MET 440 Test 2 | Frank Nguyen

(1) **Purpose**

Find the temperature profile equation for a hemisphere with heat generation that follows:

$$g = g_0 \frac{b^2}{r^2}$$

and boundary conditions:

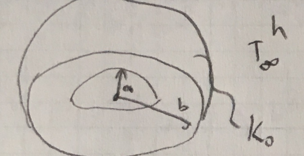
$r = a \quad \frac{dT}{dr} = 0$

$r = b \quad -k\frac{dT}{dr} = h(T - T_\infty)$

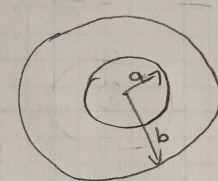
with thermal conductivity that follows:

$$k = k_0 \frac{b^2}{r^2}$$

Drawings and Diagrams:



Cross section view:



Sources

- Bopezitov, Y. Ozisik, N, "A textbook for heat transfer fundamentals, Begell House inc, (2012)
- Comsol

Design considerations

- Steady state
- Constant properties
- One dimensional radial heat transfer

Data and variables – See drawing.

Procedure – I will start by differentiating the appropriate differential equation for a hemisphere. Then I will integrate following the heat generation equation and get 2 constants (C_1 and C_2). I will evaluate the 2 boundary conditions and then plug C_1 and C_2 into equation for T.

Calculations

- Differential equation for sphere with heat generation, when thermal conductivity depends on radius.

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 k \frac{dT}{dr}\right) + g = 0 \quad W/m\cdot K.$$

$$\frac{dT}{dr} = 0 \quad \text{at } r = a$$

$$-k\frac{dT}{dr} = h(T - T_\infty) \quad \text{at } r = b$$

$$g = g_0 \frac{b^2}{r^2} \quad \text{and} \quad k = k_0 \frac{b^2}{r^2}$$

- Start to integrate:

$$\frac{d}{dr}\left(r^2 k \frac{dT}{dr}\right) = -r^2 g$$

$$\frac{d}{dr}\left(r^2 k_0 \frac{b^2}{r^2}\frac{dT}{dr}\right) = -r^2 g_0 \frac{b^2}{r^2}$$

- now:

$$dr \cdot \frac{d}{dr}\left(k_0 b^2 \frac{dT}{dr}\right) = -g_0 b^2 \, dr$$

$$d\left(k_0 b^2 \frac{dT}{dr}\right) = -g_0 b^2 dr$$

Integrate:

$$\int d\left(k_0 b^2 \frac{dT}{dr}\right) = -g_0 b^2 \int dr$$

$$\frac{k_0 b^2 \frac{dT}{dr}}{k_0 b^2} = \frac{-g_0 b^2 r + C_1}{k_0 b^2} \Rightarrow \frac{dT}{dr} = -\frac{g_0}{k_0} r + \frac{C_1}{k_0 b^2}$$

$$dr\left(\frac{dT}{dr}\right) = \left(\frac{-g_0 b^2 r}{k_0 b^2} + \frac{C_1}{k_0 b^2}\right) dr$$

Integrating again:

$$dT = -\frac{g_0}{k_0} r\, dr + \frac{C_1}{k_0 b^2} dr$$

$$\int dT = -\frac{g_0}{k_0}\int r\,dr + \frac{C_1}{k_0 b^2}\int dr$$

$$T = \frac{-g_0}{k_0}\frac{r^2}{2} + \frac{C_1}{k_0 b^2} r + C_2$$

$$\boxed{T = \frac{-g_0}{2k_0} r^2 + \frac{C_1}{k_0 b^2} r + C_2}$$

Know use boundry conditions to get C_1 and C_2

at $r=a \rightarrow \left.\frac{dT}{dr}\right|_{r=a} = 0$

we know: $\frac{dT}{dr} = -\frac{g_0}{k_0} r + \frac{C_1}{k_0 b^2}$

plug in $r=a$: $\left.\frac{dT}{dr}\right|_{r=a} = -\frac{g_0}{k_0} a + \frac{C_1}{k_0 b^2} = 0$

Solve for C_1: $\frac{C_1}{k_0 b^2} = \frac{g_0}{k_0} a$

$$\boxed{C_1 = \frac{g_0}{k_0} a k_0 b^2}$$

at $r=b \rightarrow -k\left.\frac{dT}{dr}\right|_{r=b} = h\left(T_{r=b} - T_\infty\right)$ $\quad k = k_0 \frac{b^2}{r^2}$

Plug in $r=b$

$$-k_0 \frac{b^2}{b^2}\left[-\frac{g_0}{k_0} b + \frac{C_1}{k_0 b^2}\right] = h\left[-\frac{g_0}{2k_0} b^2 + \frac{C_1}{k_0 b^2} b + C_2 - T_\infty\right]$$

Plug in C_1 and Solve for C_2:

$$T_\infty - \frac{k_0}{h}\left[-\frac{g_0}{k_0} b + \frac{g_0}{k_0} a k_0 b^2 \frac{1}{k_0 b^2}\right] = -\frac{g_0}{2k_0} b^2 + \frac{g_0}{k_0} a k_0 b^2 \frac{1}{k_0 b^2} b + C_2$$

$$C_2 = T_\infty + \frac{g_0}{h} b - \frac{g_0}{h} a + \frac{g_0}{2k_0} b^2 - \frac{g_0}{k_0} ab$$

$$\boxed{C_2 = T_\infty + \frac{g_0}{h}(b-a) + \frac{g_0 b}{k_0}\left[\frac{b}{2} - a\right]}$$

Now plug in C_1 and C_2 into equation T

$$T = -\frac{g_o}{2k_o} r^2 + \frac{\frac{g_o}{k_o} a k_o b^2}{k_o b^2} r + \frac{g_o}{h}(b-a) + \frac{g_o}{k_o} b\left(\frac{b}{2} - a\right) + T_\infty$$

Simplify:

$$\boxed{T = -\frac{g_o}{2k_o} r^2 + \frac{g_o}{k_o} a r + \frac{g_o}{h}(b-a) + \frac{g_o}{k_o} b\left(\frac{b}{2} - a\right) + T_\infty}$$

For heat transfer rate at $r=b$

$$Q = -k_{r=b} A_{r=b} \left.\frac{dT}{dr}\right|_{r=b} \qquad k = k_0 \frac{b^2}{r^2} \text{ at } r=b$$

$$A_{r=b} = 2\pi b^2 \longrightarrow \text{for hemisphere}$$

$$\left.\frac{dT}{dr}\right|_{r=b} = -\frac{g_0}{k_0} b + \frac{g_0}{k_0} a \, k_0 b^2 \frac{1}{k_0 b^2}$$

$$\left.\frac{dT}{dr}\right|_{r=b} = -\frac{g_0}{k_0} b + \frac{g_0}{k_0} a$$

Plug in values for Q

$$Q = -k_0 \frac{b^2}{b^2} (2\pi b^2) \left(-\frac{g_0}{k_0}\right) (b-a)$$

$$\boxed{Q = 2\pi g_0 b^2 (b-a)}$$

Summary

Expression for temperature profile is:

$$T = -\frac{g_0}{2k_0} r^2 + \frac{g_0}{k_0} a r + \frac{g_0}{h}(b-a) + \frac{g_0}{k_0} b\left(\frac{b}{2} - a\right) + T_\infty$$

and heat transfer rate at $r=b$ is:

$$Q = 2\pi g_0 b^2 (b-a)$$

Materials:

- Hemisphere fuel element with inner radius "a" and outer radius "b"
- Special material of fuel element.

Analysis

a) The constants of integration have units of temperature per unit length

$$C_1 = \frac{g_o}{k_o} a\, k_o b^2 \Rightarrow \frac{\frac{W}{m^3}}{\frac{W}{m \cdot K}} \times m \times \frac{W}{m \cdot K} \times m^2 = \frac{m^2}{\frac{1}{K}} \cdot \frac{W}{m \cdot K} \cdot m = W/m \cdot K \checkmark$$

C_2 has units of temperature

$$C_2 = T_\infty + \frac{g_o}{h}(b-a) + \frac{g_o b}{k_o}\left[\frac{b}{2} - a\right]$$

$T_\infty = K \checkmark$

$$\frac{g_o}{h}(b-a) \Rightarrow \frac{\frac{W}{m^3}}{\frac{W}{m^2 \cdot K}} \cdot m = K \checkmark$$

$$\frac{g_o b}{k_o}\left[\frac{b}{2} - a\right] \Rightarrow \frac{\frac{W}{m^3} \cdot m}{\frac{W}{m \cdot K}}[m - m] = K \checkmark$$

b) Unit of heat transfer are watts per unit length

$$Q = 2\pi g_o b^2 (b-a) \Rightarrow \frac{W}{m^3} \times m^2 \cdot (m - m) = W/m \checkmark$$

c) If $g = 0$, temperature profile is:

$$T = T_\infty$$

The hemisphere is insulated at $r=b$, outer boundary. At steady state the energy will be generated and the temperature of the hemisphere's outer boundary will reach ambient temperature (T_∞).

d) Heat transfer at each location along radius "r".

$$\boxed{Q = 2\pi g_o b^2 (r-a)}$$

Question 2
CONTENTS

1) Purpose

Determine the temperature profile of a hemisphere with inner radius “a” and outer radius “b” that generates heat within the entire volume as follows:

g = go * (b^2/r^2)

and a fuel element with a thermal conductivity that follows:

k=ko*(b^2/r^2)

and with boundary conditions as follows:

at r=a -> dT/dr = 0

at r=b -> -k*(dT/dr)=hinf*(T-Tinf)

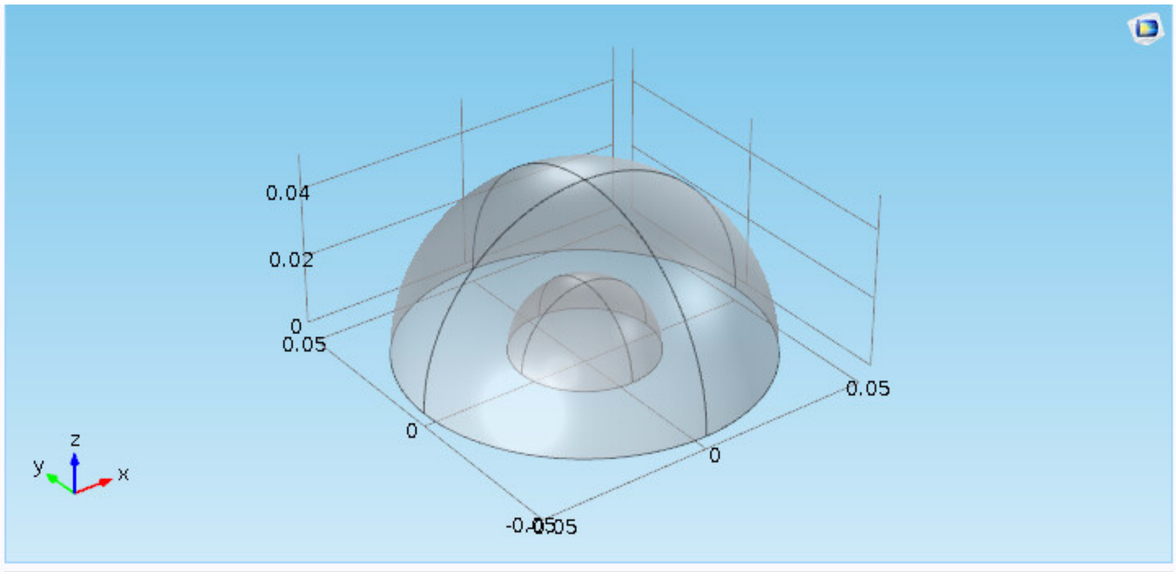
2) Data and Variables

2.1) Parameters

Name	Expression	Value	Description
a	2[cm]	.02m	
b	5[cm]	.05m	
go	1e6[w/m^3]	1E6 W/m^3	
ko	10 [W/m/K]	10 W/(m*k)	
hinf	200 [W/m^2/K]	200 W/(m^2*k)	
Tinf	(100+273.15)[K]	373.15 K	

3) <u>Drawings and Diagrams</u>

3.1) Geometry



Units

Length Unit	m
Angular Unit	Degrees

3.1.1) Cylinder 1

Position

Description	Value
Position	{0,0,0}

Axis

Description	Value
Axis type	Z-axis
Layers	

Size and Shapes

Description	Value
Radius	b

3.1.2 Cylinder 2

Position

Description	**Value**
Position	{0,0,0}

Axis

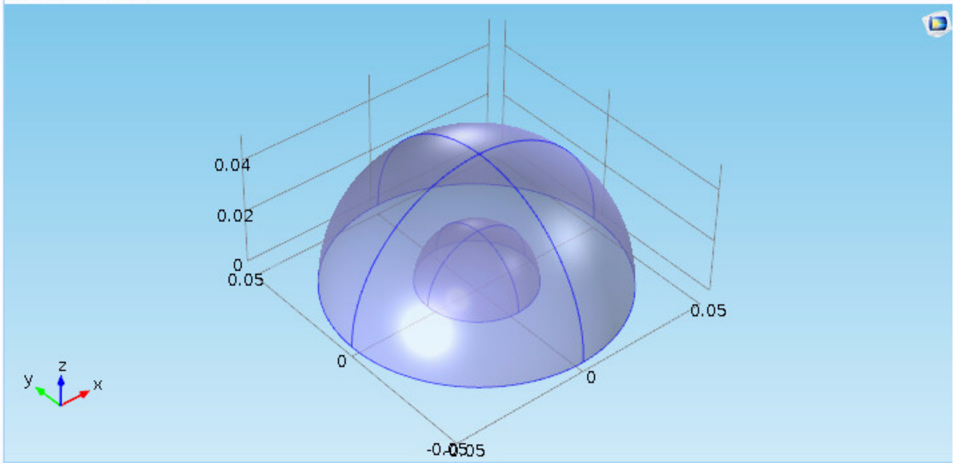
Description	**Value**
Axis type	Z-axis
Layers	

Size and Shapes

Description	**Value**
Radius	a

4) Materials

4.1 Materials



Selection

Geometric entity level	Domain
Selection	Domain 1

Material parameters

Name	Value	Unit
Thermal Conductivity	K	W/(m*K)
Density	1	Kg/m^3
Heat capacity at constant pressure	1	J/(kg*K)

Basic Settings

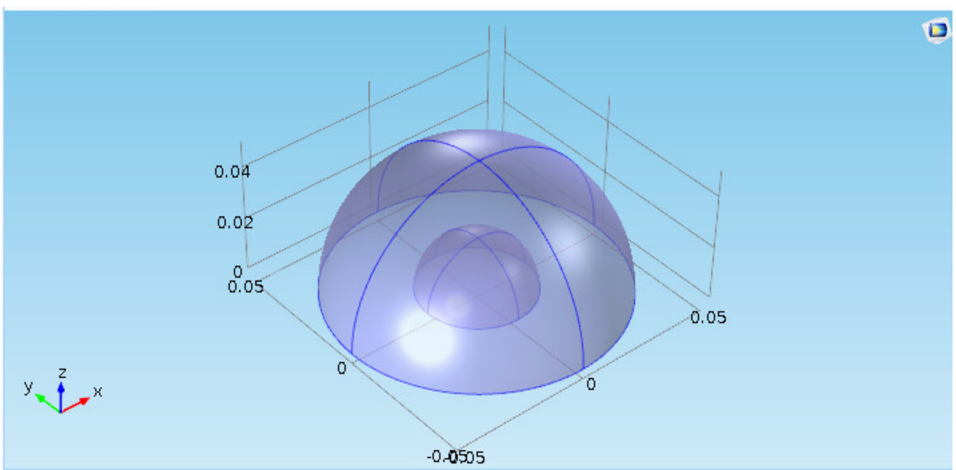
Name	Value
Thermal Conductivity	{{k, 0, 0}, {0, k, 0}, {0, 0, k}}
Density	1
Heat capacity at constant pressure	1

5) Sources

Bayazitoglu, Y., Ozisik, N., "A textbook for Heat Transfer Fudnamentals", Begell House Inc. (2012)

6) Design Considerations

6.1) Heat Transfer in Solids



Equations

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$

$$\mathbf{q} = -k \nabla T$$

Settings

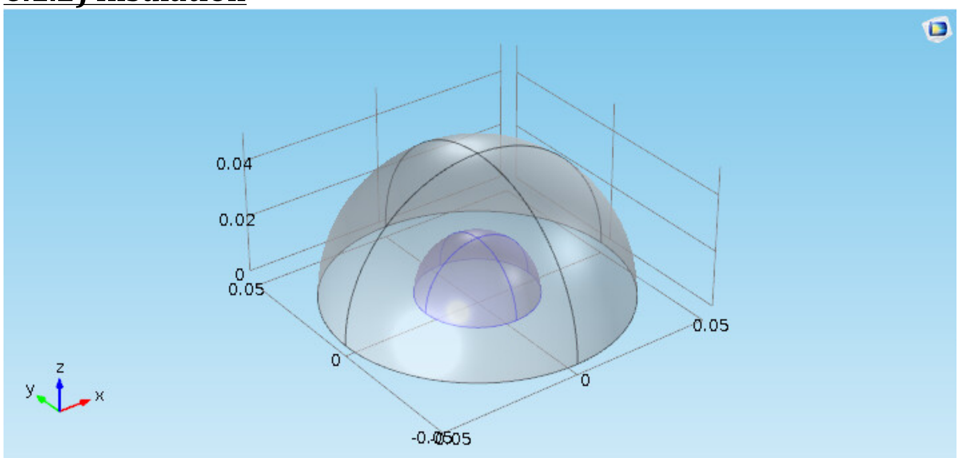
Name	Value
Thermal Conductivity	From Material
Density	From Material

Heat capacity at constant pressure	From Material

Properties from Material

Name	**Value**	**Property Group**
Thermal Conductivity	Material 1	Basic
Density	Material 1	Basic
Heat capacity at constant pressure	Material 1	Basic

6.1.2) Insulation



Equations

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

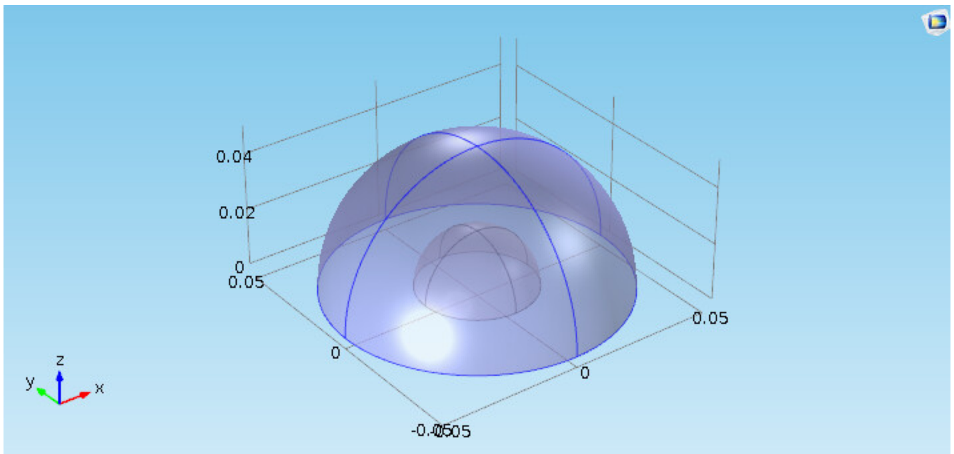
Settings

Description	**Value**
Heat Flux	General inward heat flux
Inward heat flux	0

Variables

Name	**Expression**	**Unit**	**Description**	**Selection**
ht.hf1.q0	0	W/m^2	Inward heat flux	Boundaries 4–5, 7–8

6.1.3) Convection



Equations

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

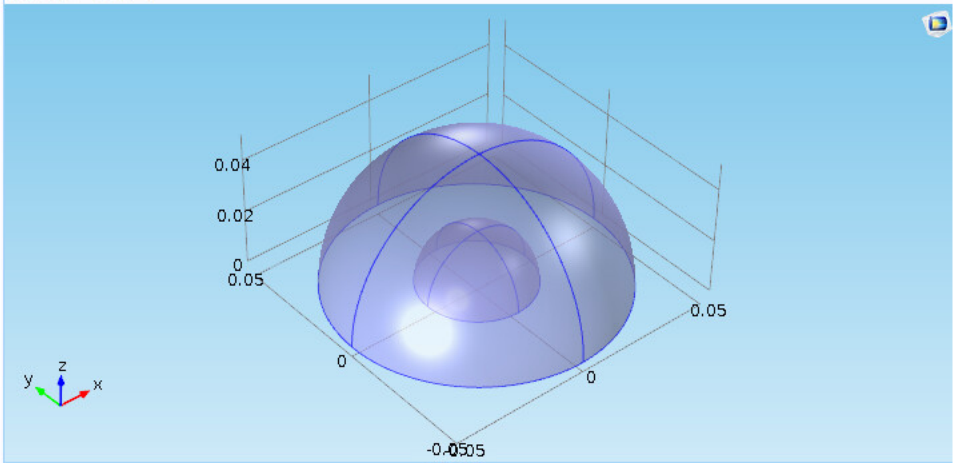
Settings

Description	**Value**
Heat flux	Convection Heat flux
Heat Transfer Coefficient	User defined
Heat Transfer Coefficient	hinf
External Temperature	Tinf

Variables

Name	**Expression**	**Unit**	**Description**	**Selection**
ht.hf2.h	hinf	W/(m^2*K)	Heat transfer coefficient	Boundaries 2–3, 6, 9
ht.hf2.Text	Tinf	K	External temperature	Boundaries 2–3, 6, 9

6.1.4 Heat Generation



Equations

$Q = Q_0$

Settings

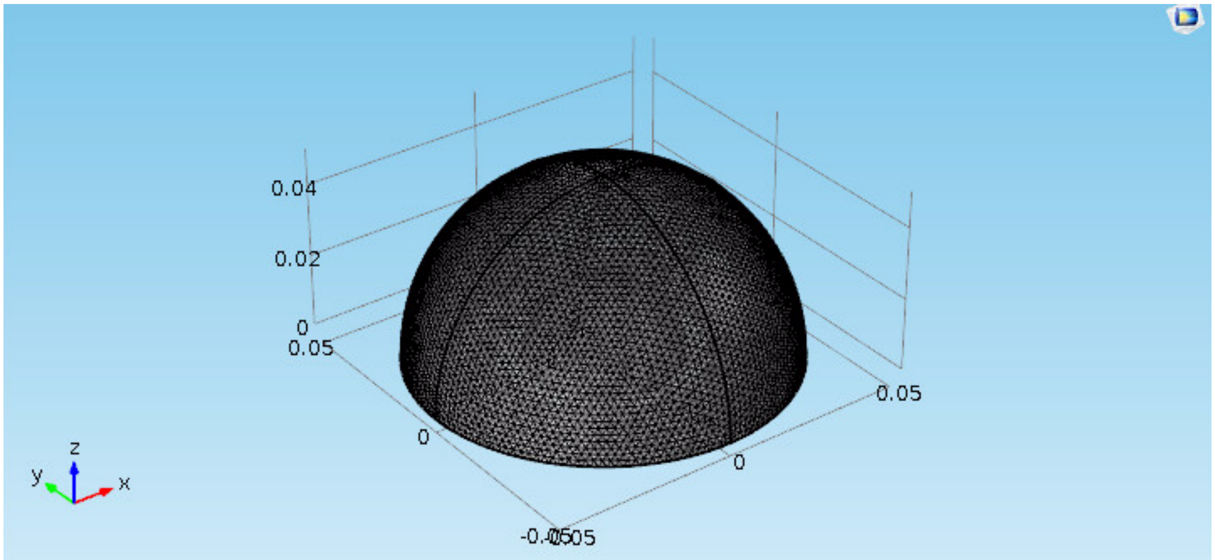
Description	**Value**
Heat Source	General Source
Heat Source	User defined
Heat Source	go*b^2/sqrt(x^2+y^2 + z^2)^2

Variables

Name	**Expression**	**Unit**	**Description**	**Selection**
ht.hs1.Q	go*b^2/sqrt(x^2+y^2 + z^2)^2	W/m^3	Heat Source	Domain 1

7) Procedure

7.1 Mesh 1



Mesh Statistics

Description	**Value**
Minimum element quality	.7698
Vertex elements	8
Edge elements	12

Settings

Description	**Value**
Curvator factor	.2
Maximmum element growth rate	1.3
Predefined size	Extremely fine

Computational Information

Computation time	**30s**
CPU	4th generation Intel® Core™ i5
Operating system	Windows 10

But using MOVEODU and specs on virtual software via HTML

7.2 Stationary

Study settings

Description	**Value**
Include geometrid nonlinearity	off

Physics and Variable selections

Physics interface	**Discretization**
Heat Transfer in solids (ht)	physics

Mesh Selection

Geometry	**Mesh**
Geometry 1 (geom1)	Mesh 1

7.3 Solver Configurations

Study and Step

Description	**Value**
Use study	Study 1
Use study step	Stationary

General

Description	**Value**
Defined by study step	Stationary

Initial Values of Variables solved for

Description	**Value**
Solution	0

Values of Variables not solved for

Description	**Value**
Solution	0

Temperature (comp1.T)

Description	**Value**
Field components	Comp1.T

Stationary Solver 1

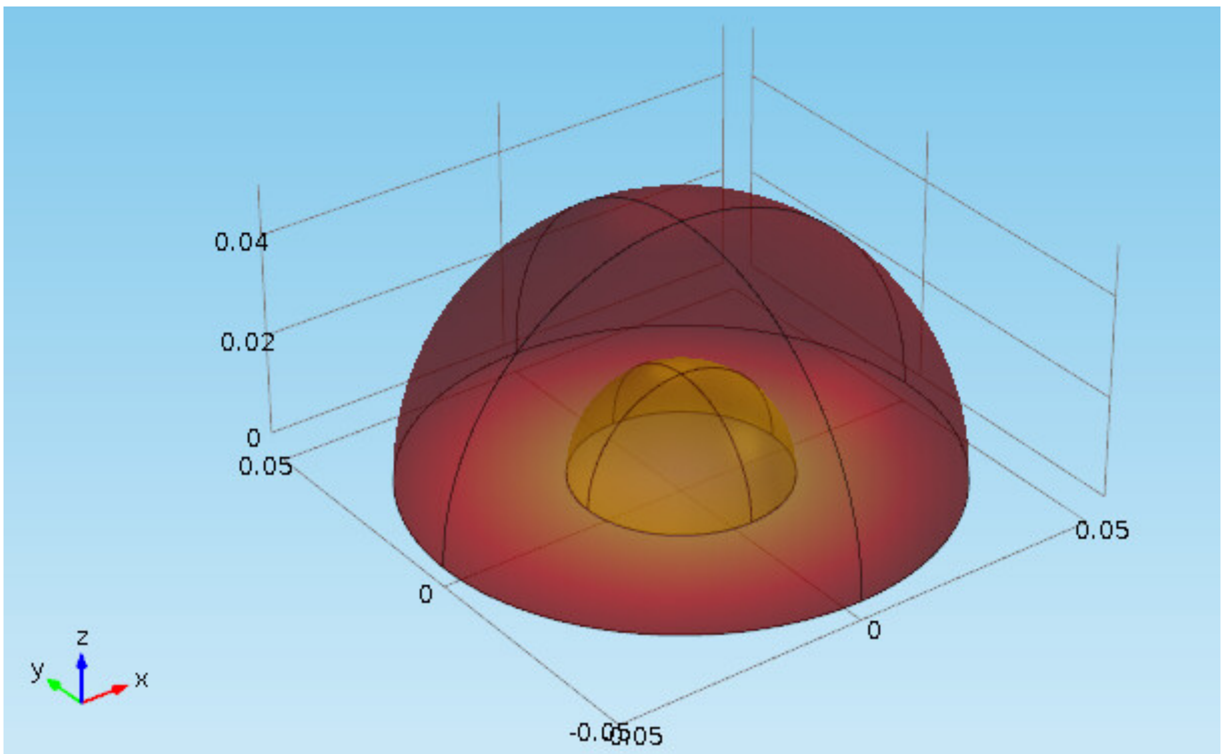
8 Calculations

8.1 Data Sets

8.1.1 Study 1 /Solutions

Solution

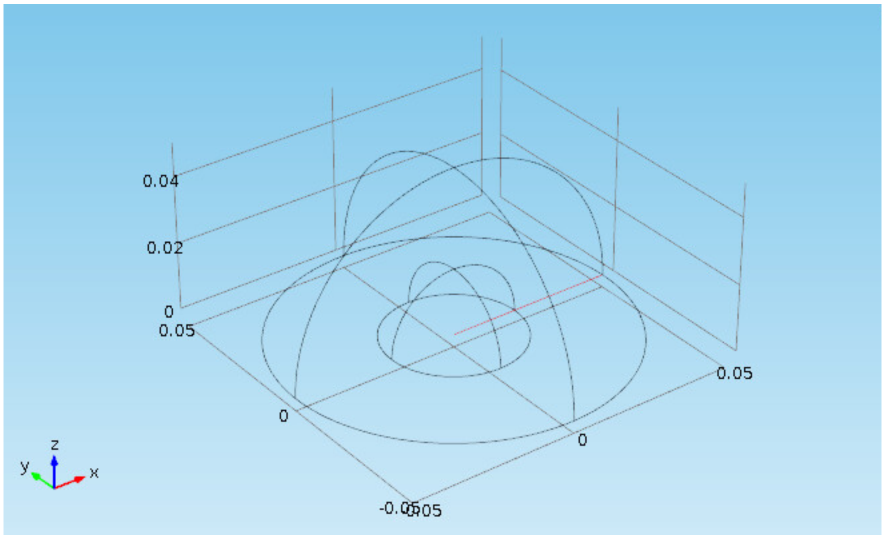
Description	**Value**
Solution	Solution 1
Component	Save point geometry 1



8.1.2 Cut Line 3D 1

Line Data

Description	**Value**
Line entry method	Two Poi
Points	{{0,0,0}, {.5,0,0}}



8.2 Heat Transfer at r=b

8.2.1 Point evaluation Numerical

Expression

Description	Value
Expression	ht.ndflux
Unit	W/m
Description	Heat at r=b (NUM)

8.2.2 Point evaluation Analytical

Expression

Description	Value
Expression	2*pi*go*b^2(b-a)
Unit	W/m
Description	Heat at r=b (ANAL)

Expression

Description	Value
Expression	!00*abs(ht.ndflux-2*pi*go*b^2(b-a)/(2*pi*go*b^2(b-a))
Unit	1
Description	%difference

Point Evaluation Numerical, Point at .01 arc length

Heat at r=b(NUM)(W/m
3250

Point Evaluation Analytical, Point at .01 arc length

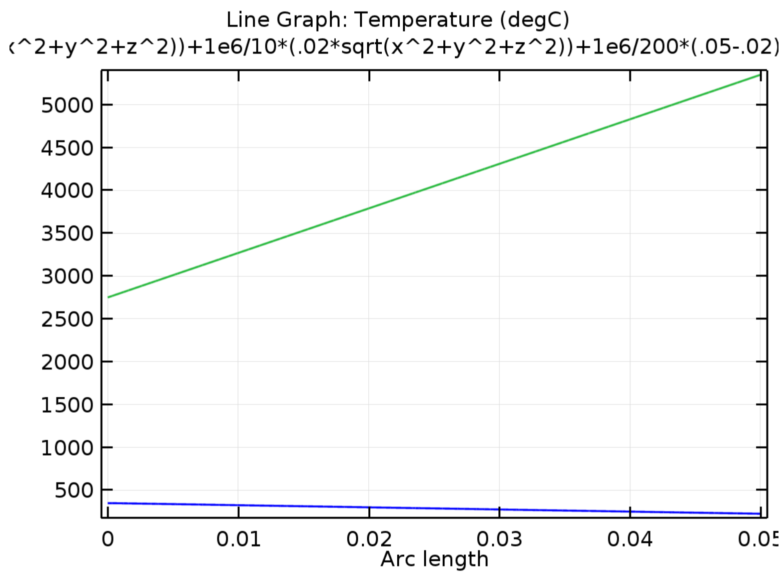
Heat at r=b(ANAL)(W/m
250

Point Evaluation Difference

% difference
92.3%

8) <u>Summary</u>

a) The percentage between the two results were 99%. I believe soimethig must have went wrong when inputting the long equation for T in COMSOL
b) The analytical and Numerical temperature profiles are not identical



9) <u>Analysis</u>

The comparison is not close, when putting my equation for T from question one of the test it was a very long equation and I must not have simplified it enough for COMSOL and I think that's why the results are so far off from each other. I included the full report here for further inspection too see where to fix error.

COMSOL MULTIPHYSICS®

MET 440 2nd Test

Report date	Oct 15, 2017 2:51:30 PM

Contents

1 Global Definitions

Date	Oct 15, 2017 2:37:24 PM

Global settings

Name	MET440 Test 2 COMSOL FINAL 2).mph
Path	C:\Users\fnguy003\Desktop\MET440 Test 2 COMSOL FINAL 2).mph
COMSOL version	COMSOL 5.1 (Build: 145)
Unit system	SI

Used products

COMSOL Multiphysics
CAD Import Module

2 Component 1

Date	Oct 14, 2017 5:01:39 PM

Component settings

Unit system	SI
Geometry shape order	automatic

2.1 Definitions

2.1.1 Coordinate Systems

Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

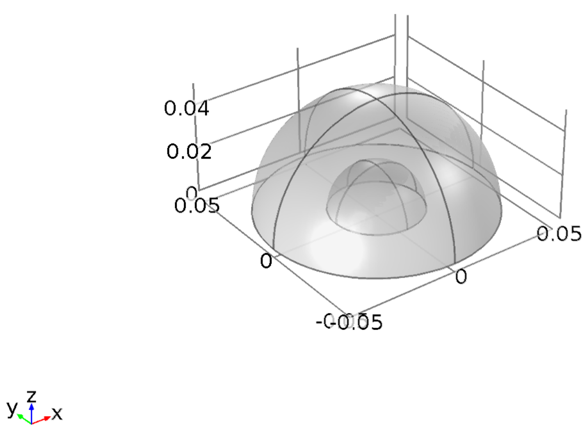
Coordinate names

First (t1)	Second (t2)	Third (n)
t1	t2	n

Settings

Description	Value
Create first tangent direction from	Global Cartesian

2.2 Geometry 1



Geometry 1

Units

Length unit	m
Angular unit	deg

Geometry statistics

Description	Value
Space dimension	3
Number of domains	2
Number of boundaries	10
Number of edges	16
Number of vertices	10

2.2.1 Sphere 1 (sph1)

Position

Description	Value
Position	{0, 0, 0}

Axis

Description	Value
Axis type	z - axis
Layers	

Size

Description	Value
Radius	5[cm]

2.2.2 Sphere 2 (sph2)

Position

Description	Value
Position	{0, 0, 0}

Axis

Description	Value
Axis type	z - axis
Layers	

Size

Description	Value
Radius	2[cm]

2.2.3 Delete Faces 1 (dfa1)

Settings

Description	Value
Heal method	Fill

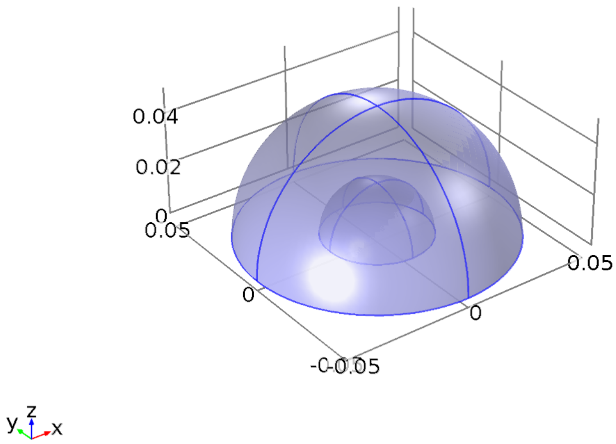
2.2.4 Delete Faces 2 (dfa2)

Settings

Description	Value
Heal method	Fill

2.3 Materials

2.3.1 Material 1



Material 1

Selection

Geometric entity level	Domain
Selection	Domains 1–2

Material parameters

Name	Value	Unit
Thermal conductivity	10	W/(m*K)
Density	1	kg/m^3
Heat capacity at constant pressure	1	J/(kg*K)

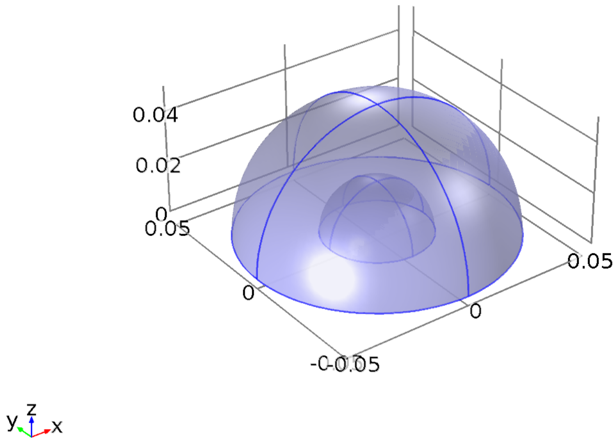
Basic Settings

Description	Value
Thermal conductivity	{{10, 0, 0}, {0, 10, 0}, {0, 0, 10}}
Density	1
Heat capacity at constant pressure	1

2.4 Heat Transfer in Solids

Used products

COMSOL Multiphysics



Heat Transfer in Solids

Selection

Geometric entity level	Domain
Selection	Domains 1–2

Equations

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\mathrm{ted}}$$
$$\mathbf{q} = -k \nabla T$$

Settings

Description	Value
Temperature	Quadratic
Compute boundary fluxes	On
Apply smoothing to boundary fluxes	On
Value type when using splitting of complex variables	Real
Surface-to-surface radiation	Off
Radiation in participating media	Off
Heat transfer in biological tissue	Off
Isothermal domain	Off
Heat transfer in porous media	Off
Streamline diffusion	On
Crosswind diffusion	On
Isotropic diffusion	Off

Variables

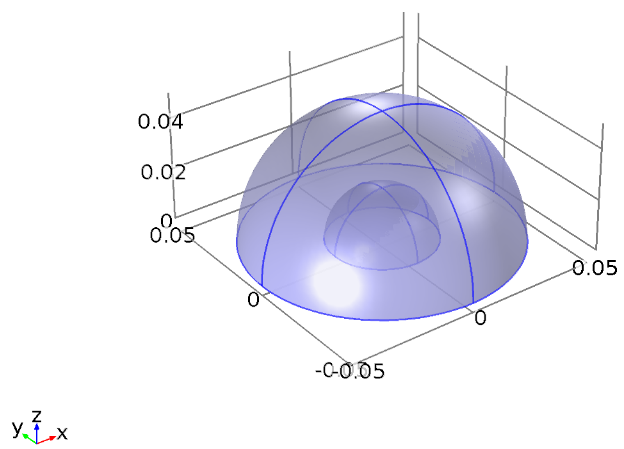
Name	Expression	Unit	Description	Selection
ht.q0	0	W/m^2	Inward heat flux	Boundaries 1–10
ht.Tu	T	K	Temperature	Boundaries 1–10

Name	Expression	Unit	Description	Selection
ht.Td	T	K	Temperature	Boundaries 1–10
ht.opaqueLayer	1		Thin layer opacity	Boundaries 1–10
ht.Tvar	T	K	Temperature	Domains 1–2
ht.Tvar	T	K	Temperature	Boundaries 1–10
ht.Tvar	T	K	Temperature	Edges 1–16
ht.Tvar	T	K	Temperature	Points 1–10
ht.addContinuityWeak	1		Boolean	Boundaries 1–10
ht.isConductiveLayer	1		Boolean	Domains 1–2
ht.d	1	1	Thickness	Domains 1–2
ht.nx	nx	1	Normal vector, x component	Boundaries 4, 6, 8–9
ht.ny	ny	1	Normal vector, y component	Boundaries 4, 6, 8–9
ht.nz	nz	1	Normal vector, z component	Boundaries 4, 6, 8–9
ht.nx	dnx	1	Normal vector, x component	Boundaries 1–3, 5, 7, 10
ht.ny	dny	1	Normal vector, y component	Boundaries 1–3, 5, 7, 10
ht.nz	dnz	1	Normal vector, z component	Boundaries 1–3, 5, 7, 10
ht.nxmesh	root.nxmesh	1	Normal vector (mesh), x component	Boundaries 4, 6, 8–9
ht.nymesh	root.nymesh	1	Normal vector (mesh), y component	Boundaries 4, 6, 8–9
ht.nzmesh	root.nzmesh	1	Normal vector (mesh), z component	Boundaries 4, 6, 8–9

Name	Expression	Unit	Description	Selection
ht.nxmesh	root.dnxmesh	1	Normal vector (mesh), x component	Boundaries 1–3, 5, 7, 10
ht.nymesh	root.dnymesh	1	Normal vector (mesh), y component	Boundaries 1–3, 5, 7, 10
ht.nzmesh	root.dnzmesh	1	Normal vector (mesh), z component	Boundaries 1–3, 5, 7, 10
ht.dnx	dnx	1	Normal vector down direction, x component	Boundaries 1–10
ht.dny	dny	1	Normal vector down direction, y component	Boundaries 1–10
ht.dnz	dnz	1	Normal vector down direction, z component	Boundaries 1–10
ht.unx	unx	1	Normal vector up direction, x component	Boundaries 1–10
ht.uny	uny	1	Normal vector up direction, y component	Boundaries 1–10
ht.unz	unz	1	Normal vector up direction, z component	Boundaries 1–10
ht.dEiInt	ht.intDom(d(ht.rho*ht.Ei,t)*ht.varIntSpa)	W	Total accumulated heat rate	Global
ht.dEi0Int	ht.intDom(d(ht.rho*ht.Ei0,t)*ht.varIntSpa)	W	Total accumulated energy rate	Global
ht.ntfluxInt	ht.intExtBnd(ht.ntflux*ht.varIntSpa)	W	Total net heat rate	Global
ht.ntefluxInt	ht.intExtBnd(ht.nteflux*ht.varIntSpa)	W	Total net energy rate	Global
ht.QInt	ht.intDom(ht.Qtot*ht.varIntSpa)-	W	Total heat source	Global

Name	Expression	Unit	Description	Selection
	ht.intIntBnd((ht.ndflux_u+ ht.ndflux_d)*ht.varIntSpa)			
ht.WnsInt	0	W	Total work source	Global
ht.WInt	0	W	Total work source	Global

2.4.1 Heat Transfer in Solids 1



Heat Transfer in Solids 1

Selection

Geometric entity level	Domain
Selection	Domains 1–2

Equations

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k\nabla T$$

Settings

Description	Value
Thermal conductivity	From material
Density	From material
Heat capacity at constant pressure	From material

Properties from material

Property	Material	Property group
Thermal conductivity	Material 1	Basic
Density	Material 1	Basic
Heat capacity at constant pressure	Material 1	Basic

Variables

Name	Expression	Unit	Description	Selection
domflux.Tx	-ht.k_effxx*Tx-ht.k_effxy*Ty-ht.k_effxz*Tz	W/m^2	Domain flux, x component	Domains 1–2
domflux.Ty	-ht.k_effyx*Tx-ht.k_effyy*Ty-ht.k_effyz*Tz	W/m^2	Domain flux, y component	Domains 1–2
domflux.Tz	-ht.k_effzx*Tx-ht.k_effzy*Ty-ht.k_effzz*Tz	W/m^2	Domain flux, z component	Domains 1–2
ht.WnsInt	ht.solid1.intDom(ht.pA*(d(ht.ux,x)+d(ht.uy,y)+d(ht.uz,z))*ht.solid1.varIntSpa)	W	Total work source	Global
ht.Q	0	W/m^3	Heat source	Domains 1–2
ht.Qtot	0	W/m^3	Total heat source	Domains 1–2
ht.kxx	material.k11	W/(m*K)	Thermal conductivity, xx component	Domains 1–2
ht.kyx	material.k21	W/(m*K)	Thermal conductivity, yx component	Domains 1–2
ht.kzx	material.k31	W/(m*K)	Thermal conductivity, zx component	Domains 1–2
ht.kxy	material.k12	W/(m*K)	Thermal conductivity, xy component	Domains 1–2
ht.kyy	material.k22	W/(m*K)	Thermal conductivity, yy component	Domains 1–2
ht.kzy	material.k32	W/(m*K)	Thermal conductivity, zy component	Domains 1–2
ht.kxz	material.k13	W/(m*K)	Thermal conductivity, xz component	Domains 1–2
ht.kyz	material.k23	W/(m*K)	Thermal conductivity, yz component	Domains 1–2
ht.kzz	material.k33	W/(m*K)	Thermal conductivity, zz component	Domains 1–2
ht.rho	material.rho	kg/m^3	Density	Domains 1–2
ht.Cp	material.Cp	J/(kg*K)	Heat capacity at	Domains 1–

Name	Expression	Unit	Description	Selection
			constant pressure	2
ht.solid1.pRef	model.input.pRef	Pa	Reference pressure level	Domains 1–2
ht.alphap	-d(ht.rho,T)/(ht.rho+eps)	1/K	Isobaric compressibility coefficient	Domains 1–2
ht.pA	model.input.minput_pressure	Pa	Absolute pressure	Domains 1–2
ht.gradTmag	sqrt(ht.gradTx^2+ht.gradTy^2+ht.gradTz^2)	K/m	Temperature gradient magnitude	Domains 1–2
ht.kmean	(ht.k_effxx+ht.k_effyy+ht.k_effzz)/3	W/(m*K)	Mean effective thermal conductivity	Domains 1–2
ht.qs	0	W/(m^3*K)	Production/absorption coefficient	Domains 1–2
ht.Qmet	0	W/m^3	Metabolic heat source	Domains 1–2
ht.rhoInt	subst(ht.rho,root.comp1.ht.solid1.minput_pressure,ht.pA)	kg/m^3	Density for integration	Domains 1–2
ht.CpInt	subst(ht.Cp,root.comp1.ht.solid1.minput_pressure,ht.pA)	J/(kg*K)	Specific heat capacity for integration	Domains 1–2
ht.gammaInt	subst(ht.gamma,root.comp1.ht.solid1.minput_pressure,ht.pA)	1	Ratio of specific heats for integration	Domains 1–2
ht.TRef	298.15[K]	K	Reference temperature	Domains 1–2
ht.pRef	ht.solid1.pRef	Pa	Reference pressure level	Domains 1–2
ht.HRef	0	J/kg	Reference enthalpy	Domains 1–2
ht.DeltaH	integrate(subst(ht.CpInt,ht.pA,ht.pRef),T,ht.TRef,T)	J/kg	Sensible enthalpy	Domains 1–2
ht.H	ht.HRef+ht.DeltaH	J/kg	Enthalpy	Domains 1–2
ht.H0	ht.H	J/kg	Total enthalpy	Domains 1–2
ht.Ei	ht.H	J/kg	Internal energy	Domains 1–2
ht.Ei0	ht.Ei	J/kg	Total internal energy	Domains 1–2
ht.Qbtot	0	W/m^2	Total boundary heat source	Boundaries 1–10
ht.k_effxx	ht.kxx	W/(m*K)	Effective thermal conductivity, xx	Domains 1–2

Name	Expression	Unit	Description	Selection
			component	
ht.k_effyx	ht.kyx	W/(m*K)	Effective thermal conductivity, yx component	Domains 1–2
ht.k_effzx	ht.kzx	W/(m*K)	Effective thermal conductivity, zx component	Domains 1–2
ht.k_effxy	ht.kxy	W/(m*K)	Effective thermal conductivity, xy component	Domains 1–2
ht.k_effyy	ht.kyy	W/(m*K)	Effective thermal conductivity, yy component	Domains 1–2
ht.k_effzy	ht.kzy	W/(m*K)	Effective thermal conductivity, zy component	Domains 1–2
ht.k_effxz	ht.kxz	W/(m*K)	Effective thermal conductivity, xz component	Domains 1–2
ht.k_effyz	ht.kyz	W/(m*K)	Effective thermal conductivity, yz component	Domains 1–2
ht.k_effzz	ht.kzz	W/(m*K)	Effective thermal conductivity, zz component	Domains 1–2
ht.C_eff	ht.rho*ht.Cp	J/(m^3*K)	Effective volumetric heat capacity	Domains 1–2
ht.ux	0	m/s	Velocity field, x component	Domains 1–2
ht.uy	0	m/s	Velocity field, y component	Domains 1–2
ht.uz	0	m/s	Velocity field, z component	Domains 1–2
ht.gradTx	Tx	K/m	Temperature gradient, x component	Domains 1–2
ht.gradTy	Ty	K/m	Temperature gradient, y component	Domains 1–2
ht.gradTz	Tz	K/m	Temperature gradient, z component	Domains 1–2
ht.Qltot	0	W/m	Total line heat source	Edges 1–16
ht.Qptot	0	W	Total point heat source	Points 1–10
ht.alphaTdxx	ht.k_effxx/ht.C_eff	m^2/s	Thermal	Domains 1–

Name	Expression	Unit	Description	Selection
			diffusivity, xx component	2
ht.alphaTdyx	ht.k_effyx/ht.C_eff	m^2/s	Thermal diffusivity, yx component	Domains 1–2
ht.alphaTdzx	ht.k_effzx/ht.C_eff	m^2/s	Thermal diffusivity, zx component	Domains 1–2
ht.alphaTdxy	ht.k_effxy/ht.C_eff	m^2/s	Thermal diffusivity, xy component	Domains 1–2
ht.alphaTdyy	ht.k_effyy/ht.C_eff	m^2/s	Thermal diffusivity, yy component	Domains 1–2
ht.alphaTdzy	ht.k_effzy/ht.C_eff	m^2/s	Thermal diffusivity, zy component	Domains 1–2
ht.alphaTdxz	ht.k_effxz/ht.C_eff	m^2/s	Thermal diffusivity, xz component	Domains 1–2
ht.alphaTdyz	ht.k_effyz/ht.C_eff	m^2/s	Thermal diffusivity, yz component	Domains 1–2
ht.alphaTdzz	ht.k_effzz/ht.C_eff	m^2/s	Thermal diffusivity, zz component	Domains 1–2
ht.alphaTdMean	ht.kmean/ht.C_eff	m^2/s	Mean thermal diffusivity	Domains 1–2
ht.dfluxx	-ht.k_effxx*Tx-ht.k_effxy*Ty-ht.k_effxz*Tz	W/m^2	Conductive heat flux, x component	Domains 1–2
ht.dfluxy	-ht.k_effyx*Tx-ht.k_effyy*Ty-ht.k_effyz*Tz	W/m^2	Conductive heat flux, y component	Domains 1–2
ht.dfluxz	-ht.k_effzx*Tx-ht.k_effzy*Ty-ht.k_effzz*Tz	W/m^2	Conductive heat flux, z component	Domains 1–2
ht.dfluxMag	sqrt(ht.dfluxx^2+ht.dfluxy^2+ht.dfluxz^2)	W/m^2	Conductive heat flux magnitude	Domains 1–2
ht.trlfluxx	0	W/m^2	Translational heat flux, x component	Domains 1–2
ht.trlfluxy	0	W/m^2	Translational heat flux, y component	Domains 1–2
ht.trlfluxz	0	W/m^2	Translational heat flux, z component	Domains 1–2
ht.trlfluxMag	sqrt(ht.trlfluxx^2+ht.trlfluxy^2+ht.trlfluxz^2)	W/m^2	Translational heat flux magnitude	Domains 1–2

Name	Expression	Unit	Description	Selection
ht.cfluxx	0	W/m^2	Convective heat flux, x component	Domains 1–2
ht.cfluxy	0	W/m^2	Convective heat flux, y component	Domains 1–2
ht.cfluxz	0	W/m^2	Convective heat flux, z component	Domains 1–2
ht.cfluxMag	sqrt(ht.cfluxx^2+ht.cfluxy^2+ht.cfluxz^2)	W/m^2	Convective heat flux magnitude	Domains 1–2
ht.tfluxx	ht.dfluxx+ht.trlfluxx+ht.cfluxx	W/m^2	Total heat flux, x component	Domains 1–2
ht.tfluxy	ht.dfluxy+ht.trlfluxy+ht.cfluxy	W/m^2	Total heat flux, y component	Domains 1–2
ht.tfluxz	ht.dfluxz+ht.trlfluxz+ht.cfluxz	W/m^2	Total heat flux, z component	Domains 1–2
ht.tfluxMag	sqrt(ht.tfluxx^2+ht.tfluxy^2+ht.tfluxz^2)	W/m^2	Total heat flux magnitude	Domains 1–2
ht.tefluxx	ht.dfluxx	W/m^2	Total energy flux, x component	Domains 1–2
ht.tefluxy	ht.dfluxy	W/m^2	Total energy flux, y component	Domains 1–2
ht.tefluxz	ht.dfluxz	W/m^2	Total energy flux, z component	Domains 1–2
ht.tefluxMag	sqrt(ht.tefluxx^2+ht.tefluxy^2+ht.tefluxz^2)	W/m^2	Total energy flux magnitude	Domains 1–2
ht.rflux	0	W/m^2	Radiative heat flux	Boundaries 1–10
ht.chflux	0	W/m^2	Boundary convective heat flux	Boundaries 1–10
ht.ntrlflux	mean(ht.trlfluxx)*ht.nx+mean(ht.trlfluxy)*ht.ny+mean(ht.trlfluxz)*ht.nz	W/m^2	Normal translational heat flux	Boundaries 1–10
ht.ntrlflux_u	up(ht.trlfluxx)*ht.unx+up(ht.trlfluxy)*ht.uny+up(ht.trlfluxz)*ht.unz	W/m^2	Internal normal translational heat flux, upside	Boundaries 4, 6, 8–9
ht.ntrlflux_d	down(ht.trlfluxx)*ht.dnx+down(ht.trlfluxy)*ht.dny+down(ht.trlfluxz)*ht.dnz	W/m^2	Internal normal translational heat flux, downside	Boundaries 4, 6, 8–9
ht.ncflux	mean(ht.cfluxx)*ht.nx+mean(ht.cfluxy)*ht.ny+mean(ht.cfluxz)*ht.nz	W/m^2	Normal convective heat flux	Boundaries 1–10
ht.ncflux_u	up(ht.cfluxx)*ht.unx+up(ht.cfluxy)*ht.uny+	W/m^2	Internal normal convective heat	Boundaries 4, 6, 8–9

Name	Expression	Unit	Description	Selection
	up(ht.cfluxz)*ht.unz		flux, upside	
ht.ncflux_d	down(ht.cfluxx)*ht.dnx+down(ht.cfluxy)*ht.dny+down(ht.cfluxz)*ht.dnz	W/m^2	Internal normal convective heat flux, downside	Boundaries 4, 6, 8–9
ht.ndflux	-dflux_spatial(T)/ht.d	W/m^2	Normal conductive heat flux	Boundaries 1–3, 5, 7, 10
ht.ndflux	0.5*(uflux_spatial(T)-dflux_spatial(T))/ht.d	W/m^2	Normal conductive heat flux	Boundaries 4, 6, 8–9
ht.ndflux_u	-uflux_spatial(T)/ht.d	W/m^2	Internal normal conductive heat flux, upside	Boundaries 4, 6, 8–9
ht.ndflux_d	-dflux_spatial(T)/ht.d	W/m^2	Internal normal conductive heat flux, downside	Boundaries 4, 6, 8–9
ht.ntflux	ht.ndflux+ht.ntrlflux+ht.ncflux	W/m^2	Normal total heat flux	Boundaries 1–10
ht.ntflux_u	ht.ndflux_u+ht.ntrlflux_u+ht.ncflux_u	W/m^2	Internal normal total flux, upside	Boundaries 4, 6, 8–9
ht.ntflux_d	ht.ndflux_d+ht.ntrlflux_d+ht.ncflux_d	W/m^2	Internal normal total flux, downside	Boundaries 4, 6, 8–9
ht.nteflux	mean(ht.tefluxx)*ht.nx+mean(ht.tefluxy)*ht.ny+mean(ht.tefluxz)*ht.nz-mean(ht.dfluxx)*ht.nx-mean(ht.dfluxy)*ht.ny-mean(ht.dfluxz)*ht.nz+ht.ndflux	W/m^2	Normal total energy flux	Boundaries 1–10
ht.nteflux_u	up(ht.tefluxx)*ht.unx+up(ht.tefluxy)*ht.uny+up(ht.tefluxz)*ht.unz-up(ht.dfluxx)*ht.unx-up(ht.dfluxy)*ht.uny-up(ht.dfluxz)*ht.unz+ht.ndflux_u	W/m^2	Internal normal total energy flux, upside	Boundaries 4, 6, 8–9
ht.nteflux_d	down(ht.tefluxx)*ht.dnx+down(ht.tefluxy)*ht.dny+down(ht.tefluxz)*ht.dnz-down(ht.dfluxx)*ht.dnx-	W/m^2	Internal normal total energy flux, downside	Boundaries 4, 6, 8–9

Name	Expression	Unit	Description	Selection
	down(ht.dfluxy)*ht.dny-down(ht.dfluxz)*ht.dnz+ht.ndflux_d			
ht.solid1.dEiInt	ht.solid1.intDom(d(ht.rho*ht.Ei,t)*ht.solid1.varIntSpa)	W	Total accumulated heat rate	Global
ht.solid1.dEi0Int	ht.solid1.intDom(d(ht.rho*ht.Ei0,t)*ht.solid1.varIntSpa)	W	Total accumulated energy rate	Global
ht.solid1.ntfluxInt	ht.solid1.intExtBnd(ht.ntflux*ht.solid1.varIntSpa)+ht.solid1.intExtBndUp(ht.ntflux_u*ht.solid1.varIntSpa)+ht.solid1.intExtBndDown(ht.ntflux_d*ht.solid1.varIntSpa)	W	Total net heat rate	Global
ht.solid1.ntefluxInt	ht.solid1.intExtBnd(ht.nteflux*ht.solid1.varIntSpa)+ht.solid1.intExtBndUp(ht.nteflux_u*ht.solid1.varIntSpa)+ht.solid1.intExtBndDown(ht.nteflux_d*ht.solid1.varIntSpa)	W	Total net energy rate	Global
ht.solid1.QInt	ht.solid1.intDom(ht.Qtot*ht.solid1.varIntSpa)-ht.solid1.intIntBnd((ht.ndflux_u+ht.ndflux_d)*ht.solid1.varIntSpa)	W	Total heat source	Global
ht.solid1.WnsInt	ht.solid1.intDom(ht.pA*(d(ht.ux,x)+d(ht.uy,y)+d(ht.uz,z))*ht.solid1.varIntSpa)	W	Total work source	Global
ht.solid1.WInt	0	W	Total work source	Global
ht.gamma	1	1	Ratio of specific heats	Domains 1–2
ht.helem	h	m	Element size	Domains 1–2
ht.res_T	-ht.k_effxx*Txx-ht.k_effxy*Txy-ht.k_effxz*Txz-ht.k_effyx*Tyx-ht.k_effyy*Tyy-ht.k_effyz*Tyz-	W/m^3	Equation residual	Domains 1–2

Name	Expression	Unit	Description	Selection
	ht.k_effzx*Tzx-ht.k_effzy*Tzy-ht.k_effzz*Tzz-(ht.qs+ht.qs_oop)*T+ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)-ht.Q-ht.Qoop			

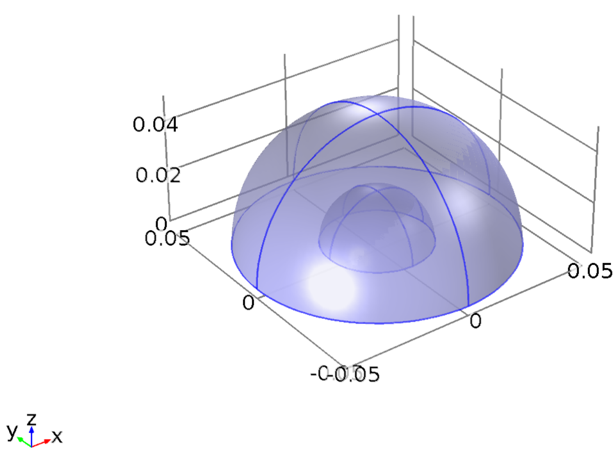
Shape functions

Name	Shape function	Unit	Description	Shape frame	Selection
T	Lagrange (Quadratic)	K	Temperature	Material	Domains 1–2

Weak expressions

Weak expression	Integration frame	Selection
(-(ht.k_effxx*Tx+ht.k_effxy*Ty+ht.k_effxz*Tz)*test(Tx)-(ht.k_effyx*Tx+ht.k_effyy*Ty+ht.k_effyz*Tz)*test(Ty)-(ht.k_effzx*Tx+ht.k_effzy*Ty+ht.k_effzz*Tz)*test(Tz))*ht.d	Material	Domains 1–2
-ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)*test(T)*ht.d	Material	Domains 1–2
ht.streamline	Material	Domains 1–2

2.4.2 Initial Values 1



Initial Values 1

Selection

Geometric entity level	Domain
Selection	Domains 1–2

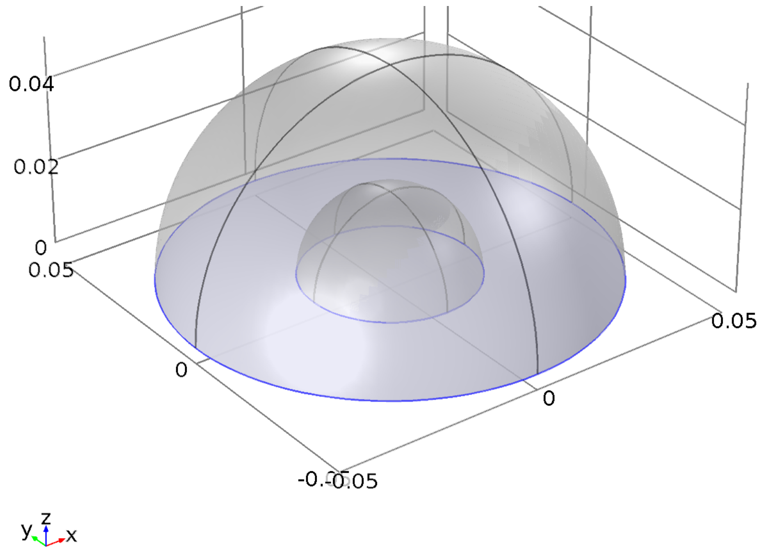
Settings

Description	Value
Temperature	293.15[K]

Variables

Name	Expression	Unit	Description	Selection
ht.Tinit	293.15[K]	K	Temperature	Domains 1–2

2.4.3 Thermal Insulation 1



Thermal Insulation 1

Selection

Geometric entity level	Boundary
Selection	Boundaries 2, 5

Equations

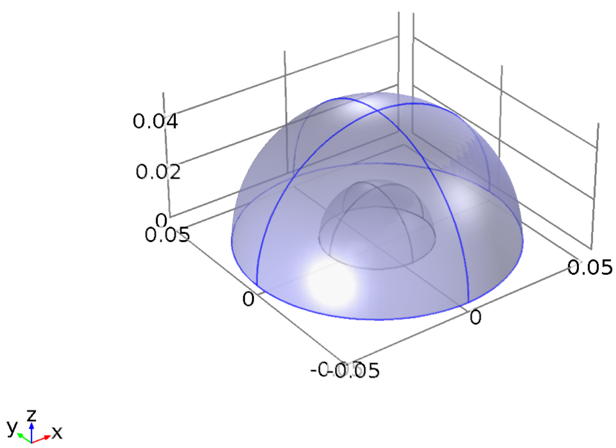
$$-\mathbf{n}\cdot\mathbf{q}=0$$

Variables

Name	Expression	Unit	Description	Selection
ht.ins1.ntfluxInt	ht.ins1.intExtBnd(ht.ntflux*ht.ins1.varIntSpa)	W	Total net heat rate	Global
ht.ins1.ntefluxInt	ht.ins1.intExtBnd(ht.nteflux*ht.ins1.varIntSpa)	W	Total net energy rate	Global
ht.ins1.ntfluxInt_u	ht.ins1.intIntBnd(ht.ntflux_u*ht.ins1.varIntSpa)	W	Total net heat rate, upside	Global
ht.ins1.ntefluxInt_u	ht.ins1.intIntBnd(ht.nteflux_u*ht.ins1.varIntSpa)	W	Total net energy rate, upside	Global
ht.ins1.ntfluxInt_d	ht.ins1.intIntBnd(ht.ntflux_d*	W	Total net	Global

Name	Expression	Unit	Description	Selection
	ht.ins1.varIntSpa)		heat rate, downside	
ht.ins1.ntefluxInt_d	ht.ins1.intIntBnd(ht.nteflux_d*ht.ins1.varIntSpa)	W	Total net energy rate, downside	Global
ht.ins1.Tave	if(ht.ins1.intBnd(ht.ins1.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))==0,ht.ins1.intBnd(ht.ins1.varIntSpa*T)/ht.ins1.intBnd(ht.ins1.varIntSpa),ht.ins1.intBnd(ht.ins1.varIntSpa*ht.rho*ht.Cp*T*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))/ht.ins1.intBnd(ht.ins1.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz)))	K	Weighted average temperature	Global

2.4.4 Heat Flux 1



Heat Flux 1

Selection

Geometric entity level	Boundary
Selection	Boundaries 1, 3, 7, 10

Equations

$$-\mathbf{n}\cdot\mathbf{q}=q_0$$

Settings

Description	Value
Heat flux	Convective heat flux

Description	Value
Heat transfer coefficient	User defined
Heat transfer coefficient	200
External temperature	100[degC]

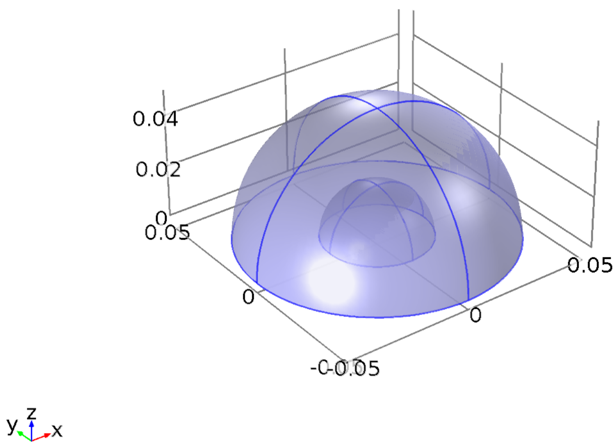
Variables

Name	Expression	Unit	Description	Selection
ht.q0	ht.hf1.q0	W/m^2	Inward heat flux	Boundaries 1, 3, 7, 10
ht.hf1.h	200	W/(m^2*K)	Heat transfer coefficient	Boundaries 1, 3, 7, 10
ht.hf1.Text	100[degC]	K	External temperature	Boundaries 1, 3, 7, 10
ht.hf1.q0	ht.hf1.h*(ht.hf1.Text-ht.hf1.Tvar)	W/m^2	Boundary convective heat flux	Boundaries 1, 3, 7, 10
ht.hf1.Tvar	ht.Tu	K	Temperature	Boundaries 1, 3, 7, 10
ht.hf1.ntfluxInt	ht.hf1.intExtBnd(ht.ntflux*ht.hf1.varIntSpa)	W	Total net heat rate	Global
ht.hf1.ntefluxInt	ht.hf1.intExtBnd(ht.nteflux*ht.hf1.varIntSpa)	W	Total net energy rate	Global
ht.hf1.ntfluxInt_u	ht.hf1.intIntBnd(ht.ntflux_u*ht.hf1.varIntSpa)	W	Total net heat rate, upside	Global
ht.hf1.ntefluxInt_u	ht.hf1.intIntBnd(ht.nteflux_u*ht.hf1.varIntSpa)	W	Total net energy rate, upside	Global
ht.hf1.ntfluxInt_d	ht.hf1.intIntBnd(ht.ntflux_d*ht.hf1.varIntSpa)	W	Total net heat rate, downside	Global
ht.hf1.ntefluxInt_d	ht.hf1.intIntBnd(ht.nteflux_d*ht.hf1.varIntSpa)	W	Total net energy rate, downside	Global
ht.hf1.Tave	if(ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))==0,ht.hf1.intBnd(ht.hf1.varIntSpa*T)/ht.hf1.intBnd(ht.hf1.varIntSpa),ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht.Cp*T*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))/ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz)))	K	Weighted average temperature	Global

Weak expressions

Weak expression	Integration frame	Selection
ht.hf1.q0*test(ht.hf1.Tvar)*ht.d	Material	Boundaries 1, 3, 7, 10

2.4.5 Heat Source 1



Heat Source 1

Selection

Geometric entity level	Domain
Selection	Domains 1–2

Equations

$$Q = Q_0$$

Settings

Description	Value
Heat source	General source
Heat source	User defined
Heat source	1e6[W/m^3]*5e-2[m]/(sqrt(x^2 + y^2 + z^2))

Variables

Name	Expression	Unit	Description	Selection
ht.Q	ht.hs1.Q	W/m^3	Heat source	Domains 1–2
ht.Qtot	ht.hs1.Q	W/m^3	Total heat source	Domains 1–2
ht.hs1.Q	1000000[W/m^3]*0.05[m]/sqrt(x^2+y^2+z^2)	W/m^3	Heat source	Domains 1–2

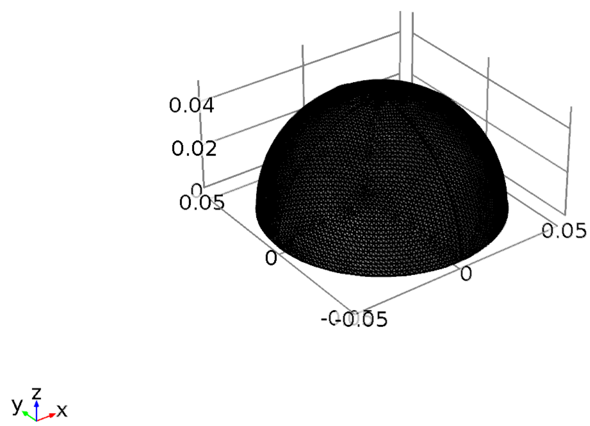
Weak expressions

Weak expression	Integration frame	Selection
ht.hs1.Q*test(T)*ht.d	Material	Domains 1–2

2.5 Mesh 1

Mesh statistics

Description	Value
Minimum element quality	0.1456
Average element quality	0.7734
Tetrahedral elements	559305
Triangular elements	17158
Edge elements	448
Vertex elements	10



Mesh 1

2.5.1 Size (size)

Settings

Description	Value
Maximum element size	0.002
Minimum element size	2.0E-5
Curvature factor	0.2
Maximum element growth rate	1.3
Predefined size	Extremely fine

2.5.2 Free Tetrahedral 1 (ftet1)

Selection

Geometric entity level	Remaining

3 Study 1

Computation information

Computation time	38 s
CPU	Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60GHz, 3 cores
Operating system	Windows 7

3.1 Stationary

Study settings

Description	Value
Include geometric nonlinearity	Off

Physics and variables selection

Physics interface	Discretization
Heat Transfer in Solids (ht)	physics

Mesh selection

Geometry	Mesh
Geometry 1 (geom1)	mesh1

3.2 Solver Configurations

3.2.1 Solution 1

Compile Equations: Stationary (st1)

Study and step

Description	Value
Use study	Study 1
Use study step	Stationary

Dependent Variables 1 (v1)

General

Description	Value
Defined by study step	Stationary

Initial values of variables solved for

Description	Value
Solution	Zero

Values of variables not solved for

Description	Value
Solution	Zero

Temperature (comp1.T) (comp1_T)

General

Description	Value

Description	Value
Field components	comp1.T

Stationary Solver 1 (s1)

General

Description	Value
Defined by study step	Stationary

Fully Coupled 1 (fc1)

General

Description	Value
Linear solver	Iterative 1

Method and termination

Description	Value
Initial damping factor	0.01
Minimum damping factor	1.0E-6
Maximum number of iterations	50

Iterative 1 (i1)

General

Description	Value
Factor in error estimate	20

Multigrid 1 (mg1)

General

Description	Value
Use hierarchy in geometries	Geometry 1

Presmoother (pr)

SOR Line 1 (sl1)

Main

Description	Value
Relaxation factor	0.2

Secondary

Description	Value
Number of secondary iterations	2
Relaxation factor	0.5

Postsmoother (po)

SOR Line 1 (sl1)

Main

Description	Value

Description	Value
Relaxation factor	0.2

Secondary

Description	Value
Number of secondary iterations	2
Relaxation factor	0.5

Coarse Solver (cs)

Direct 1 (d1)

General

Description	Value
Solver	PARDISO

Information 1 (prob1)

Warnings 1 (warning1)

Log

```
There was a warning message from the linear solver.
Ill-conditioned preconditioner. Increase factor in error estimate.
```

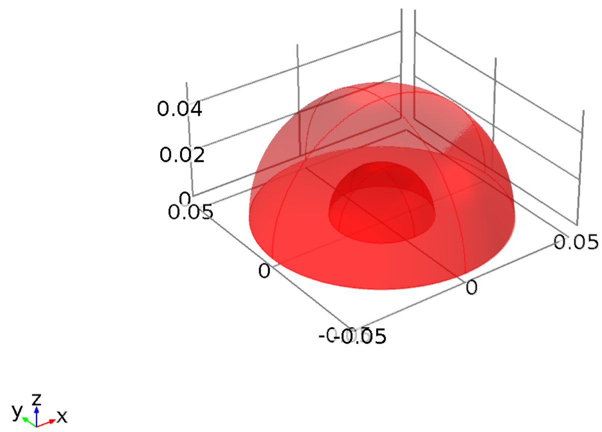
4 Results

4.1 Data Sets

4.1.1 Study 1/Solution 1

Solution

Description	Value
Solution	Solution 1
Component	Save Point Geometry 1



Data set: Study 1/Solution 1

4.1.2 Cut Line 3D 1

Data

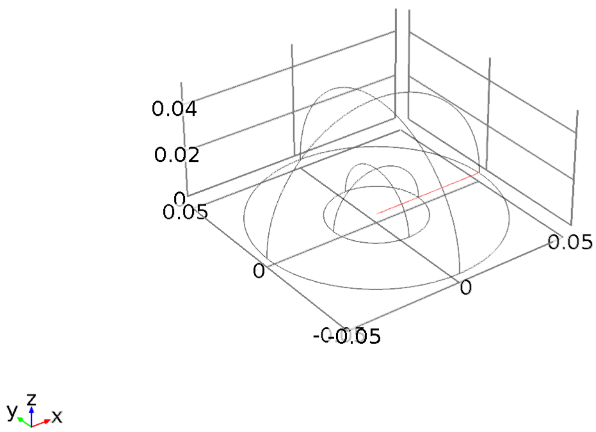
Description	Value
Data set	Study 1/Solution 1

Line data

Description	Value
Line entry method	Two points
Points	{{0, 0, 0}, {0.5, 0, 0}}

Advanced

Description	Value
Space variable	cln1x



Data set: Cut Line 3D 1

4.2 Derived Values

4.2.1 Surface Integration 1

Selection

Geometric entity level	Boundary
Selection	Boundary 2

Data

Description	Value
Data set	Study 1/Solution 1

Expression

Description	Value
Expression	ht.ndflux
Unit	W
Description	Normal conductive heat flux

4.3 Tables

4.3.1 Table 1

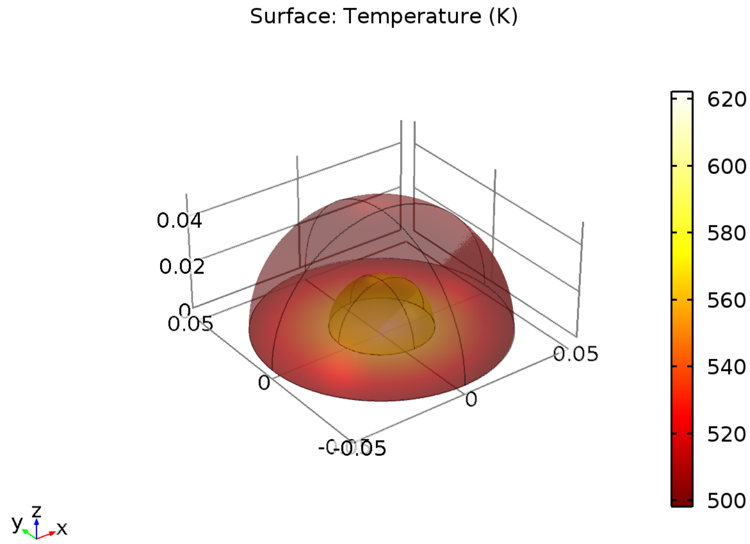
Surface Integration 1 (ht.ndflux)

Table 1

Normal conductive heat flux (W)	Normal conductive heat flux (W)
0.0022925	0.0022925

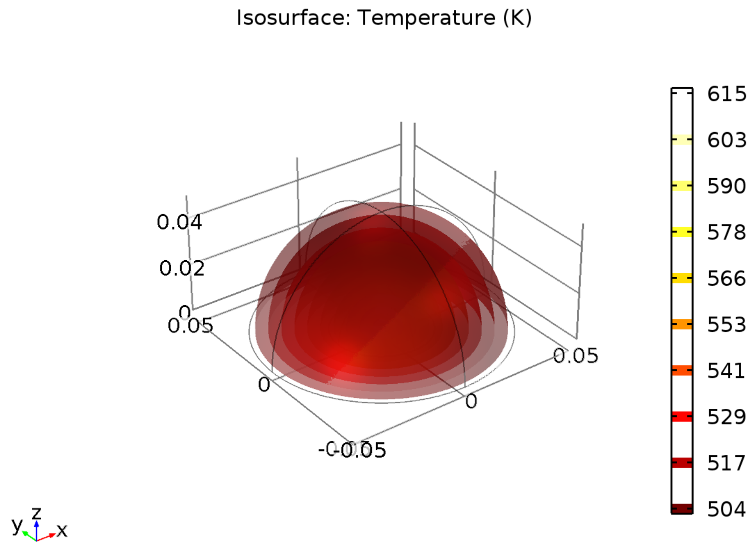
4.4 Plot Groups

4.4.1 Temperature (ht)



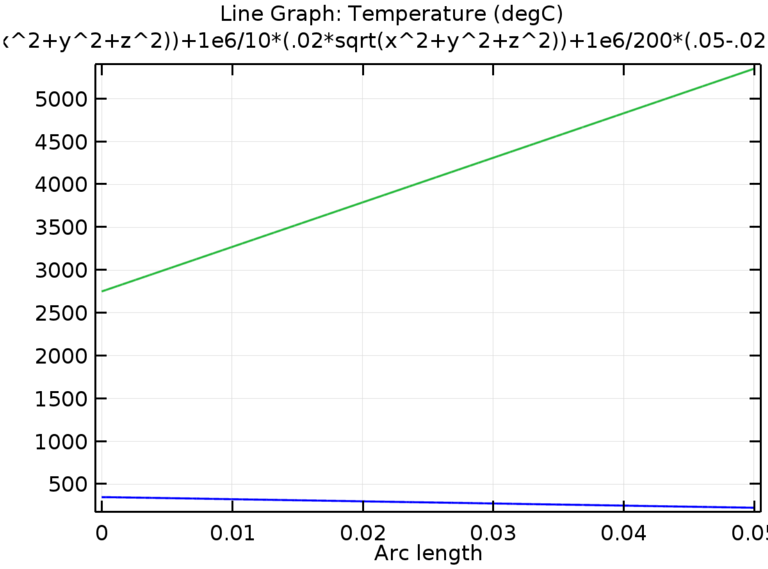
Surface: Temperature (K)

4.4.2 Isothermal Contours (ht)



Isosurface: Temperature (K)

4.4.3 1D Plot Group 3



Line Graph: Temperature (degC) Line Graph: 1e6/20(sqrt(x^2+y^2+z^2))+1e6/10*(.02*sqrt(x^2+y^2+z^2))+1e6/200*(.05-.02)+1e6/10*(.025)+(100) (m)*