **Archive Browser**:

- Select two archive nodes, right-click and choose **Compare Archives**.
- Select two builder file nodes from the **Development Files** node or from a **Source Builder File** node of an archive. Then right-click and choose **Compare Selected Files**.
- If there is an open builder file on the desktop, select one builder file, right-click and choose **Compare with Open Physics**. This compares the open file (local) with the selected file (remote).

COMSOL displays the result of the comparison in the **Comparison** section. A comparison displays the differences between a local file and a remote file. When comparing archives there are several such pairs of local files and remote files. The **Comparison** section contains a tree whose top nodes correspond to such a pair. The icon of the node tells if the files in a pair are equal ( ) or not ( ). Expand the node to browse the differences between two files. For each selected node, you can view its attributes in the table below the tree, and the bottom table displays the currently selected pair of local and remote file.

You use the option **Export As Plug-in** to export the archive to a compressed archive (`*.jar`), when you want to include it into a COMSOL installation. The next step is to

copy the compressed archive into the `plugins` folder of the COMSOL installation. To use the Run in Web Browser feature of the Application Builder for applications that use a physics interface created using the Physics Builder, the plug-ins also have to be placed in the `web/plugins` directory. Finally, you have to restart COMSOL before you can use the new plug-in.

In some system environments, the COMSOL installation folder can be write protected for ordinary users, so you cannot put the exported plug-in there without contacting the system administrator. There is an alternative location where you can put your compiled plug-ins. In your user home folder, COMSOL always creates a `.comsol` folder. Under this folder the alternative location is `<`*`version`*`>/archives`, where you replace `<`*`version`*`>` with the current version of COMSOL. The alternative folder named `archives` may not exist, and you must then create it first. Any compressed archive (with extension `.jar`) is loaded into COMSOL next time it starts.

To allow the physics interface to be used in applications running on COMSOL Server (see the *COMSOL Server Manual*), the compiled plug-ins should be placed in the `server/plugins` and `web/plugins` directories of the COMSOL Server installation directory, or in `<`*`version`*`>server/archives` (for example, `v64server/archives`).

Searching in Archives

By entering something in the **Filter** field in the **Archive Browser** section of the **Physics Builder Manager**, the browser's tree will update and only show folders and files that contains a file that contains the filter text. This update can take a few seconds, so the filtering starts when you leave the text field. The filter is not case sensitive.

The **Search in Archive** section presents a way to search through the physics builder files that you have placed under the **Archives** node in the **Archive Browser**.

The kind of search to perform is specified by the list with the options **Variables** (the default), **Node labels**, and **Override type**. The text field below the list box is where you enter the search query.

- When **Variables** is selected the search lists all nodes that declare, define, or contains a reference to the search query. The checkboxes under the combo box are used to specify if the search results should include declarations, definitions, or references.
- When **Node labels** is selected the search lists all nodes whose node label begins with the characters that are typed into the search query field.
- The **Override type** option specifies that the search should list all nodes that make use of the override type that you have entered as the search query.

Version Control and Version History

These tools are primarily intended for internal development of physics interfaces.

Under **Version Control**, you can choose a code repository from the **Repository** list. The available repositories are listed in the **Repository** list and depend on your environment. Click the **Set Connection Credentials** button ( ) to open the **Connect to SVN Repository** dialog and specify user credentials. There is also a new preference so your selected repository in the Repository list will be remembered between sessions. Just note that your preferences can sometimes be cleared after running tests.

Under **Version History**, you find a table of versions with the version number, date, author, files, and comment. Click the **Link History with Current Selection** button ( ) to update the version history when you select a new node in the **Archive Browser** tree. Click the **Update History to the Current Selection** button ( ) to update the version history to the current selection. Click the **Show Next 20** button ( ) to show the following 20 version history entries. Use the buttons underneath the table to compare two versions or to compare with a local copy.

3

Physics Builder Tools

This chapter provides a description of the tools in the Physics Builder that you can use to create custom physics interfaces for specific applications.

- Building Blocks
- External Resources
- Components
- Properties
- Physics and Multiphysics Interfaces
- Features
- Inputs
- Variables
- Equations
- Constraints
- Device Systems
- Operators and Functions
- Definitions Library
- Physics Areas
- Selections
- Extra Dimensions
- Auxiliary Definitions
- Mesh Defaults
- Study and Solver Defaults
- Result Defaults
- Migration
- Comments
- Elements

Building Blocks

Under the root of the Physics Builder tree there is the **Building Blocks** ( ) branch where you create a library of Components ( ), Properties ( ), Features ( ), and Multiphysics Couplings ( ) that you can build physics interfaces (including multiphysics interfaces).

These items are not used in any physics interface until they are referenced from a link node (see Component Link, Property Link, Feature Link, and Multiphysics Couplings).

Components

The **Components** branch ( ) has the following items:

- Component ( ). A collection of user inputs, variables, equations, and constraints. Items in this branch are available to any feature or property as component links.
- Physics Interface Component ( ). A collection of nodes that define something specific that you need in several places or that group nodes together to avoid long lists of nodes under a physics interface. Items in this branch are available to any physics interface as physics interface component links.
- Feature Component ( ). A collection of nodes that define something specific that you need in several places or that group nodes together to avoid long lists of nodes under a feature. Items in this branch are available to any feature.
- Code Editor ( ). Opens a text editor window for Java® code, providing a possibility to enter coded methods in Java.

The components are available to all Component Link nodes. The selection components are available as references in other selection components or in any other item using selections (for example Variable Definition nodes and Weak Form Equation nodes). If the component link is in the same builder file, use **Local** in the **Link from** list of the component link node. The components in the **Components** branch of another

Physics Builder file are also available, if included as an Import node under the External Resources branch ( ).

	Components

Properties

In the **Properties** branch ( ) you can add several Property nodes. The properties in this list are available to all Property Link nodes. If the property link is in the same builder file, use **Local** in the **Link from** list of the property link node. The properties in the **Properties** branch of another builder file are also available, if included as an Import node under the External Resources branch.

	Properties

Features

In the **Features** branch ( ) you can add several **Feature** nodes for defining physics features such as material models, boundary conditions, loads, and sources. The features in this list are available to all Feature Link nodes. If the feature link is in the same builder file, use **Local** in the **Link from** list of the feature link node. The features in the **Features** branch of another builder file are also available, if included as an Import node under the External Resources branch.

	Features

Multiphysics Couplings

In the **Multiphysics Couplings** branch ( ) you can add several **Coupling Feature** nodes. The coupling features in this list are available to all **Multiphysics Coupling** nodes. If the multiphysics coupling is in the same builder file, use **Local** in the **Link from** list. The coupling features in the **Multiphysics Couplings** branch of another builder file are also available if you include it as an Import node under the External Resources branch.

You can add several **Multiphysics Coupling** features under a **Physics Interface** that links to the same multiphysics coupling but uses different coupling types. The **Overriding Rule Settings** have to be the same for all these coupling features. This makes it possible to couple several instances of a physics interface when running COMSOL Multiphysics.

Physics and Multiphysics Interfaces

Code Editor

The **Code Editor** node ( ) provides the possibility to enter coded methods in Java® to perform tasks that you cannot accomplish with the nodes in the **Physics Builder** tree. A **Code Editor** node works like a Component node, so you include it through a Component Link node. Use of the code editor requires knowledge of the Java programming language and the COMSOL API for use with Java. Note that adding Java code usually makes it much harder to find and solve problems with your physics interface, so only use it when necessary. Click the **Compile** button ( ) or press F8 to compile the Java code.

The following Java interfaces are supported by the **Code Editor** node:

- Click the **Variable provider** button to create a `VariableDefinitionProvider`. Defines expressions and selections for a set of declared variables.
- Click the **Button handler** button to create a `ButtonPressedHandler`. Defines an action to perform when a button has been pressed.
- Click the **User input handler** button to create a `UserInputProvider`. Defines dynamic allowed values and default values for lists.
- Click the **Event handler provider** button to create a `ActionEventProvider`. Defines an action that is triggered when a parameter value has been changed.

Contact COMSOL support to learn more about the supported interfaces.

About Links

The Physics Builder include different types of links, such as Component Link, Property Link, Feature Link, Feature Component Link, and others. These links make it possible

to define common building blocks and then use them in the physics interfaces that you create. In the **Settings** window for these link node, **None** is the default option in the **Link** list for new and reset links. If you use the link in a physics interface that you create, you must replace **None** with an actual link to a node under Building Blocks, for example; otherwise, an error occurs when running the physics interface.

The link nodes include an indication in the upper-left corner, depending on the type of link it is. The indication is an **L** for a local link, an **E** for an external link, or a **J** for a Java® link. The links also display a warning indication if they do not link to anything.

Dependencies

The **Dependencies** window display information about dependencies for variables and user inputs for a number of nodes in the Physics Builder. For the selected node, these section display the declared and defined variables, variables it uses, user inputs it uses, and so on. To display the **Dependencies** window, right-click a node and choose **Dependencies** (ⓘ). The **Dependencies** window then appears as a separate window next to the **Settings** window unless you close it. If not applicable, the **Dependencies** window is empty. Otherwise, it contains a group of sections that provide an overview of the items that you have declared for the feature. The contents of these sections are read-only, and the sections are initially empty. The following sections are available:

- **Variable Declarations**. Lists all variable declarations found in the feature, excluding the ones declared through any component link. The table also provides information about the description, dimension, and physical quantity of the variables.
- **Variable Definitions**. Lists all variable definitions found in the feature, excluding the ones defined in component links. The table also specifies if the definition is an expression, parameter, or shape definition, and also displays the actual definition.
- **Necessary Variables**. Lists the variables found in expressions. This list corresponds to all the variables that must exist for this feature to work properly in all cases. Some of the variables can be declared by the feature itself, but others must be declared elsewhere.
- **Dependent Variable Definitions**. Lists the dependent variables defined by this feature with their names and physical quantity. All these definitions must have a corresponding declaration under the physics interface.

- **Necessary Property User Inputs**. Lists the user inputs read from properties found in this feature. These properties and user inputs must exist in any physics interface that uses this feature.
- **User Inputs**. Lists the added user inputs in this feature with their array type, dimension, and description, excluding any user inputs added by any component links.

These sections provide useful information about the feature — for example, how you can use a feature in different physics interfaces.

External Resources

To avoid reimplementing features, properties, or components, you can use items stored in a different builder file. All items that you implement under the **Building Blocks** branch in a builder file, can be used by any other builder file that imports it. Under **External Resources** ( ) you can add Import nodes ( ) for importing other builder files.

Import

Use the **Import** node ( ) to import other builder files. The **Settings** window contains the following section:

IMPORT FILE

In the **File** field, you enter the path to the builder file you want to import. As an alternative, you can also click **Browse** ( ) and choose a file from the system. Then click **Open** to import the file. With the **Import** button, you can reimport the file. This is necessary if you have changed the selected file from another COMSOL session.

Definitions Library

In the **Definitions Library** branch ( ) custom material properties groups can be added and defined using available or additional material properties. You can also create physical properties and other definitions that are used but are not part of a physics interface.

There are these subbranches: Physics Areas, Selections, Extra Dimensions, and Auxiliary Definitions.

Components

In this section:

- Creating Components
- Component
- Physics Interface Component
- Feature Component
- Local Parameters
- Usage Condition
- Equation Display
- Component Link
- Feature Component Link
- Extra Dimension Link
- Event Listener
- Event Handler
- Multiphysics Warnings and Errors

Creating Components

As an alternative to directly defining variables, user inputs, and so forth, under a feature or property, it is possible to create a collection of such items. This collection is a **Component** ( ), which is added under Building Blocks ( ) to the **Components** ( ) branch in the Physics Builder tree.

It is convenient to use a Component when you want to reuse user inputs, for example, in several different features. Grouping variables into components can also give a better overview if you have a feature containing a lot of variables. You can, for example, collect all user inputs and groups used in a section, and use a Component Link in the feature or property that needs this section. A Component can contain the same items that a Generic Feature and Property can, with a few exceptions. For example:

- Dependent Variable Definition
- Variable Declaration
- Variable Definition
- User Input
- User Input Group
- Material Property
- Feature Input
- Weak Form Equation
- Constraint

Component

Use the **Component** node ( ) to collect nodes that define something specific that are needed in several places, or to group nodes together to avoid long lists of nodes under a feature or property.

To add a **Component**:

- In the **Home** toolbar click the **Component** button ( ).
- Under **Building Blocks**, right-click **Components** and add it from the context menu.

To add a wide variety of features, right-click the **Component** node or click the buttons on the **Component**, **Model**, or **Physics Interface** toolbars. The available features are described throughout this chapter.

	Variables, Equations, Inputs, Usage Condition, Equation Display, Component Link, Extra Dimension Link, Integration Over Extra Dimension, Operators and Functions, Elements, and Device Systems.

The **Settings** window has a section to specify parameters.

For information about the **Dependencies** window's information about dependencies, see Dependencies.

PARAMETERS

Specify parameters by filling in the columns **Name**, **Description**, and **Default expression**. Select the **Read only** checkbox to prevent **Component Link** nodes from altering the expression entered in the **Default expression** field. This is useful when a complicated parameter expression is needed by the component, but the expression is not something that the **Component Link** should change. Otherwise, a parameter expression can be changed for each component link that uses this component.

Press Ctrl+Space in the **Default expression** field underneath the table or click the **Insert Expression** button ( ) in the toolbar above to open an insert expression menu of available expressions to insert. To help with distinguishing between normal parameters and target parameters in **Component Link** nodes, there are two submenus in the insert expression menu: the **Arguments** and **Target Arguments** submenus list both parameter name spaces with their respective prefixes. For **Components** nodes, only the **Target Argument** submenu is available for the **Default expression** column. In all other nodes, you only find the **Arguments** submenu.

There is also a warning in the **Expression** and **Default expression** columns when the COMSOL software detects obvious mistakes in accessing parameters (for example, missing parameters, missing target parameters, and incorrect use of the `arg` prefix when it probably refers to a target parameter).

Click the **Correct target parameters...** button (P_i) a conversion tool that can do the following:

- In **Component Link** nodes it finds all use of `arg.`*xxx* where *xxx* is not available in the parent's parameters and is available in the target's parameters. It replaces all those names with `targ.`*xxx*.
- In **Component** nodes it finds all use of `arg.`*xxx* in the default expressions where *xxx* is available in the component's parameters. Except for a few exceptions it will replace those cases with `targ.`*xxx*. The exceptions are:
  - The definition is for the parameter with the same name (for example, *xxx* `= arg.`*xxx)*.
  - The replacement cause an obvious circular dependency (for example, `AA = arg.BB`, `BB = str.append(targ.AA, '_suffix')`).
- For all read-only expressions that only contain `targ.`*xxx* (after above replacement) and `loop.`*xxx* it moves the parameter definition to a new **Local Parameters** node. Note that it is enough that the default expression contains one `arg.`*xxx* that will not be replaced to skip the move.

You can also do this conversion while you compile an archive in the **Physics Builder Manager**.

SETTINGS

From the **Loop** list, select **None** (the default), **Parameter**, **Selection**, or **Pair**.

- Select **Parameter** to activate looping over the elements of a dependent variable. Enter the **Name**, **Description**, and **Default expression** in the corresponding columns of the table.
- Select **Selection** to activate looping over the selections that was defined by the **Component Link**. Enter a name for the selection in the **Name** field.
- Select **Pair** to loop over all pairs with this component. This is equivalent to the parameter syntax `par.pairs` that also does a loop of all pairs. The Pair option is a specialized options for this parameter syntax.

SCOPE

In this section you can define a local scope for the `scope` prefix. Use the **Add** (+)and **Delete** ( ) buttons to add or remove the row for the `scope` prefix to the table, which is equivalent to activating and deactivating the possibility to use this prefix. In the **Description** column, you can enter a text explaining what the `scope` prefix is used for. Inside the component, the `scope` prefix can be used as any other scope prefix in, for example, the settings for a **Variable Declaration** node.

Entering Names and Expressions

Physics Interface Component

In the **Physics Interface Component** node ( ) you can collect nodes that define something specific that you need in several places, or to group nodes together to avoid long lists of nodes under a physics interface.

To add a **Physics Interface Component**:

- In the **Home** toolbar click the **Physics Interface Component** button ( ).
- Under **Building Blocks**, right-click **Components** and add it from the context menu.

To add a wide variety of features, right-click the **Physics Interface Component** node or click the buttons on the **Home** or **Physics Interface** toolbars. The available features are described throughout this chapter.

Variables, Feature Link, Property Link, Physics Interface Component Link, Multiphysics Coupling, Usage Condition, Equation Display, Mesh Defaults, Study and Solver Defaults, Result Defaults, Auxiliary Settings (Physics Interface), Menu, and Item and Item / Button.

The **Settings** window has a section to specify parameters.

For information about the **Dependencies** window's information about dependencies, see Dependencies.

PARAMETERS

Specify parameters by filling in the columns **Name**, **Description**, and **Default expression**. Select the **Read only** checkbox if you do not want to make it possible to alter the

content in the **Default expression** column by links. This can be useful when more complicated parameter expressions are needed by the component, but they are not something that the link should change. Otherwise, a parameter expression can be changed for each component link that uses this component.

Entering Names and Expressions

Feature Component

In the **Feature Component** node ( ) you can collect nodes that define something specific that you need in several places, or to group nodes together to avoid long lists of nodes under a feature. You can define or link to the following feature and components from this node:

- Features for domains, boundaries, and so on.
- Multiphysics Feature
- Device Model Feature.
- Mesh Defaults, Study/Solver Defaults, and Result Defaults.
- Feature Link and Component Link

To add a **Feature Component**:

- In the **Home** toolbar click the **Feature Component** button ( ).
- Under **Building Blocks**, right-click **Components** and add it from the context menu.

To add a variety of features (see above), right-click the **Feature Component** node or click the buttons on the **Home** or **Physics Interface** toolbars. The available features are described throughout this chapter.

Variables, Feature Link, Property Link, Usage Condition, Equation Display, Mesh Defaults, Study and Solver Defaults, and Result Defaults.

The **Settings** window has a section to specify parameters.

For information about the **Dependencies** window's information about dependencies, see Dependencies.

PARAMETERS

Specify parameters by filling in the columns **Name**, **Description**, and **Default expression**. Select the **Read only** checkbox if you do not want to make it possible to alter the content in the **Default expression** column by links. This can be useful when more complicated parameter expressions are needed by the component, but they are not something that the link should change. Otherwise, a parameter expression can be changed for each component link that uses this component.

Entering Names and Expressions

Local Parameters

Add a **Local Parameters** (P_i) node when you have a lot of parameter expressions that you have marked with a **Read only** flag and that contains expression in the target's name space (using the `targ` prefix), for example. Then add them to a **Local Parameters** node under the **Component** node.

The **Local Parameters** node define parameters for **Component** nodes that are neither modifiable nor visible to **Component Link** nodes that refer to the component. The **Parameters** table defines parameters in addition to the parameters defined by the **Parameters** table in a **Component**. It is not allowed to redefine a parameter, and the COMSOL software shows an error if a parameter name already exist. In the rest of the **Component**, all parameters defined by **Local Parameters** nodes can be used as any parameter using the `arg` prefix.

In general, to add a **Local Parameters** node, right-click a **Component**, property, or feature node and add it from the context menu.

PARAMETERS

You can add local parameters to the table with a **Name**, **Description**, and **Expression**. For the expression, you can edit it in the **Expression** text field underneath the table, where you have access to syntax highlighting and the possibility to use multiple lines. See the *COMSOL Multiphysics Reference Manual* for more information about syntax highlighting. Use the buttons underneath the table for moving up and down, deleting, and loading and saving local parameters from and to a file.

Usage Condition

The **Usage Condition** ( ) node (the icon will vary depending on the type of condition) puts a condition that enables or disables its children. You can use the condition in a variety of contexts — for example, for variable definitions under a feature or for solver and mesh defaults. The kind of conditions you can use differ between contexts because some conditions cannot be evaluated in all contexts.

In general, to add a **Usage Condition**, right-click a node and add it from the context menu.

Component Link nodes can exist under a **Usage Condition** node with the limitation that the target Component node adds no user inputs, sections, or other user input groups. If it does, error message appears.

The **Settings** window has one section. The description covers all possible conditions, but some are not visible based on the context.

USAGE CONDITION

Select the **Invert condition** checkbox to invert (negate) the defined condition. If selected, the icon included an overline to indicate an inverted condition.

Select a **Condition**: **Explicit**, **And condition**, or **Or condition**. For **And condition** and **Or condition** define a usage condition that evaluates as a Boolean operation (*and* or *or*) between other usage conditions. Add usage conditions to the **Input condition** list. For any choice, select the **Invert condition** checkbox to invert the entire condition.

The following settings are for an **Explicit** condition.

Restrict to Space Dimensions

Select the **Restrict to space dimension** checkbox to enable a condition on the geometry dimension used by the model in the Model Builder. Add any of the following: **0D**, **3D**, **2D**, **Axial symmetry (2D)**, **1D**, and **Axial symmetry (1D)**.

Restrict to Geometric Entity Levels

Select the **Restrict to geometric entity levels** checkbox to enable a condition on the geometric entity level of the context, which can be the entity level of a feature. The allowed levels are **Global**, **Domain**, **Boundary**, **Edge**, and **Point**.

For results and mesh defaults, the checkbox is called **Restrict to entity dimensions** and has the options **Volume**, **Surface**, **Line**, **Point**, and **Global**.

Restrict to Study Types

Select the **Restrict to study types** checkbox to enable a condition on the study type currently solved for. This is applicable for usage conditions under Features, Properties, Study and Solver Defaults, and Result Defaults. A common example is when you want to define the result of a time derivative such as:

```
timeDerivative(A)
```

in time-dependent study types but

```
iomega*A
```

in frequency-domain study types. The most important study types are **Stationary**, **Time Dependent**, **Frequency Domain**, **Eigenfrequency**, and **Eigenvalue**. There are also other alternatives, but some of these require additional licenses or modules.

Study and Study Step Types in the *COMSOL Multiphysics Reference Manual*

User Input

This section depends on user inputs in the parent feature, parent property, or some property. Select the **User input** checkbox to enter the following.

Choose an option from the **Specify user input** list: **By reference**, **By name**, or **In expression**.

If the usage condition is under a feature or property, which might contain other user inputs, choose **By reference** to directly refer to any of those user inputs by in the list. Choose an option from the **From** list: **User input from this feature** (the default) or **User input from this property**. For **User input from this property**, enter the **Property** that contains the user input in the field. Then choose the **User input** and the **User input condition**. The options available depend on the user input referred to, but the condition can either check if the **User input is active**, or if the **User input has any of certain values**, in which case enter these in the **Values** table.

Select **By name** to enter a name in the **User input** field. Choose an option from the **From** list: **User input from this feature** (the default), **User input from this study step**, or **User input from this property**. For **User input from this property**, enter the **Property** that contains the user input in the field. Also choose the **User input condition** as described above.

For usage conditions under Study and Solver Defaults, Result Defaults, and Mesh Defaults, the **By name** option is the only way to refer to a user input. Furthermore, they

can only refer to user input under a property, so there is no such choice either. Instead, there is an option to choose the type of condition in the **Condition on** list. The option **User input in property** enables the usage condition on a user input under a property. With the option **Feature is active**, the usage condition is true if there exists an active feature of a certain type. You specify the type in the **Feature type** field. Select the **Condition is not fulfilled for undefined references** checkbox to if you want the condition to be treated as not fulfilled instead of throwing an error if the property is undefined.

Select **In expression** as a general tool that can evaluate an expression of relations and Boolean operators that are entered in the **Condition** text field. It also supports some special functions and names, summarized in the following table:

TABLE 3-1: VALID SYNTAX IN THE CONDITION FIELD.

SYNTAX	DESCRIPTION
`<cond 1> && <cond 2>`	Logical *and* between conditions.
`<cond 1> || <cond 2>`	Logical *or* between conditions.
`!<cond>`	Logical *not* of a condition.
`<value 1> == <value 2>`	True if values are equal.
`<value 1> != <value 2>`	True if values are different.
`isActive(<input>)`	Active status of the given input.
`contains(<array>,<value>)`	True if the value exist in the given array.
`{<value 1>, <value 2>, …}`	Array of values.
`'<string>'`	String value.
`[par.]<input name>`	Value from an input in the current feature or property. The `par` prefix is optional.
`[par.]<property>.<input name>`	Value from an input in property. The `par` prefix is optional.
`[par]..<input name>`	Value from an input in the parent feature. The `par` prefix is optional.
`arg.<argument name>`	Value from an argument evaluation.
`entity.sdim`	Returns the space dimension as an integer.
`entity.edim`	Returns the geometric entity level for the current physics feature as an integer.
`entity.isAxisymmetric`	True if the current geometry is axisymmetric (2D or 1D),
`<int 1> + <int 2>*<int 3>`	Simple integer expression (supports: `+`, `-`, `*`, `/`, and `%`).

TABLE 3-1: VALID SYNTAX IN THE CONDITION FIELD.

SYNTAX	DESCRIPTION
`(<cond 1> || <cond 2>) && <cond 3>`	Use parentheses to override precedence.
`isStudyStep(<step 1>, <step 2>)`	True if the current study step solved for is either a `<step 1>` study step or a `<step 2>` study step (`'Stationary'` or `'Transient'`, for example. The identifier of the study step is the same one used when creating new study steps from the external API.

There are some special rules for these expressions that differ from ordinary tensor expressions:

- The `par` prefix is the default prefix and can be omitted in some situations. An input named `par` have to be accessed with `par.par`.
- All string values have to be typed within quotation marks (') unless they are numbers. A number within quotation marks is different from the number itself (for example, `'1' == 1` is false).
- A Boolean input can act as a condition that returns true or false, and can be used directly in logical expressions. Boolean inputs use the values 0 and 1 for false and true, respectively, so a Boolean input as a condition is equivalent to the expression `<input> == 1`.
- The operator `isActive` is only allowed in Usage Condition nodes. Using the operator in another context results in an error.
- The only allowed prefixes are `par`, `arg`, and `entity`. All other prefixes are not recognized and most likely cause an unknown input error.

Complex expressions with several inputs may result in poor performance for updates of the user interface due to long chains of event handling. A complex enable-disable logic might also confuse the user.

The **Require input is active** checkbox is selected by default. It is only applicable when specifying a user input to check by reference or by name, not for expressions. When selected, the activation condition is only true if the checked user input is also active as decided by its activation conditions. For expressions, you can achieve the equivalent logic using the `isActive` operator.

Require Field

This section is available for usage conditions under Study and Solver Defaults. When you select the **Require field** checkbox, you can specify a dependent variable reference and a physical quantity. See Dependent Variable Definition for more information about these settings.

Equation Display

With the **Equation Display** (∆u) node you can enter pretty-print equations in LaTeX that show up in the **Equations** section of a physics interface or feature in the Model Builder.

To add an **Equation Display**, first add a node where it is available, for example, components, physics interfaces, multiphysics interfaces, features, or properties, then right-click the node and choose it from the context menu.

You can also add an **Equation Display** under the **Auxiliary Definitions** branch. This is the button available in the **Home** toolbar. See Equation Display (Auxiliary Definitions).

The **Settings** window has the following sections:

DECLARATION

If you select the **Allow named references to equation** checkbox, the **Name** field will be the name used to reference to this equation display from other equation displays using the `symbref` command. If you clear this checkbox, the tag of the equation display will be used. Apart from named references, the automatic or given name is also used when you use equation displays in user input groups. In this case it is important that the name is not in conflict with other equation display names in the same physics feature or physics property also used in input groups. See also References in Equation Expressions.

EQUATION

Enter the LaTeX-encoded expressions in the **Enter equation in LaTeX syntax** field. There are tools you can use to get help entering specific LaTeX commands.

- Press Ctrl+Space to get lists of predefined operations to choose from.
- Click the **Add Expression** (+) or **Replace Expression** ( ) toolbar buttons for the same list of operations.

- Click the **Add Expression** toolbar button to concatenate expressions to the entered expression, and **Replace Expression** to overwrite.
- See a preview of the entered expression under the **Equation preview**.
- Use the **Refresh equation preview** button ( ) to update this preview to force it to be up to date with the expression entered in the **Enter equation in LaTeX syntax** field.

References in Equation Expressions

It can be useful to reuse parts of equations or combine multiple equation expressions into one equation. This is achieved using the syntax

```
\symbref{eq}
```

in an expression. This inserts the equation expression from the equation display node with the name `eq`. This referenced node can be local (that is, defined in the same feature or property as the referee), or it can be defined under the Definitions Library branch. It is useful to access equations from the **Definitions Library** for a file that has been imported under the External Resources node. In this case, the name of the equation should be prefixed with the tag of the import node, for example:

```
\symbref{imp1.eq}
```

It is also possible to insert the name of a dependent variable into an equation expression. If the default name of a dependent variable is `u`, then use the following syntax to access the current user-defined name of that dependent variable:

```
\symbref{dep.u}
```

See Mathematical Symbols and Special Characters in the *COMSOL Multiphysics Reference Manual* for information about available LaTeX symbols and commands.

GUI OPTIONS

This section controls how the equation is displayed in the user interface. To include an image under the equation select the **Include image below equation** checkbox and enter a file path to an **Image file**. Select the **Exclude from equation section** checkbox if the equation should not be displayed in the standard **Equation** section.

This option is useful when the **Equation Display** node is created only to be displayed in a user input group.

Component Link

Use a **Component Link** ( ) to include all items defined within a component under the **Components** branch ( ) as if they were part of the feature containing the link; see Components.

To add a **Component Link**, first add a Component, then:

- In the **Component** toolbar, click the **Component Link** button ( ).
- Under **Components**, right-click **Component** and add it from the **Links** submenu.

The **Settings** window has the following additional section:

SOURCE COMPONENT

In the **Links from** list, choose where to look for a certain property. Available options are:

- **Building blocks**. Lets you choose among the components listed under **Components** in the Building Blocks branch. Choose the component from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Choose from built-in physics interfaces available to the Physics Builder. Select the main resource (COMSOL product) from the **Package** list. For each resource, choose an interface from the **Link** list. Only the currently published interfaces are available.
- **External resources**. Lets you choose among the components listed in an imported builder file under the External Resources branch. Choose the file from the **Imported file** list. The **Link** list contains all components found in the **Building Blocks** > **Component** branch of the selected file.

When the source component has parameters declared, these are shown in the **Component parameters** table. The value in the **Expression** column changes the parameter value for this particular instance of the link. Other links to the same source component can use a different expression. If the source component uses a loop parameter, the **Loop parameter** table appears. Enter the name of the dependent variable in the **Expression** column.

Entering Names and Expressions

COMPONENT SELECTION

From the **Selection parameter** list, select one of the following options:

- **None** (the default), to not use a selection parameter.
- **Use selection parameter**, to use the **Output entities** as an input selection for the linked **Component** node.
- **Use selection loop over product selections**, to create a loop over all product selections of the parent and use the **Output entities** as an input selection for the linked **Component** node.
- **Use selection loop over nonproduct selections**, to create a loop over all nonproduct selections of the parent and use the **Output entities** as an input selection for the linked **Component** node.
- **Use selection loop over all selections**, to create a loop over all selections of the parent and use the **Output entities** as an input selection for the linked **Component** node.

To use a **Component Link** as a selection loop, the **Loop** list's setting in the linked **Component** node must set to **Selection**.

When linking from a loop component into another loop component, a **Policy for links in loop components** list becomes available. From that list, choose one of the following options:

- **Call link for each pass**. This is the logical approach were the link is executed in each loop pass of the parent loop component. This option is also applicable for nested links to loop components and simply produces a double loop.
- **Pass along current value for same loop otherwise call in first pass**. This option is only applicable for links to loop components and behaves a bit differently depending on what you loop over. If the linked component loops over the same source as the parent loop component, the current loop value is passed along to the linked component for each loop pass. The link is only executed once per loop pass, so there will be no double loop. The effect is the same as if you would pass the loop parameter to a parameter in an ordinary link, but you then cannot use the loop prefix. If the loop sources are different it behaves like the first option: the link is only called in the first loop pass and does a full loop for that link.

SCOPE SETTINGS

From **Component Link** nodes that refer to a component with a `scope` prefix, you can alter the `scope` prefix to any of the other known scope prefixes (such as `phys`, `item`,

and `parent`) in the **Scope** column. It is not possible to use any of the prefixes that do not evaluate to a scope (such as `par`, `entity coord`, and `arg`). The **Suffix** column provides a possibility to define a suffix to all variables that use the scope prefix (for example, `scope.B => root.comp1.ht.B_equ` when the **Scope** value is set to `phys` and the **Suffix** is set to `_equ`.

Feature Component Link

Use a **Feature Component Link** ( ) to include all items defined within a component under the **Components** branch ( ) as if they were part of the feature containing the link; see Components.

To add a **Component Link**, first add a Component, then:

- In the **Component** toolbar, click the **Component Link** button ( ).
- Under **Components**, right-click **Component** and add it from the **Component** node's context menu.

The **Settings** window has the following additional section:

SOURCE COMPONENT

In the **Links from** list, choose where to look for a certain property. Available options are:

- **Building blocks**. Lets you choose among the components listed under **Components** in the Building Blocks branch. Choose the component from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Choose from built-in physics interfaces available to the Physics Builder. Select the main resource (COMSOL product) from the **Package** list. For each resource, choose an interface from the **Link** list. Only the currently published interfaces are available.
- **External resources**. Lets you choose among the components listed in an imported builder file under the External Resources branch. Choose the file from the **Imported file** list. The **Link** list contains all components found in the **Building Blocks** > **Component** branch of the selected file.

When the source component has parameters declared, these are shown in the **Component parameters** table. The value in the **Expression** column changes the parameter value for this particular instance of the link. Other links to the same source

component can use a different expression. If the source component uses a loop parameter, the **Loop parameter** table appears. Enter the name of the dependent variable in the **Expression** column.

Entering Names and Expressions

Extra Dimension Link

Use an **Extra Dimension Link** to include all items defined within an extra dimension defined in the **Definitions Library**, for example, under the **Components** branch ( ) as if they were part of the feature containing the link.

To add an **Extra Dimension Link**, first add a Component, then right-click **Component** and add it from the context menu's **Links** submenu.

SOURCE EXTRA DIMENSION

In the **Links from** list, choose where to look for a certain property. Available options are:

- **Definitions library**. Lets you choose among the extra dimension nodes defined under **Definitions Library** > **Extra Dimensions**. Choose the extra dimension node from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list. With this option, see **Attachment Selection** below for additional settings.
- **External resources**. Lets you choose among the extra dimensions listed in an imported builder file under the External Resources branch. Choose the file from the **Imported file** list. The **Link** list contains all extra dimension nodes found in the selected file. With this option, see **Attachment Selection** below for additional settings.
- **Reference input**. Use this option if you want to define a link to another extra dimension source. With this option, see **Reference** below for additional settings. Also, the **Extra dimensions parameters** table is not available.

When the source extra dimensions has parameters declared, these are shown in the **Extra dimensions parameters** table. The value in the **Expression** column changes the parameter value for this particular instance of the link. Other links to the same source extra dimensions can use a different expression. If the source extra dimensions uses a

loop parameter, the **Loop parameter** table appears. Enter the name of the dependent variable in the **Expression** column.

ATTACHMENT SELECTION

Choose an option from the **Selection** list for the attachment selection to use for the linked extra dimension: **From parent** (the default), **Global**, **Operation**, **From definitions library**, **Top level entities applicable to parent**, or **Operation on sibling-feature selections**.

For any choice, except **Global**, choose the **Output entities**: **Selected entities** (the default), **Adjacent domains**, **Adjacent boundaries**, **Adjacent edges**, **Adjacent points**, **Mesh boundaries**, **Adjacent edges**, **Restricted to geometric entity types**, or **Restricted to frame type**.

- For **Adjacent boundaries**, select an option from the **Restrict to** list: **All adjacent boundaries**, **Exterior boundaries to the domain selection**, **Interior boundaries to the domain selection**, **Exterior boundaries whose up side is in the domain selection**, or **Exterior boundaries whose down side is in the domain selection**.
- For **Adjacent edges** or **Adjacent points**, select an option from the **Restrict to** list: **All adjacent entities**, **Exterior entities to the selection**, or **Interior entities to the selection**.
- For **Restricted to geometric entity types** choose the **Allowed entity types** in the table, **Interior** or **Exterior**.
- For **Restricted to frame type** choose a **Frame type**: **Material** (the default), **Mesh**, **Geometry**, or **Spatial**.

Operation

For **Operation**, choose the **Operation type**: **Union** (the default), **Intersection**, **Difference**, or **Complement**. Then define the **Input selections**, and for Difference the **Selections to subtract**. Select options from the **Output entities** list as defined above.

From definitions library

For **From definitions library**, choose an option from the **Link** list and select options from the **Output entities** list as defined above.

Operation on sibling-feature selections

For **Operation on sibling-feature selections**, choose the **Operation type**: **Union** (the default), **Intersection**, **Difference**, or **Complement**. Then define the **Input feature types**, and, for **Difference**, the **Feature types to subtract**. Select options from the **Output entities** list as defined above. Instead of writing the feature ID of the physics feature to use in the selection, you can also write a path of IDs. The first ID is then the physics ID followed by one or several feature IDs. Regular expressions are accepted to match the IDs against a pattern. If the current entity is a coupling feature, the path syntax also

accepts a coupling type instead of the physics ID. The coupling type must be preceded with the multiphysics prefix (`mph.`) and uses the coupling feature's selected physics of this coupling type. Here are some examples:

- `FeatureB`: Looks for the selections of features with ID `FeatureB`.
- `InterfaceA/FeatureB/FeatureC`: Looks for the selections under `FeatureB` with ID `FeatureC`. The interface ID must be `InterfaceA`.
- `\w+/FeatureB/Feature[A-C]`: Looks for the selections under `FeatureB` with IDs that start with `Feature` and end with any of the letters A, B, or C. The interface ID can be any nonempty sequence of word characters.
- `mph.TypeA/Feature[A-C]`: Looks for selections of features under the interface of coupling type `TypeA` in a coupling feature. The features must have IDs that start with `Feature` and end with any of the letters A, B, or C.

It is possible to write the path syntax with a leading slash (`/`), which will always treat the path as an absolute path starting with the physics interface type or a coupling type. This can be used if you want to use the selection of the physics interface, and then you can type, for example: `/typeA`, which gets the selection of interface with the given type, whereas `/mph.couplingTypeA` gets the selection of the interface representing the given coupling type.

REFERENCE

To specify the reference input for the extra dimension link, choose, from the **Specify reference input** list, **By reference** (the default) or **By name**.

If you choose **By name**, you can choose one of the following options from the **From** list: **Containing feature or property**, **Parent feature, This feature or any ancestor**, or **User input from another property**. For the last option, specify the property in the **Property** field. Select a reference input from the **Reference** list (if specified by reference) or type it in the **Reference** field (if specified by name).

From the **Extra dimension category** list, choose the category for the extra dimension source: **General** (the default), **Layered materials**, or **Porous materials**. If you select one of the two latter options, an **Integration order** list becomes available. By default, the integration order is determined automatically. To set an integration order manually, select **Custom shape order** instead of **Automatic** from the **Integration order** list and then

add an order as a positive integer in the **Order** field (default: 2). You can also select **From discretization** to specify the name of a discretization in the **Discretization** field.

	It is only possible to add selections that are from the current physics interface or a physics interface linked from a multiphysics coupling feature (this was also noted in the previous row).

	A physics feature can only match interface IDs of the physics that it belongs to. A coupling feature can only match interfaces that are part of its selected interfaces

	• Entering Names and Expressions • Integration Over Extra Dimension • Using Extra Dimensions in the *COMSOL Multiphysics Reference Manual*

Event Listener

You can add an **Event Listener** node ( ) to define event handlers as **Event Handler** subnodes (see Event Handler) that can listen to a parameter event, an attribute event, or a list event and run the handlers to set or reset a parameter value or run a coded method. The handler can be triggered with a condition.

To add an **Event Listener** node, right-click a **Component**, **Property**, or any of the physics feature nodes and select it from the context menu.

DEFINITION

From the **Specify object to listen to** list, choose **By reference** (the default) or **By name**.

From the **From** list, define from where to take the event listener's event:

- Choose **User input from this property** (the default) to choose any available user input defined in this **Property** (for event listeners under a **Property** node only) from the **User input** list, if you have chosen **By reference**, or type it into the **User input** field, if you have chosen **By name**.
- Choose **User input from another property** to choose a user input from another **Property** node, which you choose from the **Property** list, if you have chosen **By**

reference, or type it into the **Property** field, if you have chosen **By name**. Then choose the user input from the **User input** list, if you have chosen **By reference**, or type it into the **User input** field, if you have chosen **By name**.

- Choose **Entity attribute** to listen to an attribute of the entity: Select **Touched** (the default), **Label**, or **Tag** from the **Attribute** list, if you have chosen **By reference**, or type an attribute into the **Attribute** field, if you have chosen **By name**.
- Choose **List of children** to listen to operations on the list of children under the current context. If the context is a Property, the children represents the physics features under the physics interface. If the context is a physics feature, the children represents the subfeatures under that physics feature. Select **All list events** (the default), **Add child (after initialization)**, **Remove child**, or **Move child** from the **List event** list. Note that both the **By reference** and the **By name** options show this list.

If you have chosen **By name** from the **Specify object to listen** list, select the **Do not listen to undefined references** checkbox, if desired.

Event Handler

You can add an **Event Handler** subnode ( ) under an **Event Listener** node to define an event handler that can listen to a parameter event or an attribute event and run the handler to set or reset a parameter value or run a coded method. The handler can be triggered with a condition. To add an **Event Handler** node, right-click an **Event Listener** node and select it from the context menu.

COMMAND

From the **Command type** list, choose **Set value** (the default) to set a value, **Reset to default**, or **Command handler from code editor**.

For **Set value** and **Reset to default**, the following additional settings are available:

- From the **Specify parameter** list, choose **By reference** (the default) or **By name**.
- From the **From** list, define from where to take the event handler's parameter: Choose **User input from this property** (the default) or **User input from another property**. In the latter case, choose a property from the **Property** list, if you have chosen **By reference**, or type it into the **Property** field, if you have chosen **By name**. Then choose the user input from the **User input** list, if you have chosen **By reference**, or type it into the **User input** field, if you have chosen **By name**.
- If you have selected **By name** from the **Specify parameter** list, select the **Skip action for undefined references** if desired.

- If you have selected **Set value** from the **Command type** list, enter an expression for the value to set in the **Expression** field.
- Select the **Condition to run** checkbox to enter a condition for the event handler to run in the **Condition** field.

For the **Command handler from code editor** command type, the following additional settings are available:

In the **Links from** list, you choose where to look for a certain property. Available options are:

- **Building blocks**. Lets you choose among the properties listed under the **Properties** branch in the **Building Blocks** branch. You choose the property from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Lets you choose among built-in properties that are available to the Physics Builder. In the **Package** list you choose the main resource to use properties from. For each resource, you have a list of properties in the **Link** list to choose from. You can only choose among the currently published properties.
- **External resources**. Lets you choose among the properties listed in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all properties found in the **Building Blocks** > **Properties** branch of the selected file.

Multiphysics Warnings and Errors

You can add custom warnings and errors by adding **Multiphysics Warning** ( ) and **Multiphysics Error** ( ) nodes. Those nodes are available by right-clicking a **Component** node or a **Usage Condition** node under a **Component** node. When the process of generating equations and variables reaches any of these nodes, the solver will either stop with an error or show a warning (not stopping). In the nodes you can define an error message and an arbitrary number of parameter-value pairs. The latter option provides extra information to the message but is not intended for any longer text. Any parameter-value pairs that have a parsed text that becomes empty will not show. An empty parameter name is allowed. A default node name parameter Node is always included and describes the node in the **Model Builder** where the error or warning originates from.

These nodes are typically added under a usage condition, so if the condition is fulfilled, the error or warning will have an effect. When a user starts to compute a solution, the error or warning node will appear under the **Compile Equations** node in the **Model Builder**.

WARNING OR ERROR

In this section, type the warning message or the error message in the **Message** field. Optionally, add one or more parameters and corresponding extra information in the **Parameter** and **Text** columns, respectively.

Properties

In this section:

- Property
- Property Link

Property

A **Property** ( ) contains user inputs and variables that are important to the entire physics interface. A property instance always exists in only one instance for a physics interface. Any variables or equations defined by a property typically inherit the selection of the physics interface, although it is possible to change this.

To add a **Property**:

- Under **Building Blocks**, right-click the **Properties** node and select it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes and select it from the context menu.

Right-click the **Property** node to add many other features from the context menu. The **Settings** window has the following sections:

IDENTIFIER

The text you write in the **Description** field is only used as the default section description. If you create one or several manual sections using the User Input Group, the description in the **Description** field is unused. The **Type** is a unique string that identifies the property, which must be unique among all properties supported by a physics interface.

RESTRICTIONS

In the **Allowed space dimensions** list you can define what space dimensions this particular property can be used in. The option **Same as parent** (the default option) means that the feature supports the same space dimensions as the physics interface. If you want to control the space dimensions manually, choose **Customized** from the list. You can then select from a list of all space dimensions.

You can also impose a special restriction on study types for this property. If you try to solve a problem for a property that does not support the current study type, it does not add any contributions to the model. Choose **Customized** from the **Allowed study types** list to control the supported study types manually by selecting from a list of study types. The option **Same as parent** (the default option) means that the property supports the same study types as the physics interface.

Property Link

The **Property Link** ( ) refers to a common definition of a Property.

To add the **Property Link** node right-click a **Physics Interface** or **Multiphysics Interface** nodes and select it from the context menu. The **Settings** window has the following section:

SOURCE PROPERTY

In the **Links from** list you choose where to look for a certain property. Available options are:

- **Building blocks**. Lets you choose among the properties listed under the **Properties** branch in the **Building Blocks** branch. You choose the property from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Lets you choose among built-in properties that are available to the Physics Builder. In the **Package** list you choose the main resource to use properties from. For each resource, you have a list of properties in the **Link** list to choose from. You can only choose among the currently published properties.
- **External resources**. Lets you choose among the properties listed in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all properties found in the **Building Blocks** > **Properties** branch of the selected file.

GUI Options

Select the **Include in Model Wizard** checkbox to include as a property section in the Model Wizard.

For information about the **Dependencies** window's information about dependencies, see Dependencies.

Tensor-Valued Function

The **Tensor-Valued Function** node ( ) adds a possibility to create functions with tensor-valued arguments and output. It is very similar to the scalar analytical function in the Model Builder.

You can also add this node under the **Auxiliary Definitions** branch. Doing so puts the function in a more global context similar to how declarations of new physical quantities work.

SETTINGS

Enter a name for the tensor-valued function in the **Function name** field. To use this function in an expression, type `phb.`*`<function name>`*. However, if the function is declared under the **Auxiliary Definitions** branch, it is available in all Physics Builder files, which means that it will be an error to declare a function that already exists. It is therefore recommended to use an extra scope level for your functions. For example, use the name of the Physics Builder archive it belongs to, so if your archive is named `myarchive`, the function name could be set to `myarchive.myfunc`. In expressions, you can then access the function with `phb.myarchive.myfunc`.

Add the arguments to the function in the **Argument** column. An argument can have an arbitrary dimension, so it depends on the actual argument passed to the function. To use a specific dimension, select the checkbox in the **Force dimension** column, and enter the desired dimension in the **Dimension** column (as `2x2x3`, for example, for a 2-by-2-by-3 tensor dimension). This last column is ignored when the **Force dimension** checkbox is cleared.

Specify the output with the **Specify output** list, which has the options **From expression** and **Specify size and template**:

- With **From expression** the output evaluates the tensor expression in the **Expression** field. The dimension of the output depends on the expression.
- Use the **Specify size and template** option when you want to control the size of the output and enter the expression of each component in the output. Such an expression should always evaluate to a scalar, and it supports the index variables i, j, k, and l, which represent the index in the output tensor currently evaluated. If an argument has the same dimension as the output it is also possible to use these in index variables to pick up an element of the argument; for example, use `arg.i.j` to get the i:th row and j:th column in the argument tensor named `arg`.

Physics and Multiphysics Interfaces

In the Model Builder you can add physics interfaces and physics features in the Model Wizard. Depending on your license, the Model Wizard can contain different physics interfaces grouped in different physics branches. The physics interfaces shipped with COMSOL Multiphysics are referred to as *built-in physics interfaces*.

With the Physics Builder you can create new physics interfaces that show up in the Model Wizard, either in an existing physics branch or in a new physics branch.

Under each **Physics Interface** and **Multiphysics Interface**, the following can be added under **Building Blocks** ( ):

- A feature or a link to a feature in the Features branch ( ).
- A property or a link to a property in the Properties branch ( ).

The following can also be added:

- A Dependent Variable Declaration for the variable used by the physics.

This node does not add a dependent variable to the physics interface, it just declares that it exists.

- A Variable Declaration with Variable Definition as child nodes, where the definitions are expressions in terms of other declared variables. A declared variable can also be made available for plotting and results evaluation (see Variables).
- Extra Context Menu and Toolbar items, to extend the physics menu with extra menu items and toggle buttons.
- Other nodes to define default values, equation displays, and more.

In this section:

- Creating a Physics Interface or a Multiphysics Interface
- Physics Interface
- Multiphysics Interface
- Contained Interface
- Physics Interface Component Link
- Auxiliary Settings (Physics Interface)
- Disable Allowed Study Types
- Context Menu
- Toolbar
- Menu
- Menu with Action
- Item and Item / Button
- Toggle Item
- Separator
- Item Link
- Physics Interface — Preview
- Multiphysics Interface — Preview

Creating a Physics Interface or a Multiphysics Interface

These steps outline how to build a new physics interface with the Physics Builder:

1. Define the physics by formulating domain equations, domain sources, boundary conditions, and boundary sources, which represent the available nodes in the physics interface. Depending on the physics, equations, conditions, and sources for edges and points can also be added.
2. Identify the physical quantity or quantities to solve for (the dependent variables).
3. List the parameter settings that have to be available for the entire physics interface, which are the parameters that do not depend on the selection of geometric entities (geometric entities are domains, boundaries, edges, or points). Organize similar such parameters in groups representing the properties of the physics interface.
4. Add a new Physics Interface or Multiphysics Interface to the tree.
5. Enter information for the physics interface into the **Settings** window, initially in the **Identifiers**, **Restrictions**, and **Settings** sections.
6. Add the dependent variable declarations for the variables to solve for.
7. Add the features that the physics interface requires. All features can be added directly under the physics interface. Alternatively, add them to **Building Blocks** > **Features** ( ) and then add a link to the feature in the physics interface. By placing features in the **Building Blocks** branch ( ), these features can be reused by linking from several physics interfaces.
8. Add the properties to the physics interface in the same way as the features.

9 Test the physics interface in some of its supported space dimensions using one of the options on the **Preview** menu ( ) on the **Physics Interface** toolbar — **Show Preview for 3D** ( ), for example.

This preview automatically sets up a simple modeling environment with a predefined geometry and an instance of the physics interface. Experiment with the **Settings** window for all features, the GUI logic, and investigate the generated equations in the equation view. To test a physics interface more thoroughly, use The Physics Builder Manager.

10 Add Study and Solver Defaults, Mesh Defaults, Result Defaults, and Comments to make the physics interface more intuitive and easier to use.

Physics Interface

In the Model Builder you can add physics interfaces and physics features in the Model Wizard. Depending on your license, the Model Wizard can contain different physics interfaces grouped in different physics branches. The physics interfaces shipped with COMSOL are referred to as *built-in physics interfaces*.

With the Physics Builder you can create new physics interfaces that show up in the Model Wizard, either in an existing physics branch or in a new physics branch.

To add a **Physics Interface** ( ) and create a single physics interface:

- On the **Home** or **Physics Interface** toolbar, click the **Add Physics Interface** button ( ), or
- Right-click the **Root** node (the top node) and choose **Physics Interface**.

You can add features to the **Physics Interface** node in these ways:

- On the **Physics Interface** toolbar, click the available buttons, or
- Right-click the **Physics Interface** node and choose features from the context menu.

For example, see Features, Inputs, Properties, Mesh Defaults, Study and Solver Defaults, Result Defaults.

The **Settings** window has the following sections:

PHYSICS AREA

This section is initially collapsed. It contains a tree view of all physics areas (fluid flow, heat transfer, and so forth) and subareas available from built-in resources, areas defined

in the current builder file, and areas defined in any imported file under the **External Resources** branch ( ). See Physics Areas to learn about adding physics areas.

To put a physics interface under a physics area in the tree, select the relevant physics area node and then click the **Set as Parent** ( ) button below the tree. Or right-click the physics node and choose **Set as Parent** from the submenu. You can find the currently selected category under the **Parent area** divider.

IDENTIFIERS

The text written in the **Description** field is the text COMSOL Multiphysics displays for the physics interface in the Model Wizard. Click the **Rename node using this text** button ( ) to update the node in the **Physics Builder**.

Select the **Type** checkbox to define a unique string to identify the physics interface. The string should not conflict with other names for the physics interfaces present in the Model Wizard.

The entry in the **Default name and tag** field is used to generate the scope of all variables that the physics interface adds in the Model Builder. It also defines the prefix for the tag of all newly created physics interfaces in the Model Builder. The tag of a physics interface is only important for references to a created interface in model files for Java®.

In the Model Wizard and for the physics instance in the Model Builder there is an icon displayed for the particular physics interface. **Browse** ( ) to an image file to add the **Icon** to display for the physics interface if the default icon is not applicable.

RESTRICTIONS

The **Allowed space dimensions** list specifies the geometry dimensions that the physics interface supports: **3D**, **2D**, **1D**, **Axial symmetry (2D)**, **Axial symmetry (1D)**, and **0D**. Click the **Add** button (+) to open the **Allowed space dimensions** list

	Choose **0D** to create a physics interface with a global scope (for example, a system of ODEs). The default is to support all space dimensions except **0D**. Delete items from the list in cases where not all space dimensions are applicable.

The **Allowed study types** includes the study types that the physics interface can create equations for. The most important alternatives are **Stationary**, **Time-dependent**, **Frequency domain**, **Eigenfrequency**, and **Eigenvalue**. Click the **Add** button (+) to open the **Allowed study types** list to choose other study types. Some of these studies are only

for specific physics interfaces. Use the **Move Up** , **Move Down** , and **Delete** buttons under the table to organize the list.

	Study and Study Step Types in the *COMSOL Multiphysics Reference Manual*

SETTINGS

From the **Top geometric entity level** list, choose the top level for the governing equations of the physics interface: **Global**, **Domain** (the default), **Boundary**, **Edge**, or **Point**. **Domain** is the most common, which means that the top level is the same as the geometry dimension.

	It is also possible to define shell and wire interfaces that have dependent variables and equations defined on entity levels lower than the geometry dimension. For a **Shell** interface choose **Boundary**. The governing equations are then defined on faces in a 3D geometry or lines (edges) in a 2D geometry.

Select a **Default frame** to choose how the physics interface behaves together with mesh deformation. Select **Spatial** or **Material** (the default) if needed. Typically, the frame is decided by each feature or physics property.

Select the **Deformed mesh** checkbox to allow this physics interface to control frame motion, similarly to the **Moving Mesh** or **Deformed Geometry** interfaces. When this checkbox is selected, the **Moving Frame Domain Condition** and **Moving Frame Boundary Condition** nodes can be used in physics feature and physics properties to specify the frame motion. The frame control settings for this physics interface will also be available in study steps.

When the checkbox is selected,

- Select the **Moving frame**. controlled by this physics. If **Spatial** is selected (the default), the interface will control the spatial frame and use the material frame as reference frame (similarly to the Moving Mesh interface). If **Material** is selected, the interface will control the material frame and use the geometry frame as reference frame (similarly to the Deformed Geometry interface).
- The **Geometry shape function** setting controls the type and order of polynomials used for representing the geometry shape function in the moving frame. Select **Same as**

first dependent variable (the default) or **Custom**. For **Custom**, enter an **Order**. The default is 2.

GUI OPTION

Select an option from the **Hide interface in the Model Wizard**: **No** (the default) or **Yes**. This can be useful if you want to define an interface that is only used in another multiphysics interface, and does not make sense to use as a standalone interface.

Enter a **List order weight in Model Wizard**. The default is 2. The higher the weight, the lower position the physics interface gets in the tree of physics interfaces in the Model Wizard.

If you create a physics interface that users probably only want one instance of in their model, select the **Only add one interface of this type in Model Wizard** checkbox.

OVERRIDE RULE

This section summarizes the override rules defined by all features of the interface. If two features uses different override rules, you can fill in the table with rules between override types in different override rules. See Override Rule.

DEFAULT FEATURES

This section has no user input. It contains a list of all default features that you declare for the physics interface and what geometric entity level and domain type they exist on. When you create a new physics interface in the Model Builder, COMSOL Multiphysics always adds the default features in this list to the new physics interface. See Features.

Multiphysics Interface

A **Multiphysics Interface** ( ) is a combination of other physics, behaving like one single physics interface. The multiphysics interface inherits all features and properties that all the contained physics interfaces have, which are added through Contained Interface nodes. It is possible to remove features that do not work in a multiphysics context.

To add a **Multiphysics Interface** and to create a multiphysics interface that connects and add couplings between several physics interfaces:

- On the **Home** or **Physics Interface** toolbar, click the **Add Multiphysics Interface** button ( ), or
- Right-click the **Root** node (the top node) and choose **Multiphysics Interface**.

You can add features to the **Multiphysics Interface** node in these ways:

- On the **Physics Interface** toolbar, click the available buttons, or
- Right-click the **Multiphysics Interface** node and choose features from the context menu.

For example, see Features, Inputs, Properties, Mesh Defaults, Study and Solver Defaults, Result Defaults.

The **Settings** window for the multiphysics interface is similar to that for a single physics interface but with some settings removed (because it is inherited from the contained interfaces).

See the Physics Interface node for these settings: Physics Area, Identifiers, and GUI Option. Also see Override Rule.

RESTRICTIONS

The default **Intersect space dimensions** is **Contained interfaces**, which restricts the space dimensions by intersecting the allowed space dimensions from the contained interfaces. Choose **Custom dimensions and interfaces** to add extra restrictions to the space dimensions.

From the **Allowed study types** list choose **Intersection of interface types** (the default) or **Union of interface types** to control how to combine the study-type restrictions from the contained interfaces. Select **Customized** to set the study types manually.

SETTINGS

Choose the **Default frame**: **Material**, **Spatial**, **Geometry frame**, or **Mesh**. These have the same meaning as for the Physics Interface node. The top geometric entity level for the multiphysics interface is the maximum level among the contained interfaces.

GUI OPTIONS

In addition to the settings also available for a Physics Interface node, there is an **Exclude equation display from contained interfaces** checkbox. By default, the equation displays of the contained physics interfaces are shown in the multiphysics interface node. If you select this checkbox, the equations are not shown (allowing users to define their own equations).

DEFAULT FEATURES

Similar to the Default Features section of the Physics Interface node, this section only lists the features flagged as default features for the multiphysics interface. In this list, you do not see any default features added by the Contained Interface node, only the default features added directly under the multiphysics interface.

Contained Interface

The **Contained Interface** ( ) is actually a link node, similar to the Feature Link and Property Link nodes. The difference is that you do not choose an item from the **Building Blocks** branch but among the available physics interfaces.

Right-click the **Multiphysics Interface** node to add this feature from the context menu.

The **Settings** window has the following sections:

SOURCE INTERFACE

In the **Links from** list choose where to look for a certain interface:

- **Local interfaces** (the default). Choose from the interfaces defined in the same file. Choose the interface from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Choose from built-in physics interfaces available to the Physics Builder. Select the main resource (COMSOL product) from the **Package** list. For each resource, choose an interface from the **Link** list. Only the currently published interfaces are available.
- **External resources**. Choose from the interfaces found in an imported builder file under the **External Resources** branch. Choose the file from the **Imported file** list. The **Link** list contains all interfaces found in the selected file.

INTERFACE FEATURES

From the **Add default features from interface** list, choose **Default features except those below** to add the same default features as the contained interface. Choose **Customized** to select the default features manually using the buttons under the list. The list can be empty if you do not want to use any default features from this interface.

In the **Remove features** list, add features from the contained interface that you do not want in the multiphysics interface. Make sure that you do not remove a feature that you use as a default feature.

	Contained Interface (Predefined Multiphysics)

Physics Interface Component Link

Use a **Physics Interface Component Link** ( ) to include all items defined within a component under the **Building Blocks** > **Components** branch ( ) as if they were part of the physics interface containing the link; see Components.

To add a **Physics Interface Component Link** right-click the **Physics Interface** or **Multiphysics Interface** nodes and select it from the context menu.

The **Settings** window has the following section in addition to the sections described for Physics Interface:

SOURCE COMPONENT

In the **Links from** list choose where to look for a certain component:

- **Building blocks** (the default). Lets you choose among the components listed under the **Components** branch in the **Building Blocks** branch. You choose the component from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Lets you choose among built-in features that are available to the Physics Builder. In the **Package** list you choose the main resource (COMSOL product) to use features from. For each resource, you have a list of features in the **Link** list to choose from. You can only choose among the currently published features.
- **External resources**. Lets you choose among the physics interface components listed in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all components found in the **Building Blocks** > **Component** branch of the selected file.

Auxiliary Settings (Physics Interface)

A physics interface can have an **Auxiliary Settings** node ( ) that contains a collection of settings for its physics interface that you usually do not need to change.

To add an **Auxiliary Settings** node, right-click the **Physics Interface** or **Multiphysics Interface** nodes and select it from the context menu. Also right-click the **Auxiliary Settings** node to add a Disable Allowed Study Types node.

The **Settings** window includes the following sections:

PROPERTY DEFAULTS

This section contains a table with the four columns: **Property name**, **Input name**, **Default value**, and **Read only and hidden**. The purpose of this table is to specify default values for the user inputs in properties of the physics interface. Of course the user inputs already have default values specified in their own features. So this functionality is a way to redefine those default values. A situation where this is useful is when two physics interfaces make use of the same property through a Property Link node. Then this setting makes it possible to have different default values of the user inputs defined under the property for the two physics interfaces.

- **Property name** is the type of the property.
- **Input name** is the name of the user input.
- **Default value** is the value that the user input should be set to.
- **Read only and hidden** ensures that after the value of the user input is set to the default value, it becomes hidden and its value cannot change.

PHYSICS SELECTION

Click to select either of the **Not applicable on infinite element domain**, **Not applicable on perfectly matched layer domain**, **Not applicable on absorbing layer domain** (selected by default), **Not applicable on moving domains**, and **Use default settings for layered material selection** checkboxes to make sure that the physics interface cannot be applied on a domain of the particular type. To access these settings, first select the **Specify special applicability for selection** checkbox. When cleared, the settings included with this checkbox are ignored and grayed out. This is important if an interface or feature uses multiple auxiliary settings for some reason. It is then important that these settings are either identical or ignored; otherwise, an error will be thrown. The **Specify special applicability for selection** checkbox is selected by default.

From the **Domain filtering** list, choose **No filtering** (the default) or **Include entity type**. Select the **Include entity type** option to show a list of entity types, where the default is **Geometry** (equivalent to the **No filtering** option). For interfaces that exist on domains, you can only add void entity types (**Voids**, **Infinite void**, and **Finite voids**). Doing this will enable an interface for void domains. For interfaces on lower dimension (boundaries, for example), more entity types are available. Selecting **Exterior** and **Interior**, for example, makes the symmetry axis not applicable for the physics interface and its features.

Infinite Elements, Perfectly Matched Layers, and Absorbing Layers in the *COMSOL Multiphysics Reference Manual*

REMOVE STANDARD FEATURES

In this section it is possible to select what standard features to remove from the context menu of the physics interface. Possible standard features are the following, which you can add by clicking the **Add** button (+) and selecting them from the dialog that opens:

- Weak Constraint
- Weak Contribution
- Pointwise Constraint
- Global Equations
- Axial Symmetry
- Weak Contribution on Mesh Boundaries
- Global Constraint
- Discretization
- Continuity

Remove standard features that are not applicable for a physics interface.

Select the **Only hide features from context menus** checkbox to only remove them from the user interface's context menu but make it possible to open existing MPH files that include any of the removed features.

Disable Allowed Study Types

Right-click the **Auxiliary Settings** node to add a **Disable Allowed Study Types** node ( ) do disable some allowed study types from some space dimensions, for example.

STUDY TYPES

To add study types to disable, click the **Add** button + and then select from the **Disabled study types** list in the **Add** dialog that opens.

RESTRICTIONS

Select the **Restrict to space dimensions** checkbox and use the buttons under the table to add or edit the list.

Select the **User input** checkbox to define the **Condition on**.

- For **User input in property** (the default) enter a **Property** and a **User input**. Choose the **User input condition**: **User input is active** (the default) or **User input has any of certain values**.
- For **Expression**, enter a **Condition** as a conditional expression that evaluates to 0 (false) or 1 (true) in the field below.
- For **Feature is active**, enter a **Feature type**.

Select the **Condition is not fulfilled for undefined references** checkbox to if you want the condition to be treated as not fulfilled instead of throwing an error if the property is undefined.

Context Menu

The **Context Menu** node ( ) can be used to define menus and menu items in an extra context menu of a physics interface or physics feature. You add a **Context Menu** node from the **Extra Menu** submenu when right-clicking a **Physics Interface** or physics feature node.

Right-click the **Context Menu** node to add Menu, Item and Item / Button, Toggle Item, Separator, and Item Link subnodes that make up the contents of the context menu.

ORDERING

From the **Menu items ordering** list, choose **Use order of physics features (where applicable)** (the default) to use the order of the features in the tree to create the menu

items, or choose **Use weights** to order them according to the weights assigned to each **Menu Item** subnode.

Toolbar

The **Toolbar** node ( ) can be used to define toggle buttons and menu items in an extra toolbar of a physics interface or physics feature. You add a **Toolbar** node from the **Extra Menu** submenu when right-clicking a **Physics Interface** or physics feature node.

Right-click the **Toolbar** node to add Menu, Item and Item / Button, Toggle Item, Separator, and Item Link subnodes that make up the contents of the toolbar.

The **Toolbar** node itself contains no settings.

Menu

Use a **Menu** ( ) node to customize a context menu or toolbar of the physics interface. This node adds a submenu.

To add a **Menu** node, right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu.

Right-click the **Menu** node to add Item and Item / Button, Toggle Item, Separator, or Item Link nodes or another **Menu** node, which acts as a submenu. You can also add an Activation Condition.

The **Settings** window includes the following sections:

PARAMETERS

This section is only available in **Menu** nodes defined under **Definitions Library** > **Auxiliary Definitions**.

In this section, add parameters to the table with a **Name**, **Description**, and **Default expression**. With the parameters, you can parameterize the link that linked to this node. For example, the Item Link can link to a **Menu** node, but they can use different titles and icons. Select the **Ready only** checkbox to prevent editing of the expression in the **Item Link** node.

DEFINITION

In the **Settings** window for **Menu**, enter a **Title** of the menu in the text field and an icon file in the **Icon** field (or click **Browse** ( ) to pick an icon file from the file system).

Menu with Action

Use a **Menu with Action** ( ) node to customize a context menu or toolbar of the physics interface with an action connected to it. This node adds a submenu.

To add a **Menu with Action** node, right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu.

Right-click the **Menu with Action** node to add Item and Item / Button, Toggle Item, or Separator, nodes. You can also add an Activation Condition.

The **Settings** window includes the following sections:

COMMAND

Define a command type from the **Command type** list: **Internal action tag** (the default) or **Command handler from code editor**.

For **Internal action tag**, enter the tag in the **Action tag** field.

For **Command handler from code editor**, choose an option from the **Links from** list: **Building blocks** (the default), **Built in**, or **External resources**.

For **Built in**, choose a COMSOL package from the **Package** list. **COMSOL Multiphysics** is the default package.

For **External resources**, choose a file from the **Imported file** list.

From the **Link** list, choose a link for the command.

DEFINITION

Some of the settings are only available when **Command type** is **Command handler from code editor**.

Enter a **Title** of the menu in the text field and an icon file in the **Icon** field (or click **Browse** ( ) to pick an icon file from the file system).

The **Weight** field contains a factor (an integer number) that can be used to decide the order of the items in a context menu. It is available (editable) when the **Menu items ordering list** is set to **Use weighting order** in the Settings window for a **Context Menu** node. Under a toolbar menu, the weight is always 0 and this field is not editable.

Select the **Record a custom COMSOL API command** checkbox and type a name for using an API call equivalent to clicking the button as `runCommand(<name>)`, where *<name>* is a string with the name that you enter in the **Command** field.

Select the **Always show the title** checkbox to always display the title. It is selected by default if you use the button style.

Select the **Use button style if possible** checkbox if desired. This setting is only available for a button under a user input. It uses the style of a button instead of just text.

CONDITION TO RUN

This section is only available when **Command type** is **Command handler from code editor**.

Select the **Show confirmation dialog** checkbox if desired. If selected, enter a message for the confirmation dialog and an answer to use in the **Message** and **Answer** fields, respectively.

Item and Item / Button

Use an **Item** ( ) node to customize a context menu or toolbar of the physics interface. This node adds a menu item that a user can select to perform a certain task. It is also available under **Definitions Library** > **Auxiliary Definitions** as an **Item / Button** node ( ) with identical settings, which can be linked to from **Item** or **Button** nodes.

Right-click a Menu, Context Menu, or Toolbar node to add an **Item** node.

You can right-click the **Item** node to add an Activation Condition or Input Dependency subnode and the **Item / Button** node to add an Input Dependency subnode.

The **Settings** window includes the following sections:

PARAMETERS

This section is only available in **Item / Button** nodes defined under **Definitions Library** > **Auxiliary Definitions**.

In this section, add parameters to the table with a **Name**, **Description**, and **Default expression**. With the parameters, you can parameterize the link that linked to this node. For example, the Item Link can link to an **Item / Button** node, but they can use

different titles and icons. Select the **Ready only** checkbox to prevent editing of the expression in the **Item Link** node.

COMMAND

Select a **Command type**: **Create feature** (the default), **Internal action tag**, or **Command handler from code editor**.

- Use **Create feature** to place the action to add a new feature under a different menu than the one chosen by the program. Enter the type of feature in the **Type** field. Select the **Restrict to geometric entity levels** checkbox to restrict the menu item. If the feature is applicable to other entity levels than those restricted here, it displays in its default location in the context menu or toolbar.
- Use **Internal action tag** to add a general action given by its tag that you type in the **Action tag** field. This option is mainly for internal use, and there is no list of available action tags.
- The **Command handler from code editor** is similar to the **Internal action tag** option, but the action handler can be defined using the Code Editor.

The remaining two sections are only available if the **Command type** list is set to **Command handler from code editor**.

DEFINITION

Enter a title of the item in the **Title** field and an icon file in the **Icon** field or click **Browse** ( ) to pick an icon file from the file system.

If the **Item** node is a subnode under a **Context Menu** node where a weighting order is used, enter an integer in the **Weight** field to sort the items based on a weight.

Select the **Record a custom COMSOL API command** checkbox and type a name for using an API call equivalent to clicking the button as `runCommand(`*`<name>`*`)`, where *`<name>`* is a string with the name that you enter in the **Command** field.

CONDITION TO RUN

Select the **Show confirmation dialog** checkbox if you want to display a confirmation dialog as a preaction for the item's action. Type a message for the confirmation dialog in the **Message** field and a confirmation answer in the **Answer** field (default: `Yes`). The confirmation dialog also contains a **Cancel** button by default. You can use this functionality to ask for confirmation before performing the action.

Toggle Item

Use a **Toggle Item** ( ) node to customize a context menu or toolbar of the physics interface. This node adds a toggle item that a user can use to turn some functionality on or off.

Right-click a Menu, Context Menu, or Toolbar node to add a **Toggle Item** node.

You can right-click the **Toggle Item** node to add an Activation Condition or Input Dependency subnode.

The **Settings** window includes the following sections:

COMMAND

Select a **Command type**: **Create feature** (the default), **Internal action tag**, or **Command handler from code editor**.

- Use **Create feature** to place the action to add a new feature under a different menu than the one chosen by the program. Enter the type of feature in the **Type** field. Select the **Restrict to geometric entity levels** checkbox to restrict the toggle item. If the feature is applicable to other entity levels than those restricted here, it displays in its default location in the context menu or toolbar.
- Use **Internal action tag** to add a general action given by its tag that you type in the **Action tag** field. This option is mainly for internal use, and there is no list of available action tags.
- The **Command handler from code editor** is similar to the **Internal action tag** option, but the action handler can be defined using the Code Editor.

The remaining two sections are only available if the **Command type** list is set to **Command handler from code editor**.

DEFINITION

Enter a title of the toggle item in the **Title** field and an icon file in the **Icon** field or click **Browse** ( ) to pick an icon file from the file system, if the **Action type** list is set to **Action handler from code editor**.

If the **Toggle Item** node is a subnode under a **Context Menu** node where a weighting order is used, enter an integer in the **Weight** field to sort the toggle items based on a weight.

Select the **Default selected** checkbox if you want the toggle item to be selected (turned on) by default.

CONDITION TO RUN

Select the **Show confirmation dialog** checkbox if you want to display a confirmation dialog as a preaction for the toggle item's action. Type a message for the confirmation dialog in the **Message** field and a confirmation answer in the **Answer** field (default: `Yes`). The confirmation dialog also contains a **Cancel** button by default. You can use this functionality to ask for confirmation before performing the action.

Separator

Use a **Separator** ( ) node to customize a context menu or toolbar of the physics interface. This node adds a separator that you can use to separate groups of menu items or toggle items.

Right-click a Menu, Context Menu, or Toolbar node to add a **Separator** node. You can also right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu.

The **Settings** window for a **Separator** node includes no settings.

Item Link

Use an **Item Link** ( ) node to customize a context menu or toolbar of the physics interface. This node can be used to define a link to a locally defined menu under **Definitions Library** > **Auxiliary Definitions** (selecting **Locally defined**); to a built-in Java maker (selecting **Built-in**); or to an external resource (selecting **External resources**). For the built-in link, you can control the action by implementing the context action interface.

Right-click a Menu, Context Menu, or Toolbar node to add an **Item Link** node.

The **Settings** window includes the following section:

DEFINITION

From the **Links from** list, select **Locally defined** (the default), **Built in**, or **External resources**.

Locally Defined

Use this option to define a link to a locally defined menu under **Definitions Library** > **Auxiliary Definitions**, which you select from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation

if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list. Parameters appear that have been defined in the locally defined menu node, and you can edit their expressions in the **Expressions** column under **Menu item parameters** unless they have been defined as read only.

Built-In

Use this option to define a link to a built-in Java maker. From the **Package** list, select **COMSOL Multiphysics** or any other available package. Then select a link from the **Link** list (which by default is set to **Not active**). When you have selected an active link, you can also enter an icon file and a title in the **Icon** field and **Text** field, respectively. You can use this option to link from a Physics Builder maker to a Java maker. With a Java maker, you can have more control than with the Physics Builder maker.

External Resources

Use this option to define a link from an external resource, which you import from a file that you specify from the **Imported file** list. The **Imported file** list contains all **Import** nodes under **External Resources**. It is used by all link nodes in the Physics Builder, so the user interface is the same for all of them. Then select a menu or menu item from the **Link** list. Parameters appear that have been defined in the externally defined menu node, and you can edit their expressions in the **Expressions** column under **Menu item parameters** unless they have been defined as read only.

Physics Interface — Preview

This **Physics Interface** node ( ) is a preview of the physics interface that you have created in the Physics Builder. You can right-click this node to add and test all features that you have defined for the physics interface. The **Settings** window for the physics interface shows the applicable settings and properties that you have defined for the physics interface. Typically it includes a section for selections, such as a **Domain Selection** section, and an **Equation** section.

Multiphysics Interface — Preview

This **Multiphysics Interface** node ( ) is a preview of the multiphysics interface that you have created in the Physics Builder. You can right-click this node to add and test all features that you have defined for the multiphysics interface. The **Settings** window for the multiphysics interface show the applicable settings and properties that you have defined.

Features

A feature commonly contains most of the variables and equations that a specific physics interface requires. In the Model Builder, zero or more instances of a feature can exist as a child node to a physics interface instance or another feature instance. Except for global features, they always have a selection on a specific geometry dimension (domains, boundaries, edges, or points).

Typically the governing equations of a problem are defined for a feature at the domain level and constraints and flux conditions for features are defined at the boundary level.

In this section:

- Generic Feature
- Domain Condition
- Boundary Condition
- Edge Condition
- Domain Feature
- Boundary Feature
- Edge Feature
- Point Feature
- Pair Feature
- Contact Pair Feature
- Layered Material Feature
- Sector Symmetry Feature
- Device Model Feature
- Moving Frame Domain Condition
- Moving Frame Boundary Condition
- Periodic Feature
- Feature Link
- Multiphysics Feature
- Multiphysics Coupling
- Generic Multiphysics Coupling
- Global Multiphysics Coupling
- Domain Multiphysics Coupling
- Boundary Multiphysics Coupling
- Edge Multiphysics Coupling
- Point Multiphysics Coupling
- Contact Multiphysics Coupling
- Pair Multiphysics Coupling
- Layered Material Multiphysics Coupling
- Coupling Type Contribution
- Subcoupling Features
- Contained Feature
- Auxiliary Settings (Feature Nodes)
- Auxiliary Settings (Multiphysics Couplings)
- Geometric Nonlinearity
- Physics Symbol

Generic Feature

To add a **Generic Feature** node ( ):

- On the **Physics Interface** toolbar, select it from the **More Features** menu, or
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

For information about the **Dependencies** window's information about dependencies, see Dependencies.

The **Settings** window for a **Generic Feature** has the following sections:

IDENTIFIERS

The text entered in the **Description** field is the text COMSOL displays for the feature in the Model Builder. Click the **Rename node using this text** button ( ) to update the node in the **Physics Builder**.

The **Type** is a unique string that identifies a feature and it must be unique among all features supported by a physics interface. The **Default name and tag** field is used to generate the tag of newly created instances in the Model Builder.

RESTRICTIONS

From the **Allowed space dimensions** list, define what space dimension this particular feature can be used with. **Same as parent** (the default) means that the feature supports the same space dimensions as the parent instance, which can either be a physics interface or another feature. Select **Customized** to control the space dimensions manually.

Special restrictions on study types can also be controlled for this feature. If you try to solve a problem for a feature that does not support the current study type, it does not add any contributions to the model. Choose **Customized** from the **Allowed study types** list to control the supported study types manually. The option **Same as parent** (the default) means that the feature supports the same study types as the parent.

SELECTION SETTINGS

Supported Geometric Entity Levels

The **Supported geometric entity levels** list specifies the level of the selection that the feature uses when adding all its contributions like variables, equations, and constraints. The choices in this list have a slightly different meaning compared to the top level you choose in the **Top geometric entity level** list of the physics interface settings (see Physics and Multiphysics Interfaces). The choices **Same as top level (Domain condition)** and **One level below top level (Boundary condition)** are relative to the top level of the interface. If the top level of the interface is **Domain**, choosing **One level below top level (Boundary Condition)** means that the feature contains a boundary condition to the governing equations. These boundary conditions then live on faces in 3D and lines (edges) in 2D. On the other hand, if the top level is **Boundary**, choosing **One level below top level (Boundary Condition)** still means that the feature contain boundary conditions, but the conditions now live on lines (edges) in 3D and points in 2D. For such *shell interfaces*, the governing equations are defined on faces in 3D and lines (edges) in 2D. The boundary condition to a line, for example, is a point. The choices **Same as parent level** and **One level below parent level** make the feature's selection settings contain entities of

the same geometric entity level or one level below (boundaries, if the parent level is domains, for example), respectively. The choices **Edge** and **Point** always refer to the geometric entities edge and point no matter what the top level is. For more details on geometric entity levels, see Selection Terminology.

Finally, if your interface has **Global** as **Top geometric entity level**, the relative choices, **Same as top level (Domain condition)** and **One level below top level (Boundary condition)**, refers to the geometry dimension the global interface belongs to. If you add it to a 3D geometry, the entity levels becomes domains and faces. A global interface can also live on a global model (no geometry), and in this case it does not make sense to use anything else than the **Global** option. It is therefore recommended that you restrict the space dimensions of features that use any of the other options.

Applicable Entities

It is possible to limit the types of entities where a feature can be active. For example, a boundary condition can be limited to only interior boundaries. All other selected boundaries then get marked as *not applicable*. For more complex situations, you can use conditions on domain types to decide if a specific boundary is applicable or not.

Select a form of **Applicable entities** from the list: **From entity types** (the default) or **From sequence**.

- If **From entity types** is selected, select one or more of the options available when you click the **Add** button (+) add them to the list of applicable entities. **Exterior** and **Interior** boundaries are selected by default. Use the buttons under the list to organize as needed.
- If **From sequence** is selected, select a **Selection filter sequence**: **Locally defined** (the default), **From built-in quantities** or **Imported from external resource**. Select a sequence to link to from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list. If the sequence is **Imported from external resource** also select an **Imported file**.

For more details on entity types, see Selection Terminology.

Override Rule

Some features cannot exist on the same selection (for example a boundary), and COMSOL Multiphysics uses override rules to decide how the selection of one feature overrides another feature's selection.

Select an **Override rule**: **Built in** (the default), **Locally defined**, or **Imported from external resource**.

- If **Built in** is selected there are four options in the **Override type** list: **Exclusive**, **Contributing**, **Override features of same type**, and **Never overridden**:
  - **Exclusive** means that the feature should override all other features except those that are of the type **Never overridden**. An exclusive feature is overridden by other exclusive features.
  - **Contributing** means that the feature should not override other features. The exception is for entity levels below the top entity level of the physics, where features of any type override the default features.
  - **Override features of same type** means that the feature only overrides other features of the same feature type.
  - **Never overridden** ensures that a feature is never overridden and does not override any other feature.
- If **Locally defined** is selected, also select a **Link** from the list. Click the **Go to Source** button as needed.
- If **Imported from external resource** is selected, select an **Imported file** from the list. Click the **Go to Source** button as needed. Then select a **Link** from the list.

Override Type

The **Override type** list specifies if the feature is **Exclusive** or **Contributing** to other features. In the Model Builder, an *exclusive feature* (such as constraints and fixed values) replaces all previous feature instances for intersecting selections whereas a *contributing feature* (such as loads and sources) adds to other contributing features sharing the same selection. You also select to only **Override features of the same type** or to let the feature be **Never overridden**.

COORDINATE SYSTEMS

In the **Input base vector system** list, you choose what coordinate system all user inputs and material parameters are given in. This is related to the frame type and is the coordinate systems to use for spatial vectors and matrices.

The **Base vector system** list specify the coordinate system used by the equations and variables declared by this feature. If any of these lists has the selection **Selected input coordinate system**, the user gets an option to choose coordinate system in the **Settings** window of the feature instance in the Model Builder.

The **Frame type** list specifies if the equations assumes that they live on the material or spatial frame. The options are **Material** (the default), **Spatial**, **From physics**, and **Selectable by user**. Select **From physics** to use the frame specified by the physics interface. **Selectable by user** means that the frame type can be controlled when using the feature instance. The instance then gets a **Material type** list with the options **Solid**, **Nonsolid**, or **From material**. The feature uses the material frame for the solids, and the spatial frame for nonsolids (typically a fluid such as a liquid or a gas).

- Using Coordinate Systems
- Transformation Between Coordinate Systems

PREFERENCES

Select the **Singleton feature** checkbox if the physics interface only allows a single instance of the feature.

A feature instance in the Model Builder can have a section called **Model Inputs**, which shows up when you select the **Include model inputs** checkbox. A model input is an input argument to material parameters when they depend on a quantity (for example, if the density depends on temperature).

For features under a physics interface there is an **Add as default feature** checkbox. Select this checkbox if you want the feature to be a default feature. When you specify default features, specify the geometric entity level in the **Default geometric entity level** list. Newly created interfaces then add the feature on this level. The **Default entity types** specifies the entity types the default feature is added on.

In the **Advanced preferences** table, you can specify special options for the default feature. By default, default features have a selection over all domains (it cannot be changed), and you can neither remove or disable the feature. Select the checkbox columns — **Unlock selection**, **Clear selection**, **Deactivable**, and **Removable** — to alter this default behavior. The last column, **Lists order weight**, is a preference to control the order of the default features. The standard order is domain features first, then boundary features, and so on until the point features followed by the global features. The automatically added initial value features always show up last in the list. The

program uses an integer when sorting the default features. The integer depends on the geometric entity dimension and the list order weight using the following formula:

100*<*entity dimension*> + <*list order weight*>

Do small adjustments (<100) to control order within an entity dimension, and large adjustments to put a default feature first or last in the list. Initial value features has a default weight of –1000 to appear last.

GUI OPTIONS

This section is only available for a **Generic Feature** node added under a **Physics Interface** or **Multiphysics Interface** node.

Select the **Hide feature from context menus** checkbox to remove the possibility to add new features of this type. This can be useful when a feature must be kept for backward compatibility reasons, but a user cannot add them in new models. When selected, this option also enables hiding with respect to the option **Advanced Physics Options** in the **Show More Options** dialog in the Physics Builder. This is the only option there that represent a category in the **Category for hiding feature** list, which has the options **Always hidden** and **Advanced physics options**. Select **Always hidden** (the default) to hide it permanently, or select **Advanced physics options** to make it possible for users to show it by selecting **Advanced Physics Options** in the **Show More Options** dialog.

Select the **Allow changing tag in GUI** checkbox if you want users to be able to change the tag in the Model Builder.

Select the **Expand the Model Builder node by default** checkbox if you want the physics node to be expanded as soon as it is added, if it has any active default subnodes.

PARAMETERS

This section is only available for a **Generic Feature** node added under **Building Blocks** > **Features**.

Specify parameters by filling in the columns **Name**, **Description**, and **Default expression**. Select the **Read only** checkbox if you do not want to make it possible to alter the content in the **Default expression** column by links. This can be useful when more complicated parameter expressions are needed by the component, but they are not

something that the link should change. Otherwise, a parameter expression can be changed for each component link that uses this component.

Domain Condition

The **Domain Condition** node ( ) defines a feature that can only exist (have selections) on the same geometric entity level as the physics.

To add a **Domain Condition**:

- On the **Physics Interface** toolbar, click the **Domain Condition** button ( ).
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Boundary Condition

The **Boundary Condition** node ( ) defines a feature that can only exist (have selections) on one level below the geometric entity level of the physics.

To add a **Boundary Condition**:

- On the **Physics Interface** toolbar, click the **Boundary Condition** button ( ).
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Edge Condition

The **Edge Condition** node ( ) defines a feature that can only exist (have selections) on two levels below the geometric entity level of the physics (that is, it is only applicable for physics interfaces in 2D and 3D).

To add a **Edge Condition**:

- On the **Physics Interface** toolbar, select **Edge Condition** from the **More Features** menu.

- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Global Feature

The **Global Feature** node (▪) defines a feature that can only exist (have selections) on the global geometric entity level (entire geometry), which means that the **Settings** window for the feature instance does not contain any selection list.

To add a **Global Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it do not include the **Supported geometric entity levels** list.

Domain Feature

The **Domain Feature** node (▬) defines a feature that can only exist (have selections) on the domain geometric entity level of the current space dimension, which represents volumes in 3D, surfaces in 2D, and lines in 1D.

To add a **Domain Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Boundary Feature

The **Boundary Feature** node ( ) defines a feature that can only exist (have selections) on the boundary geometric entity level of the current space dimension, which represents surfaces in 3D, lines in 2D, and points in 1D.

To add a **Boundary Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Edge Feature

The **Edge Feature** node ( ) defines a feature that can only exist (have selections) on the edge geometric entity level, which represents lines in all space dimensions. This feature is normally only applicable in 3D (the default restriction), but can optionally be allowed in lower dimensions in special situations.

To add an **Edge Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Supported geometric entity levels** list.

Point Feature

The **Point Feature** node ( ) defines a feature that can only exist (have selections) on the point geometric entity level, which represents points in all space dimensions. This feature is normally only applicable in 3D, 2D, and 2D axial symmetry (the default restriction), but can optionally be allowed in other dimensions in special situations.

To add a **Point Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature except that it does not include the **Supported geometric entity levels** list.

Pair Feature

A **Pair Feature** ( ) is a special feature that defines conditions on pairs. A pair has a source and a destination side, and a pair condition typically connects the dependent variables between them using pointwise constraints.

The most common pair condition is the continuity pair condition, which simply makes the dependent variables equal on both sides. All physics interfaces gets this pair condition by default, so you do not have to add it.

This feature is useful to define other types of pair conditions. The major difference between a pair feature and an ordinary feature lies in subnodes that define selections.

For pair features, there are two extra options in the **Selection** list of the **Selection** section; **Source** and **Destination**. With these options you can specify to use the source or destination boundaries in the condition of a pair feature; see Specifying Selections for more information.

- To add a **Pair Feature** under the **Building Blocks** branch, **Features** node: On the **Physics Interface** toolbar, select it from the **More Features** menu, or right-click **Features** and add it from the context menu.
- To add a **Pair Feature** under the **Physics Interface** or **Multiphysics Interface**, Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

Except for a few excluded sections, the **Settings** window is similar to the Generic Feature node.

SELECTION SETTINGS

See Selection Settings for **Generic Feature**. For a pair feature, you do not have to specify the geometric entity level, because it is always boundary level. The same is true for the domain type setting, because all pairs belong to a special domain type, called **Pair**. Ordinary features that support this domain type also appear in a pair version among the physics interface's pair conditions.

Under **Allowed entity types**, you can add **Identity pair**, **Contact pair**, and **Sector symmetry pair** types.

All pair features also have a special rule for overriding selections. They are always exclusive to all nonpair features preceding the pair in the list. For all features, pairs, and nonpairs that lie below the pair in the list, contribute with the pair condition. As a result, you cannot set the override type for pair features.

PREFERENCES

Select the **Only use explicit pair looping over pairs** checkbox to turn off the automatic looping over pairs, so no individual pair access is supported for the nodes under the pair feature and for links to normal components. Any pair looping then have to use an explicit pair looping with a component (see the **Loop** list in Component).

Select the **Singleton feature** checkbox if the physics interface only allows a single instance of the feature.

For features under a physics interface there is an **Add as default feature** checkbox. Select this checkbox if you want the feature to be a default feature. When you specify default features, specify the geometric entity level in the **Default geometric entity level** list. Newly created interfaces then add the feature on this level. The **Default entity types** specifies the entity types the default feature is added on.

In the **Advanced preferences** table, you can specify special options for the default feature. By default, default features have a selection over all domains (it cannot be changed), and you can neither remove or disable the feature. Select the checkbox columns — **Unlock selection**, **Clear selection**, **Deactivable**, and **Removable** — to alter this default behavior. The last column, **Lists order weight**, is a preference to control the order of the default features. The standard order is domain features first, then boundary features, and so on until the point features followed by the global features. The automatically added initial value features always show up last in the list. The program uses an integer when sorting the default features. The integer depends on the geometric entity dimension and the list order weight using the following formula:

100*<*entity dimension*> + <*list order weight*>

Do small adjustments (<100) to control order within an entity dimension, and large adjustments to put a default feature first or last in the list. Initial value features has a default weight of –1000 to appear last.

- Identifiers for the Generic Feature node
- Identity, Contact, and Sector Symmetry Pairs in the *COMSOL Multiphysics Reference Manual*

Contact Pair Feature

A **Contact Pair Feature** ( ) node is almost identical to the **Pair Feature** node. The difference is only visible for the feature instance in the Model Builder. A pair feature of the contact pair type can only select contact pairs. See Pair Feature for more information.

Using this feature also forces the **Include geometric nonlinearity** switch to be selected in study steps, which introduces extra license requirements.

To add a **Contact Pair Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

Layered Material Feature

A **Layered Material Feature** ( ) node adds a layered material. It is almost identical to the **Generic Feature** node but also includes a **Layered Material** section.

To add a **Layered Material Feature**:

- On the **Physics Interface** toolbar, select it from the **More Features** menu.
- Under **Building Blocks**, right-click **Features** and add it from the context menu.

Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

LAYERED MATERIAL

From the **Selection type** list, choose **Layers** (the default) for a default layered material or **Interfaces** for a layered material side-by-side continuity.

For **Layers**, **Exterior layers** and **Interior layers** are included by default. Click the **Add** button (+) to add **Exterior layers adjacent to nonphysics** or **Exterior layers to physics** if desired.

For **Interfaces**, **Exterior interface** and **Interior interfaces** are included by default. Click the **Add** button (+) to add **Exterior interfaces adjacent to nonphysics** or **Exterior interfaces to physics** if desired.

Sector Symmetry Feature

The **Sector Symmetry Feature** node ( ) defines a feature that implements sector symmetry for a pair.

To add a **Sector Symmetry Feature**:

- Under **Building Blocks**, right-click **Features** and add it from the context menu.
- Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is almost identical to the Generic Feature, except that it does not include the **Selection Settings** section.

PREFERENCES

Select the **Only use explicit pair looping over pairs** checkbox to turn off the automatic looping over pairs, so no individual pair access is supported for the nodes under the pair feature and for links to normal components. Any pair looping then have to use an explicit pair looping with a component (see the **Loop** list in Component).

Select the **Singleton feature** checkbox if the physics interface only allows a single instance of the feature.

Device Model Feature

A **Device Model Feature** node ( ) is a combination of a Generic Feature node and a Device Model node. It behaves identically to a feature node with additional

functionality to make it work as a device model. The device model gets a type identical to the tag of the feature instance.

- To add a **Device Model Feature** under the **Building Blocks** branch, **Features** node: On the **Physics Interface** toolbar, select it from the **More Features** menu, or right-click **Features** and add it from the context menu.
- To add a **Device Model Feature** under the **Physics Interface** or **Multiphysics Interface**, Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Devices** submenu.

You can also add a Device Model to this node. It is a special device of the type that the device model feature defines, and it is placed at the same level as the device model feature in the device system hierarchy. See Device Systems for more information.

Moving Frame Domain Condition

If the physics interface controls the deformation of the material or the spatial frame, use this node to specify how the frame is deformed on a certain selection. The physics interface controls the frame deformation if the **Deformed mesh** checkbox in the physics interface node is selected.

The **Moving Frame Domain Condition** node (u,v,w) allows specifying two types of frame deformation, using the **Frame motion** list box:

- When **Free** (the default) is selected, the coordinates of the moving frame in the chosen selection will be added as dependent variables for the problem. Specify a **Smoothing equation** to use to govern the motion of the coordinates, one of **Laplace** (the default), **Hyperelastic**, **Yeoh**, or **Winslow**. See to the documentation for the Moving Mesh interface for more details on each smoothing equation. Specify also an expression for the **Initial values for displacement** as a 3-components vector. The initial values must not depend on the coordinates of the moving frame (but can depend on the coordinates of the reference frame). In order for the model to be solvable, appropriate **Moving Frame Boundary Conditions** must be applied on the boundaries of **Free** domain. The **Free** frame motion is only supported for top-entity-level selections (domain conditions).
- When **Prescribed displacement** is selected, the frame motion is determined by the **Expression** entered (a 3-component vector). The expression cannot depend on the coordinates of the moving frame, but it can depend on the coordinates of the

reference frame. The **Prescribed displacement** condition can be applied on selections of all entity level. For example, it can be used to prescribe the motion of boundaries or edges, in addition to domains.

In the **Selection** section, specify the selection on which the condition is to be applied. **Free** frame motion is only supported for top-entity-level selections (domain condition).

Only one entity in the entire model can be responsible for the frame motion on a certain selection. Multiple **Moving Frame Domain Condition** in the same physics applied on the same selection will cause an error when trying to solve the model.

The node supports the Input Dependency subnode to provide more flexibility in the setup.

Moving Frame Boundary Condition

If the physics interface controls the deformation of the material or the spatial frame, use the **Moving Frame Boundary Condition** node (u,v,w) to specify the boundary conditions for domains with Free frame motion. See the Moving Frame Domain Condition section for details. The physics interface controls the frame deformation if the **Deformed mesh** checkbox in the physics interface node is selected.

The available boundary conditions are:

- **No displacement**: Specify that there is no displacement.
- **Displacement** (the default): Specify the **Displacement vector** at the boundary as a 3-component vector.
- **Componentwise displacement**: Choose which components of the displacement to constrain by using the **Constrain displacement in direction 1/2/3** checkboxes. Then specify the expressions for the appropriate **Displacement component 1/2/3**. Use the **Input Dependency** subnode to make these specifications dependent on other user inputs.
- **Normal displacement**: Specify the expression of the normal displacement of the boundary. A positive displacement is in the direction of the normal from downside (`root.dn`).
- **Zero normal displacement**: Specify that there is no displacement in the normal direction.
- **Velocity** (the default): Specify the **Velocity vector** at the boundary as a 3-component vector. This condition is only applicable for **Transient** studies.

- **Componentwise velocity**: Choose which components of the velocity to constrain by using the **Constrain velocity in direction 1/2/3** checkboxes. Then specify the expressions for the appropriate **Velocity component 1/2/3**. Use the **Input Dependency** subnode to make these specifications dependent on other user inputs. This condition is only applicable for **Transient** studies.
- **Normal velocity**: Specify the expression of the normal displacement of the boundary. A positive displacement is in the direction of the normal from downside (`root.dn`). This condition is only applicable for **Transient** studies. The **Normal velocity** condition can also support **Boundary smoothing** by selecting the checkbox.
- **Zero normal velocity**: Specify that there is no velocity in the normal direction.

Weak constraints can be used for certain conditions, according to the value selected in the **Use weak constraint** list. If **Yes** is selected, weak constraints will be always used. If **No** is selected, weak constraints will never be used. If **From constraints settings** is selected (the default), the settings in the feature's **Constraint Settings Section** will determine if weak constraints are to be used, defaulting to **No** if the section does not exist.

Use the **Selection** section to specify the selection on which to apply the boundary condition. The selection must be adjacent to a selection with **Free** frame motion, and (except for very particular cases) boundary conditions must be specified for all **Free** domain selections in order to obtain a well-posed problem.

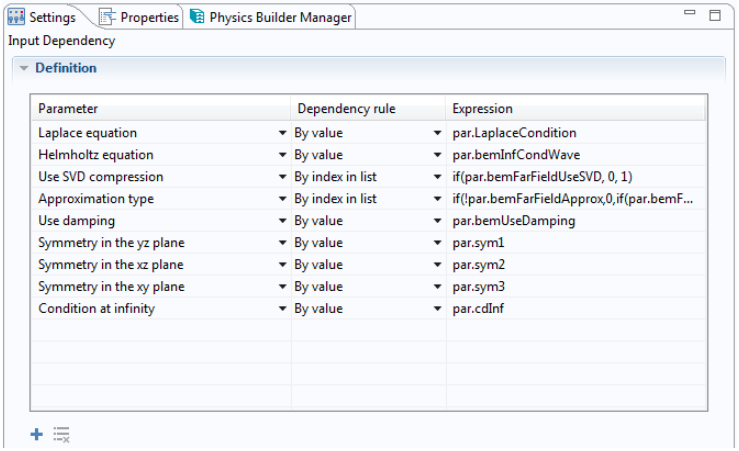
Input Dependency

Use an **Input Dependency** subnode ( ) to make the specifications in its parent node dependent on other user inputs.

DEFINITION

Click the **Add** button (+) to add an input dependency to the table above. Choose an available **Parameter**, and from the list in the **Dependency rule** column, choose **By value** (the default) or **By index in list** to determine the rule for the expression that you add

in the **Expression** column. Click the **Delete** button ( ) to remove a dependency from the table. The following screenshot shows an example:



In this example, the first line the table means that the **Laplace equation** property will get the value (**By value**) from the `LaplaceCondition` property of a physics feature instance in the Model Builder. The third line means that the value of the **Use SVD compression** property will be set **By index in list**. In this case, **Use SVD compression** is a checkbox, which means that the list is `[on, off]`. Therefore, if the evaluation of the expression is equal to 0, **Use SVD compression** will be `on`; otherwise, it will be `off`.

Periodic Feature

A **Periodic Feature** ( ) is a special boundary condition that couples, usually by pointwise constraints, dependent variables on a source side to a destination side to create a periodic boundary condition, for example. It has similarities with the Pair Feature.

The major difference between a periodic feature and an ordinary feature lies in subnodes that define selections. For periodic features, there are two extra options in the **Selection** list of the **Selection** section: **Source** and **Destination**. With these options you

can specify to use the source or destination boundaries in the condition of a periodic feature; see Specifying Selections for more information.

- To add a **Periodic Feature** under the **Building Blocks** branch, **Features** node: On the **Physics Interface** toolbar, select it from the **More Features** menu, or
- To add a **Periodic Feature** under the **Physics Interface** or **Multiphysics Interface**, Right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the **Features** submenu.

The **Settings** window is similar to the Generic Feature **Settings** window.

For information about the settings in the Identifiers and GUI Options sections, see the Generic Feature node.

SELECTION SETTINGS

Except for a few excluded settings, the sections are described for the Generic Feature node; see Selection Settings. For a periodic feature, you do not have to specify the geometric entity level because it is always boundary level. The same is true for the entity type setting because the only setting that makes sense is periodic conditions on exterior boundaries.

PREFERENCES

The **Allow simple periodic deduction of edges** checkbox is enables if you have added **Edge** to the **Supported geometric entity levels** list in the **Selection Settings** section. Select that checkbox to use the simple method for deduction of a periodic boundary without taking into account the rotation between source and destination.

For the other settings see Preferences, for the Generic Feature node.

Feature Link

The **Feature Link** ( ) refers to a common definition of a feature (for example, under the **Building Blocks** branch).

To add a **Feature Link** node, right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the context menu.

SOURCE FEATURE

Choose where to look for a certain feature from the **Links from** list. Select:

- **Building blocks** to choose from the features listed under the **Features** branch in the **Building Blocks** branch. You choose the feature from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in** to choose among built-in features that are available to the Physics Builder. In the **Package** list you choose the main resource to use features from. For each resource, you have a list of features in the **Link** list to choose from. You can only choose among the currently published features.
- **External resources** to choose among the features found in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all features found in the **Building Blocks** > **Features** branch of the selected file.

DEFAULT FEATURES

Select the **Add as default feature** checkbox to define the **Default geometric entity level**, **Default entity types**, and **Advanced preferences**.

See the Generic Feature node for the rest of the settings.

Multiphysics Feature

A **Multiphysics Feature** ( ) is a combination of other features that behave like one feature. The multiphysics feature inherits all variables and equations that all contained features has, which you add through **Contained Feature** nodes. You can right-click the **Multiphysics Feature** node to add most of the same features as for the Multiphysics Interface, including the Contained Feature node.

To add a **Multiphysics Feature**, right-click the **Multiphysics Interface** node to add this from the context menu.

The **Settings** window for the multiphysics feature is similar to a feature, but with some settings removed as they are inherited from the contained features. The entire

Restrictions section is excluded because the allowed space dimensions and allowed study types get their values from an intersection of the values in the contained features.

- Identifiers section for the Generic Feature node.

SETTINGS

Almost identical to the Selection Settings section of the Generic Feature node. For a multiphysics feature you cannot change the supported geometric entity levels, the domain type, or the override type. The contained features determine these settings. The entity level and domain type get their values from an intersection-like operation, and as override type you get the most strict one. The most strict override type is the first one in the **Override type** list.

PREFERENCES

Almost identical to the Preferences section of the Generic Feature node, except that you cannot change the model input setting. A multiphysics feature includes model inputs if any of the contained features does.

Multiphysics Coupling

You can add **Multiphysics Coupling** nodes ( ) under a **Physics Interface** or **Multiphysics Interface** node and refer to a multiphysics coupling under the **Building Blocks** branch.

To add a **Multiphysics Coupling**, right-click the **Physics Interface** or **Multiphysics Interface** nodes to add this from the context menu.

This node contains settings for specifying which coupling type the physics interface should be in regard to a coupling feature:

COUPLING FEATURE LINK

In this section you specify a coupling feature that the parent physics interface can be coupled to by selecting it from the **Link** list. The coupling feature can be linked from the same file as the physics interface (by choosing the default **Building blocks** from the **Links from** list), from a built-in package (by choosing **Built in** from the **Links from** list), or from an external file (by choosing **External resources** from the **Links from** list). Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear

and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.

MULTIPHYSICS COUPLING

From the **Coupling type** list, you specify which coupling type this physics interface is with regard to the coupling that is selected in the **Coupling Feature Link** section. The **Coupling type** list contains the coupling types that you have defined in the multiphysics coupling that this node links to.

OVERRIDE RULE SETTINGS

In this section, an override type is specified for the coupling feature by first using the **Override rule** list to determine which override rules to use — **Built in** (the default), **Locally defined**, or **Imported from external resource** — and then select a type from the **Override type** list (see Override Rule for more information). The coupling feature acts as if it were added last in the list of physics features under the physics interface, and overrides the physics features according to this override type. Note that in the coupling feature node itself an override type is also specified. That override type determines how the coupling feature should override other coupling features.

Generic Multiphysics Coupling

To add a **Generic Multiphysics Coupling** node ( ), under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Generic Multiphysics Coupling** node to add many features.

Coupling features have mostly the same subnodes as ordinary features. However, there is one difference when working with variable expressions under a coupling feature.

Under a coupling feature there is no parent physics interface, so the normal `phys` prefix is useless (unless it is used under a Coupling Type Contribution node). Instead there is the possibility to append the coupling type to the physics scope; see the **Couplings** section below. So inside a coupling feature that couples to a physics of coupling type `A`, the prefix `phys.A` works in the same way as the prefix `phys` would under the physics interface of type A.

See Generic Feature for information about the **Identifiers**, **Restrictions**, **Selection Settings** (see also below), **Coordinate Systems**, and **Preferences** sections.

COUPLINGS

This section has a table that defines the names and descriptions of the coupling types that the coupling feature requires in the **Coupling type** and **Description** columns, respectively. In the **Optional** column, use the checkbox to specify if the coupling type is optional for the coupling feature or not. An optional coupling type does not need to have a corresponding physics in the model. The coupling feature can be added to a model anyway, and if the corresponding physics is set to **None** in the coupling feature you will not get a warning.

The coupling feature is not available under the **Multiphysics** branch in the **Model Builder** unless at least one physics interface of each coupling type has been added to the same model component. To define the coupling type of a physics interface in regard to a coupling feature, see Multiphysics Coupling.

The coupling feature instance in the **Model Builder** has a section with a title given by the description of the coupling feature. This section contains one list for each coupling type. The lists are used to pick the physics interfaces that the coupling feature is coupled to. The descriptions of the lists are given by the descriptions of the coupling types, defined in the second column of the table.

RESTRICTIONS

In this section, you can specify restrictions in terms of which space dimensions and study types that are allowed for this multiphysics coupling.

The list under **Allowed space dimensions** includes all space dimensions except 0D by default. Click the **Add** button (+) to choose one or more space dimensions that are not already included from the **Allowed space dimensions** list in the **Add** window that opens. Use the **Move Up** , **Move Down** , and **Delete** buttons under the table to organize the list if needed.

The list under **Allowed study types** includes **Stationary** and **Time dependent** by default. Click the **Add** button (+) to choose one or more study types that are not already included from the **Allowed study types** list in the **Add** window that opens. Use the **Move Up** , **Move Down** , and **Delete** buttons under the table to organize the list if needed.

SELECTION SETTINGS

This section works in the same way as the same section for a Generic Feature, but there is one extra thing to keep in mind when specifying the override type of a coupling feature. The override type specified under the **Selection Settings** section is only used to determine the override behavior of the coupling feature in regard to other coupling

features in the **Multiphysics** branch. A coupling feature can also override the physics features of the physics interfaces that it is coupled to. However, the way in which that is done is determined by another override type, which you specify in the Multiphysics Coupling node.

COORDINATE SYSTEMS

In this section, you can specify the base vector systems and the frame type for the multiphysics coupling.

From the **Input base vector system** list, choose **Frame system** (the default), **Selected input coordinate system**, **Spatial coordinate system**, **Material coordinate system**, **Mesh coordinate system**, or **Geometry coordinate system**.

From the **Base vector system** list, choose **Frame system** (the default), **Selected input coordinate system**, **Spatial coordinate system**, **Material coordinate system**, **Mesh coordinate system**, or **Geometry coordinate system**.

From the **Frame type** list, choose **Selectable by user**, **Spatial**, or **Material** (the default).

PREFERENCES

Select the **Singleton feature** checkbox if this multiphysics feature only can be added once.

Select the **Include model inputs** checkbox if this multiphysics feature should include model inputs.

GUI OPTIONS

From the **Hide feature from context menus** list, choose **No** (the default); **Yes**, if you do not want this multiphysics feature to appear on context menus; **Only for develop off**; or **Technology preview disabled**. The last two options are for in-house use only.

Global Multiphysics Coupling

The **Global Multiphysics Coupling** node (▪) defines a multiphysics coupling that can only exist (have selections) on the global geometric entity level (entire model), which means that the **Settings** window for the feature instance does not contain a selection list.

To add the **Global Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Global Multiphysics Coupling** node to add many features.

See Generic Multiphysics Coupling for the settings.

Domain Multiphysics Coupling

The **Domain Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) on the domain geometric entity level of the current space dimension, which represents volumes in 3D, surfaces in 2D, and lines in 1D.

To add the **Domain Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Domain Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it does not include the **Supported geometric entity levels** list.

Boundary Multiphysics Coupling

The **Boundary Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) on the boundary geometric entity level of the current space dimension, which represents surfaces in 3D, lines in 2D, and points in 1D.

To add the **Boundary Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Boundary Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it does not include the **Supported geometric entity levels** list.

Edge Multiphysics Coupling

The **Edge Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) on the edge geometric entity level of the current space dimension, which represents lines in all space dimensions. This feature is normally only applicable in 3D (the default restriction), but it can optionally be applicable in lower dimensions in special situations.

To add the **Edge Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Edge Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it does not include the **Supported geometric entity levels** list.

Point Multiphysics Coupling

The **Point Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) on the point geometric entity level of the current space dimension, which represents points in all space dimensions. This feature is normally only applicable in 3D, 2D, and 2D axial symmetry (the default restriction), but it can optionally be applicable in other dimensions in special situations.

To add the **Point Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Point Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it does not include the **Supported geometric entity levels** list.

Pair Multiphysics Coupling

The **Pair Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) for pairs (identity pairs and contact pairs).

To add the **Pair Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Pair Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it only allows you to choose **Boundary** or **Edge** from the **Supported geometric entity levels** list in the **Selection Settings** section.

Contact Multiphysics Coupling

The **Contact Multiphysics Coupling** node ( ) defines a coupling feature that can only exist (have selections) for contacts.

To add the **Contact Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Contact Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, except that it only allows you to choose **Boundary** from the **Supported geometric entity levels** list in the **Selection Settings** section.

Layered Material Multiphysics Coupling

The **Layered Multiphysics Coupling** node ( ) defines a coupling feature for layered materials.

To add the **Layered Multiphysics Coupling** node, under **Building Blocks**, right-click the **Multiphysics Couplings** branch node to add this from the context menu. You can right-click the **Layered Multiphysics Coupling** node to add many features.

The **Settings** window is almost identical to the Generic Multiphysics Coupling node, but it also includes a **Layered Material** section.

LAYERED MATERIAL

From the **Selection type** list, choose **Layers** (the default) for a default layered material or **Interfaces** for a layered material side-by-side continuity.

For **Layers**, **Exterior layers** and **Interior layers** are included by default. Click the **Add** button (+) to add **Exterior layers adjacent to nonphysics** or **Exterior layers to physics** if desired.

For **Interfaces**, **Exterior interface** and **Interior interfaces** are included by default. Click the **Add** button (+) to add **Exterior interfaces adjacent to nonphysics** or **Exterior interfaces to physics** if desired.

Coupling Type Contribution

The **Coupling Type Contribution** node ( ), which can be added as a subnode to any of the multiphysics coupling nodes, defines a physics interface context in which you can add variable declarations, variable definitions, equations, and so forth. The contributions behave as if they were added by a physics feature under the physics interface. All contributions that do not belong to any context use the multiphysics coupling as context. The context decides the default scope of variables and function names, for example. The **Settings** window contains the following section:

RESTRICT TO COUPLING TYPE

Choose the coupling type that the contributions should be restricted to using the **Restrict to coupling type** list.

PROPERTY DEPENDENCIES

You can let inputs in physics properties enable and disable user interface controls in a multiphysics coupling feature. To do so, the coupling feature needs to know that the

physics property actually exists. You can define such properties by adding them in the **Property Dependencies** table. You need to support the name of the property and the input as well as the dimension of the input. If the **Allow not defined** checkbox is cleared, you will then get an error as soon as you try to build a model with this coupling feature and a physics that try to use this coupling but does not have the required property or a required parameter in the property. The value in the **Value when not defined** column is needed when the property or input is undefined. In that case, the coupling feature will act as if the input in the property will have this value.

When building a model, the properties required by the coupling feature will show in the **Coupled Interfaces** section in the coupling feature's Settings window. The properties will be disabled, and you need to go to the physics node to change the value. There is a possibility to hide them by clicking the **Show or Hide Physics Property Settings** button.

To let a required input in a physics property activate an input in a coupling feature, use an **Activation Condition** where you specify the user input by name and set **From** to **User input from this feature**. Set the name of the user input in the activation condition to `couplingType.propertyName.inputName` (for example. `heat.PhysicalModelProperty.HeatTransferInPorousMedia`).

Subcoupling Features

You can add a multiphysics coupling feature under another multiphysics coupling feature, by right-clicking the parent multiphysics coupling feature and choosing a multiphysics coupling feature from the **Features** submenu. The child multiphysics coupling feature cannot set the coupled interfaces; they are always the same as the parents. Therefore, they do not include a **Couplings** section in their settings. But the child multiphysics coupling feature can add contributions to the physics in the same way as an ordinary multiphysics coupling feature. The child selection is always a subset of the parent selection. If a multiphysics coupling feature is selected in the user interface, you can add children using a context menu or the **Attribute** menu in the ribbon toolbar, if the coupling supports any children.

Instead of a child directly you can also add a link to another multiphysics coupling feature. In this case, users have to make sure that the coupling types in the features are be equal.

For subcoupling features, The `mph.` syntax will give the parent scope in the same way as `phys.` does for physics features. To use feature scope for the subcoupling (that is, `comp1.parent.child`), type `item.`.

When setting up selection filters for parent couplings you use a **Multiphysics Coupling Filter** feature, which takes the coupled physics selection into account. This is not necessary for the subcoupling feature because its selection is always a subset of the parent selection. Therefore you must use a **Selection Component Filter** feature in this case.

Contained Feature

Right-click the Multiphysics Feature node to add the **Contained Feature** node ( ) and to specify the features that a multiphysics feature inherits from. This is a link node, similar to the Feature Link node, the difference being that the **Settings** window only contains the Source Feature section.

If you use a multiphysics interface that links to a built-in interface, you can choose the features of that built-in interface as a contained feature. Use such links with care, because not all built-in features support the automatic UI generation that the Physics Builder uses.

Auxiliary Settings (Feature Nodes)

A feature can have one **Auxiliary Settings** node ( ) that contains a collection of various settings for its parent feature that you usually do not need to change.

Auxiliary Settings nodes can be added to the parent **Features** nodes under the **Building Blocks** branch, or to the features added under a **Physics Interface** or **Multiphysics Interface**. Right-click the **Auxiliary Settings** node to add Geometric Nonlinearity, Physics Symbol, and Usage Condition subnodes.

The **Settings** window has the following sections:

GUI ATTRIBUTES

Enter a valid image filename in the **Icon** field to use a different icon for the feature. If this field is empty, the feature uses a default icon, which is different depending on the feature's entity level.

MODEL INPUT SECTION

This section provides the possibility to include model inputs to a built-in property group in the Model Builder. Click the **Select Quantity** button (+) to open the **Physical Quantity** dialog, from which you can choose a physical quantity to add as a model

input. Use the other buttons under the table to arrange and edit the table of model inputs if required.

Select the **Always visible** checkbox to make the model inputs ignore the materials so that they always appear in the **Settings** window of the feature instance.

Select the **Auto matched** checkbox to specify that the model input can be automatically matched by the feature input framework.

Select the **Use common model input by default** checkbox to specify that the model input use the **Common model input** option by default for its list selection. Otherwise, the **User defined** option will be used.

Under **GUI options**, make the following settings to control the visibility of the **Model Input** section:

From the **Category for hiding section** list, choose **None**, **Advanced physics options** (the default), **Equation-based contributions**, or **Stabilization**.

The **Section is initially collapsed** checkbox is selected by default. Clear it to show the **Model Input** section initially in an expanded state.

FEATURE SELECTION

This section contains settings that affect the entities on which the physics feature is applicable. The setting in the **Take selection from** list controls the maximum selection from which the feature can take its selection. That is the selection that is further restricted by the **Applicable entities** setting of the physics feature. The default option, **Parent**, means that the selection should be taken from the physics or in the case of a subfeature from the parent feature. **Physics** means that the selection should be taken from the physics even in the case of a subfeature. The last option, **Geometry**, indicates that the feature should take its selection from the entire geometry.

The other settings are the **Not applicable on infinite element domain**, **Not applicable on absorbing layer domain**, and **Not applicable on perfectly matched layer domain** checkboxes. Select any of these checkboxes to make sure that the physics feature cannot be applied on a domain of the particular type. To access these settings, first select the **Specify special applicability for selection** checkbox. When cleared, the settings included with this checkbox are ignored and grayed out. This is important if an interface or feature uses multiple auxiliary settings for some reason. It is then important that these settings are either identical or ignored; otherwise, an error will be thrown. The **Specify special applicability for selection** checkbox is cleared by default.

INPUT COORDINATE SYSTEM

When any of the base vector systems choices of the parent physics feature are **Selected input coordinate system**, this section has settings that control the input coordinate system. First, there is a **Coordinate section** list with the options **Add coordinate system section** (the default) and **Use parent's coordinate systems section**. The latter choice disables all other settings and uses the **Coordinate System Selection** section from the parent if there is any. The **Add coordinate system section** option adds a **Coordinate System Selection** section to the physics feature. It also enables a couple of other settings that control this section. Select the **Only allow orthonormal systems** checkbox to only allow the user to choose between orthonormal systems when selecting the input coordinate system of the feature. Select the **Only user-defined systems** checkbox to only allow the user to choose between user-defined systems when selecting the input coordinate system of the feature. In the **Filtering of systems** list, choose between the options **Allow boundary systems**, **No boundary systems**, and **Only boundary systems**. Note that the filtering only affects features that live on the boundary geometric entity level.

LOAD- AND CONSTRAINT GROUPING

This section has the settings **Enable load groups** and **Enable constraint groups** which can be selected to make the physics feature compatible with the **Load cases** functionality of COMSOL Multiphysics. When load- or constraint groups are enabled for a feature it gets extra menu-items so that the user can select under which group it is active. To make the physics feature useful under load grouping the variables that should be affected by the grouping need to have the **Include in load groups** setting selected in the **Variable declaration** node. Constraints are by default affected by the constraint grouping. If a particular constraint should not be affected by the grouping, then select the **Exclude from constraint grouping** setting in the **Constraint** node.

HARMONIC PERTURBATION

Select the **Perturbation method** from the list that has the following options:

- **No perturbation support** (the default).
- **Can act as contribution**. Enables an option so that a user can choose if a feature instance can act either as a stationary contribution or as a harmonic contribution. This option only makes sense for contributing features.
- **Can add contribution as child**. Adds a subfeature to this feature that adds the harmonic contribution. This is typically used for exclusive features. From the **Harmonic contribution feature** list, choose **Automatic** generation of the subfeature or link to a feature with the **From link** option. The automatically generated subfeature adds harmonic contributions for all variables in the parent feature that are defined

under a user input and that have the preference property **Interpret as right-hand-side** selected.

CREATING FEATURE

Select the **Define an equivalent pair feature** checkbox to the program create an automatic version of this feature for pairs.

You can choose **Last in list** (the default), **First in list**, or **After features of type (regular expression)** in the **Position in list for new features** list. For **After features of type (regular expression)** you can add a regular expression to set to position it after some specific feature types (such as `Boundary*` for all types that begin with `Boundary`).

The option **First in list** places new features before existing default features, so it should be used with great care.

APPLICABLE PAIR REGION

Here you control which will be the default applicable pair region of identity pairs and contact pairs. From the **Default applicable pair region** list, choose **Fallback and nonpair regions** (the default), **Nonpair region**, or **All regions**.

Auxiliary Settings (Multiphysics Couplings)

The various Multiphysics Coupling features can have one **Auxiliary Settings** node ( ) each.

GUI ATTRIBUTES

Enter a valid image filename in the **Icon** field to use a different icon for the feature. If this field is empty, the feature uses a default icon, which is different depending on the feature's entity level.

MODEL INPUT SECTION

This section makes it possible to select a list of model inputs to always show up in the coupling features if the **Include model inputs** checkbox is selected in the feature node's **Preferences** section. Click the **Select Quantity** button ( ) to open the Physical Quantity dialog, from which you can choose a physical quantity to add as a model input. Use the **Move Up** , **Move Down** , and **Delete** buttons under the table to organize the list if needed. Select the **Always visible** checkbox to make the model inputs ignore the materials so that they always appear in the **Settings** window of the

feature instance. The **Auto matched** checkbox is selected by default and sets the **Feature input match type** list to **Model input match** in the **Feature Input** node's Settings window. The **Use common model input by default** checkbox is selected by default and sets the **Default value** list to **Common model input** in the **Feature Input** node's Settings window. Often, model input sections are not needed. Use a Feature Input node for more control.

INPUT COORDINATE SYSTEM

In this section you can specify an input coordinate system if needed.

From the **Coordinate system** list, choose **Add coordinate system section** or **Use parent's coordinate system section**. If you choose **Add coordinate system section**, the following additional settings are available:

Under **Filtering of systems**, select the checkboxes for **Only allow orthonormal systems** and **Only user-defined systems** if desired to exclude all other types of coordinate systems.

Under **Only used for features defined on the boundary geometric entity level**, select one of the following options from the **Filtering of boundary systems** list for boundary features: **Allow boundary systems**, **No boundary systems**, or **Only boundary systems**.

Geometric Nonlinearity

The **Geometric Nonlinearity** node ( ) is a subnode to the **Auxiliary Settings** node (see Auxiliary Settings (Feature Nodes) and contains a setting for indicating whether the parent physics feature adds geometric nonlinearity to the problem.

GEOMETRIC NONLINEARITY

Select an option:

- **Never** (the default). This option is the same as not adding the **Geometric nonlinearity** node at all; that is, the feature does not make the model geometrically nonlinear.
- **On request**. Adding the physics feature to a model enables the geometric nonlinearity option in the study steps so that the user can choose if the model should be regarded as geometrically nonlinear. The feature must always generate linear or nonlinear equations depending on the current study step setting. Note that other

features with the geometric nonlinearity setting set to **Always** can take control over the setting, enforcing geometric nonlinearity.

- **Always**. Adding the physics feature to a model makes the geometric nonlinearity option in the study steps visible but selected and disabled so that the model is always regarded as geometrically nonlinear.

There are two parts that need to be implemented when making a physics interface compatible with geometric nonlinearity. The physics features must indicate if they listen to the geometric nonlinearity setting in the study steps, which then must be visible, or if they always add geometric nonlinearity to the problem, thus taking control of the study step setting. This part is done by using the **Geometric Nonlinearity** node.

The other part is to make physics features generate linear or nonlinear equations depending on the geometric nonlinearity setting in the current study step. This is done by placing the relevant variables and equations under a **Usage Condition** node. Typically the features that need support for both linear and nonlinear equations are the ones that have **Geometric nonlinearity** set to **On request**.

To set up a usage condition that is true when the geometric nonlinearity option is selected in the current study step, configure it in the following way: Select the **User input** checkbox, set **Specify user input** to **By name**, set **From** to **User input from Study step**, type `geometricNonlinearity` in the **User input** field, and finally add "on" as the activating value.

Physics Symbol

The **Physics Symbol** node ( ) is a subnode to the **Auxiliary Settings** node (see Auxiliary Settings (Feature Nodes) and contains settings that specify a symbol to be shown on the geometry in the **Graphics** window. The symbol displays by default on the selection of the physics feature. Right-click the **Physics Symbol** node to add a Selection Definition or Input Dependency subnode if needed.

PHYSICS SYMBOL

Enter a valid image filename in the **Icon** field to specify the image that should be used for the symbol. Next to the symbol a few extra decorations can be displayed. From the **Decoration** list choose an option:

- **None** (the default). No decoration should be used.
- **Selected input coordinate system**. A symbol indicating which coordinate system the user has selected for the physics feature.

- **Line to point**. A line from the physics feature's selection to a point that can either be specified by entering coordinates or by selecting **Centroid of selected entities** or **Centroid of source** from the **Position of icon** list. If you choose **Centroid of selected entities**, the position of icon will be computed from the selection provided by a **Selection Definition** subnode. To specify coordinates select **Specify coordinates** from the **Position of icon** list and then enter the coordinates in the **Coordinate** field; for example, you can use `{0,0,1}` or `par.someVectorInput`. The physics symbol is displayed at the given coordinate. You can specify the colors to use for this symbol when it is selected and unselected using the **Selected color** list and **Unselected color** list, respectively.
- **Joint**. You can use this decoration to show connection lines to join the source and destination attachments together. Specify its position by entering coordinates or by selecting **Centroid of selected entities**, **Centroid of source**, or **Centroid of destination** from the **Position of icon** list. If you choose **Centroid of selected entities**, the position of icon will be computed from the selection provided by a **Selection Definition** subnode. To specify coordinates select **Specify coordinates** from the **Position of icon** list and then enter the coordinates in the **Coordinate** field; for example, you can use `{0,0,1}` or `par.someVectorInput`. The physics symbol is displayed at the given coordinate. You can specify the colors to use for this symbol when it is selected and unselected using the **Selected color** list and **Unselected color** list, respectively.
- **Plane**. You can define one or more planes (in 3D) or lines (in 2D) for visualization in the Graphics window. Each of plane's information is a line in the table, and it contains:
  - In the **Coordinates** column, the coordinates of 3 points not aligned in the 3D plane (3D) or of 2 points in the line (2D) that you want to show. In 3D, the format is `{{A.1,A.2,A.3}, {B.1,B.2,B.3}, {C.1,C.2,C.3}}`, and in 2D, the format is `{{A.1,A.2}, {B.1,B.2}}`.
  - In the **Color [RGBA]** column, the color of the plane or the line in the format of values from 0 to 255 for the red (R), green (G), and blue (B) colors and for the alpha channel (A), which specifies the opacity (for example, `{222, 49, 99, 128}`). The alpha value is 0 for a fully transparent object and 255 for a fully opaque object.
- **Normal vector**. An arrow indicating a surface normal. The direction of the surface normal can be reversed by selecting the **Reverse direction** checkbox. If you select the **Reverse boundary position** checkbox, the tip of the arrow will point at the boundary instead of the base of the arrow.

- **Tangent vector**. An arrow indicating a tangent vector. The direction of the tangent vector can be reversed by selecting the **Reverse direction** checkbox.
- **Symmetry axis**. A typical usage of this symbol — a red line or cross — would be visualization of the symmetry axis in a model with sector symmetry. For 3D components, the symmetry axis is specified by providing expressions for a point and direction using the **Point on symmetry axis** and **Direction of symmetry axis** fields. A red line will be drawn in the graphics view, going through the specified point and parallel to the specified direction. For 2D components, the **Direction of symmetry axis** field is ignored, and a red cross is shown at the point specified in the **Point on symmetry axis** field.

From the **Display symbol when** list, choose one of the following options:

- Choose **Symbol is enabled** (the default) to display the symbol if symbols are enabled in the physics interface.
- Choose **Feature is selected and symbol is enabled** to display a symbol for the feature if the feature is selected and symbols are enabled in the physics interface.
- Choose **Only if the feature is selected** to display a symbol for the feature if and only if the feature is selected. The symbol settings in the physics interface are ignored.
- Choose **Physics or a feature is selected and symbol is enabled** to display a symbol for the feature if its physics, or a feature in it, is selected and symbols are enabled in the physics interface.
- Choose **Physics or a feature is selected** to display a symbol for the feature if its physics, or a feature in it, is selected. The symbol settings in the physics interface are ignored.

SELECTION

Here you specify a selection of the source attachments.

Choose an option from the **Selection** list: **From parent** (the default), **From selection input**, **Global**, **Operation**, **From definitions library**, **From external resource**, **Top level entities applicable to parent**, or **Operation on sibling-feature selections**, **From moving domains**.

For any choice, except **Global**, choose the **Output entities**: **Selected entities** (the default), **Adjacent domains**, **Adjacent boundaries**, **Adjacent edges**, **Adjacent points**, **Mesh boundaries**,

Restricted to geometric entity types, **Restricted to frame type**, **Base selection of extra dimension**, or **Attached extra dimension**.

- For **Adjacent boundaries**, select an option from the **Restrict to** list: **All adjacent boundaries**, **Exterior boundaries to the domain selection**, **Interior boundaries to the domain selection**, **Exterior boundaries whose up side is in the domain selection**, or **Exterior boundaries whose down side is in the domain selection**.
- For **Adjacent edges** or **Adjacent points**, select an option from the **Restrict to** list: **All adjacent entities**, **Exterior entities to the selection**, or **Interior entities to the selection**.
- For **Restricted to geometric entity types** choose the **Allowed entity types** in the table, **Interior** or **Exterior**.
- For **Restricted to frame type** choose a **Frame type**: **Material** (the default), **Mesh**, **Geometry**, or **Spatial**.

Operation

For **Operation**, choose the **Operation type**: **Union** (the default), **Intersection**, **Difference**, or **Complement**. Then define the **Input selections**, and for Difference the **Selections to subtract**. Select options from the **Output entities** list as defined above.

From definitions library

For **From definitions library**, choose an option from the **Link** list and select options from the **Output entities** list as defined above.

Operation on sibling-feature selections

For **Operation on sibling-feature selections**, choose the **Operation type**: **Union** (the default), **Intersection**, **Difference**, or **Complement**. Then define the **Input feature types**, and, for **Difference**, the **Feature types to subtract**. Select options from the **Output entities** list as defined above. Instead of writing the feature ID of the physics feature to use in the selection, you can also write a path of IDs. The first ID is then the physics ID followed by one or several feature IDs. Regular expressions are accepted to match the IDs against a pattern. If the current entity is a coupling feature, the path syntax also accepts a coupling type instead of the physics ID. The coupling type must be preceded with the multiphysics prefix (`mph.`) and uses the coupling feature's selected physics of this coupling type. Here are some examples:

- `FeatureB`: Looks for the selections of features with ID `FeatureB`.
- `InterfaceA/FeatureB/FeatureC`: Looks for the selections under `FeatureB` with ID `FeatureC`. The interface ID must be `InterfaceA`.

- `\w+/FeatureB/Feature[A-C]`: Looks for the selections under `FeatureB` with IDs that start with `Feature` and end with any of the letters A, B, or C. The interface ID can be any nonempty sequence of word characters.
- `mph.TypeA/Feature[A-C]`: Looks for selections of features under the interface of coupling type `TypeA` in a coupling feature. The features must have IDs that start with `Feature` and end with any of the letters A, B, or C.

Note that a physics feature can only match interface IDs of the physics that it belongs to. A coupling feature can only match interfaces that are part of its selected interfaces.

Selection Definition

Add a **Selection Definition** subnode ( ) to the **Physics Symbol** node to compute the position of icon will be computed from the selection provided by this node, if you choose **Centroid of selected entities** for the **Line to point** and **Joint** decorations.

SELECTION

Here you specify a selection of the connector position. See the documentation for the **Selection** section in the settings for Physics Symbol above.

Inputs

In this section:

- Creating Inputs
- User Input
- Selectable Input
- Selection Input
- Reference Input
- Boolean Input
- Real Input
- User Input Group
- Table
- Column
- Text Label
- Buttons
- Section
- Constraint Settings Section
- Material Property
- Material List
- Feature Input
- Activation Condition
- Additional Requirement
- Allowed Values
- Activating Allowed Values
- Button
- Button Link
- Toggle Button
- Data Binding
- Integer Values Check
- License Settings
- Real Values Check
- General Check
- Named Group Members
- Update User Input Event

Use this section in combination with the Designing the GUI Layout section.

Creating Inputs

An input is a parameter that shows up in the **Settings** window of the feature instance in the Model Builder. An input always represent data storage in a COMSOL Multiphysics

model (MPH file) built with the Model Builder. You can choose to hide an input from the **Settings** window, and then the input only represents a data storage.

One important difference between inputs and variables is that all variables created by the Physics Builder are not saved in the MPH file, but they can be recreated from the stored data (essentially user inputs) in an MPH file together with the Physics Builder file (extension `.mphphb`).

The value of a variable, on the other hand, can be read when solving or from result features in the Model Builder. This is not possible with user inputs. If you want to access a value of an input, you must first declare a variable and define its value equal to the value of the input. It is possible to add a variable definition to an input node, which represents a variable declaration and a variable definition. The declaration takes the information from the input, and the definition gives the declared variable the value of the input.

STANDARD INPUTS

There are these types of standard inputs:

- User Input. This is a general user input that supports all settings and sizes. It is a bit more complex to set up due to the number of supported settings.
- Selectable Input. A user input that a user only can set to a predefined set of allowed values. It does not support units or array types. The typical GUI component is a combo box (or dropdown menu).
- Boolean Input. A user input that only allows two values, `0` and `1` (represents false and true). It does not support units or array types. The typical GUI component is a checkbox.

SPECIAL VERSIONS OF INPUTS

There are also special versions of inputs, which add predefined declarations of one or several user inputs with a special relation, for example. These special user inputs are summarized below:

- Material Property. Defines two user inputs: one for selecting the source of the material data and the other for specifying a user-defined value.
- Material List. Defines a user input that contains a material selection.
- Feature Input. Defines two user inputs: one for selecting the source of the feature input data and the other for specifying a user-defined value.

- Selection Input. Defines an extra selection of geometrical entities for the feature to select entities on different domains when coupling them to the feature, for example

GUI OPTIONS SETTINGS

A user input also needs information about its appearance in the user interface. It is possible to control how it appears, when it appears, and where it appears in the **Settings** window of a feature or property. You control these settings from the **GUI Options** section of each user input node and through a special activation condition node; see Activation Condition.

Also see Additional Requirement, Allowed Values, Activating Allowed Values, Named Group Members, Integer Values Check, General Check, Variable Definition, and Component Settings.

User Input

A **User Input** ( ) for a feature or property becomes a data storage editable by the user for the corresponding instance in the Model Builder (see Inputs for an overview).

To add a **User Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **User Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a user input contains the following sections:

DECLARATION

In the **Declaration** section you specify the name of the parameter in the **Input name** field. The description, symbol, physical quantity, and SI unit of the user input work identical to variable declaration; see Variable Declaration and Dependent Variable Declaration. In addition, you can add a tooltip in the **Tooltip** field, using the same syntax as for a description.

The dimension and default value of the user input is a bit different compared to variables. For scalars, vectors, and matrices you set the desired dimension in the **Dimension** list. Use the **Single** array type for the **Array type** list, which also is the default. When you need user inputs that are vectors of vectors, or vector of matrices, choose

Double in the **Array type** list. You can then choose the outer dimension with the **Outer dimension** list and the inner dimension with the **Inner dimension** list. The **Inner dimension** list is identical to the **Dimension** list, but the **Outer dimension** list has fewer options. For all double-array user inputs, the default value refers to the inner dimension and fills up the outer dimension with identical defaults.

From the **Dimension** or **Inner dimension** list you can choose **Scalar** (the default), **Vector (3x1)**, **Matrix (3x3)**, **Changeable**, **Boolean**, **Real**, or **Custom** to define the dimension of the reference input. The value of a **Real** input dimension is a double (a number or a parameter), and the value can be calculated directly without solving.

When the user input is a scalar, there is an option to define a set of allowed values. In the **Allowed values** list, you can choose **Any** or **From list**. If you choose **From list**, a table shows up that you can fill the with allowed values. The **Default value** list only contains the values entered in the **Allowed values** list. If you choose **Any** in the **Allowed values** list, you specify the default in the **Default value** field.

User inputs of the type **Boolean** is a special case of a scalar with two allowed values, internally represented with `0` and `1`. The obvious control type for this user input is a checkbox that either can be cleared (`0`) or selected (`1`). To make the checkbox selected by default, select the **Default selected** checkbox.

When you want vectors where each element must be in a set of allowed values or is a Boolean, you use a double-array user input. Set the outer dimension as desired, and choose **Scalar** or **Boolean** from the **Inner dimension** list. If you choose **Scalar**, you can set the allowed values as described above.

RESTRICTIONS

In the **Allowed space dimensions** list you can define what space dimensions this particular user input can be used in. The option **Same as parent** (the default option) means that the user input supports the same space dimensions as the parent feature or property. If you want to control the space dimensions manually, choose **Customized** from the list. You can then select the allowed space dimensions from a list of all space dimensions.

If the user input does not support a space dimension, it becomes completely removed from the feature or property, not just hidden from the user interface. If you then try to access it in a variable definition, for example, an error message appears.

ADVANCED

Select the **Omit in Compact History** checkbox to omit that input from the Compact History. This means that any changes made to this input will not be recorded as an API statement when doing a reset of the model history. When select the **Omit from Compact History** checkbox, that also means that it is omitted in duplicate and paste operations, so the **Reset to default setting when duplicating or pasting the entity** checkbox (see below) is selected and disabled. Note that this checkbox will be enabled and selected if the **Omit in Compact History** checkbox is cleared again, even if the checkbox was cleared before the **Omit in Compact History** checkbox was selected.

Select the **Reset to default when duplicating or pasting the entity** checkbox if you want the settings to be reset to the default values when an entity is duplicated or pasted. This checkbox should typically be cleared.

Select the **Ensure unique default values** checkbox to make sure that the default values use unique values. From the **Method** list, choose one of the following methods to ensure unique values:

- **Among features of this type** (the default), to ensure uniqueness among features of the same type.
- **Among category of user inputs in all features**, to ensure uniqueness among a specific category of user inputs in all features, which you specify in the **Category** field.
- **Among category of user inputs in same feature list**, to ensure uniqueness among a specific category of user inputs in the same feature list, which you specify in the **Category** field.

The difference between the last two options is that the former searches for existing values among all features recursively (also subfeatures) and the latter only searches for values in the same list.

It is also possible to add a condition that includes a sibling feature in the search for existing values by selecting the **Use condition on sibling** checkbox. A condition, which you enter in the **Condition** field, can then be evaluated for each sibling (or physics property settings). No values will be collected from sibling feature where this condition is false.

GUI OPTIONS

If you want the user input to disappear when it is inactive, select the **Hide user input in GUI when inactive** checkbox. Select the **Show no description** checkbox to hide the text label containing the description above the GUI component of the user input. Similarly, you can hide the symbol from the GUI by selecting the **Show no symbol** checkbox. As

a final option, it is possible to add a divider above the GUI component and any description text label. The divider is a horizontal line with an optional descriptive text. Select the **Add divider above the user input** checkbox to add the divider. When selected, you can enter the divider text in the **Text** field.

See Designing the GUI Layout for more information

Selectable Input

A **Selectable Input** node ( ) is a special version of the **User Input** node that defines a data storage that can only contain values from a list. This node is equivalent to a **User Input** node with a scalar or scalar inner dimension and with the **Allowed values** list set to **From list**. The main difference is that the selectable input defines its allowed values through **Allowed Values** subnodes. (see Inputs for an overview).

To add a **Selectable Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Selectable Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a selectable input has the following sections:

DECLARATION

Almost the same as for the User Input. The **Default value** list can either be the **First allowed value** (the default) or **Custom default**. The latter allows you to enter an arbitrary default value as long as it is among the allowed values defined for the input.

See User Input for the rest of the settings.

Selection Input

A **Selection Input** node ( ) adds an extra selection of geometrical entities to the parent feature. Use such extra selections to show a selection in the graphics rendering or to select entities on different domains when coupling them to this feature, for example.

To add a **Selection Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a selection input has the following sections:

DECLARATION

In the **Declaration** section you specify the name and a description of the selection input in the **Input name** and **Description** fields.

You also specify the entity level from the **Geometric entity level** list. The default is the same level as the parent feature. The choices **Same as top level (Domain condition)** and **One level below top level (Boundary condition)** are relative to the top level of the interface. If the top level of the interface is **Domain**, choosing **One level below top level (Boundary Condition)** means that the selection input applies to boundaries. If the top level is **Boundary**, choosing **One level below top level (Boundary Condition)**, the selections are for lines (edges) in 3D and points in 2D. The choices **Same as parent level** and **One level below parent level** make the selections apply to entities of the same geometric entity level or one level below (boundaries, if the parent level is domains, for example), respectively.

Initially, the selection can be cleared or include all entities for the selected geometric entity level. Choose **Cleared** (the default) or **All entities** from the **Initial selection** list.

RESTRICTIONS

In the **Allowed space dimensions** list you can define what space dimensions this particular selection input can be used in. The option **Same as parent** (the default option) means that the selection input supports the same space dimensions as the parent feature or property. If you want to control the space dimensions manually, choose **Customized** from the list. You can then select the allowed space dimensions from a list of all space dimensions.

SELECTION SETTINGS

Applicable Entities

It is possible to limit the types of entities where the selection can be active. For example, a boundary selection can be limited to only interior boundaries. All other selected boundaries then get marked as *not applicable*. For more complex situations, you can use conditions on domain types to decide if a specific boundary is applicable or not.

Select a form of **Applicable entities** from the list: **From entity types** (the default) or **From sequence**.

- If **From entity types** is selected, select one or more of the options available when you click the **Add** button (+) add them to the list of applicable entities. **Exterior** and **Interior** boundaries are selected by default. Use the buttons under the list to organize as needed.
- If **From sequence** is selected, select a **Selection filter sequence**: **Locally defined** (the default), **From built-in quantities**, or **Imported from external resource**. Select a sequence to link to from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list. I the sequence is **Imported from external resource** also select an **Imported file**.

For more details on entity types, see Selection Terminology.

Override Rule

Some features cannot exist on the same selection (for example a boundary), and COMSOL Multiphysics uses override rules to decide how the selection of one feature overrides another feature's selection.

Select an **Override rule**: **Built in** (the default), **Locally defined**, **Imported from external resource**, or **None**.

- If **Built in** is selected there are four options in the **Override type** list: **Exclusive**, **Contributing**, **Override features of same type**, and **Never overridden**:
  - **Exclusive** means that the feature should override all other features except those that are of the type **Never overridden**. An exclusive feature is overridden by other exclusive features.
  - **Contributing** means that the feature should not override other features. The exception is for entity levels below the top entity level of the physics, where features of any type override the default features.
  - **Override features of same type** means that the feature only overrides other features of the same feature type.
  - **Never overridden** ensures that a feature is never overridden and does not override any other feature.
- If **Locally defined** is selected, also select a **Link** from the list. Click the **Go to Source** button as needed.
- If **Imported from external resource** is selected, select an **Imported file** from the list. Click the **Go to Source** button as needed. Then select a **Link** from the list.
- In **None** is selected, no override rule is used.

Override Type

The **Override type** list specifies if the feature is **Exclusive** or **Contributing** to other features. In the Model Builder, an *exclusive feature* (such as constraints and fixed values) replaces all previous feature instances for intersecting selections, whereas a *contributing feature* (such as loads and sources) adds to other contributing features sharing the same selection. You also select to only **Override features of the same type** or to let the feature be **Never overridden**.

GUI OPTIONS

In this section you can specify some options for the user interface.

To lock the selection so that it cannot be modified, select the **Lock selection** checkbox.

By default, the section is initially expanded. Select the **Section is initially collapsed** checkbox if it should be collapsed when first displaying the Settings window.

To hide the selection in the Settings window, select the **Hide in GUI** checkbox. Even if the selection is hidden from the Settings window, you can choose to still show the

rendering of the selected entities in the user interface by selecting the **Show rendering when hidden** checkbox. You can hide the feature in different categories in the **Category for hiding feature** list, which has the options **Always hidden**, **Advanced physics options**, **Technology preview**, and **Develop**. Select **Always hidden** (the default) to hide it permanently, or select **Advanced physics options** to make it possible for users to show it by selecting **Advanced Physics Options** in the **Show More Options** dialog.

Reference Input

A **Reference Input** node ( ) is similar to the **Selectable Input** node but the valid values are entities in a list in the model. The list can be the physics features, either the siblings to this feature of the siblings to the parent feature, the physics, the multiphysics coupling features, the materials, or the coordinate systems in the model. It is possible to add more valid values, typically **None**, by adding an Allowed Values feature as a subnode to the **Reference Input** node. You can also define a model entity list for the reference input by adding an Allowed References subnode. You can add multiple **Allowed References** subnodes to combine different model entity lists into one single reference list.

To add a **Reference Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Reference Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a reference input has the following sections:

DECLARATION

Almost the same as for the User Input.

From the **Dimension** list you can choose **Scalar** (the default), **Vector (3x1)**, **Changeable**, or **Custom** to define the dimension of the reference input.

The **Default value** list can either be the **First allowed value** (the default) or **Custom default**. The latter allows you to enter an arbitrary default value as long as it is among the allowed values defined for the input.

Select the **Is bidirectional** checkbox if you want to add a bidirectional reference input. A bidirectional reference input is a reference input that is coupled to other bidirectional inputs of the same type. If one of the inputs points at a feature, the input in that feature

will point back at the feature defining the first input. If one of the inputs is set to **None** the other automatically gets the value **None** as well. For example, if feature A has a bidirectional reference input, `input1`, of type `myType`, and feature B has a bidirectional reference input, `input2`, of the same type. When `input1` in feature A is set to feature B, `input2` will automatically be set to feature A. You specify the type in the **Bidirectional type** field.

An **Add** action is added to reference inputs if they only refer to features of certain types. The **Add** button (+) includes a list of the types of features the input can refer to and adds a new feature of the selected type.

See User Input for the rest of the settings.

Boolean Input

A **Boolean Input** node ( ) is a special version of the **User Input** node that defines a data storage that can only contain the values `0` or `1`. This node is equivalent to a **User Input** node of the type Boolean.

To add a **Boolean Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Boolean Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a Boolean input contains the following sections:

DECLARATION

Almost the same as for the User Input. Select the **Default selected** checkbox get the value `1` by default.

See User Input for the rest of the settings.

Real Input

A **Real Input** node ( ) is a special version of the **User Input** node that defines a double (a number or a parameter), and the value can be calculated directly without solving. This node is equivalent to a **User Input** node of the type real. You can add the same subfeatures to a **Real Input** node as to an **User Input** node except **Activating Allowed Values**.

To add a **Real Input**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Real Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window of a real input contains the following sections:

DECLARATION

Almost the same as for the User Input.

ADVANCED

See User Input for the settings. For a **Real Input** there are no settings for ensuring a unique default value.

GUI OPTIONS

See User Input for the settings. For a **Real Input** there is also a **Show range button (only applicable for some layouts)** checkbox, which is not selected by default.

User Input Group

The **User Input Group** node ( ) is a collection of other user inputs, user input groups, and material parameters. Use it to organize the GUI layout of the feature and property. This can be a complex task, and you can read more about the details of this process in Designing the GUI Layout.

To add a **User Input Group**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **User Input Group** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window has the following sections:

DECLARATION

The **Group name** field cannot be in conflict with any other User Input or User Input Group. In the **Description** field enter a text to display for the group. For groups that

represent a section, this description becomes the title of the section. You can pass the component's arguments to the description. The argument name must be placed between two # characters. For example, if you have an argument `arg.param = material`, the string `#Plot_in the _#arg.param#_frame` will be displayed as `Plot in the material frame`.

For other groups, the description pops up above the location of the group (if visible) and usually looks strange. Clear the **Description** field to avoid this effect, which is the default behavior.

In the **Group members** list you add members to the group. Click **Add** (+) to get a list of all possible members to add.

GUI OPTIONS

Use the **GUI Layout** list to choose how to organize the group members in the window. The options are **Group members below each other** (the default), **Group members placed in a stack**, **Create a widget for each vector component**, **Radio buttons from first user input, others interleaved**, **Group members define a section**, or **Attach activation on group members**. To make group members define a table, add a Table node.

If you choose **Group members define a section** for example, the group members are placed sequentially in a section in the window. Depending on the choice you made in the **GUI Layout** list, different options appear beneath the list.

See User Input Group GUI Options for more information

Table

The **Table** node ( ) makes it possible to define the first column of a table as a row index column. Right-click the **Table** node to add a Column, Activation Condition, or License Settings subnode as desired. The **Settings** window has the following sections:

DECLARATION

Enter a name for the table in the **Table name** field and an optional description in the **Description** field.

GUI OPTIONS

Specify a height of the table in the **Table height** field (default: 250 pixels).

Select any of the following checkboxes if desired:

- Select the **Automatically add new rows** checkbox if you want the table to add a new row underneath the one just completed.
- Select the **Rows can be added** checkbox to add a button to the table for adding rows.
- Select the **Rows can be deleted** checkbox to add a button to the table for deleting rows.
- Select the **Rows can be moved up and down** checkbox to add buttons to the table for moving rows up and down.
- Select the **Table data can be saved to file and loaded** checkbox to add buttons to the table for saving table data to a file and to load table date from a file.
- Select the **Table data can be cleared** checkbox to add a button to the table for clearing the content of the table
- Select the **Sortable** checkbox to make it possible to sort the columns of the table.

From the **Table headers** list, choose an option for the table headers:

- Choose **Use user input descriptions** (the default) to use the descriptions from the user inputs.
- Choose **Specify** to let the user specify the table headers.
- Choose **No headers** to not use any table headers.

In the table below, information about the columns that you have added as **Column** subnodes appears (see the settings for **Column** below).

Select the **Show row index on the first column** checkbox if you want to include the row index as the first column. The optional **Template** field must be used with a parameter resource string (for example, `#Play_X`).

Select the **Add divider above the group** check to add a divider above the group. Add an optional divider text in the **Text** field.

Select the **Include image below group members** checkbox to add an image that you specify in the **Image file** field, or click **Browse** ( ) to locate and add an image file.

Column

Use a **Column** node ( ) to define the column input for the table. The user input that represents for the column in the table can be specified by a reference or by name. Right-click a **Table** node to add this subnode. The **Settings** window has the following sections:

DEFINITION

You can directly refer to any of the user inputs by choosing **By reference** in the **Specify user input** list (the default). You then choose the user input from the **User input** list. The other option in the **Specify user input** list is **By name**, which means that you enter the name in the **User input** field. The name is entered in the **Input name** field of the user input you want to refer to.

You can also add a description of the column in the **Description** field, specify a **Column width** (default: 80 pixels), and a new value for added columns in the **New value** field.

GUI OPTIONS

Select the applicable checkboxes to add the following user interface options:

- **Editable** (selected by default), to make the column editable.
- **Variable**, to indicate that this is column for variable names.
- **Expression**, to indicate that this is column for expressions that should be checked for correct syntax.
- **Synchronization**, to add an extra input and synchronize it with this column.

Text Label

The **Text Label** node ( ) adds a static text to a Settings window for a feature or property. The text can provide explanations on how to use the feature or other information.

To add a **Text Label**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **User Input Group** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window has the following section:

TEXT FORM

In the **Name** field, enter a name for the text label.

Select the **Multiline text** checkbox if you want the text label to include more than one line of text.

In the **Text** field, or **Text area** field for multiline text, enter the text to display in the feature's Settings window.

Select the **Show icon and text** checkbox to include an icon, which will appear to the left of the text. Click **Browse** ( ) to search and select an icon file, or type its path and name directly in the **Icon** field.

Buttons

The **Buttons** node ( ) adds a row of buttons to the Setting windows of a feature or physics interface of the Model Builder.

To add a **Buttons** node, first add a feature node or a property node, for example, a Generic Feature, Domain Condition, or Device Model Feature, then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Buttons** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window has the following sections:

BUTTON

Add a **Name** for the buttons group.

From the **Command type** list, you choose which type of action to associate with the buttons: Choose **Command handler from subfeatures** (the default) to define the action handler from **Button** or **Button Link** subnodes, or choose **Internal action tag** to use an action manager and let the buttons refer to this action by using an internal tag that you enter in the **Action tag** field.

GUI OPTIONS

If you want the buttons to disappear when they are inactive, select the **Hide user input in GUI when inactive** checkbox. It is also possible to add a divider above the GUI component and any row of buttons. The divider is a horizontal line with an optional

descriptive text. Select the **Add divider above the material property** checkbox to add the divider. When selected, you can enter the divider text in the **Text** field.

Section

A **Section** node ( ) is a special version of the **User Input Group** node that defines a section. This node is equivalent to a User Input Group node where **GUI Layout** list has the option **Group members define a section**.

To add a **Section**, first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Section** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window has the following sections:

DECLARATION

The **Group name** field cannot be in conflict with any other section, User Input or User Input Group. In the **Description** field, enter a text for the section title. You can pass the component's arguments to the description. The argument name must be placed between two # characters. For example, if you have an argument `arg.param = material`, the string `#Plot_in the _#arg.param#_frame` will be displayed as `Plot in the material frame`.

In the **Group members** list add members to display under this section, in the order they appear in the list. Click **Add** (+) to get a list of all possible members to add.

GUI OPTIONS

In the **Category for hiding section** list, choose among possible options to hide the section with respect to the global display settings **Advanced physics options**, and **Stabilization**. The option **None** (the default) disables the hiding of this section. Select the **Section is initially collapsed** checkbox to collapse the section by default.

Designing the GUI Layout

Constraint Settings Section

A **Constraint Settings Section** node ( ) is a special section that a feature with constraints uses. A feature always have this section when there is at least one constraint. Add this node when you want to include constraint settings although there is no constraints for the feature, or if you want to modify the content of the section. The section always contains a selectable input that allows a user to select the constraint option. It also contain a selectable input to choose how to apply the reaction terms. Similar to the Selectable Input node, Allowed Values subnodes define the allowed values for the **Constraint options** and **Apply reaction terms on** selectable inputs. There can only be one **Constraint Settings Section** node for each physics feature.

To add a **Constraint Settings Section** first add a feature node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Constraint Settings Section** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

The **Settings** window has the following sections:

SETTING FOR CONSTRAINT OPTIONS

Under **Supported options defined by child nodes**, the **Default value** list can either be the **First allowed value** (the default) or **Custom default**. The latter allows you to enter an arbitrary default value as long as it is among the allowed values defined for the input.

SETTING FOR APPLYING REACTION TERMS

Under **Supported options defined by child nodes**, the **Default value** list can either be the **First allowed value** (the default) or **Custom default**. The latter allows you to enter an arbitrary default value as long as it is among the allowed values defined for the input.

CONSTRAINT METHOD

The **Default method** list controls the default value for the constraint method setting in the Constraint Settings section for physics features that adds constraints. The options are **Elemental** (the default) or **Nodal**.

GUI OPTIONS

In the **Category for hiding section** list, choose among possible options to hide the section with respect to the global display settings **Advanced physics options** (the

default), and **Stabilization**. The option **None** disables the hiding of this section; for **None**, select the **Section is initially collapsed** checkbox to make the section initially appear as collapsed instead of expanded.

Designing the GUI Layout

EXCLUDE SELECTIONS ADDED

From the **Show exclude sections** list, choose **If added by any constraint** or **Always**. The **Add exclude sections** list has the options **All dimension below the feature dimension** or **Custom**. If you choose Custom, add the applicable entity dimensions to the **Restrict to entity dimensions** list. The exclude selection functionality can be useful to avoid conflicting constraints in structural mechanics, for example.

Material Property

The **Material Property** node ( ) is a special case of a **User Input** that also supports linking with material properties from the **Materials** node in the Model Builder. A material property node is actually a collection of two user inputs: one list with the options **From material** or **User defined** and one property value field for user-defined values.

To add a **Material Property** first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Material Property** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

Also see Material Property (Auxiliary Definitions), which is a subnode to the Material Property Group node under **Auxiliary Definitions**.

The **Settings** window has the following sections:

DECLARATION

The material property can either be a basic material property or a property that belongs to a predefined material property group. Choose a **Property type**: **Basic material**

property (the default), **Built in predefined material property**, **Locally defined material property**, or **Imported material property from external resources**.

- A **Basic material property** belongs to a predefined set of quantities that are commonly used in material libraries.
  - Enter a valid **Property name**, **Description**, and **Symbol (LaTeX encoded)**. See Variable Declaration.
  - Choose a **Physical quantity**. The quantity identifies the corresponding property in the material libraries. A property in the material library has a certain dimension, but it is possible to use a smaller dimension for a material property in a feature. See Dependent Variable Declaration for more information about specifying a physical quantity.
  - Choose the **Dimension**, which can only contain **Scalar** and **Custom** for a scalar material parameter.
  - Enter and choose Default Values.
- For **Built in predefined material property**, choose a predefined **Material property group** from the list. Then choose a **Material property** and enter and choose Default Values.
- For **Locally defined material property**, choose a **Material model** from the list. Then choose a **Material property** and choose Default Values.
- For **Imported material property from external resources**, choose an **Imported file** from the list. Then choose a **Link** and a **Material property**. Then choose Default Values.

Select **Locally defined** from the top of the **Physical quantity** list to use one of the locally defined physical quantities, which you choose from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button ( ) to move to the Physical Quantity node for the selected local physical quantity.

Default Values

In the **Default value for user defined** field, which can be a table, enter the default value for the user-defined option.

Use the **Default value** list to set the default for the feature instance. Choose **From material** (the default), **User defined**, **Common model input**, **First allowed value**, or **Custom**

default. **First allowed value** takes the first active value from the values specified by the **Allowed Values** child nodes. Use the **Custom default** option to enter a value. This value must always be active for the list in the feature instance.

OPTIONS

In the Model Builder most material properties get their values from the material assigned to the geometric entities overlapping with the selection of the feature instance. You can add a Material List to the feature, which allows you to choose among all materials added to a model. Select the **Couple to material list** checkbox to specify that this property gets linked to the material selected in the list. Then choose the list to couple against in the **Material list**, either by entering a name in the **Name** field or by choosing a particular material list reference.

For a **Basic material property**, the **Pick material property from property groups in selected materials** checkbox is available. Select this checkbox to make the material property take its values from the property groups of the material that is selected in the material list.

For a **Basic material property** with the **Physical quantity** set to **Diffusion coefficient**, the values that you can choose from are the property groups of the material selected in the material list that define the output property for the diffusion coefficient.

In addition to the options **From material** and **User defined**, you can add extra items to the list in the feature instance with **Allowed Values** child nodes. An alternative option is also entering them directly to the **Extra list items** table.

A feature input supports several levels of matching that you choose from the **Feature input match type** list. You can find a brief explanation of the matching options below:

- **Always match**. If there is any matching announced variable, always use the first one found.
- **Synchronized**. Match to a matching announced variable, if the provider to that variable fulfills the following conditions (see below for an example):
  - It has a feature input of the quantity chosen in the **Synchronized physical quantity** list.
  - That feature input chooses an announced variable from the provider owning the synchronized feature input.
- **Always match within physics interface**. If there is any matching announced variable by the current physics interface, use the first one found.

- **Model input match**. Also matches within the physics interface, but you can disable the matching through an interface setting.
- **Never match**. Never do any automatic matching. The default option is **User defined**, but you can always manually choose among the found announced variables.

For all the options except **Synchronized**, it is possible to set a regular expression in the **Match tag filter** combined text field and list. The predefined options here are **None** (the default), and all physical quantity field names. **None** is equivalent to an empty tag and should be used unless it is necessary to limit matching in some sense. Use the regular expression if the input should accept several match tags; use, for example, the expression `^$|explicit` to either match the default empty tag or an announced variable using the tag `explicit`. There are several resources on the Internet that explain the exact syntax of regular expressions.

Click the **Select Physical Quantity as Tag** button ( ) to pick a physical quantity from the list in the **Physical Quantity** dialog that appears. Click the **Custom Tag** button ( ) to use a custom tag that you type in for the announce tag. Click the **Reset to None** button ( ) to reset the filter to **None**.

Use the **Synchronized** option in situations when the matching depends on another feature input in the provider (typically a physics feature) of an announced variable. For example, assume feature "A" has a feature input with the **Never match** option that picks up variables with the quantity *electric potential*. Feature "B" announces an electric potential without a tag and has a synchronized feature input that should pick up a current variable only from the feature that picks ups an electric potential from feature "B." To make feature "A" a possible match, it has to announce a current variable with an **Electric potential** match tag. The synchronized feature input uses the **Synchronized** option but also needs the **Electric potential** option in the **Synchronized physical quantity** list. When the user selects the electric potential from a physics feature of type "B" in the input list of a physics feature of type "A", the input (often hidden) in physics feature of type "B" automatically picks up (or auto-match) the electric current from physics feature "A".

From the **Preferred material type** list, choose a preferred material if desired: **Default**, **Fluid**, **Solid**, **Pellet**, or **Immobile Fluid**. Use this option if the material property prefer a material to be used. This information will be used by the Add Preferred Materials action. This property is an Input Dependency property and can be selected as a type of parameter in the **Input Dependency** node's settings.

RESTRICTIONS

See User Input for information about this setting.

GUI OPTIONS

If you want the material property to disappear when it is inactive, select the **Hide user input in GUI when inactive** checkbox. Select the **Show no description** checkbox to hide the text label containing the description above the GUI component of the property. Similarly, you can hide the symbol from the GUI by selecting the **Show no symbol** checkbox. Select the **Show no user defined input** checkbox to hide all user defined input. As a final option, it is possible to add a divider above the GUI component and any description text label. The divider is a horizontal line with an optional descriptive text. Select the **Add divider above the material property** checkbox to add the divider. When selected, you can enter the divider text in the **Text** field.

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Material List

In the Model Builder most material properties get their values from the material assigned to the geometric entities overlapping with the selection of the feature instance. As an option, add a **Material List** node ( ). Any material property coupled to a material list makes it possible to choose among all materials added to a model. See Material Property for information how to couple a property to a list. For a feature instance in the Model Builder, a list displays with the first option **Domain material** followed by all materials. The **Domain material** option is identical to the original behavior without a list. By choosing a specific material, all material properties coupled to this list get the property values stored in that material independently of any selection.

To add a **Material List** first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Material List** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

MATERIAL LIST

Specify the name of the material list in the **Name** field, and the description in the **Description** field. You can pass the component's arguments to the description. The argument name must be placed between two # characters. For example, if you have an argument `arg.param = material`, the string `#Plot_in the _#arg.param#_frame` will be displayed as `Plot in the material frame`.

From the **Type** list, select **Common** (the default), **External**, or **Layered material**.

For **Common**, similar to the Material Property and Feature Input nodes, you can add extra list items apart from the automatically added ones (**Domain materials** and list of materials in this case). You can also remove the **Domain materials** option from the list by clearing the **Allow domain material** checkbox.

Select **External** for external materials that satisfy the list of the input and output variables to the external socket. By default, the integration order is determined automatically. To set an integration order manually, select **Custom shape order** instead of **Automatic** from the **Integration order** list and then add an order as a positive integer in the **Order** field (default: 2). You can also select **From discretization** to specify the name of a discretization in the **Discretization** field. See also External Material Input/Output.

Select **Layered material** for a list of layered materials. By default, the integration order is determined automatically. To set an integration order manually, select **Custom shape order** instead of **Automatic** from the **Integration order** list and then add an order as a positive integer in the **Order** field (default: 2). You can also select **From discretization** to specify the name of a discretization in the **Discretization** field. The following options are also available:

- Select the **Allow all layered shell materials** checkbox if all layered shell materials should be allowed.
- Select the **Show no layer selections** checkbox show if no layered shell materials should be shown.
- The **Select layer selection by default** checkbox is selected by default. Clear it to deactivate this default behavior.

GUI OPTIONS

If you want the material list to disappear when it is inactive, select the **Hide user input in GUI when inactive** checkbox. Select the **Show no description** checkbox to hide the text label containing the description above the GUI component of the material list. Similarly, you can hide the symbol from the GUI by selecting the **Show no symbol** checkbox. Select the **Show no user defined input** checkbox to hide user-defined inputs.

As a final option, it is possible to add a divider above the GUI component and any description text label. The divider is a horizontal line with an optional descriptive text. Select the **Add divider above the material list** checkbox to add the divider. When selected, you can enter the divider text in the **Text** field.

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Feature Input

The **Feature Input** node ( ) is a special case of a **User Input** that also supports linking with any announced variable in the Model Builder. A feature input is matched against an announced variable by matching against a physical quantity that you have to set for both items. See Variable Declaration and Dependent Variable Declaration for information about how to set the physical quantity and the announce preference for variables. Similar to the Material Property, the feature input is a collection of two GUI components: one list with the matching variables plus a **User defined** option and one field for the user-defined value.

To add a **Feature Input** first add a feature node or property node (for example, a Generic Feature, Domain Condition, or Device Model Feature), then:

- From the contextual toolbar (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**), click the **Feature Input** ( ) button.
- Right-click the feature node (in this example, **Generic Feature**, **Domain Condition**, or **Device Model Feature**) and select it from the **Inputs** submenu.

DECLARATION

The declaration of a feature input is similar to that of a material property, where you specify the name, description, symbol, physical quantity, and dimension; see Material Property for further details. An announced quantity has a certain dimension, but it is possible to use a smaller dimension for a feature input in a feature. You set this dimension with the **Dimension** list, which can only contain **Scalar** and **Custom** for a scalar feature input.

OPTIONS

In addition to the announced variables and **User defined**, you can add extra items to the list in the feature instance with **Allowed Values** child nodes. An alternative option is also entering them directly to the **Extra list items** table.

Select the **Use as model input** checkbox to use this feature input as a model input. The feature input name will start with `minput_` and continue with the physical quantity field name. The feature input will then be placed in the model input section in the user interface and will be used as model input by the materials.

A feature input supports several levels of matching that you choose from the **Feature input match type** list. You can find a brief explanation of the matching options below:

- **Always match**. If there is any matching announced variable, always use the first one found.
- **Synchronized**. Match to a matching announced variable, if the provider to that variable fulfills the following conditions (see below for an example):
  - It has a feature input of the quantity chosen in the **Synchronized physical quantity** list.
  - That feature input chooses an announced variable from the provider owning the synchronized feature input.
- **Always match within physics interface**. If there is any matching announced variable by the current physics interface, use the first one found.
- **Model input match**. Also matches within the physics interface, but you can disable the matching through an interface setting.
- **Never match**. Never do any automatic matching. The default option is **User defined**, but you can always manually choose among the found announced variables.

For all the options except **Synchronized**, it is possible to set a regular expression in the **Match tag filter** combined text field and list. The predefined options here are **None** (the default), and all physical quantity field names. **None** is equivalent to an empty tag and should be unless it is necessary to limit matching in some sense. Use the regular expression if the input should accept several match tags; use, for example, the expression `^$|explicit` to either match the default empty tag or an announced variable using the tag `explicit`. There are several resources on the Internet that explain the exact syntax of regular expressions.

Click the **Select Physical Quantity as Tag** button ( ) to pick a physical quantity from the list in the **Physical Quantity** dialog that appears. Click the **Custom Tag** button ( )to use a custom tag that you type in for the announce tag. Click the **Reset to None** button ( ) to reset the filter to **None**.

Use the **Synchronized** option in situations when the matching depends on another feature input in the provider (typically a physics feature) of an announced variable. For example, assume feature “A” has a feature input with the **Never match** option that picks

up variables with the quantity *electric potential*. Feature "B" announces an electric potential without a tag and has a synchronized feature input that should pick up a current variable only from the feature that picks ups an electric potential from feature "B." To make feature "A" a possible match, it has to announce a current variable with an **Electric potential** match tag. The synchronized feature input uses the **Synchronized** option but also needs the **Electric potential** option in the **Synchronized physical quantity** list. When the user selects the electric potential from a physics feature of type "B" in the input list of a physics feature of type "A", the input (often hidden) in physics feature of type "B" automatically picks up (or auto-match) the electric current from physics feature "A".

GUI OPTIONS

If you want the feature input to disappear when it is inactive, select the **Hide user input in GUI when inactive** checkbox. Select the **Show no description** checkbox to hide the text label containing the description above the GUI component of the input. Similarly, you can hide the symbol from the GUI by selecting the **Show no symbol** checkbox. Select the **Show no user defined input** checkbox to hide user-defined inputs.As a final option, it is possible to add a divider above the GUI component and any description text label. The divider is a horizontal line with an optional descriptive text. Select the **Add divider above the feature input** checkbox to add the divider. When selected, you can enter the divider text in the **Text** field.

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Activation Condition

Use an **Activation Condition** node ( ) to specify the conditions to dynamically enable or disable a user input, material property, feature input, material list, menu, menu item, or toggle item. The condition can depend on user inputs in the parent feature or property, or any other user input in a property within the physics interface. Conditions can either be true if the other user input has a specified value or if it is active. Right-click any feature node to add this subnode. Also right-click the **Activation Condition** node to add an Additional Requirement subnode. The **Settings** window has the following section:

ACTIVATION CONDITION

Choose an option from the **Specify user input** list: **By reference**, **By name**, or **In expression**.

The activation condition can depend on user inputs in the parent feature, parent property, or some property. If the user input is under a feature or property, which can contain other user inputs, you can directly refer to any of those user inputs by choosing **By reference** in the **Specify user input** list. From the **From** list, choose **User input from this property**, which you specify in the **Property** field. You then choose the user input from the **User input** list, and finally add or enter the values that activates the user input in the **Activating values** list. This list differs depending on the type of user input you refer to. If you instead choose **Entity selection** from the **From** list, add or enter the values that activates the user input in the **Activating values** list.

The other option in the **Specify user input** list is **By name**, which means that you enter the name in the **User input** field. The name is entered in the **Input name** field of the user input you want to refer to. For the **By name** option, the **From** list only contains **User input from this property**. You must also enter the type of the property that contains the user input in the **Property** field. For Boolean user inputs, the values **Selected** and **Not selected** you enter as `0` and `1`. You then choose the user input from the **User input** list, and add or enter the values that activates the user input in the **Activating values** list. Select the **Condition is not fulfilled for undefined references** checkbox if an undefined reference should be treated as if the condition were not fulfilled.

The last option in the **Specify user input** list is **In expression**. This is a general tool that can evaluate an expression of relations and Boolean operators that you specify in the **Condition** field. It also supports some special functions and names, see the section about Usage Condition for more details.

For all options in the **Specify user input** list, select the **Invert condition on input values** checkbox to invert the entire condition. The **Require input is active** checkbox is selected by default. It is only applicable when specifying a user input to check by reference or by name, not for expressions. When selected, the activation condition is only true if the checked user input is also active as decided by its activation conditions. For expressions, you can achieve the equivalent logic using the `isActive` operator.

HIDING DISABLED NODES IN THE USER INTERFACE

Nodes that define GUI elements can be hidden when disabled by an **Activation Condition**. For some nodes, hiding can be achieved by selecting an option on the node itself. For example, for a **User Input**, the **Hide user input in GUI when inactive** option can be selected to hide the element when disabled. For others, the GUI element can be

hidden, when disabled, if placed in a **User Input Group** with the **GUI option** set to **Group members placed in a stack**. For more information, see Designing the GUI Layout.

Additional Requirement

An additional requirement to an activation condition is a requirement that has to be fulfilled otherwise the activation condition cannot be fulfilled.

Right-click an Activation Condition node to add this subnode.

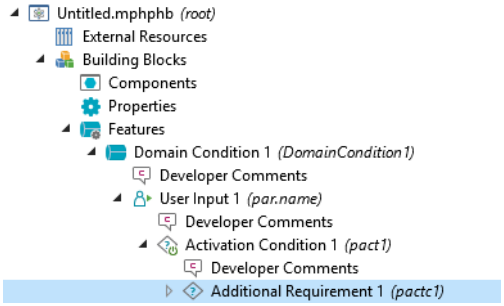


Figure 3-1: A subnode of the Activation Condition node for additional requirements.

Allowed References

Use the **Allowed References** node ( ) to define a model entity list for the parent Feature Input. The **Settings** window of this node contains the following sections:

DEFINITION

From the **Reference list**, choose one for the following options:

- **Feature list** (the default) for the physics features as the siblings to this feature.
- **Parent feature list** for the siblings to the parent feature
- **Physics feature list** for the physics features.
- **Physics list** for the physics.
- **Multiphysics list** for the multiphysics coupling features.
- **Coordinate system** list for the coordinate systems in the model.
- **Material list** for the materials.
- **Function list** for the functions.
- **Common feature list** for the common features.

- **Extra dimension list** for the extra dimension features.
- **Child list of reference input** for the child list of the selected entity by another reference input. To specify the controlled reference input for this list, you can then choose, from the **Specify reference input** list, **By reference** (the default) or **By name**. If you choose **By name**, you can choose one of the following options from the **From** list: **User input from this feature**, **Parent feature, This feature or any ancestor**, or **User input from this property**. For the last option, specify the property in the **Property** field. Select a reference input from the **Reference** list (if specified by reference) or type it in the **Reference** field (if specified by name).

From the **Filter** list, for most options, only **User defined** can be chosen. Then define the filtering using the **Filtering types** list (see below). The **Material list** has two predefined filters: **Layered materials** and **Porous materials**.

The list can be filtered by adding a type to the **Filtering types** list. A type is, for example, a physics feature ID. The filtering type also supports regular expressions and defining a subfeature list type as, for example, `FeatID/SubFeatID`.

The filtering can also be done by selecting the **Use condition on list** checkbox and then add a condition. For example, a condition that states that a user input in the features in the list should have a certain value.

ACTIVATION CONDITION

Enable the condition by selecting the **Use condition** checkbox. The activation condition can depend on user inputs in the parent feature, parent property, or some property. If the user input is under a feature or property, which can contain other user inputs, you can directly refer to any of those user inputs by choosing **By reference** in the **Specify user input** list. You then choose the user input from the **User input** list, and finally add or enter the values that activates the user input in the **Activating values** list. This list differs depending on the user input you refer to.

Select the **Invert condition on input values** checkbox to invert (negate) the condition.

When the **Require input is active** checkbox is selected, the activation condition is only true if the checked user input is also active as decided by its activation conditions. It is only applicable when specifying a user input to check by reference or by name, not for expressions. For expressions, you can achieve the equivalent logic using the `isActive` operator.

Allowed Values

Use the **Allowed Values** node ( ) to specify the allowed values of the parent node, which can be either one of the types Selectable Input, Material Property, or Feature Input. The allowed values can also be dynamic with respect to a condition. The condition can depend on user inputs in the parent feature or property, or any other user input in a property within the physics interface. Conditions can either be true if the other user input has a specified value or if it is active. This node is also a child of a Constraint Settings Section node, controlling the allowed values of the selectable inputs included in that section. The **Settings** window of this node contains the following sections:

ALLOWED VALUES

Enter the allowed values in the **Allowed values** table that this node contribute to the parent node. Enter the value in the first column and the description in the second column.

For allowed values under a Constraint Settings Section that define the constraint options, there is also a third column where you specify the name of the card use to provide extra inputs for a certain constraint option. The default cards for pointwise and weak constraints are `pointwiseConstraints_card` and `weakConstraints_cards`, respectively, and are defined automatically. For other user-defined constraint options, a new card must be defined or use an empty card.

ACTIVATION CONDITION

Enable the condition by selecting the **Use condition** checkbox. The activation condition can depend on user inputs in the parent feature, parent property, or some property. If the user input is under a feature or property, which can contain other user inputs, you can directly refer to any of those user inputs by choosing **By reference** in the **Specify user input** list. You then choose the user input from the **User input** list, and finally add or enter the values that activates the user input in the **Activating values** list. This list differs depending on the user input you refer to.

Select the **Invert condition on input values** checkbox to invert (negate) the condition.

When the **Require input is active** checkbox is selected, the activation condition is only true if the checked user input is also active as decided by its activation conditions. It is only applicable when specifying a user input to check by reference or by name, not for expressions. For expressions, you can achieve the equivalent logic using the `isActive` operator.

Activating Allowed Values

Use the **Activating Allowed Values** node ( ) to specify the conditions to dynamically allow values from the list of allowed values specified in the parent User Input node. The condition can depend on user inputs in the parent feature or property, or any other user input in a property within the physics interface. Conditions can either be true if the other user input has a specified value or if it is active. The **Settings** window has the following sections:

ALLOWED VALUES

Add the allowed values from the parent node to the **Allowed values** list that this node can activate. When the condition specified in the **Activation Condition** section is true, the allowed values for the parent user input contain the allowed values specified in the list.

ACTIVATION CONDITION

The activation condition can depend on user inputs in the parent feature, parent property, or some property. If the user input is under a feature or property, which can contain other user inputs, you can directly refer to any of those user inputs by choosing **By reference** in the **Specify user input** list. You then choose the user input from the **User input** list, and finally add or enter the values that activates the user input in the **Activating values** list. This list differs depending on the user input you refer to.

The last option in the list is **In expression**. This is a very general tool that can evaluate an expression of relations and Boolean operators. It also supports some special functions and names, see the section about Usage Condition for more details.

Select the **Invert condition on input values** checkbox to invert (negate) the condition.

The **Require input is active** checkbox is selected by default. It is only applicable when specifying a user input to check by reference or by name, not for expressions. When selected, the activation condition is only true if the checked user input is also active as decided by its activation conditions. For expressions, you can achieve the equivalent logic using the `isActive` operator.

Button

The **Button** node ( ) adds a text or image button beside a user input or selectable input.

To add a **Button** node, right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu. You can right-click the **Button** node to add an Activation Condition or Input Dependency subnode.

The **Settings** window has the following sections:

COMMAND

If the **Command type** is set to **Internal action tag** (the default), you enter a tag for the action in the **Action tag** field.

If the **Command type** is set to **Command handler from code editor**, you determine the source using the **Links from** list. Available options are:

- **Building blocks**. Lets you choose among the **Code Editor** node under the **Components** branch in the **Building Blocks** branch. You choose the code editor from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.
- **Built in**. Lets you choose among built-in code editors that are available to the Physics Builder. In the **Package** list you choose the main resource to use a code editor from (or **None**). For each resource, you have a list of code editors in the **Link** list to choose from. You can only choose among the currently published code editors. The list shows **Not active** if no links are available.
- **External resources**. Lets you choose among the code editors listed in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all code editors found in the **Building Blocks** > **Components** branch of the selected file.

The remaining two sections are only available if the **Command type** list is set to **Command handler from code editor**.

DEFINITION

Enter a title of the button in the **Title** field and an icon file in the **Icon** field or click **Browse** ( ) to pick an icon file from the file system.

The **Weight** field contains a factor (an integer number) that can be used to decide the order of the items in a context menu. It is available (editable) when the **Menu items ordering list** is set to **Use weighting order** in the Settings window for a **Context Menu** node. Under a toolbar menu, the weight is always 0 and this field is not editable.

Select the **Record a custom COMSOL API command** checkbox and type a name for using an API call equivalent to clicking the button as `runCommand(<name>)`, where *<name>* is a string with the name that you enter in the **Command** field.

Select the **Use button style if possible** checkbox if desired. This setting is only available for a button under a user input. It uses the style of a button instead of just text.

Select the **Always show the title** checkbox to always display the title. It is selected by default if you use the button style.

CONDITION TO RUN

Select the **Show confirmation dialog** checkbox if you want to display a confirmation dialog as a preaction for the toggle item's action. Type a message for the confirmation dialog in the **Message** field and a confirmation answer in the **Answer** field (default: `Yes`). The confirmation dialog also contains a **Cancel** button by default. You can use this functionality to ask for confirmation before performing the action.

Button Link

The **Button Link** node ( ) adds link to a button in a user input or selectable input.

To add a **Button Link** node, right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu.

The **Settings** window has the following section:

DEFINITION

From the **Links from** list, select **Locally defined** (the default), **Built in**, or **External resources**.

Locally Defined

Use this option to define a link to a locally defined menu under **Definitions Library** > **Auxiliary Definitions**, which you select from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list. Parameters appear that have been defined in the locally defined menu node, and you can edit their expressions in the **Expressions** column under **Menu item parameters** unless they have been defined as read only.

Built-In

Use this option to define a link to a built-in Java maker. From the **Package** list, select **COMSOL Multiphysics** or any other available package. Then select a link from the **Link** list (which by default is set to **Not active**). When you have selected an active link, you can also enter an icon file and a title in the **Icon** field and **Text** field, respectively. You can use this option to link from a Physics Builder maker to a Java maker. With a Java maker, you can have more control than with the Physics Builder maker.

External Resources

Use this option to define a link from an external resource, which you import from a file that you specify from the **Imported file** list. The **Imported file** list contains all **Import** nodes under **External Resources**. It is used by all link nodes in the Physics Builder, so the user interface is the same for all of them. Then select a menu or menu item from the **Link** list. Parameters appear that have been defined in the externally defined menu node, and you can edit their expressions in the **Expressions** column under **Menu item parameters** unless they have been defined as read only.

Toggle Button

The **Toggle Button** node ( ) adds a toggle button beside a user input or selectable input.

To add a **Toggle Button** node, right-click a **User Input** or **Selectable Input** node and select it from the **Buttons** menu. You can right-click the **Toggle Button** node to add an Activation Condition or Input Dependency subnode.

The **Settings** window has the following sections:

COMMAND

If the **Command type** is set to **Internal action tag** (the default), you enter a tag for the action in the **Action tag** field.

If the **Command type** is set to **Command handler from code editor**, you determine the source using the **Links from** list. Available options are:

- **Building blocks**. Lets you choose among the **Code Editor** node under the **Components** branch in the **Building Blocks** branch. You choose the code editor from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.

- **Built in**. Lets you choose among built-in code editors that are available to the Physics Builder. In the **Package** list you choose the main resource to use a code editor from (or **None**). For each resource, you have a list of code editors in the **Link** list to choose from. You can only choose among the currently published code editors. The list shows **Not active** if no links are available.
- **External resources**. Lets you choose among the code editors listed in an imported builder file under the **External Resources** branch. You choose the file from the **Imported file** list. The **Link** list contains all code editors found in the **Building Blocks** > **Components** branch of the selected file.

The remaining two sections are only available if the **Command type** list is set to **Command handler from code editor**.

DEFINITION

Enter a title of the button in the **Title** field and an icon file in the **Icon** field or click **Browse** ( ) to pick an icon file from the file system.

The **Weight** field contains a factor (an integer number) that can be used to decide the order of the items in a context menu. It is available (editable) when the **Menu items ordering list** is set to **Use weighting order** in the Settings window for a **Context Menu** node. Under a toolbar menu, the weight is always 0 and this field is not editable.

Select the **Record a custom COMSOL API command** checkbox and type a name for using an API call equivalent to clicking the button as `runCommand(<name>)`, where *<name>* is a string with the name that you enter in the **Command** field.

Select the **Use button style if possible** checkbox if desired. This setting is only available for a button under a user input. It uses the style of a button instead of just text.

Select the **Always show the title** checkbox to always display the title. It is selected by default if you use the button style.

Select the **Default selected** checkbox if you want the toggle item to be selected (turned on) by default.

CONDITION TO RUN

Select the **Show confirmation dialog** checkbox if you want to display a confirmation dialog as a preaction for the toggle item's action. Type a message for the confirmation dialog in the **Message** field and a confirmation answer in the **Answer** field (default: `Yes`). The confirmation dialog also contains a **Cancel** button by default. You can use this functionality to ask for confirmation before performing the action.

Data Binding

Use the **Data Binding** node ( ) to define a data binding in order to update the parent User Input node when another object updates its value. The binding object is either a user input, a selection, or an attribute value of the current entity.

USER INPUT

From the **Specify binding object** list, choose **By reference** (the default) or **By name**.

By Reference

If you choose **By reference**, use the following settings:

From the **From** list, choose **User input from this feature** (the default) for taking the user input from the parent feature, choosing a user input from the **User input** list below; **Entity selection** to use the entity's selection; or **Entity attribute**, which you select from the **Attribute** list below: **Label**, **Tag**, or **Touched**.

By Name

If you choose **By name**, use the following settings:

From the **From** list, choose **User input from this feature** (the default) for taking the user input from the parent feature, entering a user input in the **User input** field below; or **Entity attribute**, which you enter in the **Attribute** field below.

Integer Values Check

Add the **Integer Values Check** node ( ) under a User Input node to force users to enter integer values for the input. An error message notifies the user that an illegal value was entered. The **Settings** window has the following section:

BOUNDS

From the **Use min value** and **Use max value** lists, choose one of the following bounds:

- **Unbounded** (the default).
- **Open bound (<)** or **Open bound (>)**: Use a minimum value or maximum value that is smaller than the value in the **Min value** field or larger than the value in the **Max value** field, respectively.
- **Closed bound (<=)** or **Closed bound (> =)**: Use a minimum value or maximum value that is smaller than or equal to the value in the **Min value** field or larger than or equal to the value in the **Max value** field, respectively.

License Settings

This node, which you can add from Feature Input node's context menu, is used internally by COMSOL for controlling the license requirements.

Real Values Check

Add the **Real Values Check** node ( ) under a User Input node to force users to enter real values for the input. An error message notifies the user that an illegal value was entered. The **Settings** window has the following section:

BOUNDS

From the **Use min value** and **Use max value** lists, choose one of the following bounds:

- **Unbounded** (the default).
- **Open bound (<)** or **Open bound (>)**: Use a minimum value or maximum value that is smaller than the value in the **Min value** field or larger than the value in the **Max value** field, respectively.
- **Closed bound (<=)** or **Closed bound (>=)**: Use a minimum value or maximum value that is smaller than or equal to the value in the **Min value** field or larger than or equal to the value in the **Max value** field, respectively.

General Check

Add the **General Check** node ( ) under a User Input node to force users to enter values that only match a certain pattern. An error message notifies the user that an illegal value was entered. The **Settings** window has the following section:

CHECK

From the **Type of check** list, choose **Match regular expression** (the default) or **Require parables expression**.

Enter the pattern in the **Regular expression** text field. Regular expressions supports a wide variety of string matching functionality, and the table below only list a few examples:

EXPRESSION	MATCHES
\w	A word character.
\d	A digit.

EXPRESSION	MATCHES
`.`	Any character.
`[a-z]`	Characters between a and z.
`[^abc]`	Not the characters a, b, and c.
`\w*`	Zero or more word characters.
`\d+`	One or more digits.

When the match fails for an entered value, an error message displays. Enter the error message to display in the **Error message** text field.

Named Group Members

Add the **Named Group Member** node (☰) under a User Input Group or a Section to include group members by name and not by reference. Note that all named members are sensitive to name changes, so always use references if possible. The named group members always appear after the members specified in the parent node. The **Settings** window has the following section:

NAMED GROUP MEMBERS

List all group members by their names in the **Group members** column.

Update User Input Event

If you have a user input in a property that you use as a loop parameter in physics features or coupling features, you can add an **Update User Input Event** node ( ). If the value or size of the loop parameter should affect the size or user interface of the user inputs in the physics features or coupling features you need to update those user inputs every time the property user input is changed. Use an **Update User Input Event** for that purpose. To add an **Update User Input Event** node, right-click a **Property** node and select it from the context menu.

USER INPUTS SENDING THE EVENT

In this list, add the names of the user inputs in this property that should update the user inputs in features and coupling features whenever they are changed.

Variables

In this section:

- Creating Variables
- Variables for Degrees of Freedoms
- Variable Declaration
- Variable Definition
- Equation Variable Definition
- Dependent Variable Definition
- Dependent Variable Declaration
- Discretization
- Initial Values
- Hide in GUI
- Disable in Solvers
- Degree of Freedom Initialization
- External Material Input/Output
- Component Settings
- Frame Shape
- ODE States Collection
- State Variables Definition

Creating Variables

A variable is essentially defined by an expression of other variables, dependent variables, user input parameters, or entered values. You can use variables for many important purposes, including the following:

- To add a quantity for plotting and results evaluation.
- To simplify the writing and readability of expressions.
- To make evaluation of long expressions more efficient, especially if an expression occurs in several places.

All variables in the Physics Builder are tensors that are first declared and then defined. You typically do the declaration once in a central place.

It is possible to do several declarations for the same variable, but then it is important that they are consistent.

An example of two inconsistent declarations is when they have different dimensions, and this gives an error message when you try the physics interface in the Model Builder. A declaration does not specify anything about the value of a variable. This is

what you use the variable definition for. A variable definition declares the expression or shape function for the variable, and where (a selection) the definition is valid.

Variables for Degrees of Freedoms

There are two methods to create variables to solve for (dependent variables), usually referred to as the unknowns or degrees of freedom (DOF). You can either use a dependent variable or a variable with a shape definition. The dependent variable can only be declared by an interface using the Dependent Variable Declaration under the physics interface. All dependent variables need a shape function definition to add the DOFs that the solver solves for. For this purpose, use the Dependent Variable Definition under a feature or property. If you are unsure what you need, use the default Lagrange shape function.

The other method to create DOFs is to add a shape definition for a variable declared by a Variable Declaration. In contrast to the dependent variable, this variable does not show up in the Model Wizard or in the Settings window for the physics interface instance in the Model Builder. This means that the user cannot change the name of this variable. Another minor difference is that it is possible to define the scope of the variable, where the default is physics scope (`<model name>.<physics name>.<variable name>`). The dependent variable always has a component scope.

Entering Names and Expressions

Variable Declaration

A **Variable Declaration** ( ) specifies a variety of properties for a variable. You can also right-click to add and define Variable Definition, Component Settings, and Disable in Solvers subnodes.

To add a **Variable Declaration** first add a **Component**, **Feature**, **Property**, **Physics Interface**, or **Multiphysics Interface** node then:

- From the contextual toolbar for **Component**, **Feature**, **Property**, **Physics Interface**, or **Multiphysics Interface**, click the **Variable Declaration** ( ) button. For example, add

a **Component** node under **Building Blocks** > **Components**. Then on the **Component** I toolbar, click **Variable Declaration** ( ). Or

- Right-click the **Component**, **Feature**, **Property**, or **Physics Interface** node and select it from the **Variables** submenu.

To find the definitions of the variable, click the **Find Declarations of this Variable** button ( ) in the **Settings** window, or click the node and press F7, or right-click the node and choose **Search** > **Find Definitions**.

Use the **Input Dependency** subnode to make the specifications for the **Variable Declaration** node dependent on other user inputs

The **Settings** window has the following sections:

DECLARATION

Enter a **Variable name** and a **Description** to include text for the variable when shown in analysis and variable listings. You can pass the component's arguments to the description. The argument name must be placed between two # characters. For example, if you have an argument `arg.param = material`, the string `#Plot_in the _#arg.param#_frame` will be displayed as `Plot in the material frame`.

Enter a LaTeX-encoded string in the **Symbol (LaTeX encoded)** field to define a symbol (`\mu`, for example, to display the Greek letter μ).

Select a **Dimension**: **Scalar**, **Vector (3x1)**, **Matrix (3x3)**, or **Custom**. For **Custom**, you can specify a nonstandard dimension as an *M*x*N*[x*K*x*L*] array, where *M*, *N*, *K*, and *L* are integers, and K and L are optional (for example, `3x3x3` if you need a tensor of rank 3 with indices of dimension 3).

Do not use tensors of rank higher than 4 due to the rapid increase in memory usage.

For **Custom** you can enter two special formats for dynamically setting the size:

- Enter `par.`<*name*> or `arg.`<*name*>, where <*name*> is a valid user input or argument, to use the size specification stored in the value of the user input named <*name*>. If the value of the user input is `3x4`, this variable is a 3-by-4 matrix. Make sure that the user input only can contain valid size strings (`NxMx...`) before using this format.
- Enter `size(`<*prefix*>`.`<*name*>`)`, where <*prefix*> is `par` or `arg`. It tries to evaluate the size of the given argument to the size operator. In case of <*prefix*> = `par`, this returns the size of the referenced user input. This can also be used to use the size of

a different variable, although this usage is not recommended. The variable must be declared before this size evaluation, which cannot be guaranteed. All unknown variables return a scalar size.

The **Physical quantity** list defines the unit of the variable and is the same as a Dependent Variable Declaration.

If you have defined a customized Physical Quantity, choose **Locally defined** from the **Physical quantity** list and then choose the customized option from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button to move to the referenced node in the **Link** list.

If there is no physical quantity defined, enter an SI unit for the dependent variable in the **SI unit** field. It is possible, in some contexts, to use arguments and values of user inputs to define the unit; this way you can enable dynamic units from arguments or other user inputs. There is also an operator, `evalUnit`, that you can use to parse units of known variables, typically dependent variables (example, `evalUnit(dep.u)`).

Entering Names and Expressions you can find more detailed information about how you can customize variable names with scopes and parameter values.

PREFERENCES

In this section, specify options about the variable.

Operation Between Multiple Definitions

Select an option from the **Operation between multiple definitions** list: **Replace**, **Add**, **Multiply**, **Logical or**, **Logical and**, or **Inner product**.

Any variable definition for this variable uses the selected operator to combine multiple variable definitions of the same variable. You typically use the option **Add** when several contributing features add contributions to the same variable (heat sources, for example).

Interpret as Right-Hand Side

Select the **Interpret as right-hand side** checkbox if you use the variable in any right-hand side of an expression. Such variables get an extra factor

$$e^{i \cdot \text{phase}}$$

that enables plotting and animations of the entire harmonic cycle in frequency-domain simulations. It is also used to identify right-hand sides for harmonic perturbation features; see Harmonic Perturbation.

Include in Load Groups

Select the **Include in load groups** checkbox if the variable should be affected by load grouping. To enable load groups for a feature add an **Auxiliary Settings** node and select the setting **Enable load groups**.

Matrix Symmetry for Square Matrix

If the matrix is square (for example, if you select **Matrix (3x3)** from the **Dimension** list), you can force a matrix symmetry with the options in the **Matrix symmetry for square matrix** list. The choices are **Diagonal**, **Symmetric**, and **Anisotropic** (the default), and controls the cells that the user can edit. This option also adds a check to the data field, so the user cannot enter a matrix structure that is more complex than the selected option. For example, choosing **Symmetric** does not allow an anisotropic matrix but it allows both isotropic and diagonal matrices.

Show in Plot Menu

Select the **Show in plot menu** checkbox (the default) if you want the variable to show up when a user clicks the **Insert expression** (+) and **Replace expression** ( ) buttons in any of the **Results** nodes during a Model Builder session. Edit the **Menu** field to group the variable into a submenu. The default setting is to place the variable directly under the menu of the physics interface. From the **Show Add all** list, select **For more 2 components**, **Yes**, or **No** to control if the **All expressions in this group** option should appear for a plot group of related variables.

Announce Variable to Feature Inputs

Select the **Announce variable to feature inputs** checkbox so the variable notifies its existence to all physics interfaces. The variable uses the selected physical quantity as an identifier. Any feature input parameter with the same physical quantity can pick up an announced variable, so that the variable can be used by the physics interface that the feature input belongs to.

An example of a feature input is any of the model input parameters in the **Model Inputs** section of a physics feature instance in the Model Builder. It is also possible to supply an extra **Match tag** to the announced variable. The predefined options here are **None** (the default), and all physical quantity field names. **None** is equivalent to an empty tag and should be used unless it is necessary to limit the matching in some sense. In such cases, enter an arbitrary but relevant tag — for example, `relative` or `absolute` to distinguish between pressure fluctuations and absolute pressure levels. You typically need physical quantity options for synchronized matching.

Click the **Select Physical Quantity as Tag** button ( ) to pick a physical quantity from the list in the **Physical Quantity** dialog that appears. Click the **Custom Tag** button ( )to use a custom tag that you type in for the announce tag. Click the **Reset to None** button ( ) to reset the filter to **None**.

Select the **Announce variable to common inputs** checkbox to notify this variable to the common model input variable list.

ADVANCED

This section contains advanced options that you do not have to change in most cases. In the **Base vector system** list you can override the base vector system specified by the parent (for example, a feature or property) by choosing something other than the option **Same as parent**. The **Declare on all frame systems** option results in three variable declarations, one for each of the frames (geometry, material, and spatial). The naming convention for components is done by appending the coordinate names of the frames. A consequence of this strict convention is that the **Component Settings** node cannot be allowed, so you cannot add it with this setting active. Any existing **Component Settings** node will automatically be disabled. In addition, the **Base vector system** column for individual tensor indices is also disabled and locked to the **Use common setting** option.

If the **Variable Declaration** node has a **Variable Definition** subnode, there will also be one definition added per frame system. The context's frame will also change, so the parsing may behave differently depending on the current frame system used.

For 3-by-1 (vector) and 3-by-3 (matrix) tensors, the **Frame information rule** list contains the following options:

- **Automatic** (the default), which automatically adds frame information if there are split frames in the model.
- **No frame information**, which never appends any frame information for a variable.

- **Spatial frame information**, which adds spatial frame information.
- **Material frame information**, which adds material frame information.

For tensors, choose a type from the **Tensor type** list: **Normal tensor**, **Tensor density**, or **Tensor capacity**. A tensor density is a concentration, for example, where it is multiplied with the volume factor. A tensor capacity is the inverse.

- Using Coordinate Systems
- Transformation Between Coordinate Systems

Variable Definition

A **Variable Definition** (a=) specifies the expression or shape of a variable and where the definition is valid.

A variable definition can exist in several places and has a slightly different user interface depending on where you use it. For example, it is not necessary to specify a variable name if the definition is a subnode to a variable declaration or user input. For a user input it is not even necessary to specify an expression because it is always set to the value entered by the user input (see Inputs).

To add a **Variable Definition**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component I** toolbar, click **Variable Definition** (a=).
- Right-click the **Component** node and select it from the **Variables** submenu.

To find the definitions of the variable, click the **Find Declarations of this Variable** button ( ) in the **Settings** window, or click the node and press F7, or right-click the node and choose **Search** > **Find Definitions**.

The **Settings** window has the following sections:

DEFINITION

For a standalone definition (not being a subnode to a declaration, for example), enter the **Variable name**. The **Variable name** follows the rules described in Entering Names

and Expressions and must match the name of a variable declaration somewhere in the same physics interface.

For a subnode definition, there is no **Variable name** field, because it always uses the same name as the parent.

Select a **Type**: **Expression**, **Shape function**, or **Available**. For **Expression**, enter an **Expression** using the rules in Entering Names and Expressions.

For **Shape function** choose a **Shape function** and **Shape discretization**.

The shape function selection is unavailable if you use a global selection for this definition. In that case, the only type of degree of freedom (DOF) that makes sense is the ODE variable, which is the only available global DOF. When **Shape discretization** is **From discretization** you can enter the name of an **ODE States Collection** in the **Discretization** field. The ODE variable will then become part of that collection.

Shape Function Variables in the *COMSOL Multiphysics Reference Manual*

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

PREFERENCES

Select the **Zero out components** checkbox to enforce a symmetry to spatial vectors and matrices.

If you choose **Zero out-of-plane**, the out-of-plane component is set to zero in the space dimensions 1D, 2D, 1D axial symmetry, and 2D axial symmetry. The out-of-plane component in 2D axial symmetry is the second component (the ϕ-component).

The **Zero in-plane** setting does the opposite and has no effect in 3D, for scalars, or nonspatial tensors (length other than 3).

If you choose **Property dependent**, you can choose to zero out some components for specific values of some property values.

For each row in the table of property values, choose **Zero out-of-plane**, **Zero in-plane**, **Keep all components** or **Explicit** from the list under **Components to zero out** for the corresponding property value under **Property value**.

From the **Setting for other property values** list, choose **Zero out-of-plane**, **Zero in-plane**, **Keep all components** or **Explicit** to control how other property values are zeroed out.

Select the **Use the setting above for undefined references** checkbox to use the default value even when the property does not exist.

The **Explicit** setting to define which components to zero out (default: 0, 1, 2 as zero-based indexes to elements in a vector). The explicit setting is useful when the number of components is not three.

PROTECTION

Set preferences that enable protection of entered expressions. Select the **Hide expression in equation view** checkbox to remove the definition to display in the **Equation View** node, which is a subnode to a physics feature in the Model Builder. This disables any possibility to alter the expression; it also makes it harder to read the expression.

To further complicate reading of the expression, you can select the **Encrypt expression** checkbox. This turns on an encryption of the expression in the saved model file and when accessing the expression in a model file for Java® code. It also encrypts the tensor expression when you compile the archive (see Compiling an Archive), so the expression in a distributed builder file (`*.mphphb`) cannot be read.

ADVANCED

This section is available when **Shape function** is selected as the **Type** (and always in a **Dependent Variable Definition** node's **Settings** window). The **Base vector system** list is always available.

Select the **Create a slit for the selected shape** checkbox to remove a shape function from the selection.

You typically use this for slit boundary conditions, where you want to allow a jump in the shape variable across a boundary.

Select the **Declare shapes for all frames** checkbox to ensure that the spatial derivatives of the shape functions exist for all existing frames. The declaration of frame-specific time derivatives of the shape functions is disabled when this checkbox is selected. These have to be declared manually for necessary frames.

Select the **Define derivatives for all frames** checkbox to automatically add explicit expression variables that represent the derivatives on all frames, except the frame that the shape function lives on because the shape function defines the derivatives for its frame. Selecting this checkbox disables the **Declare shapes for all frames** checkbox, and selecting that checkbox disables this one.

The **Define derivatives for all frames** checkbox is usually a better option than the **Declare shapes for all frames** checkbox if you only need access to derivatives on other frames.

Select the **Disable accurate boundary flux** checkbox (in **Variable Definition** nodes only) to disable accurate boundary fluxes for a specific shape variable. A shape variable gets several important settings from a **Dependent Variable Declaration** node or a **Discretization** node in the physics interface. You control this by using the **Shape discretization** list in the **Variable Definition** node's **Definition** section above. The discretization also controls if a shape function uses accurate boundary fluxes, which is not of interest for all shape variables.

The **Solver field type** list specifies the type of degree of freedom the shape function declares. There are few cases when this setting needs to be something different than **Normal**. The option **Control** is used for optimization and sensitivity problems, whereas the **Discrete** and **Quadrature** options are used for solver events; see Event.

Select a **Value type**: **Complex** or **Real**.

The **Base vector system** setting controls the evaluation context of the definition. As a subnode of a **Variable Declaration** node, it is equivalent to adding three definition nodes, each with the **Base vector system** setting set to different frames (**Geometry coordinate system**, **Material coordinate system**, and **Spatial coordinate system**). The **Base vector system** setting also controls the preferred variable to add the contribution to. If there are multiple declarations for a variable named `A`, for example, the evaluation context will first try to find a declaration in the same context. In case no matching context can be found, it will automatically transform the evaluated expression to the context of the first declaration.

If it is not a subnode of a **Variable Declaration** node, choose one of the following options from where to take the base vector system:

- **Same as parent** — the default.
- **Selected input coordinate system**.

- **Spatial coordinate system**.
- **Material coordinate system**.
- **Mesh coordinate system**.
- **Geometry coordinate system**.
- **Nontransforming system**.
- **From variable declaration**. This option ensures that the variable is evaluated in the frame specified in its declaration node, without any transformation.

In addition, if you can add an **Input Dependency** node to any node that has a **Base vector system** list, you can now control the value of the list using an expression. Expressions should be evaluated to the following valid values:

- `global` — For the **Same as parent** list option.
- `local` — For the **Selected input coordinate system** list option.
- `spatial` — For the **Spatial coordinate system** list option.
- `material` — For the **Material coordinate system** list option.
- `mesh` — For the **Mesh coordinate system** list option.
- `geometry` — For the **Geometry coordinate system** list option.

Equation Variable Definition

An **Equation Variable Definition** (a=) specifies the expression or shape of an expression variable and where the definition is valid. An equation variable definition is suitable for overwriting variables that define weak equations and constraints. Doing so can be necessary for multiphysics coupling features that must alter the governing equation in one of the coupled physics. When clearing the solve-for in the study step flag for the coupling feature, the equation variable definitions will be ignored, and the governing equation is again defined as the physics would if it were alone.

Note that it typically does not matter what kind of definition you use for the physics and coupling feature in their own equations and constraints. This is because neither equations nor constraints are added for items with the solve-for flag cleared.

To add an **Equation Variable Definition**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** I toolbar, click **Equation Variable Definition** (a=).
- Right-click the **Component** node and select it from the **Variables** submenu.

To find the definitions of the variable, click the **Find Declarations of this Variable** button ( ) in the **Settings** window, or click the node and press F7, or right-click the node and choose **Search** > **Find Definitions**.

The **Settings** window has the following sections:

DEFINITION

Enter a **Variable name**. The **Variable name** follows the rules described in Entering Names and Expressions and must match the name of a variable declaration somewhere in the same physics interface.

Also enter an **Expression** using the rules in Entering Names and Expressions.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

PREFERENCES

Select the **Zero out components** checkbox to enforce a symmetry to spatial vectors and matrices.

If you choose **Zero out-of-plane**, the out-of-plane component is set to zero in the space dimensions 1D, 2D, 1D axial symmetry, and 2D axial symmetry. The out-of-plane component in 2D axial symmetry is the second component (the ϕ-component).

The **Zero in-plane** setting does the opposite and has no effect in 3D, for scalars, or nonspatial tensors (length other than 3).

If you choose **Property dependent**, you can choose to zero out some components for specific values of some property values.

For each row in the table of property values, choose **Zero out-of-plane**, **Zero in-plane**, **Keep all components** or **Explicit** from the list under **Components to zero out** for the corresponding property value under **Property value**.

From the **Setting for other property values** list, choose **Zero out-of-plane**, **Zero in-plane**, **Keep all components** or **Explicit** to control how other property values are zeroed out.

Select the **Use the setting above for undefined references** checkbox to use the default value even when the property does not exist.

The **Explicit** setting to define which components to zero out (default: 0, 1, 2 as zero-based indexes to elements in a vector). The explicit setting is useful when the number of components is not three.

PROTECTION

Set preferences that enable protection of entered expressions. Select the **Hide expression in equation view** checkbox to remove the definition to display in the **Equation View** node, which is a subnode to a physics feature in the Model Builder. This disables any possibility to alter the expression; it also makes it harder to read the expression.

To further complicate reading of the expression, you can select the **Encrypt expression** checkbox. This turns on an encryption of the expression in the saved model file and when accessing the expression in a model file for Java® code. It also encrypts the tensor expression when you compile the archive (see Compiling an Archive), so the expression in a distributed builder file (`*.mphphb`) cannot be read.

ADVANCED

The **Base vector system** setting controls the evaluation context of the definition. The **Base vector system** setting also controls the preferred variable to add the contribution to. If there are multiple declarations for a variable named `A`, for example, the evaluation context will first try to find a declaration in the same context. In case no matching context can be found, it will automatically transform the evaluated expression to the context of the first declaration.

Dependent Variable Definition

The **Dependent Variable Definition** node (u,v,w) is used for the definition of a dependent variable, which means you specify the shape function to use and where that shape function is to be used.

To add a **Dependent Variable Definition**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component I** toolbar, click **Dependent Variable Definition** (u,v,w), or
- Right-click the **Component** node and select it from the **Variables** submenu.

The **Settings** window has the following sections:

DEFINITION

Select a **Dependent variable reference**: **Use physical quantity** (the default), **Use physical quantity + tag**, or **Variable name**.

- If you keep the default **Use physical quantity**, you must first specify the name of the dependent variable in its **Settings** window, which is selected from the **Physical quantity** list.
- For **Use physical quantity + tag** you can specify an arbitrary unique tag. Enter the tag in the **Unique tag** field. This tag is added to the end of the name of the **Physical quantity** chosen. For example, if you choose **Area (m^2)** from the list and enter `house` in the **Unique tag** field, the name for the node (in brackets) in the Physics Builder changes to `areahouse`.
- For **Variable name**, enter a **Variable name** in the text field.

It is important to have a matching dependent variable setting under the physics interface; otherwise you get an error.

For **Use physical quantity** (the default), **Use physical quantity + tag**, choose a **Physical quantity** from the list. In addition to the predefined physical quantities you can use locally defined physical quantities or physical quantities imported from an external resource:

- Select **Locally defined** from the top of the **Physical quantity** list to use one of the locally defined physical quantities, which you choose from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button ( ) to move to the Physical Quantity node for the selected local physical quantity.
- Select **Imported from external resource** from the **Physical quantity** list to use physical quantities from another imported Physics Builder file, which you choose from the **Imported file** list. Click the **Go to Source** button ( ) to move to the **Import** node for the imported Physics Builder file.

All dependent variables need a shape function declaration to add the unknowns that the solver solves for. You choose it from the **Shape function** list. If you are unsure what you need, use the default Lagrange shape function.

To find the definitions of the variable, click the **Find Declarations of this Variable** button ( ) in the **Settings** window, or click the node and press F7, or right-click the node and choose **Search** > **Find Definitions**.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

For the rest of the settings, see the Preferences and Advanced sections for Variable Definition.

Dependent Variable Declaration

A **Dependent Variable Declaration** node ( ) declares a dependent variable (field variable) used by the physics interface. This node does not make the interface add any shape functions for this variable, it just declares that a dependent variable exists. All dependent variables in a physics interface must have a unique identifier (or reference tag) within an interface. In most cases, you only solve for one type of physical quantity per interface, so the physical quantity works fine as a reference tag. If you need two or more dependent variables for the same physical quantity, it is necessary to append a unique tag to the reference tag.

	You must use this reference tag when defining the actual shape functions for the variable, which you do under a feature or a property; see Dependent Variable Definition.
!	You can also use the same shapes as a dependent variable for constraints, and then you need the reference tag to point to the correct variable. The reason for using a reference tag instead of a variable name is that the dependent variable name can be changed in the Model Builder. In the Physics Builder, you can only declare a default name.

Add these subnodes: Dependent Variable Declaration, Initial Values, Component Settings, Disable in Solvers, and Hide in GUI.

To add a **Dependent Variable Declaration**, first add a **Physics Interface** or **Multiphysics Interface**, then:

- On the **Physics Interface** toolbar, click **Dependent Variable Declaration** ( ).
- Right-click the **Physics Interface** or **Multiphysics Interface** node and select it from the **Variables** submenu.

To find the definitions of the variable, click the **Find Declarations of this Variable** button ( ) in the **Settings** window, or click the node and press F7, or right-click the node and choose **Search** > **Find Definitions**.

The **Settings** window has the following sections:

DECLARATION

Select a **Dependent variable reference**: **Use physical quantity** (the default) or **Use physical quantity + tag**.

- Keep the default **Use physical quantity** if you want to use the physical quantity as the reference.
- For **Use physical quantity + tag** you can specify an arbitrary unique tag. Enter the tag in the **Unique tag** field. This tag is added to the end of the name of the **Physical quantity** chosen. For example, if you choose **Area (m^2)** from the list and enter `house` in the **Unique tag** field, the name for the node (in brackets) in the Physics Builder changes to `areahouse`.

The **Physical quantity** list defines what quantity the dependent variable represents, including the unit. As mentioned previously, the physical quantity is also used to generate the unique reference tag for the dependent variable. In addition to the predefined and built-in physical quantities you can use locally defined physical quantities or physical quantities imported from an external resource:

- Select **From built-in quantities** (the default) from the **Physical quantity** list to choose a built-in physical quantity. To specify a physical quantity, click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog to browse to find a physical quantity to use. You can also type a search string in the text field at the top of the dialog and then click the **Filter** button ( ) to filter the list of physical quantities. For example, type `potential` and click the **Filter** button to only list physical quantities that represent some kind of potential. Alternatively, click the **Custom Unit** button ( ) to enter a unit (for example, `m/s^2`) in the text field (the physical quantity then becomes a **Custom unit**).

- Select **Locally defined** from the **Physical quantity** list to use one of the locally defined physical quantities, which you choose from the **Link** list. Click the **Add** button (+) to display a quick menu where you can select a source to add in to the list and use it as the current reference. A **Confirm Operation** dialog will appear and ask for confirmation if there is already a reference exist in the **Link** list. Click the **Go to Source** button ( ) to move to the Physical Quantity node for the selected local physical quantity.
- Select **Imported from external resource** from the **Physical quantity** list to use physical quantities from another imported Physics Builder file, which you choose from the **Imported file** list. Click the **Go to Source** button ( ) to move to the **Import** node for the imported Physics Builder file.
- Select **Any unit (only check expression)** from the **Physical quantity** list to accept any unit and only check the expression.

It you choose **None** from the list it is recommended to use the option **Use physical quantity + tag** in the **Dependent variable reference** list. As **None** is not a physical quantity, enter an explicit unit in the **SI unit** field. It is possible, in some contexts, to use arguments and values of user inputs to define the SI unit; this way you can enable dynamic units from arguments or other user inputs. There is also an operator, `evalUnit`, that you can use to parse units of known variables, typically dependent variables (example, `evalUnit(dep.u)`).

The **Default variable name** field declares the default name for the dependent variable, and the **Description** field has the descriptive text for the variable shown in analysis and variable listings.

Enter a LaTeX-encoded string in the **Symbol (LaTeX encoded)** field to define a symbol (`\mu`, for example, to display the Greek letter μ).

Select a **Dimension**: **Scalar**, **Vector (3x1)**, **Matrix (3x3)**, and **Custom**. For **Custom**, you can specify a nonstandard dimension (for example, `3x3x3` if you need a tensor of rank 3 with indices of dimension 3).

Do not use tensors of rank higher than 4 due to the rapid increase in memory usage.

PREFERENCES

Select or clear the **Show in plot menu** and **Announce variable to feature inputs** checkboxes and edit their additional settings if required. See Preferences described for Variable Declaration.

DISCRETIZATION

This section contains settings for defining the discretization levels that control the shape-function order used in the physics interface and the **Discretization** section of the physics interface instance. By default the parameter for the shape order is set automatically and includes five levels for order 1–5. You can also specify a default level (set to 2 by default). Use the **Parameter** list to specify if the discretization parameter name and description should be defined automatically (the default) or manually. This is the list in the physics interface instance that, in its automatic configuration, has the description **Element order** and has valid values **Linear**, **Quadratic**, and so on. Below the **Parameter** setting is a table with the following columns: **Level**, **Level description**, **Shape order**, **Geometry shape function**, and **Lower level**. This table controls the values that can be selected in the discretization parameter. Each row in this table represents a discretization level, which corresponds to a shape order for the dependent variable and an allowed value for the discretization parameter. Enter the value in the **Level** column and its description in the **Level description** column. Each level has a shape order, which you define in the **Shape order** column. Select the geometric shape order from the **Geometry shape function** list. The **Lower level** column's value should point to a discretization level that has a shape function order that is smaller than the current one, so it needs to be a value that is present in the **Level** column. The **Lower level** setting is used by the multigrid preconditioner.

To support a varying, user-defined shape order, enter `-1` in the **Shape order** column. The **Level** name could then be something like `expr`, the level description `Shape expression`, and the **Geometry shape function** set to **Automatic**. When using these settings, the physics interface will then show, in the Model Builder, the **Shape order expression** field where users can add the order expression. Remember that the shape function that is set in the corresponding **Dependent Variable Definition** node has to be one of the shape functions that support this setting (an hierarchical shape function).

In the **Default level** list, select the default level for the discretization parameter (default value: 2, for a quadratic order of the shape functions).

From the **Geometry shape function rule** list, choose a rule for determining the geometry shape function for the dependent variable. The following options are available

- **Prefer maximum order (0)**: Only let this variable choose the geometry shape function order if no other variable requires a maximum order.
- **Require maximum order if first variable (1)** (the default): Let this variable require a maximum geometry shape function order if it is the first dependent variable for a physics interface.
- **Require maximum order for all variables (2)**: Let this variable require a maximum geometry shape function order no matter where it is in the list of dependent variables.
- **From expression**: Let an expression, which you enter in the **Rule index** field that appears, evaluate to an integer representing one of the above rules. The integer for a rule appears within parentheses.

Select the **Enable accurate boundary flux option** checkbox to make the **Compute boundary fluxes** checkbox visible in the **Discretization** section of the physics interface instance. The **On by default** checkbox (selected by default) controls the default value of that parameter. Note that to make the computation of accurate boundary fluxes work as well as possible, it is also necessary to add **Flux Definition** nodes that define the flux for the dependent variable anywhere it is defined.

ADVANCED

This section contains advanced options that you do not have to change in most cases. In the **Base vector system** list, you can override the base vector system specified by the parent (for example, a feature or property) by choosing something other than the option **Same as parent**.

For tensors, choose a type from the **Tensor type** list: **Normal tensor**, **Tensor density**, or **Tensor capacity**. A tensor density is a concentration, for example, where it is multiplied with the volume factor. A tensor capacity is the inverse.

Choose **Real** or **Complex** (the default) from the **Default value type** list. This becomes the default choice when solving with splitting of complex degrees of freedoms (DOFs) into real-valued and complex-valued DOFs.

- Using Coordinate Systems
- Transformation Between Coordinate Systems

Discretization

You can add a **Discretization** node ( ) to defines a *discretization field*, which is a physics field that do not declare any model-scoped dependent variable. The setting basically is the **Discretization** section from the **Dependent Variable Declaration** node (see Discretization above) but also with a name and a parameter description declaration.

A **Variable Definition** node that defines a shape function (shape variables) can refer to a discretization field and let that field determine the shape order, complex value type, and boundary flux settings for that shape. A variable definition can also refer to a dependent variable declaration node, and thereby use that variables shape order, complex value type, and boundary flux setting.

You can also refer to this node in expressions using the `order` prefix, which will return the currently selected order for the discretization field. There is also an `intOrder` prefix to get the integration order for a dependent variable or a discretization field.

Right-click the **Discretization** node to add a Hide in GUI subnode if required. You can, for example, add a condition for hiding the settings in the physics interface or to disable declaration of all shape variables that refer to this Discretization node.

Initial Values

A dependent variable needs an initial value for nonlinear and transient simulations. In the **Initial Values** node ( ) you define the initial value for the dependent variable declared in the parent node. This node represents a special type of feature in the Model Builder that you get by default when you add a physics interface.

By default an **Initial Values** node is added to the Dependent Variable Declaration.

INITIAL VALUE SETTINGS

In the **Settings** window of the variable you specify the initial value in the **Default initial expression** field. The expression you enter here follow the rules outlined in Entering Names and Expressions, but with an exception. If you use a variable name here, you must specify the scope it uses. As an example, assume that you want to use the interface variable `init` as initial condition, then enter `phys.init` in the expression field. Otherwise, the initial value expression becomes `init`, and at solution time this gets a component scope. Select the **Set initial value on time derivatives** checkbox to activate the initial values for the first time derivative. In the **Geometric entity level** list, choose the entity level that the initial value is placed on. This must match the entity level you put the dependent variable definition on.

PREFERENCES

See the Preferences section for Variable Definition for the **Zero out components** settings.

If the **Add initial value as variable** checkbox is selected, a variable will be added containing the initial value of the dependent variable. This can be used to allow other initial value expressions to depend on a dependent variable's expression. The variable will get a "physics scope" although the dependent variable itself has a "component scope". A dependent variable with the fully scoped name `root.comp1.u` will then add a variable `root.comp1.id.u_init` for the initial value. The initial value for the time derivative, if present (the **Set initial value on time derivatives** checkbox is selected), gets the name `root.comp1.id.du_dt_init`. From the Physics Builder you can access these variables with the `dep` prefix using `dep.u_init` and `dep_du_dt_init`, respectively.

Using the `dep` prefix in initial value expressions for other variables than scalars must be done with some care. An initial value feature is typically created at the same time as the physics interface, before the size of the dependent variables have been decided. In such cases it may be necessary to use component syntax to get a proper default expression for the initial value setting — for example, `{dep.u_init.1,dep.u_init.2,dep.u_init.3}` for a 3-component vector.

Hide in GUI

For each dependent variable added by a physics interface a few GUI components are added automatically. These GUI components let the user control properties of the dependent variable such as the name and element order. In some situations you might not want to display all these GUI components.

To restrict the visibility, right-click a **Dependent Variable Declaration** ( ) node and choose **Hide In GUI** ( ). Only one such subnode per Dependent Variable Declaration node is allowed. You can also right-click an **ODE States Collection** node to add a **Hide in GUI** subnode.

The **Settings** window has the following sections:

SETTINGS

By default, the checkboxes in this section, except the first one, are selected:

- Select the **Skip declaration and definition** checkbox to skip the declaration of the dependent variable. It will then not be defined, and all its properties will be hidden. By default, the dependent variable is declared and defined.
- When the **Hide in initial values feature** checkbox is selected, the text field for setting the initial value of the dependent variable is hidden from the automatically generated initial values feature.
- The **Hide in discretization** section checkbox controls if the settings for choosing element order and value type of the dependent variable are hidden from the discretization property of the physics interface.
- The **Hide in dependent variables section** checkbox controls if the settings for setting the name of the dependent variable are hidden from the Dependent variables property of the physics interface.
- The **Hide in Model Wizard** checkbox controls if the settings for specifying the name of the dependent variable are hidden from the Model Wizard.

For a **Hide in GUI** subnode under an **ODE States Collection** node, only the three last checkboxes above are available.

CONDITION

Add a condition on when the UI components are hidden as specified in the **Settings** section. This condition only has effect if you select the **Condition for hiding** checkbox. If it is left in its default state of being not selected the UI components as specified in the **Settings** section are always hidden. The settings for the condition work in the same way as the settings under the **User input** checkbox in the Usage Condition node for components.

Disable in Solvers

In some cases a physics interface may declare degrees of freedom that should only be solved for in certain situations. Use the **Disable in Solvers** ( ) subnode to provide a condition for when a degree of freedom should not be solved for.

To add this subnode, right-click a **Dependent Variable Declaration** ( ) or **Variable Declaration** ( ) node and choose **Disable in Solvers** .

Only one subnode per Dependent Variable Declaration or Variable Declaration node is allowed.

When **Disable in Solvers** is a subnode to a **Variable Declaration** node, it is only relevant when that variable is a degree of freedom; that is, when it is defined as a shape function.

SETTINGS

The **Settings** section has two groups. The first one is enabled by the **Disable for study types** checkbox, and in it you can specify the study types for which the variable should not be solved. The second group is enabled by the **Additional condition for disabling** checkbox and makes it possible to provide an extra condition on a user input that also needs to be fulfilled in order for the variable not to be solved for. The settings for the condition work in the same way as the settings under the **User input** checkbox in the Usage Condition node for components.

Degree of Freedom Initialization

A variable that has a shape function definition needs an initial value for nonlinear and transient simulations. In the **Degree of Freedom Initialization** node (u,v,w) you define the initial value for such variable definitions. You can also use this to set the initial condition for dependent variables, but it is recommended that you use the Initial Values node instead. In situations where you do not want the Initial value feature in the Model Builder, you can customize the initial value definition using this node.

To add a **Degree of Freedom Initialization**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** I toolbar, click **Degree of Freedom Initialization** (u,v,w).
- Right-click the **Component** node and select it from the **Variables** submenu.

The **Settings** window has the following sections:

DEFINITION

You type the name of the variable you add the initial value for in the **Variable name** field. The variable name follows the rules described in Entering Names and Expressions, and must match the name of a variable declaration somewhere in the same physics interface. The name should also be the name of a variable that has a shape definition,

but no errors result if this is not the case. Select the **Set initial value on time derivatives** checkbox to add the initial values for the first time derivative.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

The rest of the settings are described in the Preferences and Protection section for Variable Definition.

External Material Input/Output

The **External Material Input/Output** node ( ) can be used to define a variable that need an external material input or output. It contains the following sections:

DECLARATION

Choose to define an **Input** or an **Output** from the **Type** list. The physical quantity can be selected from the **Quantity** list — a short list of the physical quantities that are commonly used by external materials in their inputs or outputs, or it can be selected from a full list of the physical quantity by selecting **From physical quantity**.

OPTIONS

The definition can be marked as an input or output of an External Material by defining the material list's name or reference using the **Material list** and the **Name** field.

The **Show in plot menu** checkbox is selected by default. Then choose on which menu it will appear: **Physics interface menu** (the default), **Physics feature menu**, or **Parent entity menu**.

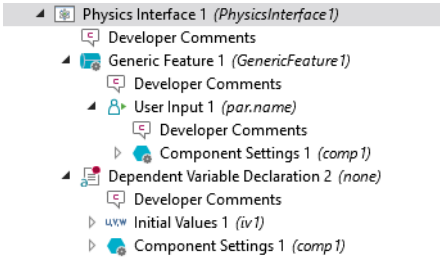
Component Settings

You can override the default names and descriptions for tensor elements with the **Component Settings** subnode ( ). This node is a valid subnode of user inputs, boolean inputs, selectable inputs, and variable declarations and simply changes the default behavior for the parent node.

It only makes sense to use this node for nonscalar tensors, like vectors or matrices.

To add a **Component Settings**:

1. Add a **Physics Interface** or **Multiphysics Interface**.
2. Add a User Input, Boolean Input, or Selectable Input to a feature node (for example a Generic Feature), or add a variable declaration (for example, a Dependent Variable Declaration).
3. Right-click the node (in this example, **Generic Feature** or **Dependent Variable Declaration**) and select it from the context menu.



The **Settings** window has the following sections:

COMPONENT SETTINGS

The **Create component names by** list contains several options for creating names and description according to different rules. The first option, **Appending coordinates to the name**, is the default behavior for spatial tensors that concatenate the tensor name with the coordinate name for each tensor component:

```
Axy
```

The option **Appending indices to the name**, concatenate the tensor name with the tensor index:

```
A12
```

This is the default for nonspatial tensors. Use the option **Specifying a template** if you have a certain naming convention for the *i*:th component. For example, assume that you want to have the following component names:

```
x_vel, y_vel, z_vel
```

Then you enter the following template:

```
str.append(coord.i,_vel)
```

To get the descriptions

```
x-velocity, y-velocity, z-velocity
```

type

```
#coord.i#-velocity
```

Another option for vector-valued variables is **Specifying each component separately**. To get the same names and descriptions as the previous example, fill in the following to the table under the **Create component names by** list:

COMPONENT NAMES	COMPONENT DESCRIPTIONS
`str.append(coord.1,_vel)`	`#coord.1#-velocity`
`str.append(coord.2,_vel)`	`#coord.2#-velocity`
`str.append(coord.3,_vel)`	`#coord.3#-velocity`

Select the **Custom symbol** checkbox to control the LaTeX symbols next to an array input where each component has its own symbol. Enter the symbol using LaTeX syntax in the **Component symbol** field. Symbols are only used by user inputs, so this setting is only applicable when you have a user input of rank 1 (array) and you place it in a layout were each component has an individual text field (not table).

The last option for vector-valued variables is **User input specify names**. Then the user specifies the names that you specify in User Input nodes.

For **Boolean Input** and **Selectable Input** nodes, only the **Specifying a template** and **Specifying each component separately** options are available from the **Create component names by** list when applicable.

SCOPE SETTINGS

Select the scope (namespace) to use for the modified names in the **Scope** list. The options are **Same as variable** (the default), **Root scope**, **Parent scope**, **Model component scope**, **Physics scope**, **Feature scope**, and **Device scope**. The selected scope is used for the created variable in the Model Builder.

Entering Names and Using Customized Names and Descriptions

PLOT MENU SETTINGS

This section only appears if you have selected **Matrix (3x3)** from the **Dimension** list in the parent **User Input** node's **Settings** window.

From the **Group matrix components** list. choose **No extra plot group level** (the default), or choose **Extra row level** or **Extra column level** to add row or column grouping to matrices in the plot menu by adding an extra plot group level for rows or columns, respectively. Then add a template for the description in the **Plot group description** field. In the default description, `Description#coord.i# components`, `#coord.i#` represent the *i*:th component of the matrix.

Frame Shape

This node has been deprecated and only appears when opening Physics Builder files created in versions earlier than 5.3. This node is no longer needed with the updated moving frame functionality added in version 5.3.

Add a **Frame Shape** node (u,v,w) to define the motion of the moving frame, either as an expression or as degrees of freedom.

To add a **Frame Shape**:

- Add a **Component** node under **Building Blocks** > **Components** (see Components). Or add feature nodes such as a **Generic Feature** or **Domain Condition** (see Features).
- Right-click the node and select it from the **Variables** submenu.

SETTINGS

Select a **Frame motion** from the list: **Free** (the default) or **Given by expression**. Choose **Free** to define degrees of freedom for the motion. If you choose **Given by expression**, enter an **Expression** to prescribe the motion.

ODE States Collection

The **ODE States Collection** node ($\frac{\partial u}{\partial t}$ODE) groups the ODE states that match a certain regular expression into a single ODE entity.

The ODE entity displays as a **Field** node under the **Dependent Variables** branch in the **Solver Sequence** branch when generating the solver sequence. This enables default solver settings to be made on each collection that affects all ODE states in the collection at once.

The **Settings** window has the following sections:

DECLARATION

Enter the default name in the **Name** field. This is the name that the collection gets in the first interface added to a model. Subsequently added interfaces automatically get the first unique name. Use the `dep.` prefix and the default name to refer the collection when specifying solver defaults. The text entered in the **Description** field appear in the **Dependent Variable** section of the physics interface. In this section you can change the name of the collection.

If the user changes the name of a collection in the **Dependent Variable** section of the physics interface, it only affects the identifier of the **Field** node in the solver sequence. The names of the ODE states are not affected.

Enter a regular expression in the **Include states pattern (regular expression)** field. The collection contains all ODE states that match this pattern.

ADVANCED

Choose **Real** or **Complex** (the default) from the **Default value type** list. This becomes the default choice when solving with splitting of complex degrees of freedoms (DOFs) into real-valued and complex-valued DOFs.

Compile Equations in the *COMSOL Multiphysics Reference Manual*

Restriction on Levels

A **Restriction on Levels** ( ) subnode provides the possibility to add a restriction on certain discretization levels. You can add it as a subnode under a Dependent Variable Declaration or Discretization node.

SETTINGS

The **Allowed space dimensions** list puts a restriction on the discretization levels selected in the **Levels** list. The applicable levels are those defined in the parent node, except for the selected default level. The default level must always be available for all space dimensions.

Adding this node with a restriction on certain levels (for example, the **Quintic** level for **3D**) means that when the physics interface is created for a 3D geometry the Quintic level will not be included.

It is important that excluded levels do not break the sequence for finding lower levels as specified in the **Dependent Variable Declaration** or **Discretization** node. Doing so may cause problems for the geometric multigrid solver.

State Variables Definition

A **State Variable Definition** ($a_{\text{⚙}}$) defines a state variable with an update expression and update event.

State variables define states that are updated using an update expression at the beginning or end of each completed solver step. You can use state variables to, for example, store the previous-step value of some expression.

To add a **State Variable Definition**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** I toolbar, click **State Variable Definition** ($a_{\text{⚙}}$).
- Right-click the **Component** node and select it from the **Variables** submenu.

The **Settings** window has the following sections:

DEFINITION

You connect the definition to the proper declaration by specifying the declared variable the **Variable name** field. The **Variable name** follows the rules described in Entering Names and Expressions and must match the name of a variable declaration somewhere in the same physics interface.

Also specify an initial value in the **Initial value** field and an expression used to update the state variable in the **Update expression** field. The expressions in the **Initial value** and **Update expression** fields must match the dimension of the declared variable.

If desired, select the **Store the first time derivative** checkbox to store the first time derivatives. You can then also add an expression for update in the **Update expression** field.

From the **Update** list, choose **At beginning of step** (the default), **After predictor step**, **At end of step**, or **Only initialization**. If you have chosen **After predictor step** or **At end of step** you can choose a value from the **Value at interpolation output** list: **Start of solver step** (the default) or **Linear interpolation**.

See the documentation for State Variables in the *COMSOL Multiphysics Reference Manual* for more information.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information. If you choose **Global** in the **Selection** list, then the State Variable will be analogous to a state variable defined in a **Global Definitions** > **State Variables** node in the Model Builder.

ADVANCED

From the **Integration order** list, choose **Automatic** (the default), **From discretization**, or **Custom shape order** to define the integration order for the state variable. If you chose **From discretization**, also specify the discretization to use in the **Discretization** field. If you chose **Custom shape order**, also specify the shape order in the **Order** field (default: 2).

From the **Value type** list, choose **Complex** (the default), for a complex-valued state variable, or **Real**.

If you select the **Associate with internal state of dependent variable** checkbox, you can specify a dependent variable or shape variable. This means that, when solving, you can find the state variable components under the solver field node corresponding to the specified dependent variable (these are found under **Solution** > **Dependent Variables**). In the **Dependent variable reference** list, you choose if you can use the physical quantity as the reference (choose **Use physical quantity**, which is the default), or if you have to append a unique tag (choose **Use physical quantity + tag** and enter a tag in the **Unique tag** field). It is possible to choose **Variable name** from the **Dependent variable reference** list and enter a name as reference in the **Variable name** field. The **Physical quantity** list defines what quantity the dependent variable represents, including the unit. As mentioned previously, the physical quantity is also used to generate the unique reference tag for the dependent variable. In addition to the predefined and built-in physical quantities you can use locally defined physical quantities or physical quantities

imported from an external resource. See Dependent Variable Declaration for more information.

If the **Associate with internal state of dependent variable** checkbox is cleared, each state variable will create its own solver field node. For the setting associated with the **Dependent variable reference** list, see the corresponding settings for Coefficient Form Equation.

Equations

You need a weak form equation (a differential equation using a weak formulation) for all features that contribute to the governing equations. The equation contributes to the weak form of representing the system of PDEs you want to solve for. You can enter the equations in these forms:

- Directly as a weak form equation, which is the most general technique to specify an equation.
- In the general form similar to the General Form PDE interface in the Model Builder.
- In the coefficient form similar to the Coefficient Form PDE interface in the Model Builder.
- In a boundary element method (BEM) equation form.

In this section:

- Weak Form Equation
- General Form Equation
- Coefficient Form Equation
- Boundary Element Equation
- Shared Quantity Definition
- Flux Definition

Weak Form Equation

As described in Equations, you need a **Weak Form Equation** ($\int du$) (a differential equation using a weak formulation) for all features that contribute to the governing equations.

To add a **Weak Form Equation**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component 1** toolbar, click **Weak Form Equation** ($\int du$).
- Right-click the **Component** node and select it from the **Equations** submenu.

The **Settings** window has the following sections:

INTEGRAND

The content of the **Expression** field adds up as a weak form contribution to the system of equations that you later solve for in the Model Builder.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

PREFERENCES

Clear the **Use volume factor in axial symmetry or for nonorthonormal systems** checkbox if you want to skip any volume factors in the weak form equation. In axial symmetry this means that you do not get the factor $2\pi r$. For more information on nonorthonormal systems. It is also possible to select the **Assume constant volume factor** checkbox in this section.

ADVANCED

If you want to use a different base vector system than the parent feature or property, you can choose a different system in the **Base vector system** list. Choose your preferred order of integration in the **Integration order** list: **Automatic** (the default); **From discretization**, where you specify a discretization as its name in the **Discretization** field; or Custom shape order, where you specify a shape order as a positive integer in the **Order** field.

- Specifying Selections
- Entering Names and Expressions
- Using Coordinate Systems
- The Weak Form PDE in the *COMSOL Multiphysics Reference Manual*

General Form Equation

As described in Equations, as an alternative to the weak form you can enter the equation using the **General Form Equation** node (▽·Γ).

To add a **General Form Equation**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** toolbar, click **General Form Equation** ($\nabla\cdot\Gamma$).
- Right-click the **Component** node and select it from the **Equations** submenu.

The **Settings** window has the following sections:

EQUATION

This section displays the equation that you define by defining the coefficients in the next section.

COEFFICIENTS

There are four coefficient in a general form equation. You define each coefficient by defining a tensor expression that requires a certain dimension. The dimensions are defined by the dimension of the dependent variable, N, and the number of spatial dimensions (always 3). The table below lists the dimensions for all four coefficients.

COEFFICIENT	DESCRIPTION	DIMENSION
Γ	Conservative flux	N-by-3
f	Source term	N-by-1
d_a	Damping or mass coefficient	N-by-N
e_a	Mass coefficient	N-by-N

If the dependent variable is a scalar, you can simplify the tensor dimensions by skipping all singleton dimensions. This simplifies the γ coefficient to be a spatial vector (length 3). The dependent variable can only be a tensor up to rank 1 (a vector), so use the weak form equation for dependent variables of higher ranks.

You also specify these coefficients for boundary conditions, which differs slightly from the General Form PDE interface in the Model Builder. It is straightforward to convert a Flux/Source boundary condition from this interface to an equivalent representation using only the f coefficient

$$f = g - qu$$

where g and q are the coefficients in the Flux/Source boundary condition, and u is the dependent variable name.

DEPENDENT VARIABLE

In the **Variable name** text field, write the name of the dependent variable you enter the general form equation for. The variable name can also be a variable that you have defined as a shape function.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

PREFERENCES

Clear the **Use volume factor in axial symmetry or for nonorthonormal systems** checkbox if you want to skip any volume factors in the weak form integration. In axial symmetry this means that you do not get the factor $2\pi r$. For more information on nonorthonormal systems. It is also possible to select the **Assume constant volume factor** checkbox in this section.

ADVANCED

If you want to use a different base vector system than the parent feature or property, you can choose a different system in the **Base vector system** list.

- Variables
- Specifying Selections
- Entering Names and Expressions
- Using Coordinate Systems
- The General Form PDE in the *COMSOL Multiphysics Reference Manual*

Coefficient Form Equation

As described in Equations, as an alternative to the weak form you can enter the equation using the **Coefficient Form Equation** node ($-c\nabla u$).

To add a **Coefficient Form Equation**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** toolbar, click **Coefficient Form Equation** ($-c\nabla u$).
- Right-click the **Component** node and select it from the **Equations** submenu.

The **Settings** window has the following sections:

EQUATION

This section displays the equation that you define by defining the coefficients in the next section.

COEFFICIENTS

There are eight coefficients in a coefficient form equation. You define each coefficient by defining a tensor expression that requires a certain dimension. The dimensions are defined by the dimension of the dependent variable, N, and the number of spatial dimensions (always 3). The table below lists the dimensions for all eight coefficients.

COEFFICIENT	DESCRIPTION	DIMENSION
γ	Conservative flux	`N-by-3`
a	Absorption coefficient	`N-by-N`
α	Conservative flux convection coefficient	`N-by-N-by-3`
β	Convection coefficient	`N-by-N-by-3`
c	Diffusion coefficient	`N-by-N-by-3-by-3`
f	Source term	`N-by-1`
d_a	Damping or mass coefficient	`N-by-N`
e_a	Mass coefficient	`N-by-N`

If the dependent variable is a scalar, you can simplify the tensor dimensions by skipping all singleton dimensions. This simplifies the γ, α, and β coefficients to be spatial vectors (length 3). The dependent variable can only be a tensor up to rank 1 (a vector), so use the weak form equation for dependent variables of higher ranks.

You also specify these coefficients for boundary conditions, which differs slightly from the General Form PDE interface in the Model Builder. It is straightforward to convert a Flux/Source boundary condition from this interface to an equivalent representation using only the f coefficient instead of the g coefficient.

DEPENDENT VARIABLE

Under this section you choose the dependent variable to use for the coefficient form equation. Similar to the dependent variable definition, you specify a reference to a dependent variable. In the **Dependent variable reference** list, you choose if you can use the physical quantity as the reference (choose **Use physical quantity**, which is the default), or if you have to append a unique tag (choose **Use physical quantity + tag** and enter a tag in the **Unique tag** field). It is possible to choose **Variable name** from the

Dependent variable reference list and enter a name as reference in the **Variable name** field.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

PREFERENCES

Clear the **Use volume factor in axial symmetry or for nonorthonormal systems** checkbox if you want to skip any volume factors in the weak form integration. In axial symmetry this means that you do not get the factor $2\pi r$. For more information on nonorthonormal systems. It is also possible to select the **Assume constant volume factor** checkbox in this section.

ADVANCED

If you want to use a different base vector system than the parent feature or property, you can choose a different system in the **Base vector system** list.

- Variables
- Specifying Selections
- Entering Names and Expressions
- Using Coordinate Systems
- Dependent Variable Definition
- The Coefficient Form PDE in the *COMSOL Multiphysics Reference Manual*

Boundary Element Equation

As described in Equations, as an alternative to the various equation forms based on the finite element method, you can also add a **Boundary Element Equation** node ($\int_{du}$) for creating an equation using the boundary element method.

To add a **Boundary Element Equation**, first add a **Component** node under **Building Blocks** > **Components**, then right-click the **Component** node and select it from the **Equations** submenu.

The **Settings** window has the following sections:

EQUATION

This section displays the equation that you define by defining the coefficients in the next section.

DECLARATION

In the **Operator name** field, enter an input that can be used to identically create a BEM entity. If more than one BEM Element Equation node have the same operator name, the boundary element selections will be merged in the group of each BEM selection types. In that case, all sharing coefficients and definitions between the nodes must be the same.

From the **Boundary type** list, select from the following types of boundary elements:

- **Single-sided BEM boundary**
- **Double-sided BEM boundaries with continuous field**. Use this option for boundaries, acting as BEM sources, that are adjacent to the same BEM domain on both sides and where the field is known to be continuous across the boundary.
- **Double-sided BEM boundaries with discontinuous field**. Use this option for boundaries, acting as BEM sources, that are adjacent to the same BEM domain on both sides and where a discontinuity across the boundary is allowed.
- **Edge flux**.
- **Edge gradient** (for an isolated edge)

COEFFICIENTS

There are four coefficient in a boundary element equation. You define each coefficient by defining a tensor expression that requires a certain dimension. The dimensions are defined by the dimension of the dependent variable, *N*, and the number of spatial dimensions (always 3). The table below lists the dimensions for all coefficients.

COEFFICIENT	DESCRIPTION	DIMENSION
a	Absorption coefficient	`N-by-N`
α	Conservative flux convection coefficient	`N-by-N-by-3`
β	Convection coefficient	`N-by-N-by-3`
c	Diffusion coefficient	`N-by-N-by-3-by-3`

If the dependent variable is a scalar, you can simplify the tensor dimensions by skipping all singleton dimensions. This simplifies the α and β coefficients to be spatial vectors (length 3).

You also specify the outward normal vector $\mathbf{n}$ in the **Outward normal** field. The default value is the vector `{root.n.1, root.n.2, root.n.3}`.

VARIABLE DEFINITION

Use this section to define the dependent variable of this BEM equation. It also used to define the boundary flux and some other requirement variables for a BEM entity. Similar to the dependent variable definition, you specify a reference to a dependent variable. In the **Dependent variable reference** list, you choose if you can use the physical quantity as the reference (choose **Use physical quantity**, which is the default), or if you have to append a unique tag (choose **Use physical quantity + tag** and enter a tag in the **Unique tag** field).

You can also define a **Boundary flux variable** and a **Background variable**.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

CONDITION AT INFINITY

For the condition at infinity in an unbounded void region for a BEM model, choose **None**, **Laplace's equation** (for Laplace-type equations), or **Helmholtz equation** (for wave equations).

QUADRATURE SETTINGS

Here you specify the orders for the integration (quadrature) of the various elements and contributions. This section evaluates the input parameters and pass them to the BEM entity to define the integration order of boundary elements.

FAR-FIELD APPROXIMATION

You can choose an approximation type for the far-field approximation: **None**, **ACA+**, or **ACA**. ACA and ACA+ are variants of adaptive-cross-approximation compression algorithms.

SYMMETRY

In this section you can specify symmetry in the *yz*, *xz*, and *xy* planes. Select **Off** for no symmetry, **Symmetry**, or **Antisymmetry**.

If you select the **Create synchronize selection inputs** checkbox, three new selections will be defined in the Model Builder (will be hidden in the user interface). The selection's

name is the name that is defined in the **Selection input** field. The selection's entities are the entities of a geometry that lies "exactly" on the symmetry planes.

POSTPROCESSING SETTINGS

In the **Interpolation distance from boundary** field, enter a value for the interpolation distance, which should be between 0 and h. This value determines how close to the boundary the results from the BEM operator should be used in postprocessing.

ADVANCED

If you want to use a different base vector system than the parent feature or property, you can choose a different system in the **Base vector system** list.

Shared Quantity Definition

Use a **Shared Quantity Definition** node ( ) to define quantities that are shared among several features in the physics interface — for example, to control mesh or solver settings.

To add a **Shared Quantity Definition**, first add a **Component**, **Feature**, or **Property** node then:

- From the contextual toolbar for **Component**, **Feature**, or **Property**, click the **Shared Quantity Definition** ( ) button.
- Right-click the **Component**, **Feature**, or **Property** node and select it from the **Variables** submenu.

The **Settings** window has the following sections:

DEFINITION

From the **Shared quantity** list, select a quantity to share (for example, **Minimum wavelength**, which can be a quantity useful for determining a suitable mesh size).

Enter a suitable name for the shared quantity variable in the **Variable name** field. Also, enter an expression for the variable in the **Expression** field.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid.

Specifying Selections

Flux Definition

Use a **Flux Definition** node (u,v,w) to define the flux for a dependent variable anywhere it is defined.

To add a **Flux Definition**, right-click a **Component**, **Feature**, or **Property** node and select it from the **Variables** submenu.

The **Settings** window has the following sections:

DEFINITION

In the **Dependent variable reference** and **Physical quantity** lists, you specify what dependent variable to change the scaling for. See Dependent Variable Declaration for the settings information. Also, enter an expression for the flux in the **Expression** field.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid.

Specifying Selections

PREFERENCES

Select the **Zero out components** checkbox to enforce a symmetry to spatial vectors and matrices using an option from the **Zero out components** list.

If you choose **Zero out-of-plane**, the out-of-plane component is set to zero in the space dimensions 1D, 2D, 1D axial symmetry, and 2D axial symmetry. The out-of-plane component in 2D axial symmetry is the second component (the ϕ-component).

The **Zero in-plane** setting does the opposite and has no effect in 3D, for scalars, or nonspatial tensors (length other than 3).

If you choose **Property dependent**, you can choose to zero out some components for specific values of some property values. For each row in the table of property values, choose **Zero out-of-plane**, **Zero in-plane**, or **Keep all components** from the list under **Components to zero out** for the corresponding property value under **Property value**. From the **Setting for other property values** list, choose **Zero out-of-plane**, **Zero in-plane**, or **Keep all components** to control how other property values are zeroed out. Select the **Use the setting above for undefined references** checkbox to use the default value even when the property does not exist.

If you choose **Explicit**, the enter the components to zero out in the **Components to zero out** field (default: 0, 1, 2).

Constraints

A feature that puts some sort of constraint on a dependent variable (a Dirichlet boundary condition, for example) needs a Constraint node (R=0). A constraint forces an expression to be zero, using the expression together with a constraint-force expression. In most cases, the constraint force can be generated from the constraint expression, but the constraint node also provides the possibility to customize the constraint force. You can add an Excluding Selection subnode to exclude selections from the selections that the parent **Constraint** node already has.

Constraints can also be formulated as a Weak Form Equation using an extra degree of freedom. This technique is called weak constraints, and you can add a Weak Constraint node (R=0) to add such a weak constraint.

Constraint

As described in Constraints, a feature that puts some sort of constraint on a dependent variable (a Dirichlet boundary condition, for example) needs a **Constraint** node (R=0).

To add a **Constraint**, first add a **Component** node under **Building Blocks** > **Components**, then:

- On the **Component** I toolbar, click **Constraint** (R=0).
- Right-click the **Component** node and select it from the **Equations** submenu.

Use the **Input Dependency** subnode to make the specifications for the **Constraint** node dependent on other user inputs.

DECLARATION

In the **Expression** field, you enter the constraint expression that the solver forces to zero when solving (for example, the expression `T-293.15[K]` makes T equal to 293.15 K). The options in the **Constraint force** list let you change how the constraint affects the governing equations. The **Use type from constraint settings** option means that the user can choose between **Bidirectional, symmetric** and **Unidirectional** constraints in the **Constraint type** list of an instance of this feature in the Model Builder. If you choose **Customized**, a **Force expression** field becomes visible. Here you can write an expression for controlling the constraint force.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this variable definition is valid. See Specifying Selections for more information.

SHAPE DECLARATION

Under the **Shape Declaration** section you choose what shape function to use for the constraint. Similar to the Dependent Variable Definition, you can choose to specify a reference to a Dependent Variable Declaration, and the constraint then uses the same shape function as that dependent variable. To use this option, choose **Same as dependent variable** from the **Constraint shape function** list. With the option **Use specific shape** in this list, you can specify an arbitrary shape function for the constraint from the **Shape function** list. If you choose **User-defined product**, you get additional choices for individual shape functions and discretization for the base geometry and extra dimensions, when working with extra dimensions.

ADVANCED

The **Base vector system** list selection similar to the Weak Form Equation.

The **Allow weak constraints** checkbox lets you deactivate support for weak constraints, which is selected by default. When selected, the constraint can potentially generate a weak form equation. You can also select **Customized** from the **Weak expression** list instead of **Automatic**, which is the default, and then enter a custom weak-form expression for the constraint in the **Weak expression** field. In addition, if you have selected **Use specific shape** from the **Constraint shape function** list in the **Shape Declaration** section above, then you can select **Customized** from the **Lagrange multiplier name** list instead of **Automatic**, which is the default, and then enter a Lagrange multiplier base name in the **Base name** field (default: `name_lm`). Otherwise, the Lagrange multiplier's name is determined automatically. Under **When selected, the Lagrange multiplier may differ from the reaction forces**, you can select the **Use volume factor in axial symmetry or for nonorthonormal systems** checkbox, which adds a $2\pi r$ volume factor in axisymmetric models. It is also possible to select the **Assume constant volume factor** checkbox in this section.

Clearing the **Allow weak constraints** checkbox means that it is not possible to activate weak constraints for an instance of the feature owning this constraint in the Model Builder. Then all the settings above are disabled.

Select the **Add excluding selections automatically** checkbox to add such excluding selections for the constraint settings automatically. Any **Excluding Selection** subnodes are then disabled and not used.

Select the **Exclude from constraint grouping** checkbox to make sure that the constraint is not affected by constraint grouping. This setting is only relevant when constraint grouping is activated for the physics feature. To activate constraint grouping add an **Auxiliary Settings** node to the parent feature and select the setting **Enable constraint groups**.

- Entering Names and Expressions
- Specifying Selections
- Using Coordinate Systems
- Constraint in the *COMSOL Multiphysics Reference Manual*

Weak Constraint

Constraints can also be formulated as a Weak Form Equation using an extra degree of freedom.

To add the **Weak Constraint** node (R=0), first add a **Component**, **Feature**, **Property**, or usage condition then:

- In the contextual toolbar, click **Weak Constraint** (R=0).
- Right-click the component, feature, property, or usage condition node and select it from the **Equations** submenu.

The **Settings** window has the following sections:

INTEGRAND

The content of the **Expression** field adds up as a weak-form contribution to the system of equations that you later solve for in the Model Builder.

SELECTION

The options in the **Selection** list and **Output entities** list define the selection where this contribution definition is valid. See Specifying Selections for more information.

PREFERENCES

Clear the **Use volume factor in axial symmetry or for nonorthonormal systems** checkbox if you want to skip any volume factors in the weak contribution. In axial symmetry this means that you do not get the factor $2\pi r$. It is also possible to select the **Assume constant volume factor** checkbox in this section.

ADVANCED

If you want to use a different base vector system than the parent feature or property, you can choose a different system in the **Base vector system** list. You can also specify the integration order from the Integration order list: **Automatic** (the default, which picks an integration order that is consistent with the shape function order) or **Customized**; if you choose **Customized**, enter an integration order (a positive integer; default value: 2) in the **Order** field.

- Entering Names and Expressions
- Specifying Selections
- Using Coordinate Systems
- Group Members Define a Section
- Weak Constraint in the *COMSOL Multiphysics Reference Manual*

Excluding Selection

Add an **Excluding Selection** subnode (R=0) to a **Constraint** node to exclude selections already added to that node.

The options in the **Selection** list and **Output entities** list define the selection that should be excluded. See Specifying Selections for more information. The excluding selection's options are similar to the selection's options, except there is no options for a global selection, and the output entities should have a dimension that is lower than the dimension of the selection of the parent **Constraint** node.

Device Systems

In this section:

- Creating Device Systems
- Device Model
- Device Package
- Port Model
- Device Constants
- Device Import
- Device Parameters
- Device
- Input Modifier
- Device Variables
- Device Equations
- Device Initial Equations
- Port
- Port Connections
- If Condition (If-Sequence Condition for Devices)
- For Loop for Devices
- Device States
- Discrete Device States
- Explicit Device Events
- Implicit Device Events

Creating Device Systems

For certain global interfaces that do not have any distributed dependent variables (no spatial dependence), the complexity of the system often lies in the large number of dependent variables it needs. It is usually rather complicated to define a set of dependent variables to solve for, so there is a special frame work for handling such systems.

You define a hierarchy of device models that defines a set of variables and equations. A Device Model specifies a type of a device. The device model also needs ports that define how devices communicate with other devices.

A port also has a type, called a Port Model. A port model defines a set of variables that take part in the communication between devices. A typical example of this rather abstract description is an electrical circuit. All resistors in a circuit belongs to the same device model, the resistor model. The resistor model defines two ports representing the two pins that a resistor has. Each resistor is a device where the two ports to communicate with other resistors and possibly other types of devices like capacitors and inductors. The port model for the port needs a voltage and a current. The voltage

represents the node potential of the connection, and is the same for all ports that are connected. The current that flows out of a port must flow into the other ports, so the sum of all currents must be zero. The port model declares this behavior.

Edit Variables for Device Variables, Device Parameters, Device Constants, Device States, Discrete Device States, and Port Variables

These nodes support an **Edit Variable** toolbar button that opens up the **Edit Variable** dialog. In this dialog, it is possible to change more settings that those visible as columns in the table. If there are several variables in the table, you can step through the table without closing the dialog using the **Previous Row (Discard Changes)**, **Previous Row (Store Changes)**, **Next Row (Discard Changes)**, and **Next Row (Store Changes)** toolbar buttons. The settings are equivalent to those for normal variables in the Physics Builder; see Variable Declaration for more details. The **Elimination weight** field under **Advanced** (only available for **Device Variables**) sets a priority order for eliminating variables in the final device system. A higher number is more likely to get eliminated. Those variables that are not eliminated either become states or are constants. All variables declared by the **Device States** and **Discrete Device States** nodes always become states.

The **Device Variables** node under a **Port Model** (port variables) includes two special settings. Select the **Flow variable** checkbox to indicate that the variable is treated as a flow in connections between ports. The second special setting is the **Declare external node connection variables and use them instead** checkbox. It is only applicable for the plot menu and not for flow variables, so it is available when the **Flow variable** checkbox is not selected and when the selection in the **Show in plot menu** list is not set to **Never**. When selected, it means that the actual variable will not be present in the plot menu but instead it shows the variable generated for the connection. A connection is two or more ports connected together, so selecting this checkbox typically gives much fewer variables in the plot menu.

Device Model

As described in Creating Device Systems, the **Device Model** ( ) defines a set of variables and equations that corresponds to a certain device characteristic. Typical examples from the field of electrical circuits are capacitors, resistors, voltages sources, and bipolar transistors.

To a device model you can add modifiable inputs, variables, equations, other devices, and ports as child nodes. Right-click the **Device Model** node to add Device Constants, Device Parameters, Device, Device Variables, Device Equations, Port, Port Connections, Port Model, Usage Condition, Discrete Device States, Explicit Device Events, and Implicit Device Events subnodes. You can also add other **Device Model** subnodes.

To add a **Device Model** to **Features** ( ):

1 Under the **Building Blocks** branch click **Features**.

2 In the **Home** toolbar, from the **Building Blocks** group, click to add any of the available features (for example, a Device Model Feature or Domain Condition).

3 Right-click the node (in this example the **Device Model Feature** or **Domain Condition** node) and choose **Device Model** from the **Devices** submenu.

To add a **Device Model** to **Components** ( ):

1 Under the **Building Blocks** branch click **Components**.

2 In the **Home** toolbar, from the **Building Blocks** group, click **Component** ( ).

3 Right-click the **Component** node and choose **Device Model** from the **Devices** submenu.

To add a **Device Model** to a **Physics Interface** ( ) or any physics feature or physics property node, right-click the node and choose **Device Model** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device item belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following sections:

DEVICE MODEL

In the **Type** field you define a unique string that identifies the device model. When you create a Device, you must specify a device model for that device. The device then instantiates the device model. A device model type should be unique, but if you declare several device models with the same type, the last one is used. In the **Inherited type** field, you can enter a parent type that this device model inherits all inputs, ports, variables, and equations from. Leave this field empty to skip inheritance. A device model can also be abstract, meaning that you can only specify this type as an inherited type of another device model. A device cannot instantiate an abstract device model. Select the **Abstract model type** checkbox to make a device model abstract.

DEVICE PARAMETERS

Fill the table in this section with the device parameters that the device model supports. Each device parameter also needs a default value. You can also define device parameters with the **Device Parameters** child node. Use the Input Modifier of a device to override the default value of a device parameter.

DEVICE SYSTEM OPTIONS

This section is only available when adding a **Device Model** node from a **Physics Interface** node.

The **Device system type** list only supports the option **Normal**.

From the **Device naming convention** list, choose from the options **Dot hierarchy and dot-separated array indices**, **Dot hierarchy and dot-separated array indices**, and **Underscore hierarchy with no support for arrays**. The first option is the default for new interfaces, and the last option is mainly used by interfaces created in a previous version before version 6.4. The setting controls the variable names generated by the device system. For example, a device named `R1` containing a variable `v` will get the full name `id.R1.v` using a dot-separated hierarchy and `id.R1_v` using an underscore-separated hierarchy. The latter version is less flexible with variable names because a variable name with an underscore have to be escaped, so using `R1_load` in the above example leads to the full name `id.R1__load_v`, while the name using dot-separation will simply be `R1_load.v`.Therefore, the dot-separated convention is the recommended choice. The dot-separated convention has two variants that controls the naming convention for the scalar component names of array variables. A 3-by-1 array variable `v` from the above example will get the scalar components `id.R1.v.1`, `id.R1.v.2`, and `id.R1.v.3`, using dot-separated array indices, or `id.R1.v_1`, `id.R1.v_2`, and `id.R1_3`, using underscore-separated array indices.

Device Package

The **Device Package** ( ) is a predefined package of Device Models, Port Models, and Device Constants. A **Device Package** node can also contain **Device Package** subnodes. A Device Model can use items declared in a package using a **Device Import** node (see Device Import below). A Device Package is typically not very useful if its content is only used within the same physics interface as the package. Instead, you typically use it when a physics interface wants to share its device models with other physics interfaces. If a **Device Package** node is added directly under the physics interface, the

interface only contributes with a package to the device repository without actually adding any real equations or variables from the device models it defines. All device models and port models defined by that interface will then be part of the interface's package. **Device Package** nodes can also be added directly under **Definitions Library** > **Auxiliary Definitions**. The device packages under this branch make it possible to use them in several different physics interfaces provided that they list the Physics Builder file or a folder containing it as a resource in the physics interface's **Device Model** node.

To add a Device Package to Features, Properties, or Components:

1 Under the **Building Blocks** branch, click **Features**, **Properties**, or **Components**.

2 In the **Home** toolbar, from the **Building Blocks** group, click to add any of the available features.

3 Right-click the add node and choose **Device Package** from the **Devices** submenu.

To add a **Device Package** to a **Physics Interface** ( ) or any physics feature or physics property node, right-click the node and choose **Device Package** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device package belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following section:

DEVICE PACKAGE

In the **Type** field you define a unique string that identifies the device package. When you create a Device for a Device Model that a package defines, you must typically include a package reference for that device model. The exact syntax for the reference is decided by a Device Import node that refers to the package. In the **Inherited type** field, you can enter a parent package that this package inherits all device models or port models form. Leave this field empty to skip inheritance.

Port Model

As described in Creating Device Systems, a **Port Model** ( ) declares types of ports that a devices use to communicate with each other. To a port model you can only add device variables and device equations, where a variable can be declared as a flow variable. When you make a connection between two or more devices, the connection sets all nonflow variables equal. For the flow variables on the other hand, the connection sets the sum of all flow variables equal to zero. You can also right-click the **Port Model** node to add Device Variables and Usage Condition subnodes.

To add a **Port Model** to **Features** ( ):

1. Under the **Building Blocks** branch click **Features**.
2. In the **Home** toolbar, from the **Building Blocks** group, click to add any of the available features (for example, a Device Model Feature or Domain Condition).
3. Right-click the node (in this example the **Device Model Feature** or **Domain Condition** node) and choose **Port Model** from the **Devices** submenu.

To add a **Port Model** to **Components** ( ):

1. Under the **Building Blocks** branch click **Components**.
2. In the **Home** toolbar, from the **Building Blocks** group, click **Component** ( ).
3. Right-click the **Component** node and choose **Port Model** from the **Devices** submenu.

To add a **Port Model** to a physics feature or physics property node, right-click the node and choose **Port Model** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the port model belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following section:

PORT MODEL

In the **Type** text field enter the port type that a port instance refers to. It is also possible to let a port model inherit from another port model. To do so, enter that port model in the **Inherited type** text field.

Select the **Abstract model type** checkbox to make the port model abstract (it can then not be instantiated by a port, for example).

Device Constants

You can use these **Device Constants** (a=) in the equations of the same device model or any device model that inherits from it. Right-click the Device Model node to add the **Device Constants** subnode.

DEVICE CONSTANTS

Fill the table with the constants you need for a device model. Enter the **Name** of the constant, the constant **Expression**, and the **Dimension**. The expression must be a constant with respect to device variables, but they can depend on ordinary variables declared outside the device context. For valid entries in the **Dimension** column, see Variable Declaration.

Device Import

The **Device Import** ( ) refers to a previously defined package in the repository to include that package's device models and port models for the current interface. To avoid name collisions with other device models of the current interface, the **Device Import** node also defines a reference convention how the content of the package extends its types to the owner of the **Device Import** node. For example, when the using **As is** in the **Import as** list, the type of the package prepends all types of device models in the package. A device model with the type `Resistor` under the package `Analog`, you can access with the full type `Analog.Resistor`.

To add a Device Import to Features, Properties, or Components:

1. Under the **Building Blocks** branch, click **Features**, **Properties**, or **Components**.
2. In the **Home** toolbar, from the **Building Blocks** group, click to add any of the available features.
3. Right-click the node and choose **Device Import** from the **Devices** submenu.

To add a **Device Import** to a physics feature or physics property node, right-click the node and choose **Device Import** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device import belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following section:

DEVICE IMPORT

In the **Package** field you specify the type of the package to import. The exact syntax to use for device models in that package, depends on the options of the **Import as** list: **As is** (the default), **All under package**, or **Named import**. The option **As is** will just prepend the type of the package to the types of all its content (Device Model, Port Model, or another Device Package); see the above example. The types are always separated with a dot. The option **All under package** does not prepend anything, so you can access the content as if it was added directly by the parent of the **Device Import** node. Be aware of the risk of type conflicts when using this option. The last option, **Named import**, lets you choose a name in the **Name** field to use when prepending the types of the content.

Device Parameters

Use the **Device Parameters** node (P_i) to declare the inputs that the device model supports. Each device input also needs a default value. These inputs can be used in the

equations of the device model. Right-click the Device Model node to add the **Device Parameters** subnode.

DEVICE PARAMETERS

Fill the table with the parameters you need for a device model. A device instantiating a device model can modify the default values through the Input Modifier. As an alternative to specifying the parameters in this node, you can add them directly in the **Device Parameters** section of a Device Model. For valid entries in the **Dimension** column, see Variable Declaration.

Device

A **Device** ( ) is a device model instance that you can add under a feature or under a device model. If you add it under a feature, the program creates one device per feature instance.

To add a **Device** to **Features** ( ):

1. Under the **Building Blocks** branch click **Features**.
2. In the **Home** toolbar, from the **Building Blocks** group, click to add any of the available features (for example, a Device Model Feature or Domain Condition).
3. Right-click the node (in this example the **Device Model Feature** or **Domain Condition** node) and choose **Device** ( ) from the **Devices** submenu.

To add a **Device** to **Components** ( ):

1. Under the **Building Blocks** branch click **Components**.
2. In the **Home** toolbar, from the **Building Blocks** group, click **Component** ( ).
3. Right-click the **Component** node and choose **Device** ( ) from the **Devices** submenu. Or add a Device Model and right-click to choose **Device** as a subnode.

To add a **Device** to a physics feature or physics property node, right-click the node and choose **Device** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

DEVICE

To make this work properly, ensure that the device gets a unique **Name**, typically by specifying the name to `entity.tag`. The device then gets the same name as the parent feature.

In the **Type** text field enter the device model that the device is an instance of. If the Device is under a Device Model you can access the variables defined by the device's device model by prepending the name of the device to the name of the variable. Assume that the device model declares a variable named `R`, and the device has the name `R1`. To use this variable in the device model that the device belongs to you then type `R1.R`.

Input Modifier

A Device Model defines a set of device inputs that you define a default value for. To change this default value for a certain device, add an **Input Modifier** ( ) subnode to a Device.

DEVICE INPUTS

Fill the table with the **Name** of the input you want to modify, and an **Expression** for the new value.

Device Variables

You can use these **Device Variables** (a=) in the equations of the same device model or any device model that inherits from it. Right-click a Device Model or Device Model Feature node and choose **Device Variables** from the **Devices** submenu.

DEVICE VARIABLES

Fill in the table columns and rows with the variables needed. Enter a **Name** and specify an **Expression** for a variable. This directly defines an equation for the variable. The **Expression** column, when nonempty, represents the right-hand side in an equation with the variable's name as the left-hand side The main difference compared to adding an equivalent **Device Equations** node is that any expression entered in the **Device Variables** node may be modified by a device model that inherits from the device model that this node is in. This is not possible or allowed if you only add a device equation.

When added under a **Port Model** node, this section is called **Port Variables**, and a **Flow variable** column is available. Select the checkbox in the **Flow variable** column for a variable to indicate that the variable is treated as a flow in connections between ports.

Click the **Edit Variable** button ( ) underneath the table to edit these settings and others for the selected variable. In the **Edit Variable** window, under **State options**, the **Rule for selecting variable as a state** list sets a priority rule for eliminating variables in the final device system. The options are **Always use as state**, **Prefer as state**, **Use as state**

if appropriate (the default), **Avoid using as state**, and **Never use as state**. Those variables that are not eliminated become states. All variables declared by the **Device States** and **Discrete Device States** nodes always become states. Enter an initial guess for a state in the **Initial guess (leave empty to skip)** field. For all eliminated variables there is no need for an initial guess, and the expression will be ignored. Leave the field empty to skip defining any initial guess. The device system analysis will then choose an initial guess, which will be zero in most cases. Select the **Collect states to** checkbox and then enter the name of an **ODE States Collection** node to ensure that any states generated by this variable will be sorted into that collection. This is an alternative to using the pattern entered in the **Include states pattern (regular expression)** field in that collection. The collection entered in the **Collect states to** field will have precedence over any collection matched by the name pattern in the **ODE States Collection** node.

See Edit Variables for Device Variables, Device Parameters, Device Constants, Device States, Discrete Device States, and Port Variables for more information.

Device Equations

Right-click a Device Model or Device Model Feature node and choose **Device Equations** ($\int du$) from the **Devices** submenu.

To add a **Device Equations** node to a physics feature or physics property node, right-click the node and choose **Device** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device equations node belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

DEVICE EQUATIONS

Fill in the table with **Left-hand side** and **Right-hand side** of an arbitrary number of **Device Equations**. You can use any device variable, device input, or device constant in these equations. If you want to use nondevice variables, add a scope specifier to the variable.

Assume for example that you want to use the variable `A` declared by a variable declaration in a device equation. In an ordinary expression you just type `A`, but in a device equation, the parser assumes that this is a device variable named `A`. Instead you type `phys.A` to specify that this is a variable outside the device context.

For valid entries in the **Dimension** column, see Variable Declaration.

Device Initial Equations

Right-click a Device Model or Device Model Feature node and choose **Device Initial Equations** (∫dv) from the **Devices** submenu.

To add a **Device Initial Equations** node to a physics feature or physics property node, right-click the node and choose **Device** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the device initial equations node belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

DEVICE INITIAL EQUATIONS

Fill in the table with **Left-hand side** and **Right-hand side** of an arbitrary number of **Device Initial Equations**. You can use any device variable, device input, or device constant in these equations. See Device Equations above for details about the conventions of expressions containing device variables.

The DAE analysis only includes the device initial equations when analyzing the initial value problem. The analysis includes normal device equations for both the initial and the normal problem. Complex problems may require that the user solves for the initial problem using a special study step, but for many cases it works fine to just let the initial-value problem enter the initial values of the normal problem.

Port

A **Port** ( ) is a port model instance that you add to define the connections that devices uses to communicate with each other. To add this subnode, right-click a Device Model or Device Model Feature node and choose **Port** from the **Devices** submenu.

To add a **Port** to a physics feature or physics property node, right-click the node and choose **Port** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the port belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

PORT

In the **Name** text field you enter the name of the port. This name defines the variable names that you use to access the variables declared in the port model that you refer to in the **Type** text field. If a port model declares a variable named `v`, and you typed `a` in the **Name** text field, you access the variable `v` by typing `a.v`.

Port Connections

The **Port Connections** ( ) defines how devices connect to each other. There are two situations when you can use port connections.

The first is when you add the port connections to a **Device Model** or **Device Model Feature**. You use this to define connections between devices that belongs to the same device model. To add this subnode, right-click a Device Model or Device Model Feature node and choose **Port Connections** from the **Devices** submenu.

The second situation is when you add port connections to a **Device**. Then you typically want to define how the ports of that device connect to another device that belongs to another feature. Right-click a Device node and choose **Port Connections** from the context menu.

To add a **Port Connections** node to a physics feature or physics property node, right-click the node and choose **Port Connections** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the port connections node belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

PORT CONNECTION

Port Connection Added to a Device Model or Device Model Feature

Fill in the table with the names of the ports that you want to connect, where the names in the **Connection, 1** column connects to the names in the **Connection, 2** column. This is typically ports defined by the device models that a device refers to, so the name of the port is appended to the device name. For example, you type `R.p` to access port `p` of the device named `R`.

Port Connection Added to a Device

Fill the table with the port name in the **Local connection** column, and a virtual connection in the **External connection** column. The virtual connections defines a temporary name space that identifies the port names in the right column in any port connections that connects. So lets assume that you have a parameter for a feature called `plus` where you want the user to enter a node that port `p` connects to. Then you enter p in the right column, and `par.plus` in the right. If two features exist where the user entered the same value for the parameter plus, the port `p` of those device gets connected.

If Condition

The **If Condition** node ( ) evaluates a condition of device parameters and constants during the instantiation of a device hierarchy. An if sequence is a sequence of nodes starting with an if condition followed by zero or more else-if conditions and finally an optional else statement. Only one of the conditions can be true for the entire sequence. The main difference compared to a normal Usage Condition feature is that the Usage Condition is always an individual condition that evaluates independently of other nodes. Another difference is that a Usage Condition never accepts device parameters or constants.

There are several kinds of if-sequence conditions, and this particular kind, called **If-Sequence Condition for Devices** on the **Devices** submenu, only applies to device and port models in a device hierarchy. It only allows the following device nodes to be part of the condition: Device Equations, Port Connections, Explicit Device Events, Implicit Device Events, other If-Sequence Condition for Devices, and For Loop for Devices.

To add an **If-Sequence Condition for Devices** node, right-click a **Device Model**, **Port Model**, **Device Package,** or **Device Model Feature** node and choose **If-Sequence Condition for Devices** from the **Devices** submenu.

To add an **If Condition** node to a physics feature or physics property node, right-click the node and choose **If-Sequence Condition for Devices** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the if condition belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following sections:

CONDITION

From the **Type** list, specify the kind of node it is in the if sequence. The options are **If**, **Else if**, and **Else**. The options **Else if** and **Else** are only allowed when the preceding is another if-sequence node using the type **If** or **Else if**. When you move nodes, an invalid option will be kept but displays an error decoration until you fix the problem. Leaving a sequence in this state will cause an error when using the physics interface.

The **Condition** field contains the condition that should evaluate to true. Any variable in the expression without a prefix will be treated as a device variable, although it is allowed to use the device prefix too (`dev.A`, for example). Most other prefixes are

allowed but not all makes sense to use in a condition. Normal physics variables (like `phys.A`) can never be evaluated in an if condition (just like in a Usage Condition).

EXTRA RESTRICTIONS ON CONTEXT

The section contains a few extra restrictions that must be fulfilled for the condition to evaluate to true. The **Invert condition on restriction** checkbox inverts the conditions when selected. Note that this only applies to the conditions in this section. It does not affect the condition in the **Condition** section. In the **Restrict to space dimensions** list, select the dimensions that the current context must be in, or not be in when the **Invert condition on restriction** checkbox is selected. Similarly, the **Restrict to study types** list requires that the context solves for an equation form equivalent to the selected study types.

For Loop for Devices

Use the **For Loop for Devices** node ( ) to evaluate one or several ranges and set a local variable equal to each range's value while looping over them. When using multiple ranges, all the ranges must have the same length.

There are several kinds of for loops and this particular kind called For Loop for Devices only applies to device and port models in a device hierarchy. It only allows the following device nodes to be part of the for loop: Device Equations, Port Connections. Explicit Device Events, Implicit Device Events, If-Sequence Condition for Devices, and other For Loop for Devices nodes.

To add a **For Loop for Devices** node, right-click a **Device Model**, **Port Model**, **Device Package**, or **Device Model Feature** node and choose **For Loop for Devices** from the **Devices** submenu.

To add a **For Loop for Devices** to a physics feature or physics property node, right-click the node and choose **For Loop for Devices** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the for loop for devices belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

The **Settings** window has the following section:

LOOP EXPRESSIONS

Enter the names of the loop variables in the **Name** column of the table, and enter the corresponding range expression in the **Expression** column. The range can either be a range using the range operator or an array variable. As an example, the expression

`range(1,2,5)` loops over the numbers 1, 3, and 5. For a device parameter A of size 4, the loop will be over values of the parameter's scalar components. You can also enter a vector-valued expression directly (for example, `{1, 10, 100, 1000}`). For multiple loop variables all range expressions must be of the same length. The loop expression must also only depend on device constants or device parameters.

Device States

Use a **Device States** node (a=) to define variables that will be forced to become states. Enter the initial expression in the corresponding column in the table under **State Components**.

The detailed settings for a device states are almost identical to the ones for the device variable, with the same **Edit Variable** toolbar button. The only difference is that there is no **Advanced** section with the **Elimination weight** field in the dialog (see Edit Variables for Device Variables, Device Parameters, Device Constants, Device States, Discrete Device States, and Port Variables). The elimination weight does not make sense in this context because a state variable can never be eliminated. It is recommended to only use state variables for variables whose time derivative also appears in a device equation.

Discrete Device States

You can use the discrete device states in a **Discrete Device States** node (a=) as any other device variable in the equations of the same **Device Model**. The states themselves have no equation and can only be assigned by an initial expression or by reinitialization expressions in **Explicit Device Events** and **Implicit Device Events** nodes (see below).

Fill the table with names of the states in the **Name** column, their initial expressions in the **Initial Expression** column, and finally the dimensions of the states in the **Dimension** column. For valid entries in the **Dimension** column, see the Variable Definition node.

Explicit Device Events

Use an **Explicit Device Events** node ( ) to create solver events at certain predefined start times and periods. Each solver event can reinitialize variables to a new value as long as the variable is a degree of freedom or discrete state. To ensure that an ordinary device variable is a degree of freedom, use an **Elimination Weight** of −1. See the Device Variables node for more details.

To add an **Explicit Device Events** node to a physics feature or physics property node, right-click the node and choose **Explicit Device Events** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the explicit device events node belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

Enter a scalar start time in the **Start time** column and a scalar period in the **Period** column. The period time accepts `inf` to only trigger an event once. The **Re-init variables** and **Re-init expressions** columns contain an array of variables names and their corresponding reinitialization expressions. It is an array to support reinitialization of multiple variables. For example, `{a, b}` and `{a+1,b*2}` to add one to `a` and multiply `b` with 2 for each triggered event.

Implicit Device Events

Use an **Implicit Device Events** node ( ) to create solver events that trigger when a condition goes from false to true. The conditions have to be written with a relation expression of any of the types `a>b`, `a>=b`, `a<b`, or `a<=b`. The equal comparison, `a==b`, should generally be avoided because it is a comparison of floating-point numbers. The reinitialization works exactly like the **Explicit Device Events** node (see above).

To add an **Implicit Device Events** node to a physics feature or physics property node, right-click the node and choose **Implicit Device Events** from the **Devices** submenu. If added under any of these nodes or a **Component** node, the implicit device events node belongs to the device models closest in the hierarchy. For most cases this will be the device model added by the physics interface.

Enter a tensor-valued condition in the **Condition** column. If the result is nonscalar, it results in one solver event per element. See the Explicit Device Eventss node for details how to fill the **Re-init variables** and **Re-init expressions** columns.

Operators and Functions

Operators

You can add an operator to a feature, property, or component.

To add an **Average**, **Integration**, **General Extrusion**, **Maximum**, **Minimum**, **Expression Operator**, **Average Over Extra Dimension**, or **Integration Over Extra Dimension** operator:

1. Under the **Building Blocks** branch click **Components**.
2. In the **Home** toolbar, from the **Building Blocks** group, click **Component** ( ).
3. Right-click the **Component** node and choose **Average**, **Integration**, **General Extrusion**, **General Projection**, **Maximum**, **Minimum**, **Expression Operator**, **Average Over Extra Dimension**, or **Integration Over Extra Dimension** from the **Operators** submenu.

Defining an operation is similar to the way it works in the Model Builder but with a few differences.

- The **Operator name** follows the same rules as variables; see Entering Names. You usually have to use feature scope for any operation defined by a feature; otherwise, you get a duplicate definition if you have more than one feature of that type.
- The **Show in plot menu** checkbox is selected by default. Clear that checkbox to remove the operator from the plot menus in results and probe features.
- For the **Selection** section, in the Physics Builder you cannot specify absolute selections as you can in the Model Builder. See Specifying Selections for more information.

The Average, Integration, General Extrusion, Maximum, and Minimum nonlocal couplings are supported as operations in the Physics Builder. The Expression Operator, Average Over Extra Dimension, and Integration Over Extra Dimension operators are also available.

- Entering Names of Operators and Functions
- For more information about the other settings, see Nonlocal Couplings and Coupling Operators in the *COMSOL Multiphysics Reference Manual*

Functions

You can add a **Function** to a feature, property, or component. The function names follow the same rules as variables; see Entering Names. You usually have to use a feature scope for any function defined by a feature; otherwise, you get a duplicate definition if you have more than one feature of that type. Apart from the name syntax, defining a function works in exactly the same way as in the Model Builder.

The following functions are available: Analytic, Gaussian Pulse, Image, Interpolation, Piecewise, Ramp, Random, Rectangle, Step, Triangle, Waveform, and Tensor-Valued Function.

To add one of the available functions:

1 Under the **Building Blocks** branch click **Components**.

2 In the **Home** toolbar, from the **Building Blocks** group, click **Component** ( ).

3 Right-click the **Component** node and choose a function from the **Functions** submenu.

In the function node's Settings windows (except for Tensor-Valued Function), the **Show in plot menu** checkbox is selected by default. Clear that checkbox to remove the operator from the plot menus in results and probe features.

SPECIAL SETTINGS FOR INTERPOLATION

In the settings for the **Interpolation** function, you can choose **User input** from the **Data source** list (in addition to **File** and **Local table**). By using the **User input** definition, the defined interpolation will read the data from the user inputs for both function and argument data. Enter an expression for the function, such as `par.time`, in the **Function expression** field and expressions for one or more arguments, such as `par.T`, in the **Arguments expression** list.

- Entering Names of Operators and Functions
- User-Defined Functions in the *COMSOL Multiphysics Reference Manual*

Average

The **Average** ( ) operator is almost identical to the average operator you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

Integration

The **Integration** (∫du) operator is almost identical to the integration nonlocal coupling you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section. There is also a special option in the **Frame** list: **Same as parent**. You can use it to dynamically refer the integration operator frame to the frame of the feature.

General Extrusion

The **General Extrusion** ( ) operator is almost identical to a general extrusion coupling you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

ADVANCED

Use the **Mesh search method** list to specify one of the options **Use tolerance** (the default), **Closest point**, and **Walk in connected component**. For **Use tolerance** and **Walk in connected component**, enter a tolerance in the **Extrapolation tolerance** field.

Select the **Use manual search distance** checkbox to enter a manual distance in the **Search distance** field.

Select the **Map between product selections** checkbox to expect the source selection to be a product selection. Two additional sections, **Destination Map for Extra Dimension** and **Source Map for Extra Dimension**, then appear. They include **Expression** fields for the destination and source maps. These maps expect a vector or matrix input using curly braces ({) with a coordinate expression of the correct size. These inputs are the equivalent of the tables in the Model Builder version of the operator. The **Source Map for Extra Dimension** section is only active when the **Expression** field in the **Source Map** section is enabled.

General Projection

The **General Projection** ( ) operator is almost identical to a general projection coupling you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

Maximum

The **Maximum** (MAX) operator is almost identical to the Maximum nonlocal coupling you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

Minimum

The **Minimum** (MIN) operator is almost identical to the Minimum nonlocal coupling you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

Expression Operator

The **Expression Operator** ( ) defines an operator that evaluates parameterized expressions on specified selections.

For information about the settings in the **Operator Name** and **Selection** sections, see the Operators section.

DEFINITION

In the **Expression** field, enter the expression for the operator. The expression can contain both the specified formal argument names and other variables, which are assumed to exist on the selection. Press Ctrl+Space to choose from previously defined parameters, mathematical constants and functions, operators, and physical constants that you can insert into the expression at the position of the cursor.

In the table of arguments, enter the name of each formal argument in the **Argument** column and its expected dimensions, in the form of a unit expression, in the **Dimensions** column. The dimensions are used when deriving the operator's dimensions and for checking unit consistency when the operator is used in expressions. In the **Argument type** column, choose **Expression** to pass the input argument as an expression, or choose **Value** to pass it by its value. Passing an input argument by value can be useful if it is a spatial coordinate in a component geometry that is then evaluated in another geometry, for example. Use the **Delete** button ( ) underneath the table to delete the selected argument, if needed.

Operator Contribution

You can add **Operator Contribution** subnodes under an **Expression Operator** node to override the operator's expression on different selections.

SELECTION

The options in the **Selection** list and **Output entities** list defines the selection where this variable definition is valid. See Specifying Selections for more information.

DEFINITION

In the **Expression** field, enter the expression for the operator that then is valid on the selection specified for this **Operator Contribution** subnode.

Average Over Extra Dimension

Use an **Average Over Extra Dimension** to add an average value over an extra dimension in the physics interface. It is similar to the Average Over Extra Dimension you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

To add an **Average Over Extra Dimension**, first add a Component, then right-click **Component** and add it from the context menu

Integration Over Extra Dimension

Use an **Integration Over Extra Dimension** to add an integration over an extra dimension in the physics interface. It is similar to the Integration Over Extra Dimension you can add in the Model Builder. The main difference is how you specify the operator name and selections, which is described in the Operators section.

To add an **Integration Over Extra Dimension**, first add a Component, then right-click **Component** and add it from the context menu.

Using Extra Dimensions in the *COMSOL Multiphysics Reference Manual*

Physics Areas

In the Model Builder you create a model with the Model Wizard. After choosing geometry, you select physics interfaces from a tree view. This tree view contains categories representing physics areas at the top level, and possible subcategories in each Physics Area or Predefined Multiphysics. When you create your own physics interface, you can always put it in an existing category; see Physics Interface for more information about how you do this. To create additional Model Wizard entries, add a Model Wizard Entry.

Physics Area

Use a **Physics Area** ( ) node to categorize the physics in different physics areas. It collects the physics interfaces into more intuitive and quick access groups.

To add a **Physics Area**:

- In the **Home** toolbar click the **Physics Area** button ( ), or
- Under Definitions Library right-click **Physics Areas** ( ) and choose it from the context menu.

The **Settings** window has the following sections:

PARENT AREA

This section contains a tree view of all physics areas and subcategories available from built-in resources, other areas defined in the current builder file, and areas defined in any imported file under the **External Resources** branch. To put your new physics area under a specific category in the tree, you first select that item. Then you click the **Set as parent** button ( ) below the tree. As an alternative, you can also right-click the selected item, and choose **Set as parent** from the submenu. You find the currently selected category under the **Parent area** divider. If you do not specify a parent area, the area has **Root** as its parent area.

Also control the position of the physics area in the list of areas it currently belongs to. Click the **Move up** ( ) or **Move down** ( ) buttons to move the area in the list.

PHYSICS AREA SETTINGS

In the **Name** field you define a unique string that identifies the physics area, which must be unique among all areas present in the Model Wizard. The text you write in the

Description field is the text COMSOL Multiphysics displays for the physics area in the Model Wizard. You can also specify an icon image in the **Icon** field, either by typing the name or by choosing an icon from the file system. The **Weight** field controls the position of your physics area in the list it currently belongs to. The higher the weight (a larger number), the further down the position in the list. The **Move up** and **Move down** buttons in the **Physics Area** section provide another way to change the weight.

Creating a New Model in the *COMSOL Multiphysics Reference Manual*

Predefined Multiphysics

Use a **Predefined Multiphysics** ( ) node to categorize the multiphysics interfaces in different physics areas. It collects the multiphysics interfaces into more intuitive and quick access groups. Right-click **Predefined Multiphysics** to add Contained Multiphysics Coupling, Contained Multiphysics Definition, and Contained Interface (Predefined Multiphysics) subnodes.

To add a **Predefined Multiphysics** node, under Definitions Library right-click **Physics Areas** and choose it from the context menu.

PHYSICS AREA

This section contains a tree view of all physics areas and subcategories available from built-in resources, other areas defined in the current builder file, and areas defined in any imported file under the **External Resources** branch. To put your new physics area under a specific category in the tree, you first select that item. Then you click the **Set as parent** button ( ) below the tree. As an alternative, you can also right-click the selected item, and choose **Set as parent** from the submenu. You find the currently selected category under the **Parent area** divider. If you do not specify a parent area, the area has **My physics interfaces** as parent area.

IDENTIFIERS

In the **Type** field you define a unique string that identifies the multiphysics interface. The text you write in the **Description** field is the text COMSOL Multiphysics displays for the multiphysics interface in the Model Wizard. You can also specify an icon image in the **Icon** field, either by typing the name or by choosing an icon from the file system. The value in the **List order weight in Model Wizard** determines where in the list the

multiphysics interface appears. The default is 2 (the higher the weight, the lower position the Model Wizard gets in the tree of physics interfaces).

RESTRICTIONS

In this section, you can specify restrictions in terms of which space dimensions and study types that are allowed.

The list under **Allowed space dimensions** includes all space dimensions except 0D by default. Click the **Add** button (+) to choose one or more space dimensions that are not already included from the **Allowed space dimensions** list in the **Add** window that opens. Use the **Move Up** , **Move Down** , and **Delete** buttons under the table to organize the list if needed.

Contained Multiphysics Coupling

Use a **Contained Multiphysics Coupling** ( ) node to create a multiphysics coupling that is contained in multiphysics interface and is added directly when a user adds that multiphysics interface in the Model Wizard, for example.

To add a **Contained Multiphysics Coupling**:

1. Under Definitions Library right-click **Physics Areas** and choose Predefined Multiphysics from the context menu.
2. Right-click **Predefined Multiphysics** and choose **Contained Multiphysics Coupling** from the context menu.

COUPLING FEATURE LINK

See Multiphysics Coupling for the settings.

COUPLINGS

See Generic Multiphysics Coupling for the settings.

Model Wizard Entry

Add a **Model Wizard Entry** ( ) node to add several entries in the Model Wizard for the same physics interface. For example, if you want to add a physics interface in both the Acoustics folder and in the Structural Mechanics folder, you can add the physics in one place (for example, in Acoustics) and then add a **Model Wizard Entry** node containing this physics in the other place (for example, Structural Mechanics). You can add a **Model Wizard Entry** node under a **Physics Areas** node.

PHYSICS AREA

Here you select a parent area for the physics interface. Right-click the physics area that you want to use as the parent physics area and choose **Set as Parent** ( ), or select a parent physics area and then click the **Set as Parent** ( ) button.

IDENTIFIERS

The additional entry in the Model Wizard needs its own type, which you add in the **Type** field. The value in the **List order weight in Model Wizard** determines where in the list the physics interface appears. The default is 2 (the higher the weight, the lower position the Model Wizard gets in the tree of physics interfaces). You can choose if you want to use the same description as the physics uses or if you want to give the entry a new description by first selecting the **Use new description** checkbox and then type a name in the **Description** field. Select the **Modify label for created interface** checkbox to use the description also for the label of the create physics interface after leaving the Model Wizard. When it is cleared (the default), you get the behavior in versions before version 6.1 and only show the description for the node in the Model Wizard.

The icon for the node in the Model Wizard is typically the same as the icon of the physics interface. This is what the default **From physics interface** setting for the **Icon** list means. You can also use a custom icon for the node by choosing **Custom** and enter an icon name in the text field below the list. Note that it is only the icon in the Model Wizard node that changes, while the icon for the created physics node in the Model Builder always uses the icon from the physics interface.

In the Contained Interface (Predefined Multiphysics) subnode, you specify which physics the entry should add. You can also set new property defaults there.

Contained Multiphysics Definition

Use a **Contained Multiphysics Definition** ( ) node to create a node from supported nodes available under the component's **Definitions** node (such as Moving Mesh nodes) that is contained in multiphysics interface and is added directly when a user adds that multiphysics interface in the Model Wizard, for example.

MULTIPHYSICS DEFINITIONS

Here you select the type of definition feature to add from the **Feature** list. You can also specify an **Initial selection**: **Cleared** (the default) or **All entities**.

DEFAULT SETTINGS

In this section, you can specify settings that the predefined multiphysics will change when adding a new feature. The setting is specified in the table's **Input name**, **Default value**, and **Ignore undefined** columns. When the **Ignore undefined** checkbox is selected, the Model Wizard will ignore all errors if the input name does not exist for the selected feature type. Click the **Add** button (+) to add another input. Use the **Move Up** ↑ , **Move Down** ↓ , and **Delete** buttons under the table to organize the list.

Contained Interface (Predefined Multiphysics)

A **Contained Interface** ( ) node is a link node, similar to the Feature Link and Property Link nodes.

To add a **Contained Interface**:

1. Under Definitions Library right-click **Physics Areas** and choose Predefined Multiphysics or Model Wizard Entry the context menu.
2. Right-click **Predefined Multiphysics** or **Model Wizard Entry** and choose **Contained Interface** from the context menu

SOURCE INTERFACE

The settings are the same as for Source Interface.

PROPERTY DEFAULTS

The settings are the same as for Property Defaults.

	Contained Interface

Selections

The **Selections** ( ) branch definition under the Definitions Library can either be an explicit selection or a selection being the result of a Boolean operation.

Right-click **Selections** to add Selection, Selection Filter Sequence, and Extra Dimension Selection subnodes. There are also other features available as subnodes to the **Selection Filter Sequence**: Override Rule Filter, Selection Component Filter, and Multiphysics Coupling Filter.

- Specifying Selections
- Named Selections in the *COMSOL Multiphysics Reference Manual*

Selection

Add the **Selection** node ( ) to create a selection that you can use to define other selections.

You can either link to a selection component directly or as part of an operation between selections such as a union, intersection, or difference. Selection components can be referenced from other selection components, or from any item that has a selection section.

To add a **Selection**:

- In the **Home** toolbar click the **Selection** ( ) button, or
- Under Definitions Library, right-click the Selections node and choose **Selection** from the menu.

- Specifying Selections
- Named Selections in the *COMSOL Multiphysics Reference Manual*

Selection Filter Sequence

The **Selection Filter Sequence** node ( ) defines the entities that a physics feature is applicable on. A feature can reference such a definition by choosing **From sequence** in

the **Applicable entities** list in the **Settings** section of a feature's window (see Generic Feature).

To add a **Selection Filter Sequence**, under **Definitions Library** right-click the Selections node and choose **Selection Filter Sequence** from the menu.

The function of a selection filter sequence is defined by right-clicking **Selection Filter Sequence** and to add Override Rule Filter, Selection Component Filter, or Multiphysics Coupling Filter subnodes.

The **Settings** window has the following section:

SETTINGS

The table displays a list of all filter subnodes under this **Selection Filter Sequence** node. For each row select **Take complement** and choose an **Operation with next** to use with the next filter: **Intersection** (the default) or **Union**. The choices in this table produce a complete filter sequence without precedence between operations. For example, if the table has the following three rows:

FILTERS	TAKE COMPLEMENT	OPERATION WITH NEXT
Filter 1	X	Intersection
Filter 2	√	Union
Filter 3	X	Intersection

The contents of this table represent the following logical expression: Filter 1 *and not* (Filter 2) *or* Filter 3.

Override Rule Filter

An **Override Rule Filter** node ( ) defines a single condition of override rules (specified through their names) and a list of applicable entities; see Override Rule. The condition represents a geometry selection given by the selection of the features that belong to the given override rules. The specified domain types define what kind of selection it should be — for example, exterior boundaries to the feature's selection.

To add an **Override Rule Filter**:

1. Under Definitions Library right-click the Selections node ( ) and choose **Selection Filter Sequence** from the context menu.
2. Right-click **Selection Filter Sequence** ( ) and choose **Override Rule Filter** from the context menu.

The **Settings** window has the following section:

SETTINGS

Fill the **Override rule names** table with the ones to use for this filter. Then add the **Allowed entity types** — **Active**, **Inactive**, **Exterior**, **Symmetry axis**, **Interior**, **Geometry**, **Perfectly matched layer**, **Infinite element domain**, or **Absorbing layer** — to the list. For more information on entity types, see Selection Terminology.

Selection Component Filter

A **Selection Component Filter** node ( ) filters the selection by using selection components. It is basically a reference to a Selection. This filter is versatile and can be used to, for example, find the selections that are adjacent to features of certain types. The output selection of this filter can be of an entity level that is higher than that of the physics feature that should use the selection. In this case the entity level of the selection is lowered by taking the adjacent entities of the selection.

To add a **Selection Component Filter**:

1. Under Definitions Library right-click the Selections node ( ) and choose **Selection Filter Sequence** from the context menu.
2. Right-click **Selection Filter Sequence** ( ) and choose **Selection Component Filter** from the context menu.

The **Settings** window has the following section:

SELECTION

Choose a **Selection**: **Operation on sibling-feature selections** (the default), **From external resource**, or **From definitions library**.

For **Operation on sibling-feature selections** also choose an **Operation type**: **Union**, **Intersection**, **Difference**, or **Complement** and enter information in the table.

From the **Restrict to** list, choose an option for limiting the types of entities where a selection can be active:

- **All entity types** (the default), to allow all types of entities.
- Allowed entity types, to control which types of entities to allow selections to be active for in the list below. By default, Exterior and Interior entities are allowed. Click the **Add** button (+) to add more entity types from the list in the **Add** dialog that opens; click the **Delete** button ( ) to remove the selected entity type from the

list of allowed entity types. See Selection Terminology for more information about the entity types.

- Specifying Selections
- Named Selections in the *COMSOL Multiphysics Reference Manual*

Multiphysics Coupling Filter

A selection filter sequence that uses **Multiphysics Coupling Filter** nodes ( ) can only be used by a multiphysics coupling feature. Otherwise, this filter works almost exactly like the **Selection Component Filter** but it also has a setting to specify the input selection to the filter.

To add a **Multiphysics Coupling Filter**:

1. Under Definitions Library, right-click the Selections node ( ) and choose **Selection Filter Sequence** from the context menu.
2. Right-click **Selection Filter Sequence** ( ) and choose **Multiphysics Coupling Filter** from the context menu.

The **Settings** window has the following section:

SETTINGS

Choose an **Input selection**: **Intersection of coupled physics selections** (the default) or **Union of coupled physics selections**:

- **Intersection of coupled physics selections** restricts the selection to the entities that are selected by all physics that are coupled to the coupling feature.
- **Union of coupled physics selections** restricts the selection to entities that are selected by any of the physics that are coupled to the coupling feature.

- Specifying Selections
- Named Selections in the *COMSOL Multiphysics Reference Manual*

Extra Dimension Selection

Use the **Extra Dimension Selection** node ( ) to add selections to an extra dimension for the connection to an ordinary space-dimension part of the model.

To add a **Extra Dimension Selection**, under Definitions Library right-click the Selections node ( ) and choose it from the context menu.

SELECTION

See Specifying Selections for information.

SOURCE EXTRA DIMENSION

Choose an option from the **Specify extra dimension** list: **By reference** (the default), **By tag suffix**, or **From parent**. For **By reference**, select an option from the **Links from** and **Link** lists. For **By tag suffix**, enter a **Tag suffix**.

SELECTION ON EXTRA-DIMENSIONAL GEOMETRY

Select a **Type**: **Predefined**, **User defined**, or **From definitions library**.

For **Predefined**, select an existing predefined selection from the **Selection** list.

For **User defined**, choose an **Entity dimension**: **Domain** or **Boundary**. From the **Entities** list, choose **Specified** or whether **All entities** are used. For **Specified** enter the **Entity indices** in the text field. The **Entity indices** field supports the following special characters:

- `n`, for the latest index of the extra-dimension geometry
- `-` (hyphen), for a range of indices. For example, `2-n` means `[2,3,...,n]`.

For **From definitions library**, select an existing selection from the **Definitions library**.

	Using Extra Dimensions in the *COMSOL Multiphysics Reference Manual*

Extra Dimensions

The **Extra Dimensions** branch ( ) under the Definitions Library is used to create extra dimensions for use in a physics interface.

Right-click **Extra Dimensions** to add 1D Interval, Multiple 1D Intervals, 2D Rectangle, 2D Circle, and 3D Sphere nodes.

- Extra Dimension Link, Integration Over Extra Dimension, Extra Dimension Selection
- Using Extra Dimensions in the *COMSOL Multiphysics Reference Manual*

1D Interval

Use the **1D Interval** node ( ) to add a 1D extra dimension as a 1D interval.

To add a **1D Interval**, under Definitions Library right-click the Extra Dimensions node and choose **1D Interval** from the context menu.

PARAMETERS

Specify parameters by filling in the columns **Name**, **Description**, **Default expression**, and **Read only**.

EXTRA DIMENSION SPECIFICATION

Enter a **Tag suffix**.

In the table you can edit the **First**, **Second**, and **Third Default coordinate names**, which are **xd1**, **xd2**, and **xd3**, respectively.

INTERVAL

Enter a value for the **Left endpoint**, **Right endpoint**, and the **Number of mesh points**. Select the **Points to attach** checkbox to enter one or several points in the extra dimension geometry that are identified with the base geometry in the associated text field. `1` is the first point; `n` is the last point.

Multiple 1D Intervals

Use the **Multiple 1D Intervals** node ( ) to add a 1D extra dimension as multiple 1D intervals.

To add a **Multiple 1D Intervals** under Definitions Library right-click the Extra Dimensions node and choose **Multiple 1D Intervals** from the context menu.

See 1D Interval for the **Parameters** and **Extra Dimension Specification** settings.

MULTIPLE INTERVALS

Enter values for the **Points** and **Mesh points**. Select the **Points to attach** checkbox to enter one or several points in the extra dimension geometry that are identified with the base geometry in the associated text field. `1` is the first point; `n` is the last point.

2D Rectangle

Use the **2D Rectangle** node ( ) to add 2D extra dimension as a rectangle.

To add a **2D Rectangle** under Definitions Library right-click the Extra Dimensions node and choose **2D Rectangle** from the context menu.

See 1D Interval for the **Parameters** and **Extra Dimension Specification** settings.

RECTANGLE

Under **Size**, enter values for the **Width** and **Height**.

Under **Position**, choose the **Base** position: **Center** (the default) or **Corner**. Enter values for **x** and **y**.

Under **Mapped mesh**, enter values for the **Mesh points in x direction** and **Mesh points in y direction**.

2D Circle

Use the **2D Circle** node ( ) to add 2D extra dimension as a circle.

To add a **2D Circle** under Definitions Library right-click the Extra Dimensions node and choose **2D Circle** from the context menu.

See 1D Interval for the **Parameters** and **Extra Dimension Specification** settings.

CIRCLE

Enter a radius for the circle in the **Radius** field.

Under **Position**, enter values for the circle's center coordinates in the **x** and **y** fields.

Under **Object type**, choose **Solid** or **Curve** from the **Type** list for a filled circle or a circle as a curve only.

Under **Element size parameters**, enter values for the following element-size parameters:

- The **Maximum element size**
- The **Minimum element size**
- The **Maximum element growth rate**
- The **Curvature factor**
- The **Resolution of narrow regions**

See the documentation in the *COMSOL Multiphysics Reference Manual* for the **Size** node in a meshing sequence for more information about these parameters.

3D Sphere

Use the **3D Sphere** node ( ) to add 3D extra dimension as a sphere.

To add a **3D Sphere** under Definitions Library, right-click the Extra Dimensions node and choose **3D Sphere** from the context menu.

See 1D Interval for the **Parameters** and **Extra Dimension Specification** settings.

SPHERE

Enter a radius for the circle in the **Radius** field.

Under **Position**, enter values for the sphere's center coordinates in the **x**, **y**, and **z** fields.

Under **Object type**, choose **Solid** or **Surface** from the **Type** list for a filled sphere or a sphere as a surface only.

Under **Element size parameters**, enter values for the following element-size parameters:

- The **Maximum element size**
- The **Minimum element size**
- The **Maximum element growth rate**
- The **Curvature factor**
- The **Resolution of narrow regions**

See the documentation in the *COMSOL Multiphysics Reference Manual* for the **Size** node in a meshing sequence for more information about these parameters.

Auxiliary Definitions

In this section:

- Material Property Group
- Material Property (Auxiliary Definitions)
- Physical Quantity
- Override Rule
- Plot Menu Definition
- Equation Display (Auxiliary Definitions)
- Synchronization Rule
- Identity Rule

Material Property Group

When adding a Material Property node as an input under a feature or property, you can choose a basic property type or, among other options, a property type defined locally in the current Physics Builder file. The latter choice refers to a **Material Property Group** node.

A **Material Property Group** ( ) contains a set of material properties, which can be selected from a list of basic material properties or be customized. When defining a material property group, physics interfaces can use its properties through a material property, and you can also add values to a material library database.

To add a **Material Property Group** node:

- In the **Home** toolbar, click **Material Property Group** ( ), or
- Right-click the **Auxiliary Definitions** node ( ) and select it from the context menu.

In addition to the settings here, it is also possible to add predefined functions to a built-in property group. The analytic, interpolation, and piecewise analytic function types are available. For interpolation functions, only interpolation tables are allowed. To add a function, right-click the **Material Property Group** node and select the function type to add from the **Functions** submenu. A new function node (**Analytic**, for example) then appears as a subnode under the **Material Property Group** node.

The **Settings** window has the following sections:

PARENT CATEGORIES FOR GROUPS

Each material property group can be categorized under one or several group categories. This simplifies access in the **Material** node in the Model Builder. To create a new parent for the current property group, click the **Create New Parent** button ( ) under the **Root** tree.

Click the **Set As Parent** button ( ) to choose an existing category as parent. For created categories, you can edit the name in the field under **Category**, enabled when the **Create New Parent** button is clicked.

The tree also contains built-in property groups ( ) and categories ( ), for example the **Solid Mechanics** property group. Available groups are based on your license.

You can use a built-in category as a parent, but the name cannot be changed.

MATERIAL PROPERTY GROUP

In the **Name** field define a string that identifies the property group. It must be unique among all property groups available to materials. COMSOL Multiphysics displays the text entered in the **Description** field for the property group in the **Material properties** section of the **Material** node in the Model Builder.

MODEL INPUTS

This section provides the possibility to include model inputs to a built-in property group in the Model Builder. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, from which you can choose a physical quantity to add as a model input. Use the other buttons under the table to arrange and edit the table of model inputs if required.

LOCAL PARAMETERS

This section provides the possibility to include local parameters to a built-in property group in the Model Builder. To add a local parameter, enter a name, a description, and a default expression for the parameter in the **Name**, **Default expression**, and **Description** columns, respectively.

Materials in the *COMSOL Multiphysics Reference Manual*

Material Property (Auxiliary Definitions)

The **Material Property** subnode (P_i) declares a new property for a node. It is similar to the Material Property node used in features or properties but with fewer options.

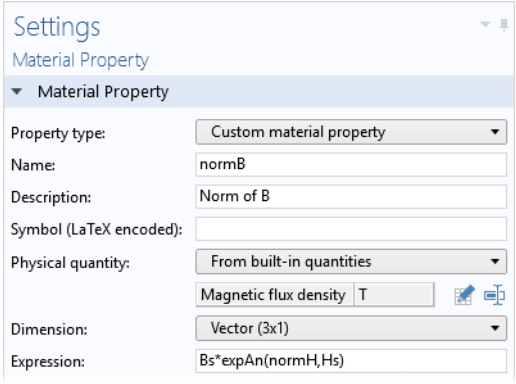
To add a **Material Property** node right-click **Material Property Group** and select it from the context menu.

The **Settings** window has the following section:

MATERIAL PROPERTY

Select a **Property type**: **Custom material property** (the default) or **Basic material property**. For **Basic material property**, select a material **Physical quantity**. For **Custom material property** see the Variable Declaration node for the settings.

The **Expression** field is empty by default. You can use it to add a nonempty default expression. In some situations, however, properties can get a default value. The example property in the figure below uses an analytical function to supply a more complex default expression. The properties `Bs` and `Hs` are empty by default and must be supplied by the user.



Physical Quantity

Add a **Physical Quantity** node ( ) to a Physics Builder file to define variable declarations and definitions of material properties. These are in addition to the predefined physical quantities available.

To add a **Physical Quantity** node:

- In the **Home** toolbar, click **Physical Quantity** ( ), or
- Right-click the **Auxiliary Definitions** node ( ) and select it from the context menu.

To use this customized physical quantity when defining a Variable Declaration, Dependent Variable Definition, Dependent Variable Declaration, Material Property (Auxiliary Definitions), or Material Property node (or any node with the Physical quantity list), select **Locally defined** from the **Physical quantity** list (the top item in the list), and then select the added physical quantity from the **Link** list.

The **Settings** window has the following sections:

PHYSICAL QUANTITY

Enter a **Name** for the physical quantity (`seebeck_coefficient`, for example). Enter a **Variable name** to be used to define a common model input variable. The variable name can be the same as the name.

Enter a **Description** for the physical quantity (`Seebeck coefficient`, for example).

Enter a symbol for the property in the **Symbol (LaTeX encoded)** field (`S`, for example). You can use LaTeX syntax for Greek letters, subscripts, superscripts, and mathematical symbols if desired. See Mathematical Symbols and Special Characters in the *COMSOL Multiphysics Reference Manual*.

Define the dimension of the physical quantity by typing the corresponding **SI unit** (`V/K`, for example).

From the **Category** list, choose the category. The default category is **General**.

The **Dimension** list determines the dimension of the physical quantity: Use the default value, **Scalar**, for a scalar quantity or select **Vector (3x1)** for a vector-valued quantity, **Matrix (3x3)** for a tensor quantity, or **Custom** to type a dimension in the *N*x*M* format.

In the **Default value** field (or fields, depending on the selection in the **Dimension** list above), enter a default value for this quantity.

PREFERENCES

To specify that the physical quantity also is a material property, select the **Is material property** checkbox.

To specify that the physical quantity can be used as a common model input, select the **Is model input property** checkbox. This setting requires that the variable name is not empty and that it has not been used by the other physical quantities.

Override Rule

Add an **Override Rule** node ( ), to define new override rules in addition to the exclusive and contributing types.

When creating a model in the Model Builder, you add several feature instances as children to a physics interface. If these features support selections, they obey certain rules about how a feature of one type overrides or gets overridden by another feature. This is not to be confused with features being applicable to a certain entity, for example some features only apply on interior boundaries.

The overriding of selections is based on grouping features into override types, and the rules apply between override types. The four standard built-in override types are. **Exclusive**, **Contributing**, **Override features of same type**, and **Never overridden**. In addition to the built-in override types you can create custom override types. The names and behavior of override types are defined in an **Override Rule** node.

To add an **Override Rule** node:

- In the **Home** toolbar, click **Override Rule** ( ), or
- Right-click the **Auxiliary Definitions** node ( ) and select it from the context menu.

You can access all added rules from any feature in the same file, or in any other file that has the former file added as an Import node under the External Resources branch.

OVERRIDE RULE

The table that displays all override types as a matrix with the types as rows, and what types they override as columns. A selected cell means that the row type overrides the column type. The predefined rules are **exclusive**, which overrides other exclusive or contributing nodes, and **contributing**, which does not override other exclusive or contributing nodes. You can add and define new override types by clicking the

Add ( ) button. The override rule table defines the override behavior of the included override types. There are two things to keep in mind when editing these tables:

- Firstly, the defined override rules need to obey the following rule: If type A overrides type B and type B overrides type C, then type A must also override type C.
- Secondly, an override table does only define the override behavior of the types included in the table. A physics interface can use override types defined in different tables for its features. In this situation the override behavior between some features might not be well defined. To remedy this, you can provide the missing information in an override table that is available in the Physics Interface node's **Override Rule** section. This table contains all the override types used by the features under the physics interface.

The **Settings** window also allows for setting a name for the override rule. This is done by changing the **Identifier** setting from **Default** to **Customized** and then typing a name in the **Name** field that is made visible. The reason for setting the name is that the override rule may then be used in an Override Rule Filter node.

	Physics Exclusive and Contributing Node Types in the *COMSOL Multiphysics Reference Manual*

Plot Menu Definition

A **Plot Menu Definition** node ( ) defines the plot menus that you can group related variables into (see Variable Declaration).

A plot menu shows up as a submenu in the **Replace Expression** ( ) menu of the result nodes in the Model Builder. Specify another menu name as parent if you need several levels of submenus; otherwise leave the parent field blank.

	A blank parent field means that the menu is a submenu to the menu of the physics interface.

The plot menu that a variable belongs to is specified under the variable declaration node below the **Show in plot menu** option. Using plot menu definitions you can create a structure where related variables are grouped into separate menus.

To add a **Plot Menu Definition** node:

- In the **Home** toolbar, click **Plot Menu Definition** ( ), or
- Right-click the **Auxiliary Definitions** node ( ) and select it from the context menu.

The **Settings** window has the following section:

MENUS

In the table under each column, enter the **Name**, **Description**, and **Parent** to define a new menu. Select the checkbox in the **Show Add all** column to add the **All expressions in this group** option to that group of plot variables.

Equation Display (Auxiliary Definitions)

Add an **Equation Display** node ( ) to define a display of an equation that you can type using LaTeX syntax.

To add an **Equation Display** node, in the **Home** toolbar, click **Equation Display** ( ). Or right-click the **Auxiliary Definitions** node and select it from the context menu.

DECLARATION

Enter a **Name**.

EQUATION

Add the LaTeX syntax to the **Enter equation in LaTeX syntax** field.

You can also add a different kind of Equation Display node ( ) to many other features, for example, components, physics interfaces, multiphysics interfaces, features, or properties. This is different from this node and it is selected from the context menu for these specific features.

Synchronization Rule

Add a **Synchronization Rule** node ( ) to let a material property group define material properties in another material property group using combinations of the material properties in this group you can add a synchronization rule.

To add a **Synchronization Rule** node, right-click a **Material Property Group** node ( ) and select **Synchronization Rule** from the context menu. To add synchronization rules to the *Basic* material property group, add a synchronization rule directly under the

Auxiliary Definitions node ( ). Here you select from the physical quantities when specifying the needed material properties.

You can access all added rules from any feature in the same file, or in any other file that has the former file added as an Import node under the External Resources branch.

SYNCHRONIZATION RULE

Select **Built in predefined material property**, **Locally defined material property**, or **Imported material property from external resources** from the **Property type** list.

- When the **Property type** list is set to **Built in predefined material property**, then, from the **Material property group** list, select the property group that you want to synchronize with.
- When the **Property type** list is set to **Locally defined material property**, then, from the **Material model** list, select the material model that you want to synchronize with.
- When the **Property type** list is set to **Imported material property from external resources**, select a file and link from the **External Resources** branch from the **Imported file** and **Link** lists.

Then add the material properties needed to define the rule to the **Needed material property** list by clicking the **Add** ( ) button and choosing material properties from the **Add** dialog.

For each material property in the synchronized material property group, you need to add a **Synchronized Property** subnode (see below). There you select the property to define and enter the rule.

Synchronized Property

For each material property in the synchronized material property group, you need to add a **Synchronized Property** node ( ) by right-clicking the **Synchronization Rule** node and selecting **Synchronized Property** from the context menu.

DECLARATION

The **Property type** list and associated settings are always disabled and are displayed to provide information about those setting used in the parent **Synchronization Rule** node.

From the **Material property** list, select the property to be synchronized. Then, in the **Expression** field, enter an expression to define how the synchronized properties are related. For that expression, use the local namespace; that is, use the names specified in the **Material Property** nodes.

OPTIONS

From the **Matrix symmetry for square matrix** list, choose **Full** (the default), **Isotropic**, **Diagonal**, or **Symmetric** depending on the symmetry of a property that is represented as a square matrix.

Identity Rule

Add a **Identity Rule** node ( ) to define new identity rules. If a material property in one material property group is identical to a material property in another material property group, they can be used instead of each other if there are identity rules in the material property groups.

To add an identity rule, add an **Identity Rule** node under the material property group by right-clicking the **Material Property Group** node ( ) and selecting **Identity Rule** from the context menu. Here you select which of the material properties in the group that should be part of the identity rule; then add an **Identity Property** subnode (see below) for each material property it is equal to. Adding an identity rule adds corresponding identity rules in all material property groups that are part of the rule. You can also add an **Identity Rule** node by right-clicking the **Auxiliary Definitions** node ( ) to add identity rules to the *Basic* material property group.

IDENTITY RULE

Select a material property from the **Material property** list.

Identity Property

Add an **Identity Property** subnode ( ) under an **Identity Rule** node for each material property it is equal to. To do so, right-click the **Identity Rule** node and select **Identity Property**.

DECLARATION

Select **Built in predefined material property**, **Locally defined material property**, or **Imported material property from external resources** from the **Property type** list.

- When the **Property type** list is set to **Built in predefined material property**, then, from the **Material property group** list, select the property group with the property that you want to create an identity rule for.

- When the **Property type** list is set to **Locally defined material property**, then, from the **Material model** list, select the material model with the property that you want to create an identity rule for.
- When the **Property type** list is set to **Imported material property from external resources**, select a file and link from the **External Resources** branch from the **Imported file** and **Link** lists that contains the property that you want to create an identity rule for.

Then add the material property for the identity rule from the **Material property** list.

Mesh Defaults

Use a **Mesh Defaults** node to customize the mesh generation if your physics controls the mesh. One **Mesh Defaults** node is available for each physics or multiphysics interface.

To add a **Mesh Defaults** node, first add a Physics Interface or Multiphysics Interface then,

- On the **Physics Interface** toolbar, click the **Mesh Defaults** button , or
- Right-click the **Physics Interface** or **Multiphysics Interface** node and select it from the context menu.

Right-click the **Mesh Defaults** node to add a Usage Condition subnode if you need to vary the mesh generation depending on space dimension or user input value. Also right-click to add a Mesh Size subnode or a Boundary Layers subnode.

Meshing in the *COMSOL Multiphysics Reference Manual*.

Mesh Size

In the **Mesh Size** node ( ) specify how the predefined mesh sizes generate meshes. If the physics interface is the controlling interface for the mesh, these settings are used when automatically generating the mesh each time it is solved. Right-click the Mesh Defaults node to add a **Mesh Size** node.

MESH SIZE SUGGESTION

Fill in the table with suitable values for the **Size** settings:

- **Maximum element size**
- **Minimum element size**
- **Curvature factor**
- **Maximum element growth rate**
- **Resolution of narrow regions**

Also define these values for each of the predefined mesh sizes: **Extremely fine**, **Extra fine**, **Finer**, **Fine**, **Normal**, **Coarse**, **Coarser**, **Extra coarse**, and **Extremely coarse**.

Boundary Layers

The **Boundary Layers** node ( ) can only be used for features that represents a boundary condition, using the boundaries of that feature. The domain selection can be specified in the **Domain Selection** section in the same way as other selection sections in the Physics Builder.

BOUNDARY LAYERS

This section contains settings for setting up the boundary layers in the same way as the **Boundary Layers** feature under the meshing sequence. The fields in this section for **Number of boundary layers**, **Boundary stretching factor**, and **Thickness adjustment** or **Thickness** — depending of if **Thickness of first layer** is set to **Automatic** or **Manual** — accept the same builder parser syntax as the expression fields in the **Usage Condition** nodes. The most important syntax limitation for that context is that no variables are allowed in the expression, and some fields must be evaluated to an integer or number. If the value comes from a user input, that input must then do proper syntax check.

Study and Solver Defaults

To define **Study/Solver Defaults** ( ) for a physics or multiphysics interface, create a solver sequence, or part of a solver sequence. The sequence is then used as a solver suggestion when solving a model that includes the interface.

There are many options available when creating a solver default, but the most important rule is to try to specify as little as possible.

One **Study/Solver Defaults** node is available for each physics or multiphysics interface.

To add a **Study/Solver Defaults** node, first add a Physics Interface or Multiphysics Interface, and then use one of these options:

- On the **Physics Interface** toolbar, click the **Study/Solver Defaults** button , or
- Right-click the **Physics Interface** or **Multiphysics Interface** node and select it from the context menu.

Right-click the **Study/Solver Defaults** node to add a variety of subnodes to further define it. Add a Usage Condition node, for example, to specify one default for stationary problems and another for time-dependent problems.

For most of the nodes in the actual solver sequences this works in exactly the same way as in the Model Builder. This section only describes the nodes that differ significantly or do not have a counterpart in the Model Builder.

In this section:

- Field
- Absolute Tolerance
- Segregated Step
- Outer Job Parameters
- Eigenvalue Transform
- Study Sequence
- Stationary
- Time Dependent

Introduction to Solvers and Studies in the *COMSOL Multiphysics Reference Manual*.

Field

Use the **Field** node ( ) to set the default scaling for a dependent variable. Right-click the **Study/Solver Defaults** node to add this node.

The **Settings** window has the following sections:

GENERAL

In the **Dependent variable reference** and **Physical quantity** lists, you specify what dependent variable to change the scaling for. See Dependent Variable Declaration for the settings information.

SCALING

Set the scaling method in the **Method** list.

See Dependent Variables in the *COMSOL Multiphysics Reference Manual* for more about scaling.

Absolute Tolerance

Use the **Absolute Tolerance** node ( ) if you want to set the default absolute tolerance for a dependent variable.

To add an **Absolute Tolerance** node:

1. Right-click **Study/Solver Defaults** ( ) and select **Time-Dependent Solver** ( ) from the **Solvers** menu, then
2. Right-click **Time-Dependent Solver** to add **Absolute Tolerance** as a subnode.

The **Settings** window has the following sections:

GENERAL

In the **Dependent variable reference** and **Physical quantity** lists, you specify what dependent variable to change the absolute tolerance for. See Dependent Variable Declaration for more information about the dependent variable reference. Use the option **Variable name pattern (regular expression)** in the **Dependent variable reference** list to specify a variable defined as a degree of freedom.

ABSOLUTE TOLERANCE

Set the absolute tolerance method in the **Method** list.

See Time-Dependent Solver in the *COMSOL Multiphysics Reference Manual* for more information about setting absolute tolerances.

Segregated Step

The **Segregated Step** node ( ) specifies the corresponding node in the solver sequence.

To add a **Segregated Step** node:

1. Right-click **Study/Solver Defaults** ( ) and select **Segregated** ( ), then
2. Right-click **Segregated** to add **Segregated Step** as a subnode.

GENERAL

Specify the variables to be included in the segregated step by adding them to the **Variables** table. For a dependent variable add it to the table by typing the name of the physical quantity into the **Dependent variable reference** column or by typing the default name of the dependent variable into the **Shape variable name** column. Note that the name of the physical quantity needs to be spelled out in lowercase letters (for example, `electricpotential`). To include an ordinary variable that is defined as a shape function simply type its variable name in the **Shape variable name** column.

For information about the **Method and Termination** settings, see Segregated Step in the *COMSOL Multiphysics Reference Manual*

Outer Job Parameters

If the interface uses predefined parameters that must be in an outer sweep, add these to the **Outer Job Parameters** node ( ). To add an **Outer Job Parameters** node, right-click **Study/Solver Defaults** ( ) and select it from the context menu.

OUTER JOB PARAMETERS

Enter the parameters in the **Parameter names** column.

Eigenvalue Transform

Use the **Eigenvalue Transform** node ( ) to define a transform between the internal eigenvalue computed by the eigenvalue solver and a more user-friendly quantity. To add an **Eigenvalue Transform** node, right-click **Study/Solver Defaults** ( ) and select it from the context menu.

The **Settings** window has the following sections:

DECLARATION

In the **Study types** list, choose among study types that use the eigenvalue solver. Enter a unique name and description for the transform in the **Name** and **Description** text fields.

RELATION BETWEEN EIGENVALUES

Enter the name of the variable name in the **Eigenvalue name** text field. This name is used in the transform definitions. In the **Transform to lambda** text field, enter the expression that computes the internal eigenvalue, `lambda`, when the transform's eigenvalue is known. Enter the inverse transform in the **Transform from lambda** text field.

Study Sequence

A study sequence is a sequence of study steps that a user can choose in the last step of the Model Wizard. Use the **Study Sequence** node ( ) to define such predefined study sequences. To add a **Study Sequence** node, right-click **Study/Solver Defaults** ( ) and select it from the context menu.

Right-click **Study Sequence** to add the study steps that are part of the sequence. For example, Stationary or Time Dependent. For other study steps, see the *COMSOL Multiphysics Reference Manual*.

It is only possible to add the study steps that the physics interface supports. If you add a sequence under a physics interface component, all available study steps can be added to the sequence, but it is then not allowed to link to this component from an interface that does not support the study steps in the list.

The Identifiers section is described for the Physics Interface node.

Study Steps for Coupling Features

Under the **Study/Solver Defaults** node for coupling features, you can add **Study Sequence** nodes with several study step nodes. For each such study step (**Stationary**, for example), you can specify, in the **Coupling type** table, if a physics interface corresponding to a particular coupling type will be solved for or not in the generated study. You can also disable the current coupling feature from the study by clearing it in the **Multiphysics couplings** table. These tables are found in the **Physics Selection** section.

RESTRICTIONS

Select the **Restrict to space dimensions** checkbox and use the buttons under the table to add or edit the list.

Select the **User input** checkbox to define the **Condition on**.

- For **User input in property** (the default) enter a **Property** and a **User input**. Choose the **User input condition**: **User input is active** (the default) or **User input has any of certain values**.
- For **Expression**, enter a **Condition** as a conditional expression that evaluates to 0 (false) or 1 (true) in the field below.
- For **Feature is active**, enter a **Feature type**.

Select the **Condition is not fulfilled for undefined references** checkbox to if you want the condition to be treated as not fulfilled instead of throwing an error if the property is undefined.

If the **Study Sequence** node is added under a coupling feature, the only option for the **Condition on** list is **Expression**. The restriction is then defined by the **Condition** field and is a conditional expression that must evaluate to 0 or 1 (false or true).

Stationary

The **Stationary** ( ) study is used when field variables do not change over time, such as in stationary problems.

To add a **Stationary** node:

1 Right-click **Study/Solver Defaults** ( ) and select Study Sequence ( ), then

2 Right-click **Study Sequence** to add **Stationary** as a subnode.

	For settings details, see Stationary in the *COMSOL Multiphysics Reference Manual*. For the **Physics Selection** section, when applicable, see Study Steps for Coupling Features.

Time Dependent

The **Time Dependent** ( ) study is used when field variables change over time.

To add a **Time Dependent** node:

1 Right-click **Study/Solver Defaults** ( ) and select Study Sequence ( ), then

2 Right-click **Study Sequence** to add **Time Dependent** as a subnode.

	For settings details, see Time Dependent in the *COMSOL Multiphysics Reference Manual*. For the **Physics Selection** section, when applicable, see Study Steps for Coupling Features.

Result Defaults

The Results Defaults Node

Add a **Result Defaults** node ( ) to a physics interface or multiphysics interface to create customized plot groups that are added to a model you solve for it in the Model Builder. One **Result Defaults** node is available for each physics or multiphysics interface.

To add a **Result Defaults** node, first add a Physics Interface or Multiphysics Interface then,

- On the **Physics Interface** toolbar, click the **Result Defaults** button , or
- Right-click the **Physics Interface** or **Multiphysics Interface** node and select it from the context menu.

Right-click the **Result Defaults** node to add plot groups, plots, derived values, and datasets. Add the Usage Condition node to vary the result defaults. Also right-click to add the Plot Defaults subnode and further define default expression of variables to use for newly created plots of certain types.

	It is common to specify one default for 3D and another for 2D, because you usually use different plot groups and different plot types.

	Most of the nodes you can add to **Result Defaults** work in the same way as in the Model Builder. This section only describes the nodes that differ significantly or do not have a counterpart in the Model Builder.

	In the **Settings** window form most of the nodes you can add to **Result Defaults**, there is **Settings** section where you can define a description for the node. By default, it uses the default name of the node. Select the **Description** checkbox to enter and use another node description.

The **Settings** window has one section:

SETTINGS

Select the **Plot in spatial frame** checkbox if you want the result plots to be plotted in the spatial frame instead of the default material frame. Select it if plotting for the parent physics interface should be done in the spatial frame by default.

If the **Results policy** checkbox is selected, you can add a results policy suitable for the physics interface. When you click the **Add** button (+) underneath the list, you can choose and add a results policy to the list from the list of available result policies. You can add more than one results policy to the list. These policies determine which results features that are available, excluding features that are not applicable.

Most of the nodes in a result defaults setting work in exactly the same way as in the Model Builder. This chapter only describes the nodes that differ significantly or do not have a counterpart in the Model Builder. This section includes all the information about the Plot Defaults.

Results Analysis and Plots in the *COMSOL Multiphysics Reference Manual*

Plot Defaults

All child nodes to the **Plot Defaults** branch ( ) define the default expression of variables to use for newly created plots of certain types.

To add a **Plot Defaults** subnode, first add a Result Defaults node then right-click the **Plot Defaults** node to select the following supported types of plots from the context menu: **Default Scalar Plot**, **Default Vector Plot**, **Default Deformation Plot**, **Default Multi Scalar Plot**, or **Default Plot Parameters**.

Entering Names and Expressions

DEFAULT SCALAR PLOT

For the **Default Scalar Plot** ( ), enter the expression in the **Expression** field. The expression is used in all new plots created by the user that requests a scalar value — for example, a surface plot. Enter the **Description** for the expression. Click the **Change Color Table** button ( ) to open the **Color Table** window and choose another default color table than **Rainbow**.

DEFAULT VECTOR PLOT

For the **Default Vector Plot** ( ), enter a valid vector variable name in the **Variable name** field. The components of the vector are used in all new plots created by the user that requires a vector quantity — for example, an arrow plot.

DEFAULT DEFORMATION PLOT

For the **Default Deformation Plot** ( ), enter a valid vector variable name in the **Variable name** field. The components of the vector are used in all new deformation plots created by the user. Deformation plots show a deformed shape, typically using a displacement vector as the vector variable.

DEFAULT MULTISCALAR PLOT

For the **Default Multiscalar Plot** ( ), fill the table with expressions and descriptions in the **Expression** column and **Description** column. It is used in all new plots created by the user that requests several scalar values — for example, a global plot.

DEFAULT PLOT PARAMETERS

For the **Default Plot Parameters** ( ), fill the columns **Name**, **Value**, **Unit**, and **Description** in table for the parameters that you need in your new plots. Any result node in the Model Builder that has the **Parameters** table is filled with the values entered here.

Results Analysis and Plots in the *COMSOL Multiphysics Reference Manual*

3D, 2D, 1D Plot Group and Other Results Nodes

The Results nodes that you can add under **Results Defaults** have settings that are similar to those nodes under **Results** in the **Model Builder**. See the *COMSOL Multiphysics Reference Manual* for details.

In addition, there are settings specific to the Physics Builder in the **Settings** section.

SETTINGS

If desired, add an **Identifier** (default: `none`).

If you want to use a custom description, select the checkbox next to **Description** and enter another description in the associated text field.

Select the **Allow to merge with other node using the same identifier** checkbox if you want the software to make that simplification.

From the **Result default** list, choose **Create when solving** to create the result plots directly when solving the model. Otherwise, choose **Include in Result Templates window** to add the plot, evaluation group, or derived value to the **Result Templates** window from which users can add the plot if desired.

Migration

In this section:

- About Backward Compatibility
- Version
- Physics Interface (Migration)
- Feature (Migration)
- Property (Migration)
- Change Type
- Rename Inputs
- Migration Links

About Backward Compatibility

Migration or backward compatibility has to be considered in situations when you make changes to your physics interface design but still want users of this interface to use COMSOL Multiphysics model files created in the old version of the interface. If the migration is done properly, the old model file is corrected when opened, and the user can continue working with it without any problems. Otherwise, the user can get a series of error messages, complaining about invalid names and values, for example.

Another situation occurs if users have saved their models as model files for Java®. The change you made in the interface can then break that model file for Java, so the user cannot run it. It is possible to define migration for this as well, so generated files can run although they contain Java code in an old syntax. This procedure is referred to as compatibility for the Model Object API. Generally, API migration is more complex to handle, and there are situations when you cannot avoid breaking old model files for Java.

There are settings that you can change without any need for migration. There are also settings that you cannot handle with migration at all — for example, if you change the

list of supported space dimensions. The table below summarizes some common changes and whether you should consider migration for the change.

CHANGE OPERATION	OPEN MODEL MIGRATION	API MIGRATION
Change type	Yes	Yes
Rename input	Yes	Yes
Remove feature	No	Not possible
Remove input	No	Not possible
Remove input group	No	No
Change description	No	No
Change expression	No	No
Change icon	No	No
Change symbol	No	No
Remove supported space dimension	Not possible	Not possible
Add supported space dimension	No	No
Remove supported study types	Not possible	Not possible
Add supported study types	No	No

For the most common operations that do require migration, you automatically get the proper migration operation included under the last version. This only works if there is a version when you did the change. There can be occasions when you do not want to register a migration operation for every change you do. To turn off the automatic migration, click the **Migration** node and then clear the **Add migration operations automatically** checkbox in the **Migration settings** section.

The nodes for the migration operations appear in a **Version** under **Building Blocks** and under the following container nodes: **Components**, **Properties**, and **Features**.

Version

Right-click the **Migration** node ( ) to add a **Version** branch ( ), which contains migration operations from an older version to a newer version. The old version is the current version at the time when the version node was created. It then handles all migration operations to the current version until you create a new version node. This means that the last node in the list of versions performs the migration to the current version. All other nodes perform the migration from an older version to the next version node.

Physics Interface (Migration)

A **Physics Interface** node ( ) contains all migration operations for the interface's settings, and for the features that you use in the interface. If an interface uses feature links to a feature under the **Building Blocks** branch, there must be a feature link node under the physics interface. You handle the migration of the linked feature in a feature node under the **Version** > **Building Blocks** branch. You handle property links in a similar manner.

Feature (Migration)

A **Feature** node contains all migration operations for the feature's settings and for the subfeatures that you use for the feature. If a feature uses feature links to a feature under the **Building Blocks** branch ( ), there must be a feature link node under the feature. You handle the migration of the linked feature in a feature node under the **Version** > **Building Blocks** branch.

Property (Migration)

A **Property** node ( ) contains all migration operations for the property's settings.

Change Type

Use the **Change Type** node ( ) to change the type of a physics interface or a feature. Changing the type makes all files saved in an old version unusable unless you handle the migration properly. The **Settings** window has the following sections:

CHANGE TYPE

In the **Old type** label you see the old type, and you can adjust the new type in the **New type** field. The automatic logging of changes should prepare new **Change Type** nodes with the correct new type.

COMPATIBILITY

This section contains two checkboxes. One for activating migration or backward compatibility when opening COMSOL Multiphysics files, and the other for activating compatibility for the model object API. The default is to use both types of compatibility, but you can clear any of the checkboxes to deactivate the particular compatibility.

Rename Inputs

The following nodes are used to rename the associated node:

- **User Input**
- **Material Parameter**
- **Feature Input**
- **Material List**

You can rename a user input, which makes a file saved in an old version unaware of that the old user input value is the value of the new input. Nothing actually breaks, but the input gets its default value, so you should handle migration. The situation can be worse for API migration because a model file for Java® cannot run if you try to access the old input.

The **Settings** window has the following sections:

CHANGE NAME

In the **Old name** label you see the old name, and you can adjust the new name in the **New name** field. The automatic logging of changes should prepare new **Rename User Input** nodes with the correct new type.

COMPATIBILITY

Identical to the Compatibility section of the Change Type node.

Migration Links

The following nodes are described:

- Feature link
- Property link
- Contained interface
- Contained feature

The migration link nodes contain a link to the actual node under the **Building Blocks** branch that handles the actual migration. You specify the link in the **Link** list.

Comments

In this section:

- Introduction to Comments
- Comments

Introduction to Comments

Depending on the use of the created physics interfaces, the need for internal documentation (comments about implementation and for simplifying extending and maintaining the implementation) and external documentation (user documentation and context help) varies. The Physics Builder includes **Comments** nodes, where you can add comments about each feature for internal use. Those comments can provide information about the implementation, its benefits and limitations, any remaining issues, or ideas for future extensions. You can add a **Comments** node to each individual node in a physics interface, including the components that you use to create a physics interface feature (such as **User Input** and **Variable Declaration** nodes). By default, the preferences are set up so that a **Comments** nodes labeled **Developer Comment** appear under the nodes in the interface that needs comments.

Comments

The **Comments** node ( ) contains developer comments about the implemented feature or other builder component. When added by default as a subnode to a node that you add in the **Physics Builder**, its called **Developer Comments**. These comments can include known capabilities and limitations, ideas for further development, and implementation detail that can be useful for maintaining and extending the functionality. You can add Comment nodes to other nodes in the Physics Builder tree when applicable. Right-click the node and choose **Documentation** > **Comments**. For nodes with comments (predefined **Developer Comments** and user-defined **Comments**), you can add additional **Comments** nodes as desired. For all **Comments** nodes with nonempty comments, the comments appear under **Comments** sections in the **Settings** window for the parent node, if you have selected the **Display Comments in Settings** checkbox under **Comments** in the **Show More Options** dialog.

In the **Text** section you add this information. You can use the character formatting tools above and below the text field to format parts of the text. The reference that is

included by default, `<ref entity="doc.entity">`, is a general reference to the entity that the comment is about.

By default, **Developer Comments** nodes are added as subnodes to some physics builder nodes that you add, and the **Comments** nodes can be added where applicable. If you do not want to show any **Comments** nodes, clear the **Show Comments Nodes** checkbox under **Comments** in the **Show More Options** dialog.

Elements

You can create low-level *elements* that are not supported by any other standard node. A variable definition is actually an element, but it is much easier to use the Variable Definition node than creating the low-level element from scratch. Using these elements requires in-depth knowledge about the element syntax and is considered advanced usage. There is also limited documentation on the low-level element syntax.

In this section:

- Element
- GeomDim
- Src
- Array
- Record
- String
- Elinv
- Elpric
- Event
- DG Wave Element, General Form
- Degree of Freedom Re-Initialization
- Shape Interpolation Element

Element

An **Element** node creates a new element of the type entered in the **Element type** field. This node is a special type of Record node that represents the top level of an element.

In addition to the type entered in the **Element type** field, selecting the **Auxiliary element** checkbox enables the use of a special family of elements called *auxiliary elements*. These are used to define solver events, which the **Event** node also creates.

To add this node, go to **Building Blocks**. Right-click **Components** to add a **Component** node. Then select **Element** from the **Elements** menu.

GeomDim

The **GeomDim** node ( ) is a selection specification of the `geomdim` type. See Specifying Selections for more information.

To add this node, go to **Building Blocks**. Right-click **Components** to add both a **Component** and **Element** node. Then select **GeomDim**.

Src

An **SRC** node ( ) is a selection specification of the `src` type. See Specifying Selections for more information.

To add a **SRC** node:

1. Right-click **Components** ( ) to add **Component** ( ) as a subnode.
2. Right-click **Component** and select **Element** from the **Elements** menu.
3. Right-click **Element** and select **SRC**.

Array

The **Array** node (+) is a container for other nodes of the types Array, String, and Record. If this node is a child to a Record node, you specify the name of this record in the **Name** field.

To add an **Array** node:

1. Right-click **Components** ( ) to add **Component** ( ) as a subnode.
2. Right-click **Component** and select **Element** from the **Elements** menu.
3. Right-click **Element** and select **Array**.

Or add it as a child node to an **Array**, **Record**, or **String** node.

Record

The **Record** node ( ) is a container for other named nodes of the types Array, String, and Record. All children to this node have to specify a unique record name to identify the record. If this node is a child to a Record node, you specify the name of this record in the **Name** field.

To add a **Record** node:

1. Right-click **Components** ( ) to add **Component** ( ) as a subnode.
2. Right-click **Component** and select **Element** from the **Elements** menu.
3. Right-click **Element** and select **Record**.

Or add it as a child node to an **Array**, **Record**, or **String** node.

String

A **String** node ( ) is used for string data for the element. The **Settings** window contains one or two sections, depending on if it is a child to a record node or not.

To add a **String** node:

1. Right-click **Components** ( ) to add **Component** ( ) as a subnode.
2. Right-click **Component** and select **Element** from the **Elements** menu.
3. Right-click **Element** and select **String**.

Or add it as a child node to an **Array**, **Record**, or **String** node.

STRING VALUE

In the **Value type** list, you choose the type of string data that you enter in the **Value** field. The option **Custom string** means that the data can be an arbitrary string. Use **Variable name** to interpret the value as a variable name according to the rules outlined in Entering Names. Choose **Expression** to interpret the value as an expression.

RECORD NAME

If this node is a child to a Record node, you specify the name of this record in the **Name** field.

Elinv

The **Elinv** node ( ) is a special element for inverting square matrices using numerical algorithms, which is more efficient than an analytical inversion for large matrices (size > 3). The declaration is similar to the Variable Declaration node, and this node also generates a new matrix variable for the inverse. You enter the expression to be inverted in the **Expression** field under the **Input Matrix Definition** section.

To add this node, go to **Building Blocks**:

1. Right-click **Components** ( ) to add **Component** ( ) as a subnode.
2. Right-click **Component** and select **Elinv** from the **Elements** menu.

Elpric

The **Elpric** node ( ) is a special element for computing the eigenvectors and eigenvalues of square 3-by-3 symmetric matrices. The declaration is similar to the Variable Declaration node, and this node also generates three new vector variables plus

three scalar eigenvalues. You enter the expression of the input matrix in the **Expression** field under the **Input Matrix Definition** section. The Elpric element also works with unsymmetric matrices, in which case it takes the upper-triangular part of the matrix and mirrors it to the lower-triangular part to get a symmetric matrix.

The **Elpric** node declares six variables: three scalar eigenvalues and three eigenvectors. The eigenvalues get the names using the template `<name><i>[_<suffix>]` where `i` is the eigenvalue number and can be 1, 2, or 3. Similarly, the eigenvector has the same name but with a `vec.` prefix in front of the name. As an example, let the name be `eig` and the suffix be empty. This gives the following variables: `eig1`, `eig2`, `eig3`, `vec.eig1`, `vec.eig2`, and `vec.eig3`. The scalar components of the first eigenvector become: `eig2x`, `eig2y`, and `eig2z`.

The `vec.` prefix is not used for the components. It is only used to access the entire vector.

To add this node, go to **Building Blocks**:

1 Right-click **Components** ( ) to add **Component** ( ) as a subnode.

2 Right-click **Component** and select **Elpric** from the **Elements** menu.

Event

The **Event** node ( ) defines a solver event that can trigger the solver to stop, reinitialize some dependent variables, and then continue. For more information about solver events see The Events Interface in the *COMSOL Multiphysics Reference Manual*. The reinitialization step can either be defined by adding a **Degree of Freedom Initialization** node to the **Event** node, or adding a **Degree of Freedom Re-Initialization** node somewhere else.

To add this node, go to **Building Blocks**. Right-click **Components** to add a **Component** node. Then select **Event** from the **Elements** menu.

DECLARATION

Enter a unique tag in the **Event tag** field to identify the event to **Degree of Freedom Re-Initialization** nodes. In the **Event type** list, choose the **Explicit** or **Implicit** event type. For explicit events, specify a **Start time** and optionally a **Period** for cyclic events. The implicit event requires a **Condition** that triggers the event when the value of the condition goes from 0 to 1. The condition must contain a degree of freedom with the

Solver field type set to **Quadrature** in the **Advanced** section of either a **Variable Definition** node or a **Dependent Variable Definition** node. Note that this option is currently only supported for global states. Set the **Solver field type** to **Discrete** for global states that are discontinuous in time. Such states are typically used as logical help variables in if-statements to turn on and off equations.

You can choose **Consistent initialization (1)**, **From expression**, or **None (0)** from the **Initialization method** list.

DG Wave Element, General Form

Using this element to create an element optimized for solving wave equation using the *discontinuous Galerkin method*. The section settings for the **DG Wave Element, General Form** node ($\nabla\cdot\Gamma$) are similar to the ones for the General Form Equation node, with the following exceptions:

COEFFICIENTS

Use the **Type** list to select the type of the equation: **Normal** (the default) and **Interior boundary source**. The latter option can only be used in boundary conditions. Also note that boundary conditions do not support the Γ and d_a coefficients. Those settings are disabled for the **Interior boundary source** type; otherwise they are simply ignored when the equation is used on a boundary.

For this element, the conservative flux Γ, the source term f, and the damping or mass coefficient d_a are applicable.

DEPENDENT VARIABLE

The **Variable names** field supports a comma-separated list of dependent variable names. It is important that you enter multiple dependent variables in the same order for all element nodes. Multiple dependent variables are necessary to allow cross-coupling in the d_a and Γ coefficients. All dependent variables must use the nodal discontinuous Lagrange shape function. For multiple dependent variables, the value of N in the **Coefficients** section is the sum of all lengths of the dependent variables.

ADVANCED

From the **Method** list, choose **Lax–Friedrichs** (the default) or **General** for the method to compute the flux. For **Lax–Friedrichs**, enter numerical values in the **Lax–Friedrichs flux parameter** field with the length N, the sum of all lengths of the dependent variables. For **General**, enter a flux expression in the **Numerical flux** field.

To include filter coefficients, select **Always use filter (1)**, **Only use filter on absorbing layers (2)**, or **From expression** from the **Filter rule** list. The filter coefficients — α, η, and s — can be NaN (not-a-number, which is the default value) to disable that filter coefficient. Each filter coefficient expects a scalar value. It is also possible to not include filter coefficients by selecting **Never use filter (0)** from the **Filter rule** list.

Axial symmetry is not automatically handled by the equation form. The coefficients have to be reformulated to include gradients and volume factors for axial symmetry.

Degree of Freedom Re-Initialization

The **Degree of Freedom Re-Initialization** node (u,v,w) is identical to the **Degree of Freedom Initialization** node that initializes degrees of freedom (dependent variables, shape variables, and global states). There is only one extra section for needed for reinitialization after triggered solver events:

REFERENCE

Enter the unique tag in the **Event tag** field that points to the **Event** node that triggers this reinitialization step.

See Degree of Freedom Initialization for the rest of the settings.

To add this node, go to **Building Blocks**. Right-click **Components** to add a **Component** node. Then select **Degree of Freedom Re-Initialization** from the **Elements** menu.

Shape Interpolation Element

The **Shape Interpolation Element** node (a=) (which you add from a feature or **Component** node's **Elements** submenu) adds a special contribution to declared variables that adds an element. The element behaves as a shape function but instead of solving for the shape's degrees of freedoms, an expression defines their values directly. The variable the shape defines uses the shape function interpolation to compute the variable's values everywhere. The **Settings** window contains the sections:

DEFINITION

Enter the name of the variable you add the definition for in the **Variable name** field. The variable name follows the rules described in Entering Names and Expressions and must match the name of a variable declaration somewhere in the same physics interface. The **Shape function** list contains the shape functions that this definition supports. Choose **Continuous** or **Discontinuous** in the **Expression type** list. Enter the degree of freedom expression in the **Expression** field. This is the expression the shape function use to find the values of the variable it defines.

SELECTION

The options in the **Selection** list and **Output entities** list defines the selection where this variable definition is valid. See Specifying Selections for more information.

4

Examples of Custom Physics

The examples in this chapter show how to create custom physics interfaces for different applications:

- Joule heating is a well-known fundamental multiphysics phenomenon, but it is not the only type of electrothermal interaction. In addition, there is the thermoelectric effect, which historically is known under three different names: the Seebeck, Peltier, and Thomson effects. The first example in this chapter shows how to use the Physics Builder to create a custom physics interface for solving generic combined Joule heating and thermoelectric effects. See The Thermoelectric Effect and the following sections.
- The Schrödinger equation describes the behavior of a quantum state in quantum mechanics. The second example in this chapter shows how to use the Physics Builder to create a custom physics interface for solving a version of the Schrödinger equation. See The Schrödinger Equation and the following sections.

Both the Physics Builder files (MPHPHB-files) and model examples (MPH-files) for these two custom physics are included in the COMSOL installation. You find the files in the `demo/builder` directory in your COMSOL installation directory.

The Thermoelectric Effect

In this section:

- Introduction to the Thermoelectric Effect
- Equations in the Physics Builder

A predefined Thermoelectric Effect multiphysics interface is available in the Heat Transfer Module.

Introduction to the Thermoelectric Effect

The *thermoelectric effect* is the direct conversion of temperature differences to electric voltage or the other way around. It is the mechanism behind devices such as thermoelectric coolers for electronic cooling or portable refrigerators. While *Joule heating* (resistive heating) is an irreversible phenomenon, the thermoelectric effect is in principle reversible. Historically, the thermoelectric effect is known under three different names, reflecting its discovery in experiments by Seebeck, Peltier, and Thomson. The *Seebeck effect* is the conversion of temperature differences into electricity, the *Peltier effect* is the conversion of electricity to temperature differences, while the *Thomson effect* is heat produced by the product of current density and temperature gradients. These three effects are thermodynamically related by the Thomson relations:

$$P = ST$$

$$\mu = T\frac{dS}{dT}$$

where P is the Peltier coefficient (SI unit: V), S is the Seebeck coefficient (SI unit: V/K), T is the temperature (SI unit: K), and μ is the Thomson coefficient (SI unit: V/K). These relations show that all three effects can be considered as one and the same effect. This example primarily uses the Seebeck coefficient and also, merely as an intermediate variable, the Peltier coefficient. The Thomson coefficient is not used.

The flux quantities of interest when simulating the thermoelectric effect are the heat flux $\mathbf{q}$ and the flux of electric current $\mathbf{J}$:

$$\mathbf{q} = -k\nabla T + P\mathbf{J}$$
$$\mathbf{J} = -\sigma\nabla V - \sigma S\nabla T$$

Some other quantities of relevance are:

$$\mathbf{E} = -\nabla V$$
$$Q = \mathbf{J} \cdot \mathbf{E}$$

where $\mathbf{E}$ is the electric field and Q is the Joule heating.

Conservation of heat energy and current gives:

$$\rho C\frac{\partial T}{\partial t} + \nabla \cdot \mathbf{q} = Q$$

$$\nabla \cdot \mathbf{J} = -\frac{\partial \rho_c}{\partial t}$$

where ρ is the density, C is the heat capacity, and ρ_c is the space charge density. In this example, consider the stationary case only:

$$\nabla \cdot \mathbf{q} = Q$$
$$\nabla \cdot \mathbf{J} = 0$$

More explicitly, the thermoelectric equations become:

$$\nabla \cdot (-k\nabla T + P(-\sigma\nabla V - \sigma S\nabla T)) = (-\sigma\nabla V - \sigma S\nabla T) \cdot (-\nabla V)$$
$$\nabla \cdot (-\sigma\nabla V - \sigma S\nabla T) = 0$$

It is pretty clear that the explicit form of the equations are cumbersome to work with, and this example makes use of a series of intermediate variables to simplify entering them in the Physics Builder.

Equations in the Physics Builder

The Physics Builder requires partial differential equations to be entered in the weak form. To transfer to weak form, multiply each of the two equations with the test functions corresponding to the unknowns T and V (here called v_T and v_V, respectively) and integrate over the whole computational domain D:

$$\int_D (\nabla \cdot \mathbf{q}) v_T dD = \int_D Q v_T dD$$

$$\int_D (\nabla \cdot \mathbf{J}) v_V dD = 0$$

Partial integration gives:

$$-\int_D \mathbf{q} \cdot \nabla v_T dD + \int_B \mathbf{n} \cdot \mathbf{q} v_T dB = \int_D Q v_T dD$$

$$-\int_D \mathbf{J} \cdot \nabla v_V dD + \int_B \mathbf{n} \cdot \mathbf{J} v_V dB = 0$$

where B is the boundary of D, and $\mathbf{n}$ is the unit normal of D.

Assuming that there are known values for the heat and current flux in the direction of the boundary normal as q_0 and J_0, respectively, the equations become:

$$-\int_D \mathbf{q} \cdot \nabla v_T dD + \int_B q_0 v_T dB = \int_D Q v_T dD$$

$$-\int_D \mathbf{J} \cdot \nabla v_V dD + \int_B J_0 v_V dB = 0$$

The Physics Builder requires you to enter the domain parts of the weak form equations while the boundary parts are more or less automatically available.

The integrands of the domain parts are:

$$0 = \mathbf{q} \cdot \nabla v_T + Q v_T$$

$$0 = \mathbf{J} \cdot \nabla v_V$$

The COMSOL convention collects all terms on the right side.

Using Physics Builder syntax, the right-side expressions become:

$$\mathbf{q} \cdot \text{test}(\nabla T) + Q\,\text{test}(T)$$

$$\mathbf{J} \cdot \text{test}(\nabla V)$$

and this is what you enter into the weak form text fields for the integrands' expressions when creating the Thermoelectric Effect physics interface.

This example also uses the fact that you get the heat equation as a subset of the thermoelectric equation system. To handle cases where one or more domains are electrically insulating but thermally conductive, first create a heat transfer equation interface and then define the full thermoelectric equations as a second step. The weak form integrand for "pure" heat transfer is:

$$\mathbf{q} \cdot \text{test}(\nabla T)$$

In this way you only need to solve for one degree of freedom, T, in the electrically insulating domains.

In addition to the domain weak form equations, a number of different boundary conditions are implemented:

$$T = T_0$$
$$V = V_0$$
$$q_0 = 0$$
$$J_0 = 0$$
$$q_0 = q_{\text{in}}$$

- The first condition sets a temperature T_0 on a boundary.
- The second condition sets a voltage V_0 on a boundary.
- The two conditions that set the heat flux and current density on the boundary to zero are so-called *natural boundary conditions*. They are called natural because they arrive "naturally" as part of the weak form partial integration. The natural boundary conditions represent thermal and electrical insulation. The implementation in this example bundles these two conditions into one single insulation boundary condition. It is not even necessary to define this bundled boundary condition because that would anyway have been available: any boundaries not explicitly set to a certain condition automatically obey the natural conditions. However, for better usability of the thermoelectric physics interface, the natural boundary condition is available as one of the choices. This way you can clearly see which boundaries are insulated.
- The last boundary condition sets the value of the heat flux in the direction of the boundary normal. The heat flux boundary condition is implemented with a weak equation:

$$\int_B q_0 v_T$$

which is one of the terms in the complete weak form equation for the heat transfer part of the thermoelectric equations, as seen earlier.

The following table summarizes all quantities relevant for the thermoelectric physics interface:

NAME	DESCRIPTION	SI UNIT	SIZE	GEOMETRY LEVEL	USER INPUT
k	Thermal conductivity	W/(m·K)	Scalar	Domain	Yes
sigma	Electric conductivity	S/m	Scalar	Domain	Yes
S	Seebeck coefficient	V/K	Scalar	Domain	Yes
T0	Temperature	K	Scalar	Boundary	Yes
V0	Electric potential	V	Scalar	Boundary	Yes
qin	Heat flux	W/m^2	Scalar	Boundary	Yes
T	Temperature	K	Scalar	Domain	No
V	Electric potential	V	Scalar	Domain	No
q	Heat flux	W/m^2	3-by-1 vector	Domain	No
J	Current density	A/m^2	3-by-1 vector	Domain	No
P	Peltier coefficient	V	Scalar	Domain	No
E	Electric field	V/m	3-by-1 vector	Domain	No
Q	Joule heating	W/m^3	Scalar	Domain	No

Thermoelectric Effect Implementation

In this section:

- Overview
- Thermoelectric Effect Interface — Creating It Step by Step

Overview

To implement a physics interface for the thermoelectric effect, you need to specify the following items:

- The name and description for the physics interface.
- The supported space dimension for the physics interface.
- The study types (Stationary, Time Dependent, Eigenvalue, and so on) that the physics interface supports.
- The equations, written using a weak formulation, to solve, and the input variables that they need.
- The boundary conditions that the physics interface needs, including the default boundary condition, and the inputs that they need.
- Any additional variables that are relevant to define for use in, for example, results analysis and visualization.
- A suitable default plot to be displayed when the solver has finished and possibly custom quantities as default plot expressions for new plots.

Optionally, you can also add customized default settings for the mesh generation and the solvers.

NAME AND DESCRIPTION

The name of this interface is *Thermoelectric Effect*. The short name is `tee`. There is also a type, `ThermoelectricEffect`, which is primarily used by the Java® and LiveLink™ *for* MATLAB® interfaces.

SUPPORTED SPACE DIMENSIONS

The Thermoelectric Effect interface is available in all space dimensions.

THE STUDY TYPES

The Thermoelectric Effect can be made available as a Stationary and Time Dependent study types (and perhaps even other study types for more unusual applications). In this example, stationary is the only study type.

THE EQUATIONS

Heat Transfer Model

The first equation is called a Heat Transfer Model and is represented by the following weak form equation:

$$\mathbf{q} \cdot \text{test}(\nabla T)$$

The weak formulation using the COMSOL tensor syntax becomes

```
q·test(∇T)
```

In this expression, ∇ is the *del* vector differential operator, and · (dot) represents the *dot product* (*scalar product*).

Thermoelectric Model

The second equation is called the Thermoelectric Model and is represented by the following weak form equation:

$$\mathbf{q} \cdot \text{test}(\nabla T) + Q\,\text{test}(T)$$
$$\mathbf{J} \cdot \text{test}(\nabla V)$$

The weak formulation using the COMSOL tensor syntax becomes

```
q·test(∇T)+Q*test(T)
J·test(∇V)
```

where * is ordinary multiplication between scalars.

A number of parameters are defined in order to efficiently use the COMSOL tensor syntax for defining the weak form equations and also variables available for results and visualization:

- The thermal conductivity `k` is a user input to both the Heat Transfer Model and the Thermoelectric Model. The default value is set equal to `1.6[W/(m*K)]`, which corresponds to the thermoelectric material Bismuth telluride.
- The electric conductivity σ is a second user input for the Thermoelectric Model. The default value is set equal to `1.1e5[S/m]`, which also corresponds to the thermoelectric material Bismuth telluride.
- The Seebeck coefficient `S` is a third and final user input for the Thermoelectric Model. The default value is set equal to `200e-6[V/K]`, which once again corresponds to the thermoelectric material Bismuth telluride.
- To make the definition of the weak equation easier you define a variable for the heat flux `q` as a 3-by-1 vector with the following expression:

  `P*J-k·∇T`

  There is a dot product between the thermal conductivity and the temperature gradient. This makes it easy to generalize the physics interface to an anisotropic thermal conductivity at a later time, if needed.
- A variable for the current density `J` is defined as a 3-by-1 vector with the following expression:

  `-sigma·(∇V+S*∇T)`
- A variable for the Peltier coefficient `P` is defined as a scalar with the following expression:

  `S·T`
- A variable for the electric field `E` is defined as a 3-by-1 vector with the following expression:

  `-∇V`
- A variable for the Joule heating `Q` is defined as a scalar with the following expression:

  `J·E`

THE BOUNDARY CONDITIONS

The Thermoelectric Effect interface includes the following boundary conditions:

- A constraint for the temperature:

  `T0-T`

  where `T0` is a user input. The expression given for a constraint is understood to be set to zero, so the above constraint equation expression means: $T = T_0$.

- A constraint for the voltage:

  `V0-V`

  where `V0` is a user input.

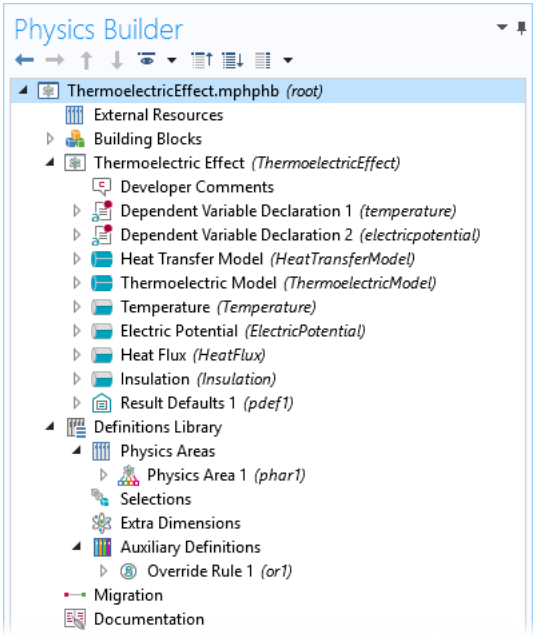
- A heat flux

  `qin`

  where `qin` is a user input.

- An insulation boundary condition with no user inputs. See the above theory section.

The constraint boundary conditions and the flux condition are *contributing*, while the insulation boundary condition is *exclusive*. A contributing boundary condition allows for more than one instance of the same boundary condition on a given boundary, where the model includes the combined effect of these boundary conditions. An exclusive boundary condition overrides any other previously defined boundary conditions on the given boundary. Ideally, the constraint conditions should also be exclusive; however, this prevents you from having a boundary with simultaneous temperature and voltage constraints. If you accidentally set several contributing constraint boundary conditions on the same boundary, then the last boundary condition overrides all previously defined. The final Physics Builder tree displays as below:



Thermoelectric Effect Interface — Creating It Step by Step

The following steps show how to define the Thermoelectric Effect physics interface using the implementation defined in the previous section.

CREATING THE BASICS

1 Open COMSOL Multiphysics.

2 From the **File** menu (Windows) or the **Options** menu (the cross-platform version), choose **Preferences**. In the **Preferences** window, click **Physics Builder** and then select the **Enable Physics Builder** checkbox if not selected already.

3 From the **File** menu, choose **New** ( ). On the **New** page, click the **Physics Builder** button ( ). The **Physics Builder** window replaces the **Model Builder** window on the COMSOL Desktop.

4 In the **Home** toolbar, click **Add Physics Interface** ( ) (or right-click the root node (**Untitled.mphphb**) and select **Physics Interface**). This adds a **Physics Interface** node.

5 Go to the **Settings** window for **Physics Interface**. In the **Identifiers** section:

- In the **Description** field enter `Thermoelectric Effect`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- The **Type** field defaults to `ThermoelectricEffect`.
- In the **Default name and tag** field type `tee`.
- If you have a custom **Icon** for the interface, click the **Browse** button to locate the icon file. The default is to use the `physics.png` icon ( ).

6 The Thermoelectric Effect interface should support all space dimensions except 0D, so under **Restrictions**, leave the **Allowed space dimensions** list with the default contents, which includes all space dimensions except 0D.

7 Under **Restrictions** in the **Allowed study types** list, select the default **Time dependent** study type and click the **Delete** button ( ) underneath the list. For this example only the **Stationary** study type is used.

8 In the **Settings** section, verify that **Domain** is selected in the **Top geometric entity level** list. This means that the equations in the physics interface apply to the domains in the geometry, which is the case for most physics interfaces. Leave the setting in the **Default frame** list at the default value (**Material**).

9 It is good practice to save the physics interface after completing some steps. From the **File** menu, choose **Save** and create a physics builder file, `ThermoelectricEffect.mphphb` in the default location. Click **Save**.

This concludes the initial steps that set up the fundamentals for the physics interface. The next steps add equations, boundary conditions, and variables.

ADDING THE DEPENDENT VARIABLES

First declare the dependent variables T and V:

1 In the **Physics Interface** toolbar click **Dependent Variable Declaration** ( ). Or right-click **Thermoelectric Effect** (Physics Interface 1) node and from the **Variables** menu select **Dependent Variable Declaration**.

2 In the **Settings** window for **Dependent Variable Declaration** locate the **Declaration** section:

- Keep the default setting in the **Dependent variable reference** list as **Use physical quantity**.
- Click the **Select Quantity** button ( ), and from the **Physical Quantity** dialog select **Temperature (K)** under **General**, which makes suitable default values appear for the variable name and description.
- In the **Symbol (LaTeX encoded)** field, enter `T`.
- Keep the default **Dimension** as **Scalar** because `T` is a scalar temperature field.
- Leave all other settings at their default values.

3 Keep the default **Preferences** settings that make the dependent variable available for plotting (**Show in plot menu**) and for use as an input in other physics interfaces (**Announce variable to common inputs**).

4 Keep the default **Discretization** settings (for second-order Lagrange elements).

5 Add another **Dependent Variable Declaration** ( ) node.

6 In the **Settings** window locate the **Declaration** section.

- Keep the default setting in the **Dependent variable reference** list as **Use physical quantity**.
- Click the **Select Quantity** button ( ), and from the **Physical Quantity** dialog select **Electric potential (V)** under **Electromagnetics**, which makes suitable default values appear for the variable name and description.
- In the **Symbol (LaTeX encoded)** field enter `V`.
- Keep the default **Size** setting as **Scalar** because `V` is a scalar electric potential field.
- Leave all other settings at their default values

7 Keep the default **Discretization** and **Preferences** sections settings.

ADDING THE HEAT TRANSFER MODEL

Next add the Heat Transfer Model as a domain feature:

1 Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Domain Feature** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Heat transfer model`. Click the **Rename Node Using This Text** button ( ) to update the node name in the **Physics Builder** tree.
- The **Type** field updates automatically to `HeatTransferModel`.
- In the **Default name and tag** field enter `htm`.

3 Under **Restrictions** keep the default setting **Same as parent** for both the **Allowed space dimensions** and **Allow study types** lists. If you select **Customized**, you can restrict the feature to a subset of the allowed space dimensions or study types for the physics interface.

4 Keep the default values for the rest of the sections for the **Heat Transfer Model** node.

5 Right-click the **Heat Transfer Model** node and from the **Variables** menu select **Dependent Variable Definition** ( ).

6 In the **Settings** window locate the **Definition** section. From the **Physical quantity** list select **From built-in quantities**.

7 Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Temperature (K)** under **General**. Click **OK**.

8 Keep the default settings for the rest of the **Dependent Variable Definition** node.

9 Right-click the **Heat Transfer Model** node and from the **Inputs** menu select **User Input** ( ).

10 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `k`.
- In the **Description** field enter `Thermal conductivity`.
- If desired, you can add a tooltip.
- In the **Symbol (LaTeX encoded)** field enter `k`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Thermal conductivity (W/(m*K))** under **Transport**. Click **OK**.
- Keep the default settings for the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also keep the default **Allowed values** to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `1.6[W/(m*K)]` (a typical value for bismuth telluride).

11 Keep all other default values for the **User Input** node.

I2 Right-click the **User Input** node and select **Variable Definition** (a=) or click the same button in the toolbar.

This user input then declares a variable with the name `k` and the expression `par.k`, which evaluates to the value entered for the user input. You can also refer to `k` directly in the weak form equation. A user of this physics interface refers to this variable as `tee.k` in the predefined expressions for results evaluation, for example.

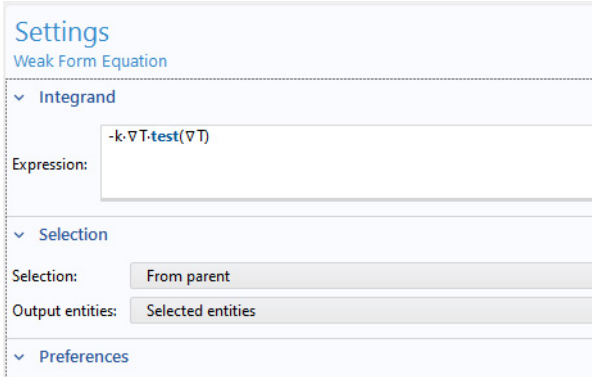
I3 Keep all other default values for the **Variable Definition** subnode.

I4 Right-click the **Heat Transfer Model** node and from the **Equations** menu select **Weak Form Equation** ($\int du$). Or click the same button in the toolbar.

This adds a **Weak Form Equation** node where you specify an equation for the domains in the physics interface.

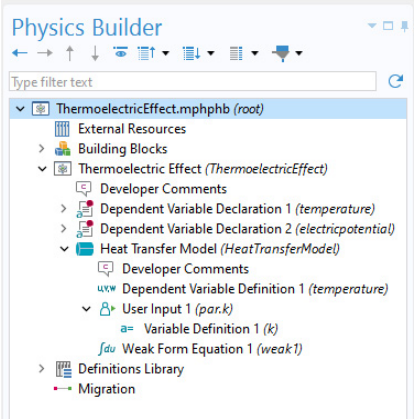
I5 In the **Settings** window, locate the **Integrand** section. In the **Expression** field enter `-k·∇T·test(∇T)`. This expression implements the heat equation formulation for this interface.

Press Ctrl+Space to get lists of the supported operations, including any special characters. See Tensor Operators and Other Operators for the keyboard entries to create the del operator (∇) and the dot product ($\cdot$).



I6 Keep all other default values for the **Weak Form Equation** node.

So far your Physics Builder tree should match the following figure:



ADDING THE THERMOELECTRIC MODEL

Next add the Thermoelectric Model as a domain feature:

1. Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Domain Feature** ( ).
2. In the **Settings** window for **Domain Feature** locate the **Identifiers** section.
   - In the **Description** field enter `Thermoelectric model`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
   - The **Type** field updates automatically to `ThermoelectricModel`.
   - In the **Default name and tag** field enter `tem`.
3. In the **Preferences** section select the **Add as default feature** checkbox. Keep the setting in the **Default entity types** list to make this a default physics model in all domains.
4. Keep the rest of the settings for the **Thermoelectric Model**.
5. Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Dependent Variable Definition** (u,v,w).
6. In the **Settings** window locate the **Definition** section. From the **Physical quantity** list select **From built-in quantities**. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Temperature (K)**. Click **OK**. Keep the other default settings.
7. Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Dependent Variable Definition** (u,v,w).

8 In the **Settings** window locate the **Definition** section. From the **Physical quantity** list select **From built-in quantities**. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Electric potential (V)** under **Electromagnetics**. Click **OK**. Keep the other default settings.

ADDING THREE USER INPUTS AND VARIABLE DEFINITIONS

1 Right-click the **Thermoelectric Model** node and from the **Inputs** menu select **User Input** ( ).

2 In the **Settings** window, locate the **Declaration** section.

- In the **Input name** field enter `k`.
- In the **Description** field enter `Thermal conductivity`.
- Add a tooltip if desired.
- In the **Symbol (LaTeX encoded)** field enter `k`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Thermal conductivity (W/(m*K))**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `1.6[W/(m*K)]` (a typical value for bismuth telluride).

3 Keep all other default settings for the **User Input 1** node.

4 Right-click the **User Input 1** node and select **Variable Definition** (a=).

You can then refer to `k` directly in the weak form equation. A user of this interface refers to this variable as `tee.k` in the predefined expressions for results evaluation, for example.

5 Keep all default settings for the **Variable Definition** subnode.

6 Right-click the **Thermoelectric Model** node and from the **Inputs** menu select **User Input** ( ).

7 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `sigma`.
- In the **Description** field enter `Electric conductivity`.
- Add a tooltip if desired.
- In the **Symbol (LaTeX encoded)** field enter `\sigma` to create a Greek σ symbol.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Electric conductivity (S/m)**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `1.1e5[S/m]` (a typical value for bismuth telluride).

8 Keep all other default settings for the **User Input 2** node.

9 Right click **User Input 2** and select **Variable Definition** (a=) from the context menu.

You can then refer to `sigma` directly in the weak form equation. A user of this interface refers to this variable as `tee.sigma` in the predefined expressions for results evaluation, for example.

10 Keep all default settings for the **Variable Definition** subnode.

11 Add another **User Input** ( ) node to the **Thermoelectric Model** node.

12 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `S`.
- In the **Description** field enter `Seebeck coefficient`.
- Add a tooltip if desired.
- In the **Symbol (LaTeX encoded)** field enter `S`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Seebeck coefficient (V/K)**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `200e-6[V/K]` (typical value for p-type bismuth telluride).

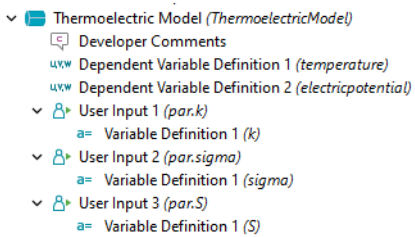
13 Keep all other default settings for the **User Input 3** node.

14 Right click **User Input 3** and select **Variable Definition** (a=) from the context menu.

You can then refer to `S` directly in the weak form equation. A user of this interface refers to this variable as `tee.S` in the predefined expressions for results evaluation, for example.

15 Keep all default settings for the **Variable Definition** subnode.

The Physics Builder tree for the Thermoelectric Model User Inputs and Variable Definitions should match the figure so far:



ADDING FIVE VARIABLE DECLARATIONS AND DEFINITIONS

1 Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Variable Declaration** ( ).

2 In the **Settings** window, locate the **Declaration** section.

- In the **Variable name** field enter `q`.
- In the **Description** field enter `Heat flux`.
- In the **Symbol (LaTeX encoded)** field enter `q`.
- As **Dimension**, select **Vector (3x1)**.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Inward heat flux (W/m^2)**. Click **OK**.

3 Right-click the **Variable Declaration 1** node and select **Variable Definition** (a=).

4 In the **Settings** window locate the **Definition** section. In the **Expression** field, enter `P*J-k·∇T`.

Press Ctrl+Space to get lists of the supported operations, including any special characters. See Tensor Operators and Other Operators for the keyboard entries to create the del operator (∇) and the dot product (·).

5 Keep all other default settings for the **Variable Definition 1** subnode.

6 Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Variable Declaration** ( ).

7 In the **Settings** window, locate the **Declaration** section.

- In the **Variable name** field enter `J`.
- In the **Description** field enter `Current density`.
- In the **Symbol (LaTeX encoded)** field enter `J`.
- As **Dimension**, select **Vector (3x1)**.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Current density (A/m^2)**.

8 Right-click the **Variable Declaration 2** node and select **Variable Definition** (a=).

9 In the **Settings** window locate the **Definition** section. In the **Expression** field, enter `-sigma·(∇V+S*∇T)`. Keep all other default settings for the **Variable Definition 1** subnode.

10 Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Variable Declaration** ( ).

11 In the **Settings** window locate the **Declaration** section.

- In the **Variable name** field enter `P`.
- In the **Description** field enter `Peltier coefficient`.
- In the **Symbol (LaTeX encoded)** field enter `P`.
- Keep the default **Dimension** as **Scalar**.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Electric potential (V)**. Click **OK**.

12 Right-click the **Variable Declaration 3** node and select **Variable Definition** (a=).

13 In the **Settings** window locate the **Definition** section. In the **Expression** field enter `S*T`. Keep all other default settings for the **Variable Definition 1** subnode.

14 Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Variable Declaration** ( ).

15 In the **Settings** window locate the **Declaration** section.

- In the **Variable name** field enter `E`.
- In the **Description** field enter `Electric field`.
- In the **Symbol (LaTeX encoded)** field enter `E`.
- As **Dimension**, select **Vector (3x1)**.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Electric field (V/m)**. Click **OK**.

16 Right-click the **Variable Declaration 4** node and select **Variable Definition** (a=).

17 In the **Settings** window locate the **Definition** section. In the **Expression** field enter –∇V. Keep all other default settings for the **Variable Definition 1** subnode.

18 Right-click the **Thermoelectric Model** node and from the **Variables** menu select **Variable Declaration** ( ).

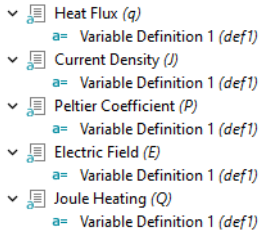
19 In the **Settings** window, locate the **Declaration** section.

- In the **Variable name** field enter `Q`.
- In the **Description** field enter `Joule heating`.
- In the **Symbol (LaTeX encoded)** field enter `Q`.
- Keep the default **Dimension** as **Scalar**.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Heat source (W/m^3)**. Click **OK**.

20 Right-click the **Variable Declaration 5** node and select **Variable Definition** (a=).

21 In the **Settings** window locate the **Definition** section. In the **Expression** field, enter `J·E`. Keep all other default settings for the **Variable Definition 1** subnode.

If you then click the **Rename Node Using This Text** button for all Variable Declaration nodes, the Variable Declaration and Variable Definitions subnodes should match the following figure so far:



ADDING TWO WEAK FORM EQUATIONS

1 Right-click the **Thermoelectric Model** node and from the **Equations** menu select **Weak Form Equation** (∫du). Or click the **Weak Form Equation** button in the toolbar.

2 In the **Settings** window locate the **Integrand** section. In the **Expression** field, enter `q·test(∇T)+Q*test(T)`. Press Ctrl+Space to enter the del operator (∇) and the dot product (·).

3 Right-click the **Thermoelectric Model** node and from the **Equations** menu select **Weak Form Equation** (∫du).

4 In the **Settings** window, locate the **Integrand** section. In the **Expression** field, enter `-J·test(E)`. Note that `-E` is used instead of ∇V. Either syntax would work.

ADDING BOUNDARY CONDITIONS

Boundary conditions are defined in a way that is similar to domain features. Boundary conditions can have their own user inputs and equations. This physics interface requires a special rule for overriding the temperature boundary condition and the electric potential boundary condition.

Override Rule for Boundary Conditions

1 Under **Definitions Library** ( ) right-click **Auxiliary Definitions** ( ) and select **Override Rule** ( ).

2 Click the **Add** button (+) twice to add two rows and two columns.

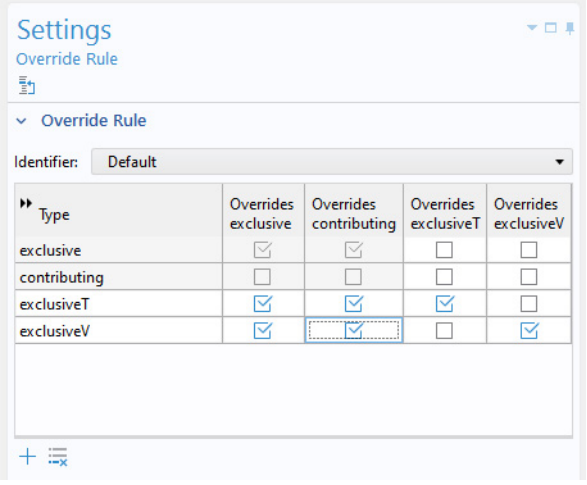
3 In the third row of the **Type** column, enter `exclusiveT` (replace `type_id_0`).

4 In the fourth row of the **Type** column, enter `exclusiveV` (replace `type_id_1`).

5 Click to set the **Overrides exclusive** and **Overrides contributing** columns for `exclusiveT` and `exclusiveV` to a green check mark.

6 Click in column **Overrides exclusiveT** across from `exclusiveT` to set to a green check mark.

7 Click in column **Overrides exclusiveV** across from `exclusiveV` to set to a green check mark. The **Settings** window should match the figure.



The Temperature Boundary Condition

1 Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window for **Boundary Condition** locate the **Identifiers** section.

- In the **Description** field enter `Temperature`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- The **Type** field defaults to `Temperature`.
- In the **Default name and tag** field enter `tp`.

3 In the **Restrictions** section, keep the default setting (**Same as parent**) for the **Allowed space dimensions** and **Allow study types** lists.

4 In the **Selection Settings** section keep **Exterior** and **Interior**.

- Click the **Add** button + underneath the list. Select **Pair** and click **OK**. It is added to the list under **Applicable entities**. This makes the boundary condition available for all those boundary types.
- From the **Override rule** list choose **Locally defined**. Select **Override Rule 1** from the **Link** list.
- From the **Override type** list choose **exclusiveT**.

5 Right-click the **Temperature** node and from the **Inputs** menu select **User Input** ( ).

6 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `T0`.
- In the **Description** field enter `Temperature`.
- Add a tooltip if desired.
- In the **Symbol (LaTeX encoded)** field enter `T`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog and then select **Temperature (K)**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `293.15[K]` corresponding to a room temperature of 20 degrees Celsius.

7 Keep all other defaults for the **User Input 1** node.

8 Right-click the **User Input 1** node and select **Variable Definition** (a=).

You can then refer to `T0` directly in the constraint equation. A user of this interface refers to this variable as `tee.T0` in the predefined expressions for results evaluation, for example.

9 Keep all defaults for the **Variable Definition 1** subnode.

Now define a section in the **Settings** window for the boundary condition:

10 Right-click the **Temperature** node and from the **Inputs** menu select **Section** ( ).

11 In the **Settings** window, locate the **Declaration** section.

- In the **Group name** field enter `TemperatureSection`.
- In the **Description** field enter `Temperature`.
- Click the **Add** (+) button and choose **User Input 1 (par.T0)**. Click **OK** and it is added the **Group members** list.

Now define the constraint equation that constrains the temperature to the specified value on the boundary:

12 Right-click the **Temperature** node and from the **Equations** menu select **Constraint** (R=0). Or click the same button in the toolbar.

13 In the **Settings** window locate the **Declaration** section. In the **Expression** field enter `T0-T` to make the temperature `T` equal to `T0` on the boundary (the constraint makes the expression equal to zero).

14 Locate the **Shape Declaration** section and from the **Physical quantity** list select **From built-in quantities**.

15 Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Temperature (K)**.

16 Keep all other default values for the **Constraint 1** node.

The Electric Potential Boundary Condition

1 Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Electric potential`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- The **Type** field defaults to `ElectricPotential`.
- In the **Default name and tag** field enter `ep`.

3 In the **Selection Settings** section:

- From the **Override rule** list choose **Locally defined**. Keep the default **Override Rule 1** in the **Link** list.
- From the **Override type** list choose **exclusiveV**.

4 Right-click the **Electric Potential** node and from the **Inputs** menu select **User Input** ( ).

5 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `V0`.
- In the **Description** field enter `Electric potential`.
- In the **Symbol (LaTeX encoded)** field enter `V`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Electric potential (V)**. Click **OK**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- Keep the **Default value** at `0`.

6 Keep all other defaults for the **User Input 1** node.

7 Right-click the **User Input 1** node and select **Variable Definition** (a=).

You can then refer to `V0` directly in the constraint equation. A user of this interface refers to this variable as `tee.V0` in the predefined expressions for results evaluation, for example.

8 Keep all other defaults for the **Variable Definition 1** subnode.

Now define a section in the **Settings** window for the boundary condition:

9 Right-click the **Electric Potential** node and from the **Inputs** menu select **Section** ( ).

10 In the **Settings** window locate the **Declaration** section.

- In the **Group name** field enter `ElectricPotentialSection`.
- In the **Description** field enter `Electric potential`.
- Click the **Add** (+) button and choose **User Input 2 (par.V0)**. Click **OK** and it is added the **Group members** list.

Now define the constraint equation for constraining the potential at the boundary to a specified potential.

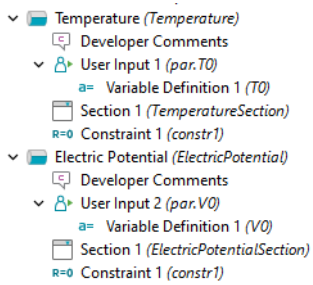
11 Right-click the **Electric Potential** node and from the **Equations** menu select **Constraint** (R=0).

I2 In the **Settings** window locate the **Declaration** section. In the **Expression** field, enter `V0-V`, which constrains the value of the potential `V` to `V0`.

I3 Locate the **Shape Declaration** section and from the **Physical quantity** list select **From built-in quantities**.

I4 Click the **Select Quantity** button ( ) to open the Physical Quantity dialog, and then select **Electric potential (V)**.

The Temperature and Electric Potential boundary conditions in the Physics Builder tree should match the following figure:



The Heat Flux Boundary Condition

1 Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Heat flux`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- The **Type** field updates automatically to `HeatFlux`.
- In the **Default name and tag** field enter `hf`.

3 In the **Selection Settings** section from the **Override type** list choose **Contributing** (that is, more than one heat flux can contribute to the total heat flux across a boundary).

4 Right-click the **Heat Flux** node and from the **Inputs** menu select **User Input** ( ).

5 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `qin`.
- In the **Description** field enter `Normal heat flux`.
- In the **Symbol (LaTeX encoded)** field enter `q_{in}` (for displaying q_{in}).
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Inward heat flux (W/m^2)**. Click **OK**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- Keep the **Default value** at `0`.

6 Right-click the **User Input 1** node and select **Variable Definition** ( ).

You can then refer to `qin` directly in the weak form equation. A user of this interface refers to this variable as `tee.qin` in the predefined expressions for results evaluation, for example.

7 Leave all other default settings for the **Variable Definition 1** subnode.

Now define a section in the **Settings** window for the boundary condition:

8 Right-click the **Heat Flux** node and from the **Inputs** menu select **Section** ( ).

9 In the **Settings** window locate the **Declaration** section.

- In the **Group name** field enter `HeatFluxSection`.
- In the **Description** field enter `Heat flux`.
- Click the **Add** (+) button and choose **User Input1 (par.qin)**. Click **OK** and it is added the **Group members** list.

Now define the weak form equation for the heat flux:

10 Right-click the **Heat Flux** node and from the **Equations** menu select **Weak Form Equation** ( ).

11 In the **Settings** window locate the **Integrand** section. In the **Expression** field, enter `qin*test(T)`. For a theoretical explanation of this expression, see the earlier theory section.

The Insulation Condition

1 Right-click the **Thermoelectric Effect** node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window locate the **Identifiers** section.

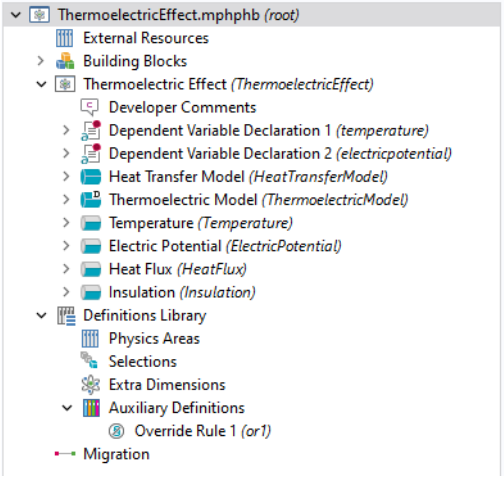
- In the **Description** field enter `Insulation`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- The **Type** field updates automatically to `Insulation`.
- In the **Default name and tag** field enter `in`.

3 In the **Selection Settings** section keep the default **Override type** (**Exclusive**).

4 In the **Preferences** section, select the **Add as default feature** checkbox. Keep the default setting in the **Default entity types** list to make this a default boundary condition on **Exterior** boundaries only.

5 Keep all other default settings. If you do not add an explicit boundary condition, it is the same as adding a homogeneous Neumann condition (that is, thermal insulation in this case).

The Physics Builder tree should match this figure so far:



DEFINING DEFAULT PLOTS AND DEFAULT PLOT QUANTITIES

Define a default 3D plot group for plotting the temperature and make the temperature the default scalar quantity for user-defined plots:

1 Right-click **Thermoelectric Effect** and select **Result Defaults** ( ).

2 Right-click **Result Defaults** ( ) and select **3D Plot Group** ( ).

3 Right-click the **3D Plot Group** ( ) node and select **Surface** ( ).

4 In the **Settings** window for **Surface** ( ) under the **Expression** section:

- In the **Expression** field enter `T`.
- In the **Unit** field enter `K`.
- Click the **Description** checkbox and enter `Temperature` in the text field.

5 Keep all other default settings.

6 Right-click the **Surface** ( ) node and select **Rename** (or click **Surface** and press F2) In the **Rename Surface** dialog, in the **New label** field enter `Temperature`. Click **OK**.

7 Right-click **Result Defaults 1** ( ) and select **Plot Defaults** ( ).

8 Right-click the **Plot Defaults 1** ( ) node and select **Default Scalar Plot** ( ).

- In the **Expression** field enter `T`.
- In the **Description** field enter `Temperature`. This makes temperature the default for all scalar plots.

MAKING A THERMOELECTRIC DEVICES PHYSICS AREA

To add the Thermoelectric Effect interface to a new physics area for Thermoelectric Devices under the Heat Transfer branch, follow these steps:

1 Under **Definitions Library** right-click **Physics Areas** ( ) and select **Physics Area** ( ).

2 In the **Settings** window for **Physics Area** under **Parent Area**, expand the **Root** > **Heat Transfer** folder ( ). Right-click **Heat Transfer** and select **Set as Parent** ( ) to sort this physics area under the **Heat Transfer** branch in the Model Wizard and Add Physics windows.

3 In the **Physics Area Settings** section:

- In the **Name** field enter `ThermoelectricDevices`.
- In the **Description** field enter `Thermoelectric Devices`.
- The default **Icon** is `physics.png` ( ), which is appropriate for this physics. Otherwise, click **Browse** to use another icon.
- In the **Weight** field enter 10 to make the **Thermoelectric Devices** area appear last in the list under **Heat Transfer** (the higher the weight, the lower position the physics area gets in the tree of physics interfaces).

4 Click the **Thermoelectric Effect** node. In the **Settings** window for **Physics Interface**, expand the **Physics Area** section.

5 Expand the **Heat Transfer** folder. Right-click **Thermoelectric Devices** ( ) and select **Set as Parent** ( ). This sorts the physics interface under the selected physics area.

6 Save the file that contains the physics interface as `ThermoelectricEffect.mphphb`.

This completes the definition of the **Thermoelectric Effect** interface. The next section tests the physics interface.

Testing the Thermoelectric Effect Interface

At any time during the implementation of a physics interface using the Physics Builder, you can launch an updated preview of the physics interface so that you can add feature nodes and check that the contents and behavior of the associated **Settings** windows and other functionality is as expected.

To do this select the main node for the physics interface implementation (for example, **Thermoelectric Effect** and then click the **Show Preview** button ( ) in the **Settings** window toolbar (or press F8). An instance of the physics interface then displays at the bottom of the Physics Builder tree.

When you are finished, update COMSOL Multiphysics to check that the new physics interface is in the Model Wizard and that the functionality and settings are as expected.

1. From the **Windows** menu or the **Home** toolbar, choose **Physics Builder Manager** ( ).
2. Under **Archive Browser**, right-click the **Development Files** node ( ) and select **Add Builder File**. Browse to locate `ThermoelectricEffect.mphphb`. Click to select it and then right-click and select **Open Selected**, or double-click the file to open it.
3. From **File** menu select **New** ( ).
4. Click **Model Wizard** ( ).
5. Select a space dimension, **3D** ( ) for example.
6. On the **Select Physics** page, under **Heat Transfer** > **Thermoelectric Devices** click **Thermoelectric Effect (tee)**. Click **Add**.
7. Click **Study** ( ).
8. On the **Select Study** page, verify that **Stationary** is the only available study type under **Preset Studies**. Select it and click **Done** ( ).
9. In the **Model Builder**, verify that the default nodes appear as expected and that their **Settings** windows contain the user inputs specified.
10. Continue by building an example model (see Example Model — Thermoelectric Leg) to verify that the Thermoelectric Effect interface solves the correct equation using the correct boundary conditions and that you can plot the various physics quantities.

II Correct any errors or problems found and save the Physics Builder file again.

The Physics Builder Manager

When you have successfully created a first instance of a physics interface you can consider improvements or additions for future development. Typically you can save a model file and then reload it after updating the physics definitions to see how it behaves after applying some extensions or corrections.

The Thermoelectric Effect interface has some natural extensions:

- Adding additional boundary conditions for current input and convective cooling.
- Adding a Time Dependent study type, which requires user inputs for density and heat capacity.
- Allowing for the thermal and electric conductivities to be anisotropic.
- Making use of Material Groups in order to be able to reuse material properties from one modeling session to another.
- Using Building Blocks to make the physics interface easier to maintain and extend.
- Creating additional variables for the separate heating contributions from Thomson heating and Joule heating. These correspond to the right-hand terms in the first of the thermoelectric equations:

$$\nabla \cdot (-k\nabla T + P(-\sigma\nabla V - \sigma S\nabla T)) = (-\sigma\nabla V - \sigma S\nabla T) \cdot (-\nabla V)$$

In other words:

$$\text{Joule heating} = \sigma\nabla V \cdot \nabla V = \mathbf{J} \cdot \mathbf{E}$$
$$\text{Thomson heating} = \sigma S\nabla T \cdot \nabla V = \mathbf{J} \cdot S\nabla T$$

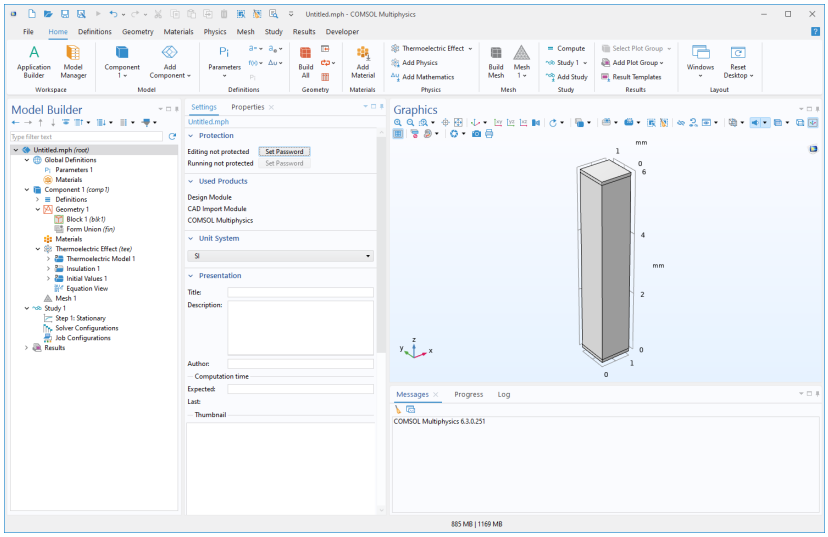
Example Model — Thermoelectric Leg

In this section:

- Introduction to the Thermoelectric Leg Model
- Results
- Reference
- Modeling Instructions

Introduction to the Thermoelectric Leg Model

A thermoelectric leg is a fundamental component of a thermoelectric cooler (or heater). The component in this example is 1-by-1-by-6 mm, capped by two thin copper electrodes. The thermoelectric part is made of bismuth telluride.



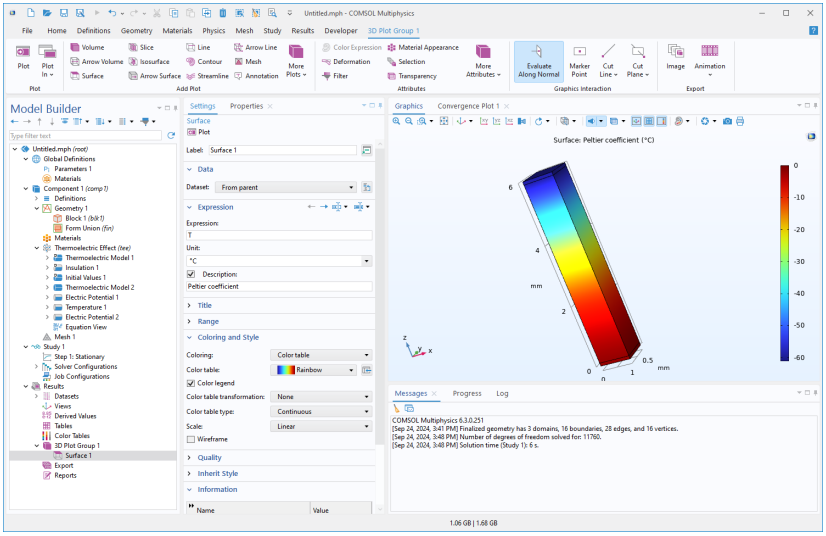
The material properties needed are the thermal conductivity, the electric conductivity, and the Seebeck coefficient of copper and bismuth telluride. The material properties of this model is taken from the paper in Ref. 1:

PROPERTY	SYMBOL AND UNIT	BISMUTH TELLURIDE	COPPER
Thermal conductivity	k (W/(m·K))	1.6	350
Electric conductivity	σ (S/m)	1.1e5	5.9e8
Seebeck coefficient	S (V/K)	p: 200e-6 n: -200e-6	6.5e-6

The bottom electrode surface is held at 0 degrees C and is electrically grounded at 0 V. The top electrode is set to 0.05 V and is thermally insulated. Applying a constraint for only one degree of freedom automatically sets a natural boundary condition for the other.

Results

The results agree with those of Ref. 1 and shows a 61 degree C cooling of the top part of the thermoelectric leg.



Reference

1. M. Jaegle, *Multiphysics Simulation of Thermoelectric Systems — Modeling of Peltier-Cooling and Thermoelectric Generation*, in "Proceedings of the COMSOL Conference 2008," Hannover, Germany. ISBN: 978-0-9766792-8-8.

Modeling Instructions

The following steps show how to build this model using the Thermoelectric Effect interface built in the Thermoelectric Effect Implementation section.

MODEL WIZARD

1 Open COMSOL Multiphysics.

2 On the **New** page click **Model Wizard** ( ) then click the **3D** button ( ) on the **Select Space Dimension** page.

3 On the **Select Physics** page under **Heat Transfer** > **Thermoelectric Devices** click **Thermoelectric Effect** ( ).

4 Click **Add** and then the **Study** button ( ).

5 On the **Select Study** page, under **Preset Studies** click **Stationary** ( ). Click **Done** ( ).

GEOMETRY MODELING

1 Under **Component 1** click **Geometry 1** ( ).

2 In the **Settings** window for **Geometry** select `mm` from the **Length unit** list.

3 Add a **Block** ( ) with **Width** `1` mm, **Depth** `1` mm, and **Height** `6` mm.

4 In the **Settings** window, expand the **Layers** section. Add two layers to the table: **Layer 1** with **Thickness** `0.1` mm and **Layer 2** with **Thickness** `5.8` mm.

PHYSICS SETTINGS

1 Right-click the **Thermoelectric Effect** node ( ) and select **Thermoelectric Model** ( ). This is in addition to the default node.

2 In the **Settings** window for the second **Thermoelectric Model**, add the copper electrodes (domains 1 and 3) to the selection list under **Domain Selection**.

3 Under **Thermoelectric Model** replace the defaults with the following:

- In the **Thermal conductivity** field enter `350`.
- In the **Electric conductivity** field enter `5.9e8`.
- In the **Seebeck coefficient** field enter `6.5e-6`.

The default **Thermoelectric Model** already has the correct values for bismuth telluride and is assigned to domain 2.

4 Right-click **Thermoelectric Effect** ( ) and select **Electric Potential** ( ).

5 In the **Settings** window for **Electric Potential**, select boundary 3 (bottom surface) and keep the default **Electric potential** (0 V).

6 Right-click **Thermoelectric Effect** ( ) and select **Temperature** ( ).

7 In the **Settings** window for **Temperature** select boundary 3. In the **Temperature** field replace the default with `273.15` K (0 degrees C).

8 Right-click **Thermoelectric Effect** ( ) and select **Electric Potential** ( ).

9 In the **Settings** window for **Electric Potential** select boundary 10 (top surface). Enter an **Electric potential** of `0.05` V.

MESH GENERATION AND COMPUTING THE SOLUTION

A mesh with default parameters is good enough for this very simple model. The default mesh is automatically created if nothing else is specified when solving.

1 Right-click the **Study** node and select **Compute** ( ).

RESULTS AND VISUALIZATION

The default plot under the **3D Plot Group** is for the temperature `T`. Click the **Surface** node and under **Expression**, replace the default **Unit** with `degC`. This is to verify the 61 degree C temperature drop.

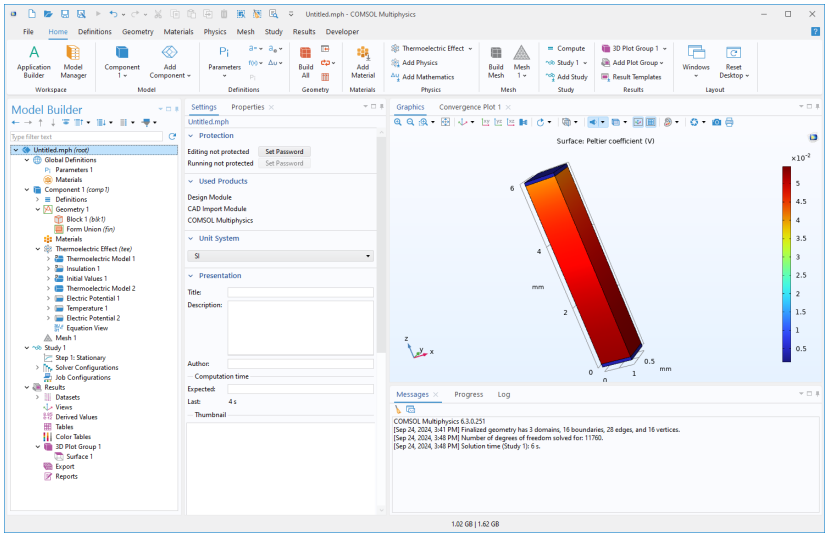
To visualize other predefined expressions defined when creating the physics interface:

1 Under **Results** > **3D Plot Group**, click the **Temperature** node.

2 In the **Settings** window for **Surface**, click the **Replace Expression** button ( ).

3 Under **Model** > **Component 1** > **Thermoelectric Effect** choose a predefined expression; for example, the **Peltier coefficient** `tee.P`.

4 Click the **3D Plot Group** node and the **Temperature** plot updates in the **Graphics** window.



The Schrödinger Equation

This section is an Introduction to the Schrödinger Equation.

Introduction to the Schrödinger Equation

The *Schrödinger equation* (from the Austrian physicist Erwin Schrödinger) is an equation that describes the behavior of the quantum state of a physical system as it changes in time:

$$E\Psi = \hat{H}\Psi$$
$$i\frac{h}{2\pi}\frac{\partial \Psi}{\partial t} = \hat{H}\Psi$$

where Ψ is the quantum mechanical wave function (the probability amplitude for different configurations of the system) and $\hat{H}$ is the *Hamiltonian*. h, the Planck constant, over 2π is often called the *reduced Planck constant* (h-bar).

For describing the standing wave solutions of the time-dependent equation, which are the states with definite energy, the equation can be simplified to a stationary Schrödinger equation. The following version of the stationary Schrödinger equation models the atom as a one-particle system:

$$-\nabla \cdot \left(\frac{h^2}{8\mu\pi^2}\nabla\Psi\right) + V\Psi = E\Psi \tag{4-1}$$

The equation parameters are:

- h (approximately $6.626 \cdot 10^{-34}$ Js) is the Planck constant
- μ is the reduced mass
- V is the potential energy
- E is the unknown energy eigenvalue
- Ψ is the quantum mechanical wave function

The physics interface in this example implements this form of the stationary Schrödinger equation.

Schrödinger Equation Implementation

In this section:

- Overview
- Schrodinger Equation Interface — Creating It Step by Step

A predefined Schrödinger Equation interface is available in the Semiconductor Module.

Overview

To implement a physics interface for solving Equation 4-1 above, you need to specify the following items:

- The name and description for the physics interface.
- The supported space dimension for the physics interface.
- The study types (Stationary, Time Dependent, Eigenvalue, and so on) that the physics interface supports.
- The equation, written using a weak formulation, to solve, and the input variables that it needs.
- The boundary conditions that the physics needs, including the default boundary condition, and the inputs that they need.
- Any additional variables that are relevant to define for use in, for example, results analysis and visualization.
- A suitable default plot to be displayed when the solver has finished and possibly custom quantities as default plot expressions for new plots.

NAME AND DESCRIPTION

The name of this physics interface is *Schrodinger Equation* (avoiding using the character “ö” in the interface). The short name is `scheq`. There is also a type, `SchrodingerEq`, which is primarily used by the Java and LiveLink™ *for* MATLAB® interfaces.

SUPPORTED SPACE DIMENSIONS

The Schrodinger Equation interface is available in all space dimensions.

THE STUDY TYPES

The Schrödinger equation is an eigenvalue equation, so an eigenvalue study is the only applicable study type.

THE EQUATION

With scalar coefficients in the equation, and using C as a replacement for the coefficient $\frac{h^2}{8\mu\pi^2}$, the weak formulation using the COMSOL tensor syntax becomes

```
-C*∇psi·test(∇psi)-V*psi·test(psi)+lambda*psi·test(psi)
```

In this expression, ∇ is the *nabla* or *del* vector differential operator, and · represents an inner *dot product* (*scalar product*). * represents normal scalar multiplication. The variable lambda represents the eigenvalues (E in Equation 4-1).

The following equation parameters must be defined:

- The reduced Planck constant, which is a predefined physical constant, `hbar_const`.
- The reduced mass μ, which for a one-particle system like the hydrogen atom can be approximated as

$$\mu = \frac{Mm_e}{M + m_e} \approx m_e \tag{4-2}$$

  where M equals the mass of the nucleus and m_e represents the mass of an electron ($9.1094 \cdot 10^{-31}$ kg). The hydrogen nucleus consists of a single proton (more than 1800 times heavier than the electron), so the approximation of μ is valid in this case. The Schrodinger Equation interface therefore includes a user input for the reduced mass μ with a default value equal to the electron mass m_e, which is a predefined physical constant, `me_const`.
- The potential energy V, which for a one-particle system's potential energy is

$$V = -\frac{e^2}{4\pi\varepsilon_0 r} \tag{4-3}$$

  where e is the electron charge ($1.602 \cdot 10^{-19}$ C), ε_0 represents the permittivity of vacuum ($8.854 \cdot 10^{-12}$ F/m), and r gives the distance from the center of the atom. The Schrodinger Equation interface includes a user input for the potential energy V with a default value of 0. You can easily enter the expression above, where the electron charge e and the permittivity of vacuum ε_0 are physical constants (`e_const` and `epsilon0_const`, respectively) and r is a distance that you can formulate using the space coordinates in the space dimension of the model.

THE BOUNDARY CONDITIONS

The Schrodinger Equation interface includes the following boundary conditions:

- Typically you assume that the exterior boundary is such that there is zero probability for the particle to be outside the specified domain. Such a zero probability boundary condition is equivalent to a Dirichlet condition $\Psi = 0$. This is the default boundary condition.
- There is also a Wave Function Value boundary condition $\Psi = \Psi_0$ for the case that you do not want to specify a zero probability. This boundary condition defines one user input for Ψ_0.
- For axisymmetric models the cylinder axis $r = 0$ is not a boundary in the original problem, but here it becomes one. For these boundaries the artificial Neumann boundary condition $\mathbf{n} \cdot (\nabla\Psi) = 0$ serves as an axial symmetry condition. This is the default boundary condition for axial symmetry boundaries, and COMSOL Multiphysics adds these automatically.

All boundary conditions are exclusive (that is, only one of them can be active for any of the boundaries).

ADDITIONAL VARIABLES

One variable to add is the quantity $|\Psi|^2$, which corresponds to the unnormalized probability density function of the electron's position. By adding it as a variable, you can make it available as a predefined expression in plots and results evaluation.

Schrodinger Equation Interface — Creating It Step by Step

The following steps show how to define the **Schrodinger Equation** interface using the implementation defined in the previous section.

CREATING THE BASICS

1 Open COMSOL Multiphysics.

2 From the **File** menu (Windows) or the **Options** menu (the cross-platform version), choose **Preferences**. In the **Preferences** window box, click **Physics Builder** and then select the **Enable Physics Builder** checkbox if not selected already.

3 From the **File** menu, choose **New** ( ). On the **New** page, click the **Physics Builder** button ( ). The **Physics Builder** window replaces the **Model Builder** window on the COMSOL Desktop.

4 In the **Home** toolbar, click **Add Physics Interface** ( ) (or right-click the root node (**Untitled.mphphb**) and select **Physics Interface**).

5 Go to the **Settings** window for **Physics Interface**. In the **Identifiers** section:

- In the **Description** field enter `Schrodinger Equation`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- Select the **Type** checkbox and replace the default with `SchrodingerEq`.
- In the **Default name and tag** field enter `scheq`.
- If you have a custom **Icon** for the interface, click the **Browse** button to locate the icon file. The default is to use the `physics.png` icon ( ).

6 The **Schrodinger Equation** interface should support all space dimensions except 0D. Under **Restrictions** keep the defaults for the **Allowed space dimensions**, which already excludes 0D.

7 In the **Allowed study types** list, select the default study types (**Stationary** and **Time dependent**) and click the **Delete** button ( ) underneath the list. Click the **Add** button (+) and select **Eigenvalue** from the **Allowed study types** list. Click **OK**.

8 In the **Settings** section, confirm that **Domain** is selected from the **Top geometric entity level** list. This means that the equations in the physics interface apply to the domains in the geometry, which is the case for most physics. Leave the default setting for the **Default frame** list as **Material**.

9 It is good practice to save the physics use interface after completing some steps. From the **File** menu, choose **Save** and create a physics interface file, `SchrodingerEquation.mphphb` in the default location. Click **Save**.

This concludes the initial steps to set up the structure for the physics interface. The next steps add equations, boundary conditions, and variables.

ADDING FEATURES

First declare the dependent variable Ψ:

1 Right-click the **Schrodinger Equation** node and from the **Variables** menu select **Dependent Variable Declaration** ( ). Or, in the **Physics Interface** toolbar, click the button with the same name.

2 In the **Settings** window locate the **Declaration** section.

- Keep the default for the **Dependent variable reference** list (**Use physical quantity**).
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)**. Click **OK**.
- In the **Default variable name** field enter `psi`.
- In the **Description** field enter `Wave function`.
- In the **Symbol (LaTeX encoded)** field enter `\psi` (the LaTeX syntax for the Greek letter ψ).
- Keep the default **Dimension** (**Scalar**), because Ψ is a scalar field.

3 In the **Preferences** section, both checkboxes are selected by default. Keep these settings.

You also need to add a **Dependent Variable** node in the Schrödinger equation domain feature to create the shape function (element type) for the dependent variable in the domain (see Step 16 below).

ADD A SCHRODINGER EQUATION MODEL DOMAIN FEATURE

Next add the Schrödinger equation in a domain feature:

1 Right-click the **Schrodinger Equation** node and from the **Features** menu select **Domain Feature** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Schrodinger equation model`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- Select the **Type** checkbox and replace the default with `SchrodingerEqu`.
- In the **Default name and tag** field enter `schequ`.

3 In the **Restrictions** section, keep the default setting (**Same as parent**) for the **Allowed space dimensions** and **Allow study types** lists. By selecting **Customized** you can restrict the feature to a subset of the allowed space dimensions or study types for the physics.

4 In the **Selection Settings** section, confirm that **Active** is displayed in the **Applicable entities** list. Keep the **Override rule** default setting (**Built in**), and the **Override rule** default (**Exclusive**).

5 Under **Coordinate Systems**, keep the default settings (**Frame system**) for the **Input base vector system** and **Base vector system** lists. Also keep the default **Frame type** as **Material**.

6 Under **Preferences** click to select the **Add as default feature** checkbox to make this the default feature for all domains.

7 Right-click the **Schrodinger Equation Model** node and from the **Inputs** menu select **User Input** ( ).

8 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `mu`.
- In the **Description** field enter `Reduced mass`.
- In the **Symbol (LaTeX encoded)** field enter `\mu` (LaTeX syntax for the Greek letter μ).
- If desired, here and elsewhere, add a tooltip in the **Tooltip** field.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Mass (kg)**. Click **OK**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- In the **Default value** field enter `me_const` (the electron mass, which is a built-in physical constant) in the **Default value** field.

9 Right-click the **User Input** node and select **Variable Definition** (a=).

This user input then becomes available as a variable `schequ.mu` in, for example, the predefined expressions for results evaluation. You can also refer to `mu` directly in the weak equation. Keep all other default settings for this node.

10 Right-click the **Schrodinger Equation Model** node and from the **Inputs** menu select **User Input** ( ).

11 In the **Settings** window, locate the **Declaration** section.

- In the **Input name** field enter `V`.
- In the **Description** field enter `Potential energy`.
- In the **Symbol (LaTeX encoded)** field enter `V`.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Energy (J)**. Click **OK**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- Use the default value `0` in the **Default value** field.

I2 Right-click the **User Input 2** node and select **Variable Definition** (a=).

This user input then becomes available as a variable `schequ.V` in, for example, the predefined expressions for results evaluation. You can also refer to `V` directly in the weak equation. Keep all other default settings for this node.

I3 Right-click the **Schrodinger Equation Model** node and from the **Equations** menu select **Weak Form Equation** (∫du). This is where you specify the equation for the domains in the physics interface.

I4 In the **Settings** window locate the **Integrand** section. In the **Expression** field, enter `-hbar_const^2/(2*mu)*∇psi·test(∇psi)-(V-lambda)*psi·test(psi)`

This expression implements the Schrödinger equation formulation for this interface. Here, `lambda` is the eigenvalue. Press Ctrl+Space to get lists of the supported operations, including any special characters. See Tensor Operators and Other Operators for the keyboard entries to create the del operator (∇) and the dot product (·).

I5 In the **Selection** section keep the default **Selection** setting (**From parent**), which means it inherits the selection from the top node. Also keep the default **Output entities** setting (**Selected entities**) to use the selected domains as the output. Keep all other defaults.

I6 Right-click the **Schrodinger Equation Model** node and from the **Variables** menu select **Dependent Variable Definition** (u,v,w).

I7 In the **Settings** window, locate the **Definition** section. From the **Physical quantity** list, choose **From built-in quantities**. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)**. Click **OK**. Lagrange elements are the most widely used and are suitable for this physics interface. The default shape-function order becomes 2. Keep the other defaults.

ADD A DEFAULT ZERO PROBABILITY BOUNDARY CONDITION

Add the default boundary condition:

1 Right-click the **Schrodinger Equation** (Physics Interface 1) node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Zero probability`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- Select the **Type** checkbox and replace the default with `ZeroProb`.
- In the **Default name and tag** field enter `zpb`.

3 Keep all the defaults for the **Restrictions**, **Selection Settings**, and **Coordinate Systems** sections.

4 In the **Preferences** section, select the **Add as default feature** checkbox. Keep the **Default entity types** as **Exterior** to make this a default condition on exterior boundaries only.

5 Right-click the **Zero Probability** node and from the **Equations** menu select **Constraint** (R=0).

6 In the **Settings** window locate the **Declaration** section. Enter `0-psi` in the **Expression** field to make $\Psi = 0$ on the boundary (this expression is set equal to zero by the constraint).

7 In the **Shape Declaration** section, from the **Physical quantity** list select **From built-in quantities**. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)** to declare the correct dimension for the constrained variable Ψ. Click **OK**. Keep all other default settings.

	Click the **Schrodinger Equation** node. In the **Settings** window under **Default Features**, note that the Schrodinger Equation Model and the Zero Probability boundary condition are listed.

ADD A WAVE FUNCTION VALUE BOUNDARY CONDITION

Add the Wave Function Value boundary condition $\Psi = \Psi_0$:

1 Right-click the **Schrodinger Equation** node and from the **Features** menu select **Boundary Condition** ( ).

2 In the **Settings** window locate the **Identifiers** section.

- In the **Description** field enter `Wave function value`. Click the **Rename Node Using This Text** button ( ) to update the node in the **Physics Builder**.
- Select the **Type** checkbox and replace the default with `WaveFunc`.
- In the **Default name and tag** field enter `wvfcn`.

3 Keep all the defaults for the **Restrictions**, **Selection Settings**, and **Coordinate Systems** sections.

4 Right-click the **Wave Function Value** node and from the **Inputs** menu select **User Input** ( ).

5 In the **Settings** window locate the **Declaration** section.

- In the **Input name** field enter `psi0`.
- In the **Description** field enter `Wave function value`.
- In the **Symbol (LaTeX encoded)** field enter `\psi_0`. This is for the symbol Ψ_0.
- Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)**. Click **OK**.
- Keep the default settings in the **Array type** (**Single**) and **Dimension** (**Scalar**) lists for a basic scalar quantity. Also leave the **Allowed values** setting to **Any** for an entry of a general scalar number.
- Keep the **Default value** at `0`.

6 Right-click the **Wave Function Value** node and from the **Equations** menu select **Constraint** (R=0).

7 In the **Settings** window locate the **Declaration** section. Enter `par.psi0-psi` in the **Expression** field to make $\Psi = \Psi_0$ on the boundary. The `par` prefix indicates a local parameter scope and is necessary in order to refer to a user input that is not defined as a variable.

8 In the **Shape Declaration** section, from the **Physical quantity** list select **From built-in quantities**. Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)** to declare the correct dimension for the constrained variable Ψ. Click **OK**.

This feature uses a user input that should appear in a section in the **Settings** window. The constraint automatically adds an extra section for enabling weak constraints and set the type of constraint, but it is necessary to specify a section for the user input.

9 Right-click the **Wave Function Value** node and from the **Inputs** menu select **User Input Group** ( ).

10 In the **Settings** window locate the **Declaration** section. In the **Group name** field enter `WaveFunc_section` and in the **Description** field enter `Wave function`.

11 Under the **Group members** list, click the **Add** button (+) and from the **Group members** list select **User Input 1 (par.psi0)**. Click **OK**.

12 In the **GUI Options** section, from the **GUI Layout** list select **Group members define a section**. See User Input Group GUI Options for more information.

The remaining boundary condition, Axial Symmetry, appears automatically on symmetry boundaries in axisymmetric models.

ADDING AN ADDITIONAL VARIABLE

Add the probability density function $|\Psi|^2$ as a variable that is available in the model and for plotting (when the **Show in plot menu** checkbox is selected in the **Preferences** section, which is the default setting) or evaluating:

1. Right-click the **Schrodinger Equation** node and from the **Variables** menu select **Variable Declaration** ( ).
2. In the **Settings** window locate the **Declaration** section.
   - In the **Variable name** field enter `probdens`.
   - In the **Description** field enter `Probability density function`.
   - In the **Symbol (LaTeX encoded)** field enter `{\mid\psi\mid}^2` to display $|\Psi|^2$.
   - For the **Dimension** list, keep the default setting (**Scalar**).
   - Click the **Select Quantity** button ( ) to open the **Physical Quantity** dialog, and then select **Dimensionless (1)**. Click **OK**.
3. Keep all the default settings in the **Preferences** section. The **Show in plot menu** list is set to **Always** for this variable to always appear as a predefined expression in plots.
4. Right-click the **Variable Declaration 1** node and select **Variable Definition** ( ).
5. In the **Settings** window locate the **Definition** section. Enter `abs(psi)^2` in the **Expression** field.

DEFINING DEFAULT PLOTS AND DEFAULT PLOT QUANTITIES

Define a default 2D plot group for plotting the probability density function and make the probability density function the default scalar quantity for user-defined plots:

1. Right-click the **Schrodinger Equation** node and select **Result Defaults** ( ).
2. Right-click the **Result Defaults 1** node and select **2D Plot Group** ( ).
3. Right-click the **2D Plot Group 1** ( ) node and select **Surface** ( ).
4. In the **Settings** window for **Surface** in the **Description** field, select the checkbox and enter `Probability density`, and then in the **Expression** field under **Expression**, enter `probdens`.
5. Right-click the **Surface 1** node and select **Rename** (or press F2). In the **Rename Surface** dialog, in the **New label** field enter `Probability Density`. Click **OK**.
6. Right-click **Result Defaults 1** node and select **Plot Defaults** ( ).
7. Right-click the **Plot Defaults 1** node and select **Default Scalar Plot** ( ).

8 In the **Settings** window, in the **Expression** field enter `probdens`. In the **Description** field enter `Probability density`. This makes the probability density function the default plot for all scalar plots.

MAKING A QUANTUM MECHANICS PHYSICS AREA

To add the Schrodinger Equation interface to a new physics area for Quantum Mechanics under the Mathematics branch:

1 Under **Definitions Library** right-click **Physics Areas** ( ) and select **Physics Area** ( ).

2 In the **Settings** window locate the **Physics Area Settings** section.

- In the **Name** field enter `QuantumMechanics`.
- In the **Description** field enter `Quantum Mechanics`.
- The default **Icon** is `physics.png` ( ), which is appropriate for this physics. Otherwise, click **Browse** to use another icon.
- In the **Weight** field enter 10 to make the **Quantum Mechanics** area appear last in the list under **Mathematics** (the higher the weight, the lower position the physics area gets in the tree of physics interfaces).

3 Under **Parent Area** click the **Mathematics** node. Click the **Set as Parent** button ( ). This moves the new physics area under the **Mathematics** node.

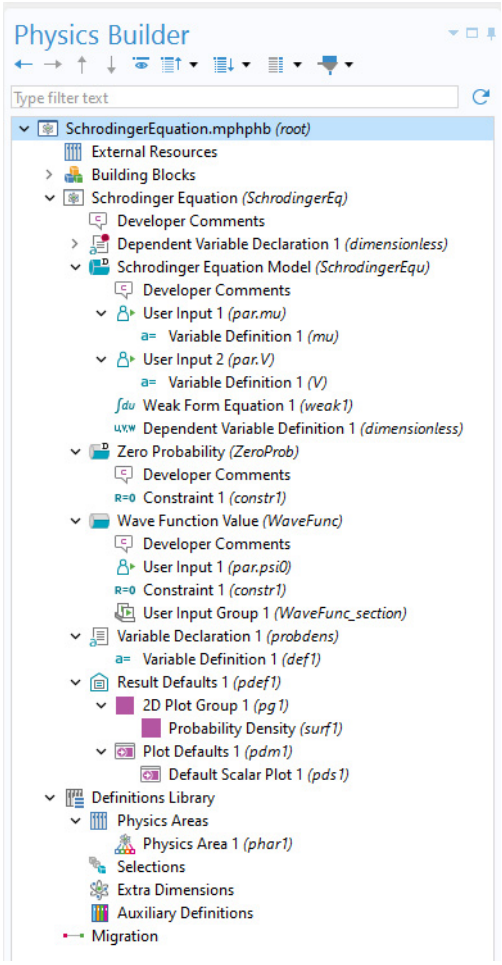
4 Click the **Schrodinger Equation** node. Locate the **Physics Area** section and click to expand it.

5 Expand the **Mathematics** branch and click **Quantum Mechanics**. Click the **Set as Parent** button ( ). This places the Schrodinger Equation interface under the **Quantum Mechanics** physics area.

6 Save the file that contains the physics interface as `SchrodingerEquation.mphphb`.

This completes the definition of this Schrodinger Equation interface. Save the file that contains the physics interface.

The final node sequence in the Physics Builder tree should match this figure:



Testing the Schrodinger Equation Interface

At any time during the implementation of a physics interface using the Physics Builder, you can launch an updated preview of the physics interface so that you can add feature nodes and check that the contents and behavior of the associated **Settings** windows and other functionality is as expected. To do so, select the main node for the physics interface implementation (for example, **Schrodinger Equation**) and then click the **Show Preview** button ( ) in the **Settings** window toolbar, or press F8. An instance of the physics interface then appears at the bottom of the Physics Builder tree.

When you are finished, update COMSOL Multiphysics to check that the Schrodinger Equation interface appears in the Model Wizard and that the functionality and settings appear as expected.

1 From the **Windows** menu or the **Home** toolbar, click **Physics Builder Manager** ( ).

2 Under **Archive Browser**, right-click the **Development Files** node ( ) and select **Add Builder File**. Browse to locate `SchrodingerEquation.mphphb`, select it, and click **Open**.

3 From **File** menu select **New** ( ).

4 Click **Model Wizard** ( ).

5 Select any space dimension except 0D.

6 On the **Select Physics** page, under **Mathematics** > **Quantum Mechanics** select **Schrodinger Equation (scheq)**. Click **Add**.

7 Click **Study** ( ).

8 On the **Select Study** page, verify that **Eigenvalue** is the only available study type under **General Studies**. Select it and click **Done** ( ).

9 In the Model Builder, verify that the default nodes appear as expected and that their **Settings** windows contain the user inputs that you specified. Also right-click the **Schrodinger Equation** node to add the **Wave Function Value** boundary condition, which is not available by default.

10 Proceed by building an example model (see Example Model — Hydrogen Atom) to verify that the Schrodinger Equation interface solves the correct equation using the correct boundary conditions and that you can plot the probability density function as a predefined expression.

11 Correct any errors or problems that you find and save the physics interface again.

When you have successfully created a first instance of a physics interface you can consider improvements or additions for future development. Typically you can save a model file and then reload it after updating the physics definitions to see how it behaves after applying some extensions or corrections.

The Physics Builder Manager

Example Model — Hydrogen Atom

In this section:

- Introduction to the Hydrogen Atom Model
- Results
- Modeling Instructions

Introduction to the Hydrogen Atom Model

The quantity $|\Psi|^2$ corresponds to the probability density function of the electron's position in a hydrogen atom. In this example,

$$\mu = \frac{Mm_e}{M + m_e} \approx m_e$$

where M equals the mass of the nucleus and m_e represents the mass of an electron ($9.1094 \cdot 10^{-31}$ kg). The hydrogen nucleus consists of a single proton (more than 1800 times heavier than the electron), so the approximation of μ is valid with a reasonable accuracy. Thus you can treat the problem as a one-particle system.

The system's potential energy is

$$V = -\frac{e^2}{4\pi\varepsilon_0 r}$$

where e equals the electron charge ($1.602 \cdot 10^{-19}$ C), ε_0 represents the permittivity of vacuum ($8.854 \cdot 10^{-12}$ F/m), and r is the distance from the center of the atom.

In the model, the boundary condition for the perimeter of the computational domain is a zero probability for the electron to be outside the specified domain. This means that the probability of finding the electron inside the domain is 1. It is important to have this approximation in mind when solving for higher-energy eigenvalues because the solution of the physical problem might fall outside the domain, and no eigenvalues are found for the discretized problem. Ideally the domain is infinite, and higher-energy eigenvalues correspond to the electron being further away from the nucleus.

Results

The solution provides a number of the lowest eigenvalues.

Three quantum numbers (n, l, m) characterize the eigenstates of a hydrogen atom:

- n is the principal quantum number.
- l is the angular quantum number.
- m is the magnetic quantum number.

These quantum numbers are not independent but have the following mutual relationships:

$$n = 1, 2, 3, \ldots$$
$$0 \le l \le n - 1$$
$$-l \le m \le l.$$

An analytical expression exists for the energy eigenvalues in terms of the quantum number n

$$E_n = -\frac{h^2}{8\pi^2 \mu a_0^2 n^2}$$

where

$$a_0 = \frac{h^2 \varepsilon_0}{\pi \mu e^2} \tag{4-4}$$

This expression is called the Bohr radius and has an approximate value of $5.3 \cdot 10^{-11}$ m.

The first three energy eigenvalues, according to the above expression with $\mu \approx m_e$, are:

- $E_1 \approx -2.180 \cdot 10^{-18}$ J
- $E_2 \approx -5.450 \cdot 10^{-19}$ J
- $E_3 \approx -2.422 \cdot 10^{-19}$ J

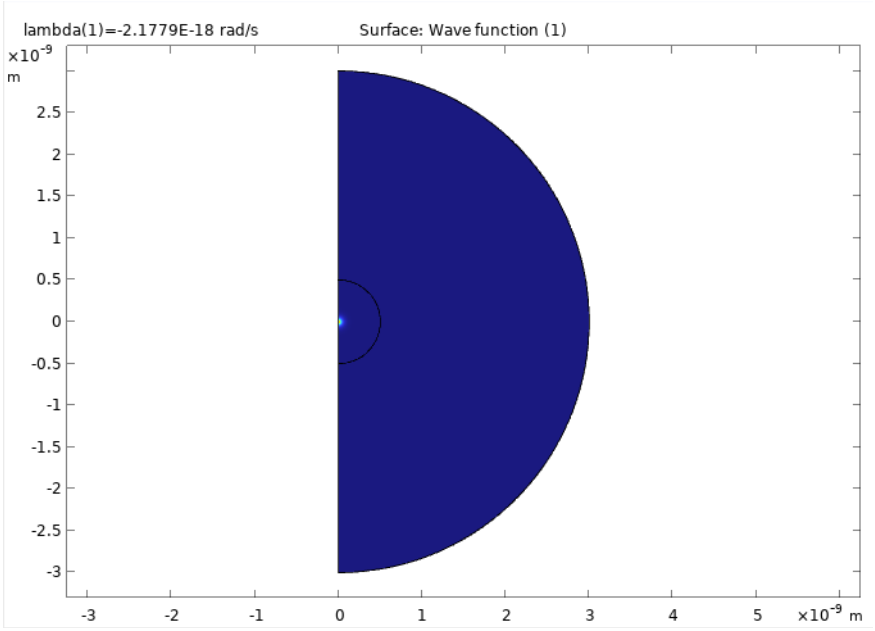


Figure 4-1: The wave function ψ *for the first energy eigenvalue.*

Comparing these numbers with the computed eigenvalues, you can see a 2-fold degeneracy for $n = 2$ and a 3-fold degeneracy for $n = 3$. This degeneracy corresponds to the following quantum triplets: (2,0,0) and (2,1,0); (3,0,0), (3,1,0), and (3,2,0). The computed values are separated due to the approximate numerical solution.

By refining the mesh and solving again, you can achieve more accurate results. The states with $l = 0$ correspond to spherically symmetric solutions, while states with $l = 1$ or 2 correspond to states with one or two radial node surfaces. The 0 energy level corresponds to the energy of a free electron no longer bounded to the nucleus. Energy levels closer to 0 correspond to excited states.

The wave function by itself has no direct physical interpretation. Another quantity to plot is $|\Psi|^2$, which is proportional to the probability density (unnormalized) function for the electron position after integration about the z-axis. The plot shows the unnormalized probability density function.

To determine the ground state energy, you can use adaptive mesh refinement.

Modeling Instructions

The following steps show how to build this model using the Schrodinger Equation interface.

MODEL WIZARD

1 Open COMSOL Multiphysics.

2 On the **New** page click **Model Wizard** ( ) then click the **2D Axisymmetric** button ( ) on the **Select Space Dimension** page.

3 On the **Select Physics** page under **Mathematics** > **Quantum Mechanics** click **Schrodinger Equation (scheq)** ( ).

4 Click **Add** and then the **Study** button ( ).

5 On the **Select Study** page, under **General Studies** click **Eigenvalue** ( ). Click **Done** ( ).

GEOMETRY MODELING

1 Under **Component 1** click **Geometry 1** ( ).

2 Add a **Circle** ( ). In the **Settings** window under **Size and Shape**, in the **Radius** field enter `3e-9` (3 nm). In the **Sector angle** field enter `180`.

3 Under **Position** from the **Base** list select **Center**. In the **r** field enter `0` and in the **z** field enter `0`, which centers the circle at the origin (these are the default settings).

4 Under **Rotation Angle**, in the **Rotation** field, enter `-90` degrees to create a semicircle in the right half-plane.

5 Click **Geometry 1**, and add a **Circle** ( ). In the **Settings** window under **Size and Shape**, in the **Radius** field enter `0.5e-9` (0.5 nm). In the **Sector angle** field enter `180`.

6 Under **Position** from the **Base** list select **Center**. In the **r** field enter `0` and in the **z** field enter `0`, which centers the circle at the origin (these are the default settings).

7 Under **Rotation Angle**, in the **Rotation** field, enter `-90` degrees to create a semicircle in the right half-plane.

8 Build the geometry by pressing F8. The final geometry consists of two semicircles in the $r > 0$ half-plane.

PHYSICS SETTINGS

1 Click the **Schrodinger Equation Model** node. In the **Settings** window the default in the **Reduced mass** field is the electron mass, m_e.

2 In the **Potential energy** field enter the following expression:

`-e_const^2/(4*pi*epsilon0_const*sqrt(r^2+z^2))`

where `e_const` and `epsilon0_const` are built-in physical constants for the electron charge and the permittivity of vacuum, respectively. `sqrt(r^2+z^2)` is the distance r from the origin. This expression is the potential energy in Equation 4-3.

3 Verify that the default boundary conditions are correct. Click the **Axial Symmetry** node and confirm it applies to the symmetry boundaries at $r = 0$. Click the **Zero Probability** node to confirm it applies to the exterior boundaries of the geometry.

MESH GENERATION

The reason for the inner circular domain is to use a finer mesh in that part because the solution shows greater variations in the center region than in the outer regions for low-energy eigenvalues.

1 Right-click the **Mesh** node ( ) and select **Size** ( ) to add a second **Size** node to define the mesh size in the inner circular domain (Domain 2).

2 In the **Settings** window for **Size 1**, select **Domain** from the **Geometric entity level** list.

3 Add domain `2` to the **Selection** list.

4 In the **Element Size** section click the **Custom** button.

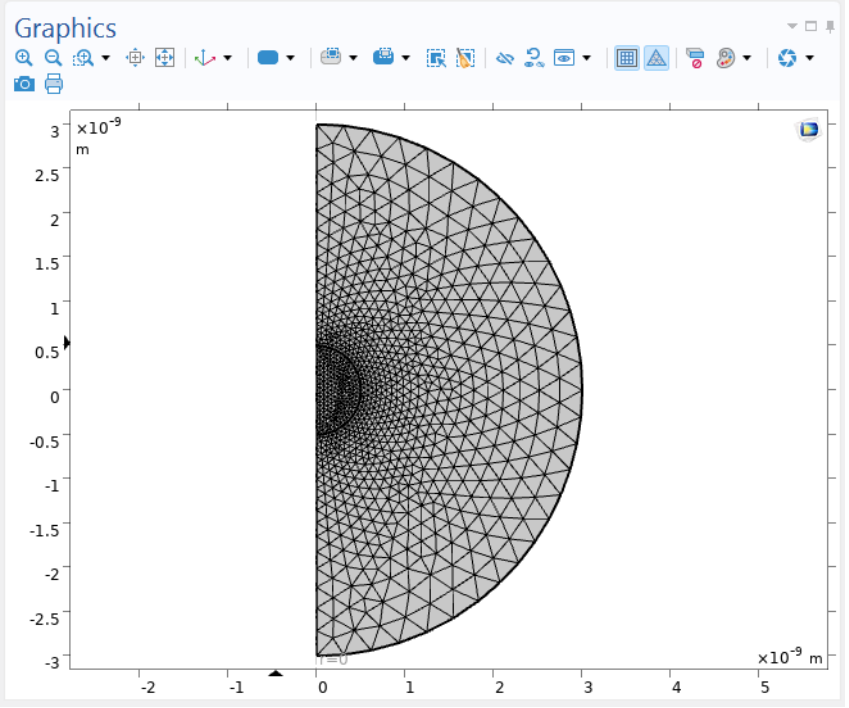
5 In the **Element Size Parameters** section, select the **Maximum element size** checkbox and enter `0.05e-9` in the corresponding field to use a mesh size no larger than 0.05 nm in domain 2.

6 Right-click the **Mesh** node ( ) and select **Free Triangular** ( ) to add a node that meshes domain 2 using the specified mesh size.

7 Click the top **Size** node. In its **Settings** window click to expand the **Element Size Parameters** section.

8 In the **Maximum element growth rate** field replace the default with `1.1` to make the mesh size grow more slowly toward the perimeter of the geometry.

9 In the Settings window click **Build All** ( ) to create the mesh.



COMPUTING THE SOLUTION

Specify that the eigenvalue solver should solve for 10 eigenvalues, searching around a small negative number where the first energy eigenvalues are located.

1 Under **Study 1** click **Step 1: Eigenvalue** ( ).

2 In the **Settings** window locate the top **Study Settings** section.

- In the **Desired number of eigenvalues** field enter `10` (after first selecting the checkbox).
- In the **Search for eigenvalues around shift** field enter `-2e-18` (after first selecting the checkbox).

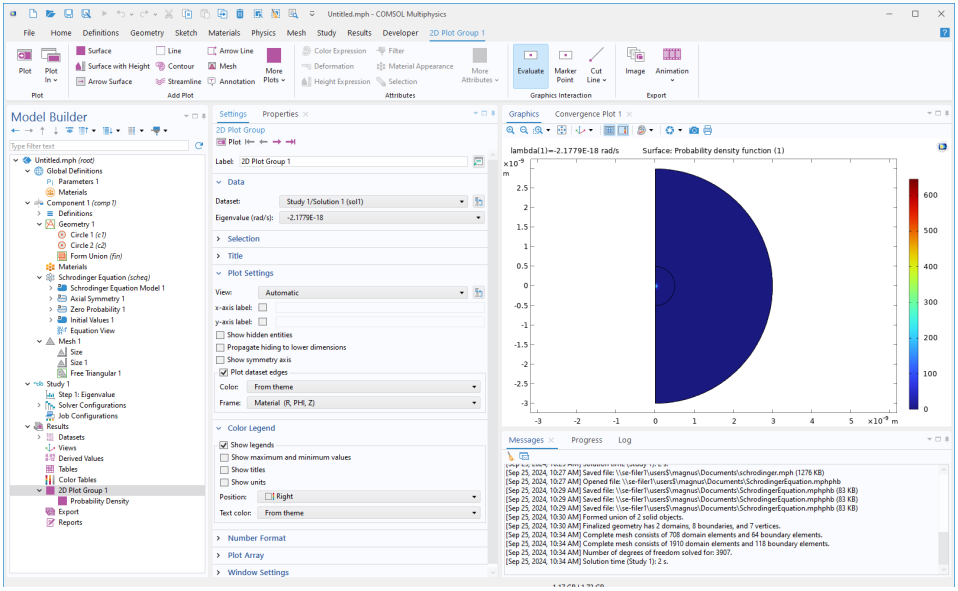
3 In the **Settings** window click **Compute** ( ) to start the eigenvalue solver.

RESULTS AND VISUALIZATION

By default, COMSOL Multiphysics shows a surface plot of the probability density function $|\Psi|^2$ for the first eigenmode. In the **Settings** window for the **Probability**

Density plot, you can also click the **Replace Expression** button ( ) and select **Schrodinger Equation** > **Wave function (psi)** to plot the variable `psi`, which is the complex-valued wave function for the electron position.

In the **Settings** window for the **2D Plot Group 1**, you can select which eigenmode to plot. Under **Data**, select the corresponding eigenvalue from the **Eigenvalue** list. You can also verify that the eigenvalues correspond to the first energy eigenvalues listed in Results.



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