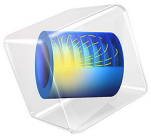


Model created in COMSOL Multiphysics 6.4

Cooling of a Prismatic Battery

Introduction

This tutorial models the internal temperature distribution in a prismatic battery during a high-rate charge.

The electrochemical model deploys a lumped two-electrode model to define the active layers of the battery cell (the "jelly roll"), in combination with a space-dependent model for the electronic current conduction in the current collectors plates (arrester tabs), the current collector foils and the terminals.

The resulting heat sources from the electrochemical model are coupled to a heat transfer model, where anisotropic thermal conductivities are used to define the layer orientation within the homogenized jelly roll domains.

Some model parameters and the geometry design were taken from Ref. 1. Experimental verification, using internal temperature probes, of a similar model has previously been reported in Ref. 2.

Model Definition

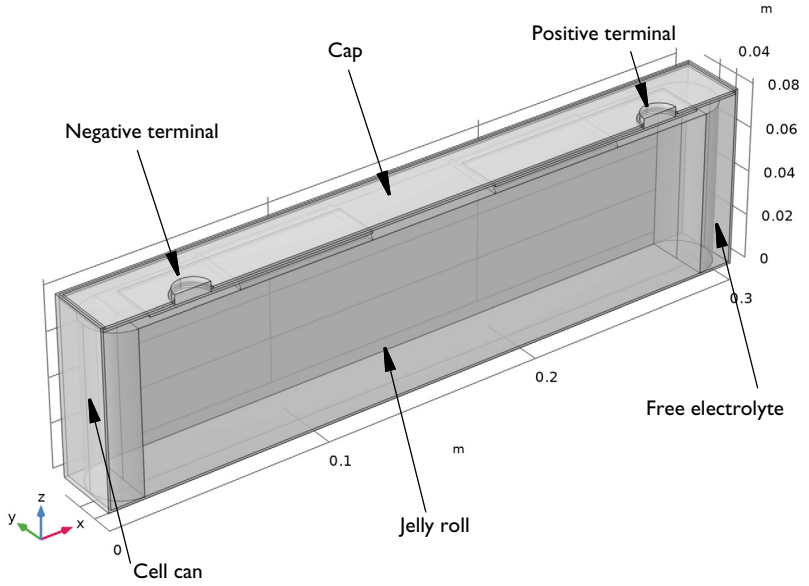


Figure 1: Model geometry.

The following domains and materials (taken from the **Built-in** material library, when available) are defined in the model geometry:

- Cell can (**Aluminum**)
- Cap (**Aluminum**)
- Spacer (**Acrylic plastic**)
- Seal (**Acrylic plastic**)
- Terminals (**Copper/Aluminum**)
- Current collector plates (**Copper/Aluminum**)
- Free electrolyte (user-defined **Electrolyte** material)
- Metal foils (homogenized mixture of **Copper/Aluminum** and **Electrolyte**)
- Jelly roll (user-defined properties, including anisotropic thermal conductivities)

Figure 1 shows the model geometry. Due to the symmetric design of the prismatic battery, comprising two jelly rolls, the model geometry defines one half of the full battery. The terminals, electrically insulated from the cap by the use of a plastic spacer and seal, are placed at the top of the geometry. The jelly roll is defined as a union of a rectangular block and two semi cylinders.

Figure 2 shows a closeup of the region around the negative terminal. The bundle of metal foils protruding from the jelly roll are defined as a single domain in the geometry.

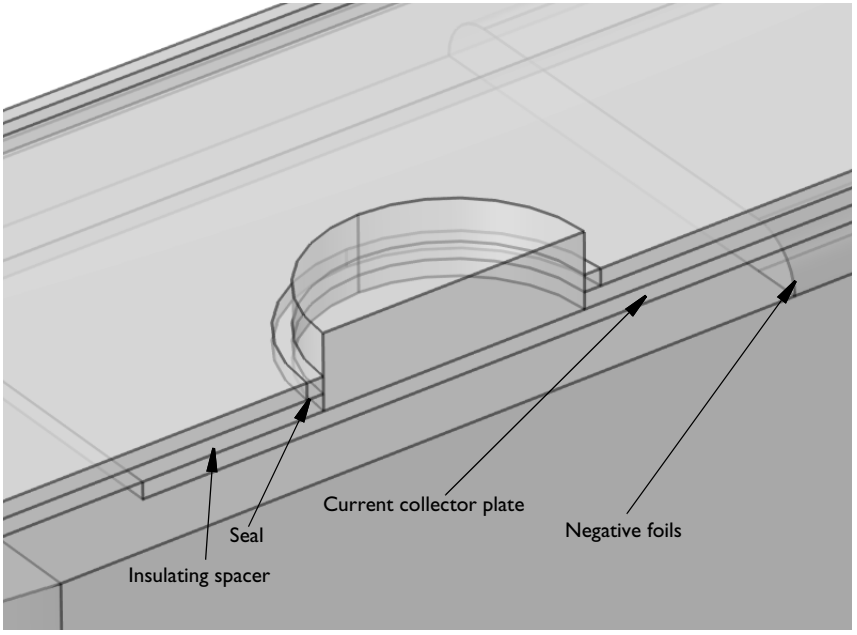


Figure 2: Closeup of the negative terminal, current collector plate and foils.

BATTERY CELL MODEL

The battery cell model in the jelly roll is defined using the **Lumped Battery, Two Electrodes** interface. The half-cell equilibrium potential curves for the two electrode materials, representing graphite and $LiFePO_4$ (LFP) are taken from the **Battery** material library.

The cell model is set to an initial state of charge (SOC) of 10% and is subjected to a 4C galvanostatic charge up to 80% SOC. The end SOC is implicitly defined by end time in the **Time Dependent** study node.

ELECTRIC POTENTIAL DISTRIBUTION IN THE CURRENT CONDUCTORS

A **Primary Current Distribution** interface is used to model the electric potential distribution in the current conductors (the terminals, the current collector plates and the foil domains). **Ground** conditions are used at the topmost boundaries of the terminals, whereas **Electrode Current** conditions corresponding to the 4C cell current are defined on the boundaries between the jelly roll and foil domains.

HEAT TRANSFER

A **Heat Transfer** interface is used to model the temperature distribution in the whole geometry, where the heat sources derived in the Lumped Battery and Primary Current Distribution interfaces are added by the use of **Electrochemical Heating** multiphysics nodes.

The metal foils bundles are treated as homogenized domains, where the thermal properties in the metal/electrolyte mix is defined by the use of **Porous Material** material nodes.

To handle the anisotropic thermal conductivity in the jelly roll, the **Battery Layers** node is used, defining different in-layer and through-layer thermal conductivities. This node automatically defines cylindrical coordinate systems, with different defined origins, for the two half cylinders, and a cartesian coordinate system for the rectangular block.

The battery is assumed to be placed on a cooling plate with a defined constant temperature. This is modeled using a **Temperature** boundary node, setting a fixed temperature of 35°C at the bottom exterior boundary. In addition, convective cooling conditions are added by the use of a **Heat Flux** node on the top and side boundaries. It is assumed that the battery is placed in an array of identical batteries, extending in the y direction. For this reason the default Thermal Insulation boundary condition is used on the front and back exterior boundaries.

The initial temperature of the battery is set to 35°C.

Figure 3 shows the battery voltage versus time. The plateaus in the cell voltage over time stem from the equilibrium potential profile of graphite (the negative electrode material).

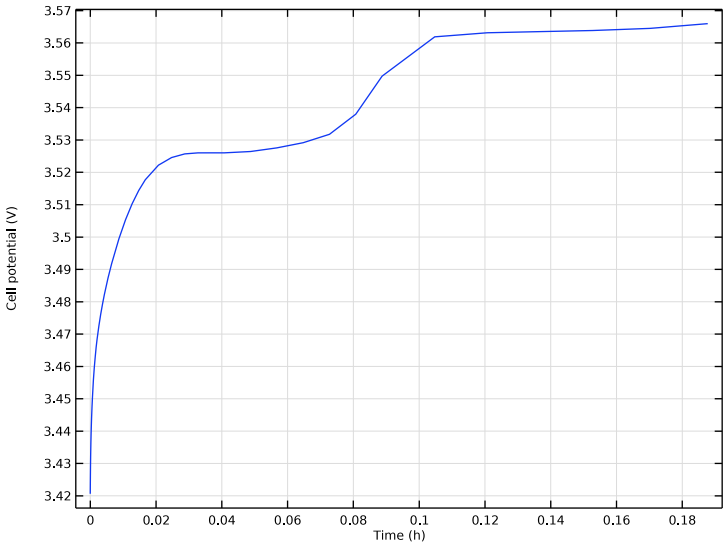


Figure 3: Cell voltage versus time.

Figure 4 shows the electric potential with respect to the end terminal boundaries in the current conductors. Slightly higher potential drops are seen in the positive current conductors. This an effect of the lower electrical conductivity of aluminum.

Figure 5 shows the temperature distribution (at the end of the simulation) in the whole battery. The highest temperatures are observed close to the terminals.

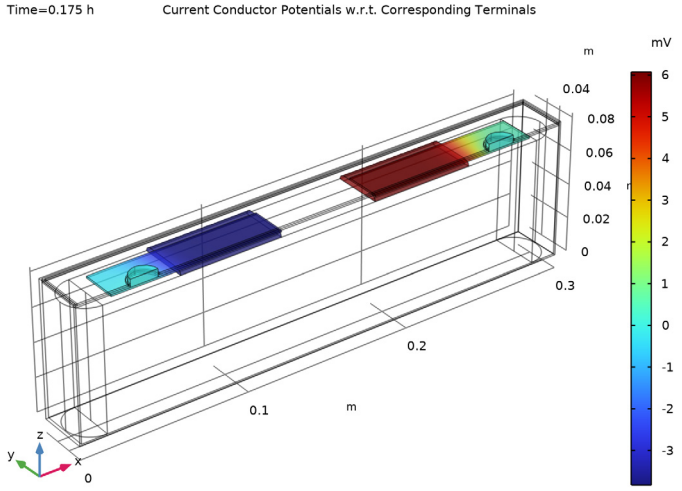


Figure 4: Electric potentials in the current conductors.

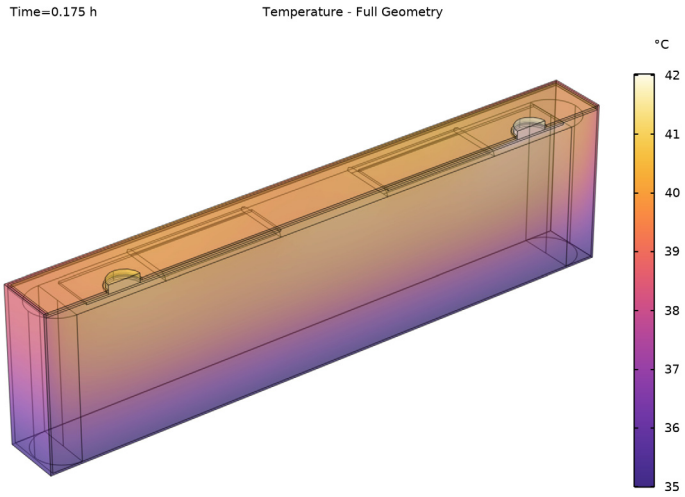


Figure 5: Temperature distribution in the whole battery.

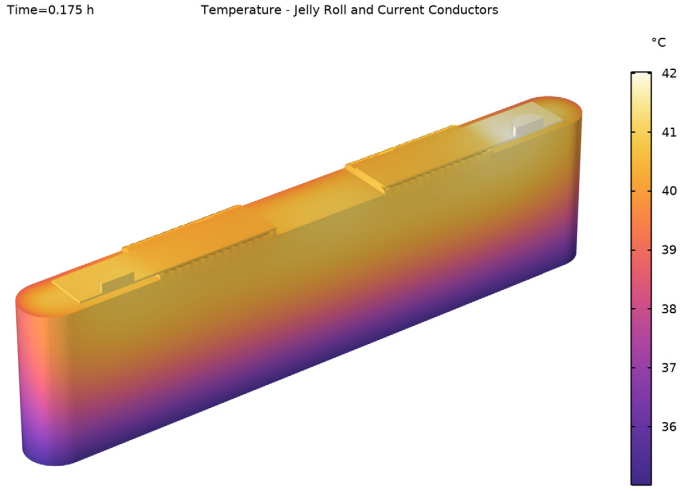


Figure 6: Temperature distribution in the current conductors and the jelly roll.

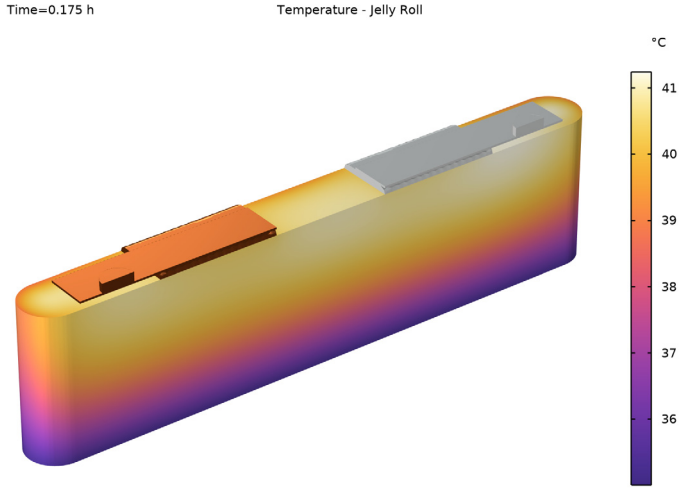


Figure 7: Temperature distribution in the jelly roll.

Figure 6 and Figure 7 shows the temperature distribution in the jelly roll and current conductors, and the jelly roll only, respectively, whereas Figure 8 shows a slice plot of the temperature in the jelly roll. The jelly roll temperature is generally higher in the regions closer to the positive terminal. This is an effect of the lower electric conductivity of the aluminum current conductors, giving rise to higher Joule heating heat sources.

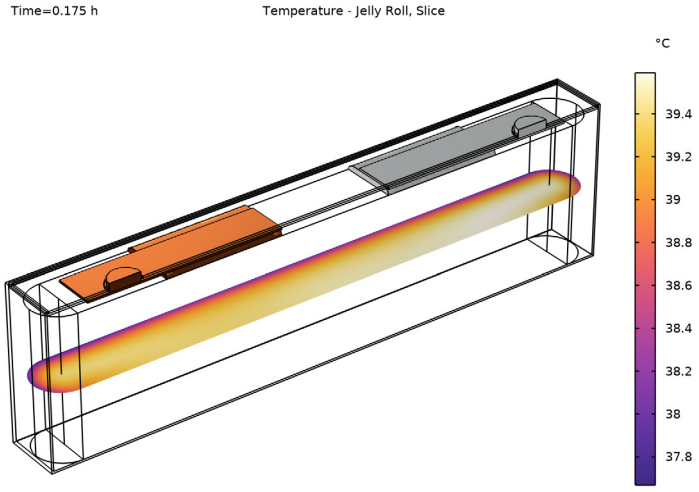


Figure 8: Temperature slice plot in the jelly roll.

References

1. *S.* Stock and others, "Cell teardown and characterization of an automotive prismatic LFP battery," *Electrochim. Acta*, vol. 471, 143341, 2023.

2. H. Lundgren and others, "Thermal Management of Large-Format Prismatic Lithium-Ion Battery in PHEV Application," *J. Electrochem. Soc.*, vol. 163, p. A309, 2016.

Application Library path: `Battery_Design_Module/Thermal_Management/prismatic_battery_cooling`

Modeling Instructions

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

NEW

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

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

In the first part of this tutorial, only the battery cell model for the jelly roll will be added. Current conduction in the other components and heat transfer will be added later.

2 In the **Select Physics** tree, select **Electrochemistry** > **Batteries** > **Lumped Battery, Two Electrodes (lb)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies** > **Time Dependent**.

6 Click **Done**.

GEOMETRY 1

First, load the geometry sequence of a full prismatic battery cell from a file. Next, partition the prismatic battery in half, in the zx-plane. Also use the **Mesh Control Faces** virtual operation to use the partitioned geometry for meshing, while maintaining the original domain numbers for selections and physics settings.

1 In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.

2 Browse to the model's Application Libraries folder and double-click the file `prismatic_battery_cooling_geom_sequence.mph`.

Mesh Control Faces 1 (mcf1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Mesh Control Faces**.

2 On the object **fin**, select Boundaries 6, 9, 19, 69, 72, 137, 140, and 157 only.

Work Plane 5 - Partition Plane

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, type `Work Plane 5 - Partition Plane` in the **Label** text field.

3 Locate the **Plane Definition** section. From the **Plane** list, choose **zx-plane**.

4 In the **y-coordinate** text field, type `D_can/2`.

Partition Objects 1 (par1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Partition Objects**.

2 Select the object **csol1** only.

3 In the **Settings** window for **Partition Objects**, locate the **Partition Objects** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click **Build Selected**.

Delete Entities 1 (del1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Delete Entities**.

2 In the **Settings** window for **Delete Entities**, locate the **Entities or Objects to Delete** section.

3 From the **Geometric entity level** list, choose **Domain**.

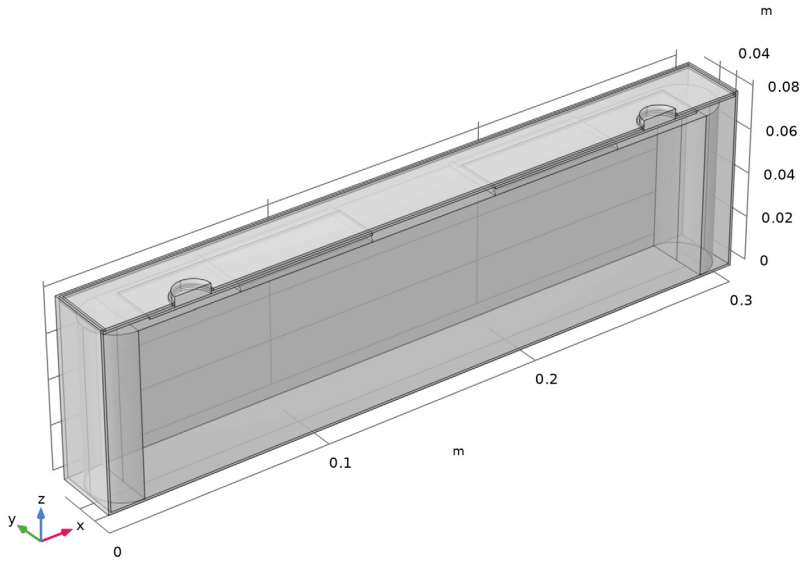
4 Click the **Select Box** button in the **Graphics** toolbar.

5 On the object **par1**, select Domains 1–3, 7–10, 15, 17, 19, 21, 24, 25, 27, 29, 31, 33, 34, 38, 39, 41, 43, 45, and 46 only.

6 In the **Geometry** toolbar, click **Build All**.

7 Click the **Transparency** button in the **Graphics** toolbar.

8 In the **Model Builder** window, click **Geometry 1**.



9 In the **Settings** window for **Geometry**, locate the **Cleanup** section.

10 Clear the **Automatic detection of small details** checkbox.

11 In the **Model Builder** window, collapse the **Geometry 1** node.

GLOBAL DEFINITIONS

Geometry Parameters

Some parameters were imported with the geometry sequence.

1. In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
2. In the **Settings** window for **Parameters**, type `Geometry Parameters` in the **Label** text field.

Physics Parameters

Add additional parameters for setting up the physics as follows:

1. In the **Home** toolbar, click **Parameters** and choose **Add** > **Parameters**.
2. In the **Settings** window for **Parameters**, type `Physics Parameters` in the **Label** text field.
3. Locate the **Parameters** section. Click **Load from File**.
4. Browse to the model's Application Libraries folder and double-click the file `prismatic_battery_cooling_physics_parameters.txt`.

Add some data for the graphite and LFP electrode from the **Battery** material library as follows:

ADD MATERIAL

1. In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.
2. Go to the **Add Material** window.
3. In the tree, select **Battery** > **Electrodes** > **Graphite, LixC6 MCMB (Negative, Li-ion Battery)**.
4. Right-click and choose **Add to Global Materials**.
5. In the tree, select **Battery** > **Electrodes** > **LFP, LiFePO4 (Positive, Li-ion Battery)**.
6. Right-click and choose **Add to Global Materials**.
7. In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

LUMPED BATTERY (LB)

1. In the **Settings** window for **Lumped Battery**, locate the **Domain Selection** section.
2. From the **Selection** list, choose **Jelly Roll**.
3. Locate the **Operation Mode** section. From the list, choose **C-rate multiple**.
4. In the C_{rate} text field, type `C_rate`.
5. Locate the **Initial Capacity** section. In the $Q_{host,neg,0}$ text field, type `Q_host_neg`.
6. In the $Q_{host,pos,0}$ text field, type `Q_host_pos`.

7 Locate the **Initial Cell Charge Distribution** section. In the $\mathrm{SOC}_{\mathrm{cell},0}$ text field, type `SOC_init`.

Negative Equilibrium Potential 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Lumped Battery (lb)** click **Negative Equilibrium Potential 1**.

2 In the **Settings** window for **Negative Equilibrium Potential**, locate the **Material** section.

3 From the **Electrode material** list, choose **Graphite, LixC6 MCMB (Negative, Li-ion Battery) (mat1)**.

Positive Equilibrium Potential 1

1 In the **Model Builder** window, click **Positive Equilibrium Potential 1**.

2 In the **Settings** window for **Positive Equilibrium Potential**, locate the **Material** section.

3 From the **Electrode material** list, choose **LFP, LiFePO4 (Positive, Li-ion Battery) (mat2)**.

Voltage Losses 1

1 In the **Model Builder** window, click **Voltage Losses 1**.

2 In the **Settings** window for **Voltage Losses**, locate the **Ohmic Overpotential** section.

3 In the $\eta_{\mathrm{IR},1\mathrm{C}}$ text field, type `eta_1C`.

4 Locate the **Activation Overpotential, Negative** section. In the $J_{0,\mathrm{neg}}$ text field, type `J0`.

5 Locate the **Activation Overpotential, Positive** section. In the $J_{0,\mathrm{pos}}$ text field, type `J0`.

6 Locate the **Concentration Overpotential, Negative** section. Select the **Include concentration overpotential, negative** checkbox.

7 In the τ_{neg} text field, type `tau_neg`.

8 Locate the **Concentration Overpotential, Positive** section. Select the **Include concentration overpotential, positive** checkbox.

9 In the τ_{pos} text field, type `tau_pos`.

DEFINITIONS (COMP1)

Global Variable Probe 1 (var1)

In the **Definitions** toolbar, click  **Probes** and choose **Global Variable Probe**.

STUDY 1

The battery cell model for the jelly roll is now ready for solving.

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 1** click **Step 1: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 From the **Time unit** list, choose **h**.

4 In the **Output times** text field, type `range(0,0.1/C_rate,SOC_window/C_rate)`.

5 In the **Study** toolbar, click **Compute**.

RESULTS

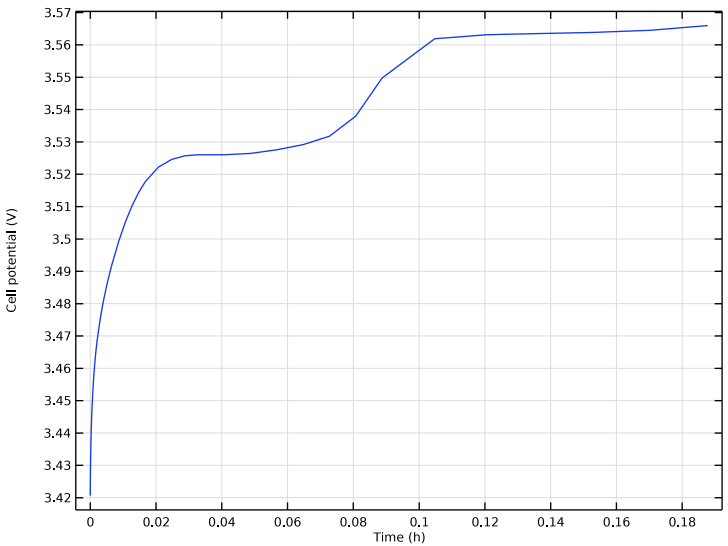
Jelly Roll Voltage Probe

1 In the **Model Builder** window, under **Results** click **Probe Plot Group 1**.

2 In the **Settings** window for **1D Plot Group**, type `Jelly Roll Voltage Probe` in the **Label** text field.

3 Locate the **Legend** section. Clear the **Show legends** checkbox.

4 In the **Jelly Roll Voltage Probe** toolbar, click **Plot**.



Now add a model for the current distribution in the current conductors external to the jelly roll.

ADD PHYSICS

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

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

3 In the tree, select **Electrochemistry** > **Primary and Secondary Current Distribution** > **Primary Current Distribution (cd)**.

4 Click the **Add to Component 1** button in the window toolbar.

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

PRIMARY CURRENT DISTRIBUTION (CD)

1 In the **Settings** window for **Primary Current Distribution**, locate the **Domain Selection** section.

2 From the **Selection** list, choose **Current Conductors**.

Current Conductor 1

1 In the **Physics** toolbar, click **Domains** and choose **Current Conductor**.

2 In the **Settings** window for **Current Conductor**, locate the **Domain Selection** section.

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

Electric Ground 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Electric Ground**.

2 In the **Settings** window for **Electric Ground**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Negative Terminal Boundary**.

Electric Ground 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Electric Ground**.

2 In the **Settings** window for **Electric Ground**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Positive Terminal Boundary**.

Electrode Current 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Current**.

2 In the **Settings** window for **Electrode Current**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Negative Foils - Jelly Roll Boundaries**.

The total current is defined by making use of a variable defined by the **Lumped Battery** interface.

4 Locate the **Electrode Current** section. In the $I_{\mathrm{s,total}}$ text field, type `-lb.I_1C_cell* C_rate`.

Electrode Current 2

1 Right-click **Electrode Current 1** and choose **Duplicate**.

2 In the **Settings** window for **Electrode Current**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Positive Foils - Jelly Roll Boundaries**.

4 Locate the **Electrode Current** section. In the $I_{s,total}$ text field, type `lb.I_1C_cell*C_rate`.

MATERIALS

Add the needed material data for the current conductors as follows:

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.
2 Go to the **Add Material** window.
3 In the tree, select **Built-in** > **Aluminum**.
4 Right-click and choose **Add to Component 1 (comp1)**.

MATERIALS

Aluminum (mat3)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Materials** click **Aluminum (mat3)**.
2 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
3 From the **Selection** list, choose **Battery Aluminum Domains**.

ADD MATERIAL

1 Go to the **Add Material** window.
2 In the tree, select **Built-in** > **Copper**.
3 Right-click and choose **Add to Component 1 (comp1)**.
4 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Copper (mat4)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
2 From the **Selection** list, choose **Negative Foils, CCs and Terminal**.

STUDY 1

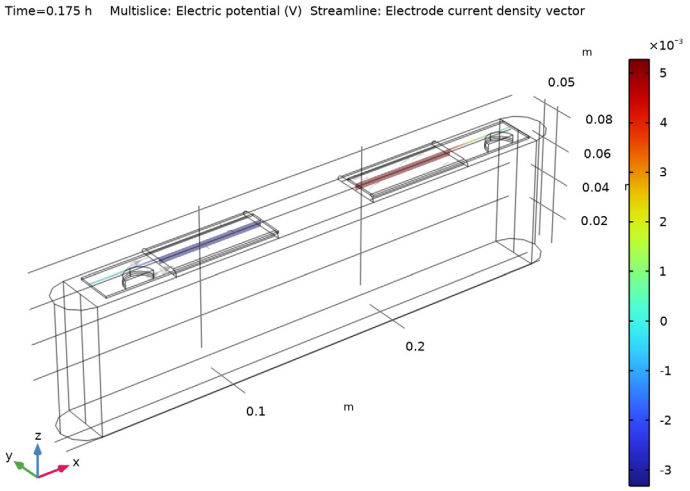
Solver Configurations

1 In the **Model Builder** window, under **Study 1** right-click **Solver Configurations** and choose **Delete Configurations**.
2 In the **Study** toolbar, click **Compute**.

RESULTS

Electrode Potential with Respect to Ground (cd)

Inspect the default plot for the electric potential in the current conductors.



You will create a more polished version of this plot later.

COMPONENT 1 (COMP1)

Now proceed to add the heat transfer part of the model.

ADD PHYSICS

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

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

3 In the tree, select **Heat Transfer** > **Heat Transfer in Solids (ht)**.

4 Click the **Add to Component 1** button in the window toolbar.

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

HEAT TRANSFER IN SOLIDS (HT)

Initial Values 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Heat Transfer in Solids (ht)** click **Initial Values 1**.

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

3 In the T text field, type `T0`.

Porous Medium 1

The foil domains are modeled as porous media, consisting of a mix of metal conductors and electrolyte.

1 In the **Physics** toolbar, click **Domains** and choose **Porous Medium**.

2 In the **Settings** window for **Porous Medium**, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Foils**.

Battery Layers 1

Define the heat transfer within the jelly roll as follows:

1 In the **Physics** toolbar, click **Domains** and choose **Battery Layers**.

2 In the **Settings** window for **Battery Layers**, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Jelly Roll**.

4 Locate the **Battery Layers** section. From the **Layer configuration** list, choose **Flat-sided oval (prismatic)**.

5 In the k_{tl} text field, type `kT_batt_tl`.

6 In the k_{il} text field, type `kT_batt_il`.

7 In the ρ_{eff} text field, type `rho_batt`.

8 In the $C_{\mathrm{p,eff}}$ text field, type `Cp_batt`.

Rectangular Block Selection 1

1 In the **Model Builder** window, click **Rectangular Block Selection 1**.

2 In the **Settings** window for **Rectangular Block Selection**, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Jelly Roll Rectangular Blocks**.

4 Locate the **Battery Layers** section. From the **Through-layer direction** list, choose **y-axis**.

Temperature 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Temperature**.

2 Select Boundary 3 only.

3 In the **Settings** window for **Temperature**, locate the **Temperature** section.

4 In the T_0 text field, type `T0`.

Heat Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Battery Convective Boundaries**.

4 Locate the **Heat Flux** section. From the **Flux type** list, choose **Convective heat flux**.

5 In the h text field, type `htc`.

6 In the T_{ext} text field, type `T0`.

MATERIALS

Now add the remaining required material properties for the heat transfer model.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

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

3 In the tree, select **Built-in** > **Acrylic plastic**.

4 Right-click and choose **Add to Component 1 (comp1)**.

5 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Acrylic plastic (mat5)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Selection** list, choose **Spacer and Seal**.

Electrolyte

1 In the **Model Builder** window, right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Electrolyte` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Selection** list, choose **Free Electrolyte**.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	1	W/(m·K)	Basic
Density	rho	1000	kg/m³	Basic
Heat capacity at constant pressure	Cp	1000	J/(kg·K)	Basic

Porous Material - Homogenized Negative Foils

1 Right-click **Materials** and choose **More Materials** > **Porous Material**.

2 In the **Settings** window for **Porous Material**, type `Porous Material - Homogenized Negative Foils` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Selection** list, choose **Negative Foils**.

Fluid 1 (pmat1.fluid1)

1 Right-click **Porous Material - Homogenized Negative Foils** and choose **Fluid**.

2 In the **Settings** window for **Fluid**, locate the **Fluid Properties** section.

3 From the **Material** list, choose **Electrolyte (mat6)**.

Solid 1 (pmat1.solid1)

1 In the **Model Builder** window, right-click **Porous Material - Homogenized Negative Foils (pmat1)** and choose **Solid**.

2 In the **Settings** window for **Solid**, locate the **Solid Properties** section.

3 From the **Material** list, choose **Copper (mat4)**.

4 In the θ_s text field, type `eps_cc_neg`.

Porous Material - Homogenized Negative Foils (pmat1)

1 In the **Model Builder** window, click **Porous Material - Homogenized Negative Foils (pmat1)**.

2 In the **Settings** window for **Porous Material**, locate the **Homogenized Properties** section.

3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Electric conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	`eps_cc_neg* 5.998e7[S/m]`	S/m	Basic

Porous Material - Homogenized Positive Foils

1 In the **Model Builder** window, right-click **Materials** and choose **More Materials** > **Porous Material**.

2 In the **Settings** window for **Porous Material**, type `Porous Material - Homogenized Positive Foils` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Selection** list, choose **Positive Foils**.

Fluid 1 (pmat2.fluid1)

1 Right-click **Porous Material - Homogenized Positive Foils** and choose **Fluid**.

2 In the **Settings** window for **Fluid**, locate the **Fluid Properties** section.

3 From the **Material** list, choose **Electrolyte (mat6)**.

Solid 1 (pmat2.solid1)

1 In the **Model Builder** window, right-click **Porous Material - Homogenized Positive Foils (pmat2)** and choose **Solid**.

2 In the **Settings** window for **Solid**, locate the **Solid Properties** section.

3 From the **Material** list, choose **Aluminum (mat3)**.

4 In the θ_s text field, type `eps_cc_pos`.

Porous Material - Homogenized Positive Foils (pmat2)

1 In the **Model Builder** window, click **Porous Material - Homogenized Positive Foils (pmat2)**.

2 In the **Settings** window for **Porous Material**, locate the **Homogenized Properties** section.

3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Electric conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	`eps_cc_pos*3.774e7[S/m]`	S/m	Basic

MULTIPHYSICS

Finally, add **Multiphysics** nodes to couple the heat transfer model to the electrochemistry interfaces.

Electrochemical Heating 1 (ech1)

In the **Physics** toolbar, click **Multiphysics Couplings** and choose **Domain** > **Electrochemical Heating**.

Electrochemical Heating 2 (ech2)

1 In the **Physics** toolbar, click **Multiphysics Couplings** and choose **Domain** > **Electrochemical Heating**.

2 In the **Settings** window for **Electrochemical Heating**, locate the **Coupled Interfaces** section.

3 From the **Electrochemical** list, choose **Primary Current Distribution (cd)**.

MESH 1

For this model, create a user-defined mesh, where you make use of swept meshes in the *z* direction in order to reduce the number of mesh elements.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Sequence Type** section.

3 From the list, choose **User-controlled mesh**.

4 In the **Mesh** toolbar, click  **Clear Sequence**.

Free Tetrahedral 1

1 In the **Mesh** toolbar, click  **Free Tetrahedral**.

2 In the **Settings** window for **Free Tetrahedral**, locate the **Domain Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Battery Free Tet Domains**.

Size 1

1 Right-click **Free Tetrahedral 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Edge**.

4 From the **Selection** list, choose **Jelly Roll Envelope Edges**.

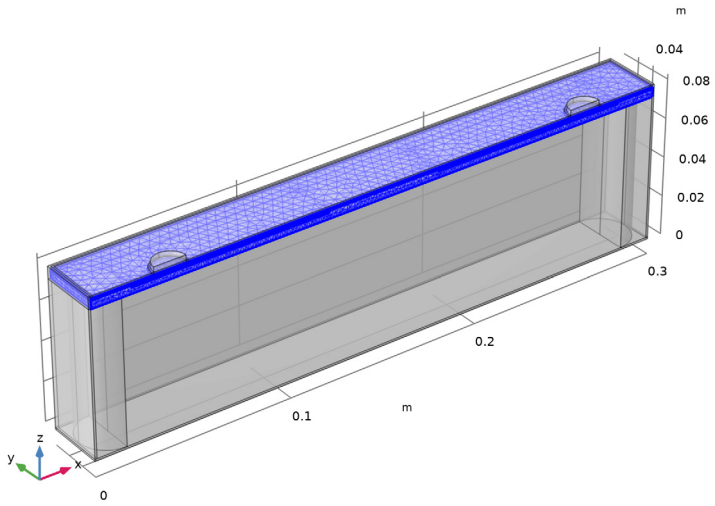
5 Locate the **Element Size** section. Click the **Custom** button.

6 Locate the **Element Size Parameters** section.

7 Select the **Maximum element size** checkbox. In the associated text field, type `s_can*2`.

Free Tetrahedral 1

In the **Model Builder** window, right-click **Free Tetrahedral 1** and choose **Build Selected**.



Swept 1

1 In the **Mesh** toolbar, click **Swept**.

2 In the **Settings** window for **Swept**, locate the **Domain Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Battery Upper Sweep Domains**.

Size 1

1 Right-click **Swept 1** and choose **Size**.

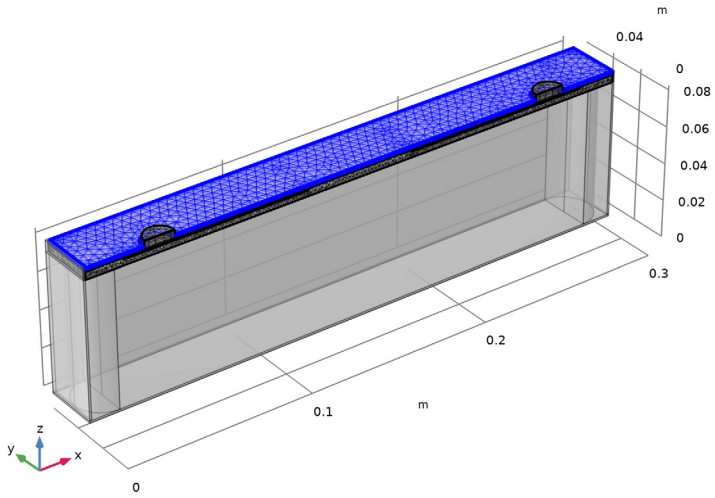
2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section.

5 Select the **Maximum element size** checkbox. In the associated text field, type `s_can`.

6 Click **Build Selected**.



Free Tetrahedral 2

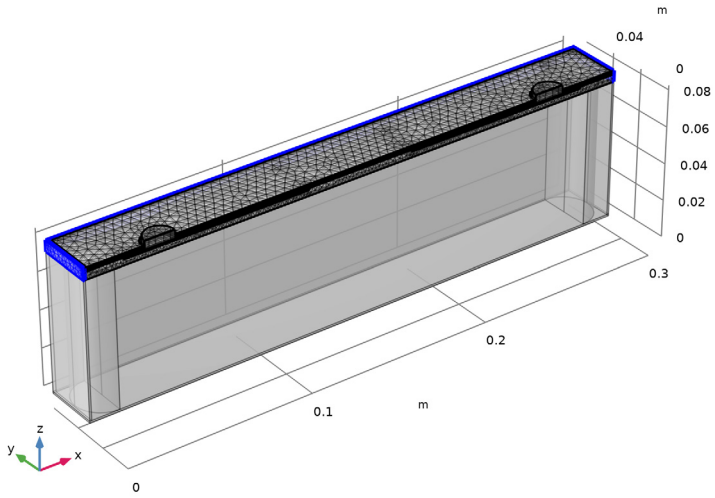
1 In the **Mesh** toolbar, click **Free Tetrahedral**.

2 In the **Settings** window for **Free Tetrahedral**, locate the **Domain Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Battery Other Free Tet Domains**.

5 Click **Build Selected**.



Swept 2

In the **Mesh** toolbar, click **Swept**.

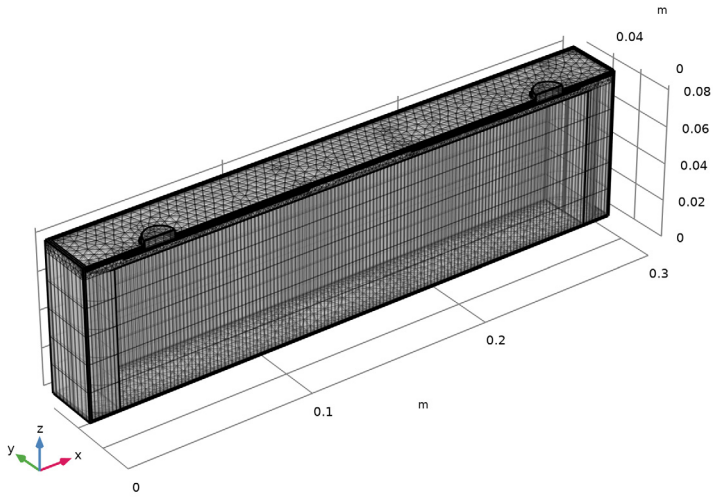
Distribution 1

1 Right-click **Swept 2** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Extrude - Jelly Roll and Can**.

4 In the **Model Builder** window, right-click **Mesh 1** and choose **Build All**.



STUDY 1

The full model is now ready for solving.

Solver Configurations

1 In the **Model Builder** window, under **Study 1** right-click **Solver Configurations** and choose **Delete Configurations**.

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

3 Clear the **Generate default plots** checkbox.

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

RESULTS

Current Conductor Potentials w.r.t. Corresponding Terminals

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Current Conductor Potentials w.r.t. Corresponding Terminals` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **Label**.

4 Locate the **Color Legend** section. Select the **Show units** checkbox.

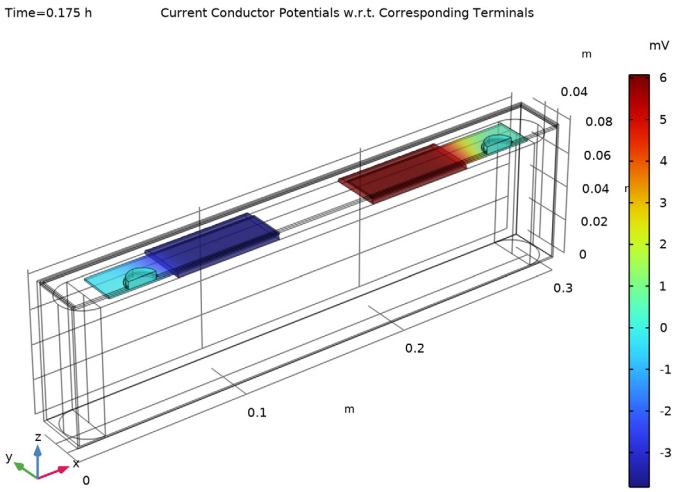
Surface 1

1 Right-click **Current Conductor Potentials w.r.t. Corresponding Terminals** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Primary Current Distribution** > **cd.phis - Electric potential - V**.

3 Locate the **Expression** section. From the **Unit** list, choose **mV**.

4 In the **Current Conductor Potentials w.r.t. Corresponding Terminals** toolbar, click **Plot**.



Temperature - Full Geometry

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Temperature - Full Geometry` in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **Label**.

4 Locate the **Color Legend** section. Select the **Show units** checkbox.

Volume 1

1 Right-click **Temperature - Full Geometry** and choose **Volume**.

2 In the **Settings** window for **Volume**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Heat Transfer in Solids** > **Temperature** > **T - Temperature - K**.

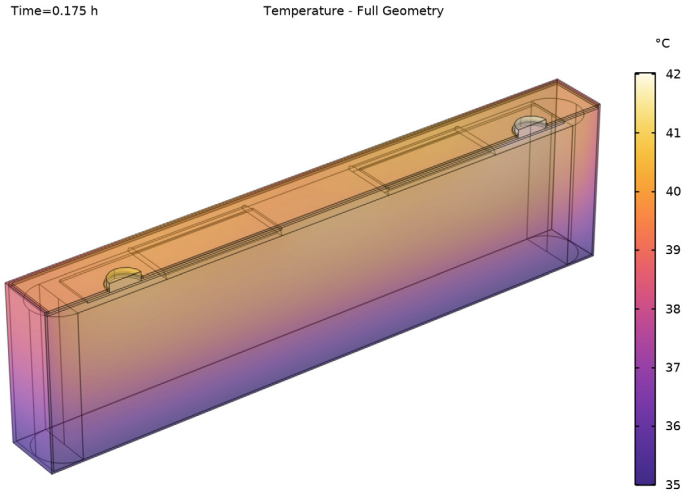
3 Locate the **Expression** section. From the **Unit** list, choose **°C**.

4 Locate the **Coloring and Style** section. From the **Color table** list, choose **HeatCameraLight**.

5 Click the **Show Grid** button in the **Graphics** toolbar.

6 Click the **Show Axis Orientation** button in the **Graphics** toolbar.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.



Temperature - Jelly Roll and Current Conductors

1 In the **Model Builder** window, right-click **Temperature - Full Geometry** and choose **Duplicate**.

2 In the **Settings** window for **3D Plot Group**, type `Temperature - Jelly Roll and Current Conductors` in the **Label** text field.

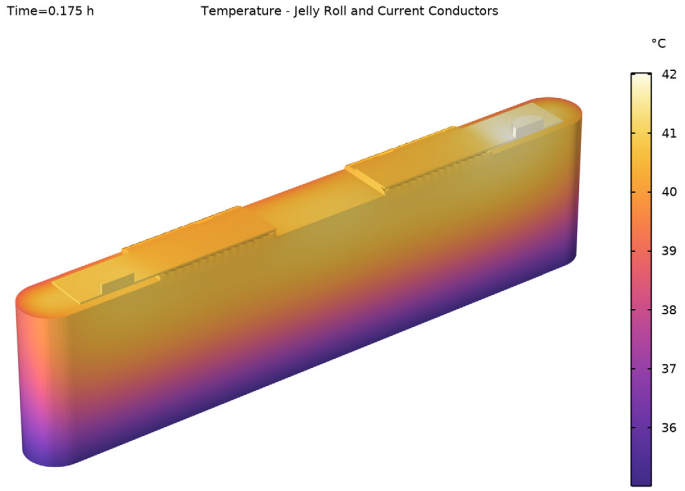
3 Click to expand the **Selection** section. From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Jelly Roll and Current Conductors**.

5 Locate the **Plot Settings** section. Clear the **Plot dataset edges** checkbox.

6 Click the **Transparency** button in the **Graphics** toolbar.

7 In the **Temperature - Jelly Roll and Current Conductors** toolbar, click **Plot**.



Temperature - Jelly Roll

1 Right-click **Temperature - Jelly Roll and Current Conductors** and choose **Duplicate**.

2 In the **Settings** window for **3D Plot Group**, type `Temperature - Jelly Roll` in the **Label** text field.

3 Locate the **Selection** section. From the **Selection** list, choose **Jelly Roll**.

Volume 2

1 Right-click **Temperature - Jelly Roll** and choose **Volume**.

2 In the **Settings** window for **Volume**, locate the **Expression** section.

3 In the **Expression** text field, type `1`.

Selection 1

1 Right-click **Volume 2** and choose **Selection**.

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

3 From the **Selection** list, choose **Current Conductors**.

Material Appearance 1

In the **Model Builder** window, right-click **Volume 2** and choose **Material Appearance**.

Selection 1

1 In the **Settings** window for **Selection**, locate the **Selection** section.

2 From the **Selection** list, choose **Negative Foils, CCs and Terminal**.

Material Appearance 1

1 In the **Model Builder** window, click **Material Appearance 1**.

2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.

3 From the **Material** list, choose **Copper (mat4)**.

Volume 3

In the **Model Builder** window, under **Results** > **Temperature - Jelly Roll** right-click **Volume 2** and choose **Duplicate**.

Selection 1

1 In the **Model Builder** window, expand the **Volume 3** node, then click **Selection 1**.

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

3 From the **Selection** list, choose **Positive Foils, CCs and Terminal**.

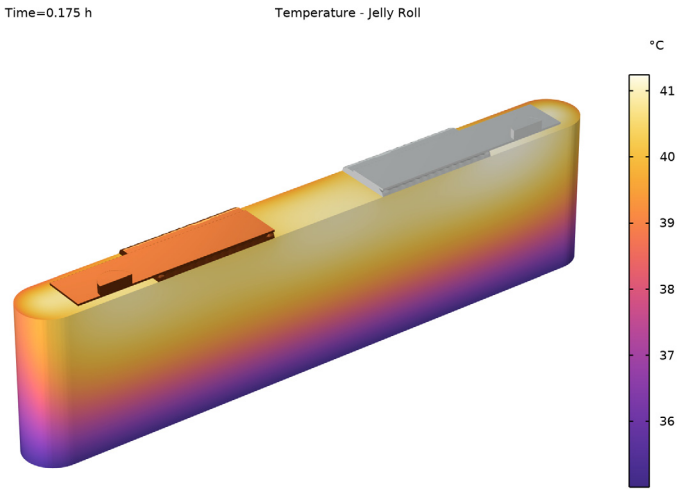
Material Appearance 1

1 In the **Model Builder** window, click **Material Appearance 1**.

2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.

3 From the **Material** list, choose **Aluminum (mat3)**.

4 In the **Temperature - Jelly Roll** toolbar, click **Plot**.



Temperature - Jelly Roll, Slice

1 In the **Model Builder** window, right-click **Temperature - Jelly Roll** and choose **Duplicate**.

2 In the **Settings** window for **3D Plot Group**, type `Temperature - Jelly Roll, Slice` in the **Label** text field.

Volume 1

1 In the **Model Builder** window, expand the **Temperature - Jelly Roll, Slice** node.

2 Right-click **Volume 1** and choose **Delete**.

Temperature - Jelly Roll, Slice

1 In the **Model Builder** window, under **Results** click **Temperature - Jelly Roll, Slice**.

2 In the **Settings** window for **3D Plot Group**, locate the **Plot Settings** section.

3 Select the **Plot dataset edges** checkbox.

Slice 1

1 Right-click **Temperature - Jelly Roll, Slice** and choose **Slice**.

2 In the **Settings** window for **Slice**, locate the **Expression** section.

3 In the **Expression** text field, type `T`.

4 From the **Unit** list, choose **°C**.

5 Locate the **Plane Data** section. From the **Plane** list, choose **XY-planes**.

6 From the **Entry method** list, choose **Coordinates**.

7 In the **Z-coordinates** text field, type `H_jelly/2`.

8 Locate the **Coloring and Style** section. From the **Color table** list, choose **HeatCameraLight**.

9 In the **Temperature - Jelly Roll, Slice** toolbar, click **Plot**.