Heat Transfer Mechanisms

1-44C The thermal conductivity of a material is the rate of heat transfer through a unit thickness of the material per unit area and per unit temperature difference. The thermal conductivity of a material is a measure of how fast heat will be conducted in that material.

1-45C The mechanisms of heat transfer are conduction, convection and radiation. Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas which is in motion, and it involves combined effects of conduction and fluid motion. Radiation is energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

1-46C In solids, conduction is due to the combination of the vibrations of the molecules in a lattice and the energy transport by free electrons. In gases and liquids, it is due to the collisions of the molecules during their random motion.

1-47C The parameters that effect the rate of heat conduction through a windowless wall are the geometry and surface area of wall, its thickness, the material of the wall, and the temperature difference across the wall.

1-48C Conduction is expressed by Fourier's law of conduction as $\dot{Q}_{cond} = -kA\frac{dT}{dx}$ where dT/dx is the temperature gradient, k is the thermal conductivity, and A is the area which is normal to the direction of heat transfer.

Convection is expressed by Newton's law of cooling as $\dot{Q}_{conv} = hA_s(T_s - T_\infty)$ where h is the convection heat transfer coefficient, A_s is the surface area through which convection heat transfer takes place, T_s is the surface temperature and T_∞ is the temperature of the fluid sufficiently far from the surface.

Radiation is expressed by Stefan-Boltzman law as $\dot{Q}_{rad} = \varepsilon\sigma A_s(T_s{}^4 - T_{surr}{}^4)$ where ε is the emissivity of surface, A_s is the surface area, T_s is the surface temperature, T_{surr} is average surrounding surface temperature and $\sigma = 5.67\times10^{-8}\ \mathrm{W/m^2.K^4}$ is the Stefan-Boltzman constant.

1-49C Convection involves fluid motion, conduction does not. In a solid we can have only conduction.

1-50C No. It is purely by radiation.

1-51C In forced convection the fluid is forced to move by external means such as a fan, pump, or the wind. The fluid motion in natural convection is due to buoyancy effects only.

1-52C Emissivity is the ratio of the radiation emitted by a surface to the radiation emitted by a blackbody at the same temperature. Absorptivity is the fraction of radiation incident on a surface that is absorbed by the surface. The Kirchhoff's law of radiation states that the emissivity and the absorptivity of a surface are equal at the same temperature and wavelength.

1-53C A blackbody is an idealized body which emits the maximum amount of radiation at a given temperature and which absorbs all the radiation incident on it. Real bodies emit and absorb less radiation than a blackbody at the same temperature.

1-54C No. Such a definition will imply that doubling the thickness will double the heat transfer rate. The equivalent but "more correct" unit of thermal conductivity is W.m/m^2.°C that indicates product of heat transfer rate and thickness per unit surface area per unit temperature difference.

1-55C In a typical house, heat loss through the wall with glass window will be larger since the glass is much thinner than a wall, and its thermal conductivity is higher than the average conductivity of a wall.

1-56C Diamond is a better heat conductor.

1-57C The rate of heat transfer through both walls can be expressed as

$$\dot{Q}_{\text{wood}} = k_{\text{wood}} A \frac{T_1 - T_2}{L_{\text{wood}}} = (0.16\ \text{W/m.°C}) A \frac{T_1 - T_2}{0.1\ \text{m}} = 1.6A(T_1 - T_2)$$

$$\dot{Q}_{\text{brick}} = k_{\text{brick}} A \frac{T_1 - T_2}{L_{\text{brick}}} = (0.72\ \text{W/m.°C}) A \frac{T_1 - T_2}{0.25\ \text{m}} = 2.88A(T_1 - T_2)$$

where thermal conductivities are obtained from table A-5. Therefore, heat transfer through the brick wall will be larger despite its higher thickness.

1-58C The thermal conductivity of gases is proportional to the square root of absolute temperature. The thermal conductivity of most liquids, however, decreases with increasing temperature, with water being a notable exception.

1-59C Superinsulations are obtained by using layers of highly reflective sheets separated by glass fibers in an evacuated space. Radiation heat transfer between two surfaces is inversely proportional to the number of sheets used and thus heat loss by radiation will be very low by using this highly reflective sheets. At the same time, evacuating the space between the layers forms a vacuum under 0.000001 atm pressure which minimize conduction or convection through the air space between the layers.

1-60C Most ordinary insulations are obtained by mixing fibers, powders, or flakes of insulating materials with air. Heat transfer through such insulations is by conduction through the solid material, and conduction or convection through the air space as well as radiation. Such systems are characterized by apparent thermal conductivity instead of the ordinary thermal conductivity in order to incorporate these convection and radiation effects.

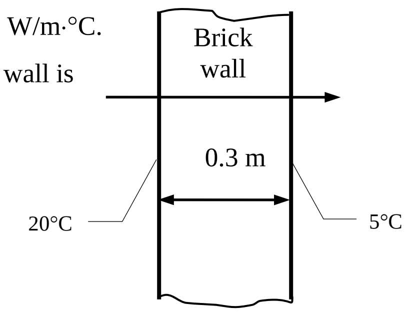
1-61C The thermal conductivity of an alloy of two metals will most likely be less than the thermal conductivities of both metals.

1-62 The inner and outer surfaces of a brick wall are maintained at specified temperatures. The rate of heat transfer through the wall is to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Thermal properties of the wall are constant.

Properties The thermal conductivity of the wall is given to be k = 0.69 W/m·°C.

Analysis Under steady conditions, the rate of heat transfer through the wall is



$$\dot{Q}_{cond} = kA\frac{\Delta T}{L} = (0.69\,\text{W/m}\cdot{}^\circ\text{C})(5\times 6\,\text{m}^2)\frac{(20-5)^\circ\text{C}}{0.3\,\text{m}} = \mathbf{1035\,W}$$

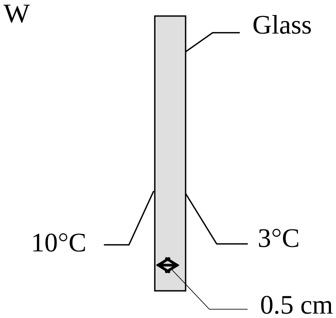
1-63 The inner and outer surfaces of a window glass are maintained at specified temperatures. The amount of heat transfer through the glass in 5 h is to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the glass remain constant at the specified values. **2** Thermal properties of the glass are constant.

Properties The thermal conductivity of the glass is given to be k = 0.78 W/m·°C.

Analysis Under steady conditions, the rate of heat transfer through the glass by conduction is

$$\dot{Q}_{cond} = kA\frac{\Delta T}{L} = (0.78\,\text{W/m}\cdot{}^\circ\text{C})(2\times 2\,\text{m}^2)\frac{(10-3)^\circ\text{C}}{0.005\,\text{m}} = 4368\,\text{W}$$



Then the amount of heat transfer over a period of 5 h becomes

$$Q = \dot{Q}_{cond}\Delta t = (4.368\,\text{kJ/s})(5\times 3600\,\text{s}) = \mathbf{78{,}620\ kJ}$$

If the thickness of the glass doubled to 1 cm, then the amount of heat transfer will go down by half to **39,310 kJ**.

1-64

```
"GIVEN"
"L=0.005 [m], parameter to be varied"
A=2*2 "[m^2]"
T_1=10 "[C]"
T_2=3 "[C]"
k=0.78 "[W/m-C]"
time=5*3600 "[s]"

"ANALYSIS"
Q_dot_cond=k*A*(T_1-T_2)/L
Q_cond=Q_dot_cond*time*Convert(J, kJ)
```

L [m]	**Q_{cond} [kJ]**
0.001	393120
0.002	196560
0.003	131040
0.004	98280
0.005	78624
0.006	65520
0.007	56160
0.008	49140
0.009	43680
0.01	39312

1-65 Heat is transferred steadily to boiling water in the pan through its bottom. The inner surface of the bottom of the pan is given. The temperature of the outer surface is to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the pan remain constant at the specified values. **2** Thermal properties of the aluminum pan are constant.

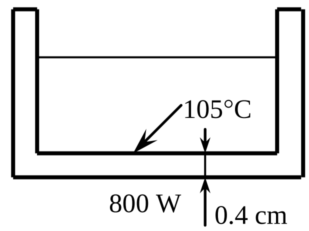
Properties The thermal conductivity of the aluminum is given to be k = 237 W/m·°C.

Analysis The heat transfer area is

$$A = \pi r^2 = \pi(0.1\text{ m})^2 = 0.0314\text{ m}^2$$

Under steady conditions, the rate of heat transfer through the bottom of the pan by conduction is

$$\dot{Q} = kA\frac{\Delta T}{L} = kA\frac{T_2 - T_1}{L}$$



Substituting,

$$800\text{W} = (237\text{W/m}\cdot°\text{C})(0.0314\text{m}^2)\frac{T_2 - 105°\text{C}}{0.004\text{m}}$$

which gives

$$T_2 = \mathbf{105.43\ °C}$$

1-66E The inner and outer surface temperatures of the wall of an electrically heated home during a winter night are measured. The rate of heat loss through the wall that night and its cost are to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values during the entire night. **2** Thermal properties of the wall are constant.

Properties The thermal conductivity of the brick wall is given to be k = 0.42 Btu/h.ft.°F.

Analysis (*a*) Noting that the heat transfer through the wall is by conduction and the surface area of the wall is $A = 20\text{ ft}\times 10\text{ ft} = 200\text{ ft}^2$, the steady rate of heat transfer through the wall can be determined from

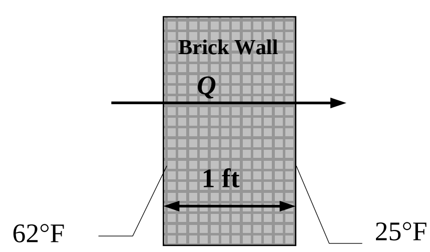
$$\dot{Q} = kA\frac{T_1 - T_2}{L} = (0.42\text{ Btu/h.ft.°F})(200\text{ ft}^2)\frac{(62-25)°\text{F}}{1\text{ ft}} = \mathbf{3108\ Btu/h}$$

or 0.911 kW since 1 kW = 3412 Btu/h.

(*b*) The amount of heat lost during an 8 hour period and its cost are

$$Q = \dot{Q}\Delta t = (0.911\text{ kW})(8\text{ h}) = 7.288\text{ kWh}$$

$$\begin{aligned}\text{Cost} &= (\text{Amount of energy})(\text{Unit cost of energy})\\ &= (7.288\text{ kWh})(\$0.07/\text{kWh})\\ &= \mathbf{\$0.51}\end{aligned}$$



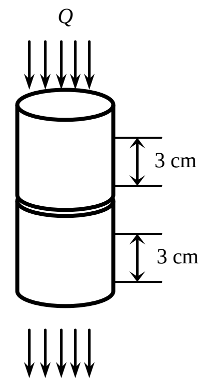
Therefore, the cost of the heat loss through the wall to the home owner that night is $0.51.

1-67 The thermal conductivity of a material is to be determined by ensuring one-dimensional heat conduction, and by measuring temperatures when steady operating conditions are reached.

Assumptions 1 Steady operating conditions exist since the temperature readings do not change with time. **2** Heat losses through the lateral surfaces of the apparatus are negligible since those surfaces are well-insulated, and thus the entire heat generated by the heater is conducted through the samples. **3** The apparatus possesses thermal symmetry.

Analysis The electrical power consumed by the heater and converted to heat is

$$\dot{W}_e = VI = (110 \text{ V})(0.6 \text{ A}) = 66 \text{ W}$$



The rate of heat flow through each sample is

$$\dot{Q} = \frac{\dot{W}_e}{2} = \frac{66 \text{ W}}{2} = 33 \text{ W}$$

Then the thermal conductivity of the sample becomes

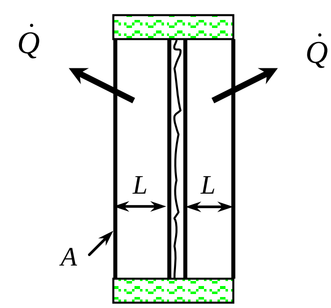
$$A = \frac{\pi D^2}{4} = \frac{\pi (0.04 \text{ m})^2}{4} = 0.001257 \text{ m}^2$$

$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{Q}L}{A\Delta T} = \frac{(33 \text{ W})(0.03 \text{ m})}{(0.001257 \text{ m}^2)(10^\circ\text{C})} = \mathbf{78.8 \text{ W/m.}^\circ\text{C}}$$

1-68 The thermal conductivity of a material is to be determined by ensuring one-dimensional heat conduction, and by measuring temperatures when steady operating conditions are reached.

Assumptions 1 Steady operating conditions exist since the temperature readings do not change with time. **2** Heat losses through the lateral surfaces of the apparatus are negligible since those surfaces are well-insulated, and thus the entire heat generated by the heater is conducted through the samples. **3** The apparatus possesses thermal symmetry.

Analysis For each sample we have



$$\dot{Q} = 35/2 = 17.5 \text{ W}$$

$$A = (0.1 \text{ m})(0.1 \text{ m}) = 0.01 \text{ m}^2$$

$$\Delta T = 82 - 74 = 8^\circ\text{C}$$

Then the thermal conductivity of the material becomes

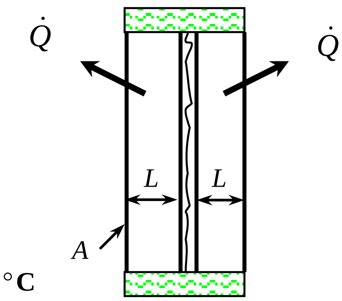
$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{Q}L}{A\Delta T} = \frac{(17.5 \text{ W})(0.005 \text{ m})}{(0.01 \text{ m}^2)(8^\circ\text{C})} = \mathbf{1.09 \text{ W/m.}^\circ\text{C}}$$

1-69 The thermal conductivity of a material is to be determined by ensuring one-dimensional heat conduction, and by measuring temperatures when steady operating conditions are reached.

Assumptions 1 Steady operating conditions exist since the temperature readings do not change with time. **2** Heat losses through the lateral surfaces of the apparatus are negligible since those surfaces are well-insulated, and thus the entire heat generated by the heater is conducted through the samples. **3** The apparatus possesses thermal symmetry.

Analysis For each sample we have

$$\dot{Q} = 28/2 = 14 \text{ W}$$
$$A = (0.1 \text{ m})(0.1 \text{ m}) = 0.01 \text{ m}^2$$
$$\Delta T = 82 - 74 = 8°\text{C}$$



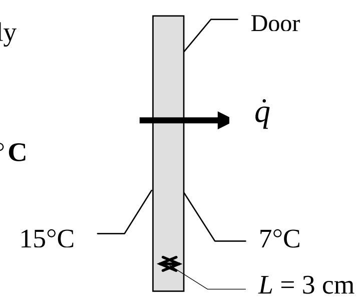
Then the thermal conductivity of the material becomes

$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{Q}L}{A\Delta T} = \frac{(14 \text{ W})(0.005 \text{ m})}{(0.01 \text{ m}^2)(8°\text{C})} = \mathbf{0.875 \ W/m.°C}$$

1-70 The thermal conductivity of a refrigerator door is to be determined by measuring the surface temperatures and heat flux when steady operating conditions are reached.

Assumptions 1 Steady operating conditions exist when measurements are taken. **2** Heat transfer through the door is one dimensional since the thickness of the door is small relative to other dimensions.

Analysis The thermal conductivity of the door material is determined directly from Fourier's relation to be



$$\dot{q} = k\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{q}L}{\Delta T} = \frac{(25 \text{ W/m}^2)(0.03 \text{ m})}{(15-7)°\text{C}} = \mathbf{0.09375 \ W/m.°C}$$

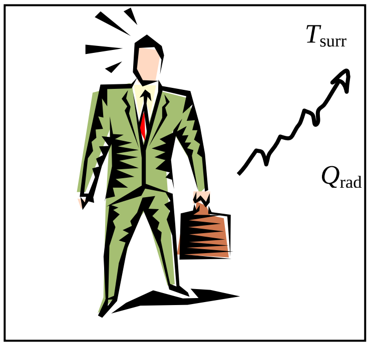
1-71 The rate of radiation heat transfer between a person and the surrounding surfaces at specified temperatur es is to be determined in summer and in winter.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by convection is not considered. **3** The person is completely surrounded by the interior surfaces of the room. **4** The surrounding surfaces are at a uniform temperature.

Properties The emissivity of a person is given to be ε = 0.95

Analysis Noting that the person is completely enclosed by the surrounding surfaces, the net rates of radiation heat transfer from the body to the surrounding walls, ceiling, and the floor in both cases are:

(*a*) Summer: T_{surr} = 23+273=296



$$\begin{aligned}\dot{Q}_{\text{rad}} &= \varepsilon\sigma A_s (T_s^4 - T_{\text{surr}}^4) \\ &= (0.95)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.6\,\text{m}^2)[(32+273)^4 - (296\,\text{K})^4]\text{K}^4 \\ &= \mathbf{84.2\,W}\end{aligned}$$

(*b*) Winter: T_{surr} = 12+273= 285 K

$$\begin{aligned}\dot{Q}_{\text{rad}} &= \varepsilon\sigma A_s (T_s^4 - T_{\text{surr}}^4) \\ &= (0.95)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.6\,\text{m}^2)[(32+273)^4 - (285\,\text{K})^4]\text{K}^4 \\ &= \mathbf{177.2\,W}\end{aligned}$$

Discussion Note that the radiation heat transfer from the person more than doubles in winter.

1-72

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"GIVEN"
T_infinity=20+273 "[K]"
"T_surr_winter=12+273 [K], parameter to be varied"
T_surr_summer=23+273 "[K]"
A=1.6 "[m^2]"
epsilon=0.95
T_s=32+273 "[K]"

"ANALYSIS"
sigma=5.67E-8 "[W/m^2-K^4], Stefan-Boltzman constant"
"(a)"
Q_dot_rad_summer=epsilon*sigma*A*(T_s^4-T_surr_summer^4)
"(b)"
Q_dot_rad_winter=epsilon*sigma*A*(T_s^4-T_surr_winter^4)
```

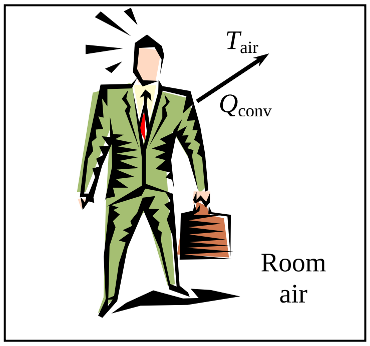
$T_{surr, winter}$ [K]	$Q_{rad, winter}$ [W]
281	208.5
282	200.8
283	193
284	185.1
285	177.2
286	169.2
287	161.1
288	152.9
289	144.6
290	136.2
291	127.8

1-73 A person is standing in a room at a specified temperature. The rate of heat transfer between a person and the surrounding air by convection is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The environment is at a uniform temperature.

Analysis The heat transfer surface area of the person is

$$A_s = \pi DL = \pi(0.3 \text{ m})(1.70 \text{ m}) = 1.60 \text{ m}^2$$



Under steady conditions, the rate of heat transfer by convection is

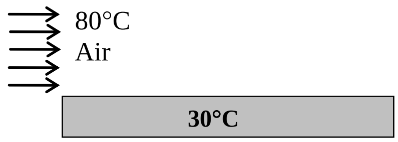
$$\dot{Q}_{conv} = hA_s\Delta T = (15 \text{W/m}^2\cdot{}^\circ\text{C})(1.60 \text{m}^2)(34-20)^\circ\text{C} = \mathbf{336 W}$$

1-74 Hot air is blown over a flat surface at a specified temperature. The rate of heat transfer from the air to the plate is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The convection heat transfer coefficient is constant and uniform over the surface.

Analysis Under steady conditions, the rate of heat transfer by convection is

$$\dot{Q}_{conv} = hA_s\Delta T = (55\,\text{W/m}^2\cdot{}^\circ\text{C})(2\times 4\,\text{m}^2)(80-30)^\circ\text{C} = \mathbf{22{,}000\,W}$$



1-75

```
"GIVEN"
T_infinity=80 "[C]"
A=2*4 "[m^2]"
T_s=30 "[C]"
"h=55 [W/m^2-C], parameter to be varied"

"ANALYSIS"
Q_dot_conv=h*A*(T_infinity-T_s)
```

h [W/m^2.C]	Q_{conv} [W]
20	8000
30	12000
40	16000
50	20000
60	24000
70	28000
80	32000
90	36000
100	40000

1-76 The heat generated in the circuitry on the surface of a 3-W silicon chip is conducted to the ceramic substrate. The temperature difference across the chip in steady operation is to be determined.

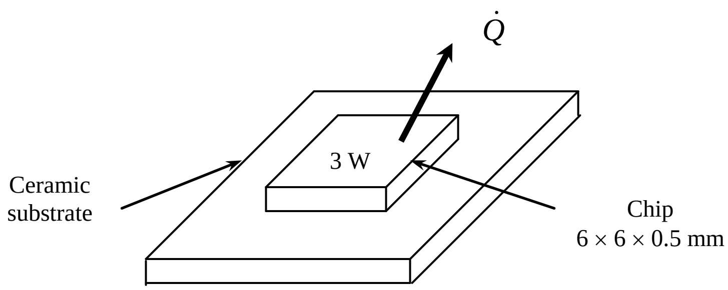
Assumptions **1** Steady operating conditions exist. **2** Thermal properties of the chip are constant.

Properties The thermal conductivity of the silicon chip is given to be k = 130 W/m·°C.

Analysis The temperature difference between the front and back surfaces of the chip is

$$A = (0.006\text{ m})(0.006\text{ m}) = 0.000036\text{ m}^2$$

$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow \Delta T = \frac{\dot{Q}L}{kA} = \frac{(3\text{ W})(0.0005\text{ m})}{(130\text{ W/m.°C})(0.000036\text{ m}^2)} = \mathbf{0.32\ °C}$$

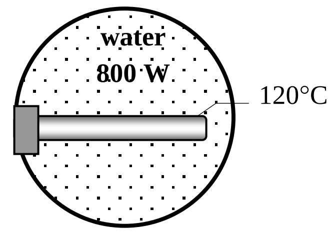


1-77 An electric resistance heating element is immersed in water initially at 20°C. The time it will take for this heater to raise the water temperature to 80°C as well as the convection heat transfer coefficients at the beginning and at the end of the heating process are to be determined.

Assumptions **1** Steady operating conditions exist and thus the rate of heat loss from the wire equals the rate of heat generation in the wire as a result of resistance heating. **2** Thermal properties of water are constant. **3** Heat losses from the water in the tank are negligible.

Properties The specific heat of water at room temperature is C = 4.18 kJ/kg·°C (Table A-2).

Analysis When steady operating conditions are reached, we have $\dot{Q} = \dot{E}_{\text{generated}} = 800\text{ W}$. This is also equal to the rate of heat gain by water. Noting that this is the only mechanism of energy transfer, the time it takes to raise the water temperature from 20°C to 80°C is determined to be



$$Q_{in} = mC(T_2 - T_1)$$

$$\dot{Q}_{in}\Delta t = mC(T_2 - T_1)$$

$$\Delta t = \frac{mC(T_2 - T_1)}{\dot{Q}_{in}} = \frac{(60\text{ kg})(4180\text{ J/kg.°C})(80-20)\text{°C}}{800\text{ J/s}} = 18{,}810\text{ s} = \mathbf{5.225 h}$$

The surface area of the wire is

$$A_s = (\pi D)L = \pi(0.005\text{ m})(0.5\text{ m}) = 0.00785\text{m}^2$$

The Newton's law of cooling for convection heat transfer is expressed as $\dot{Q} = hA_s(T_s - T_\infty)$. Disregarding any heat transfer by radiation and thus assuming all the heat loss from the wire to occur by convection, the convection heat transfer coefficients at the beginning and at the end of the process are determined to be

$$h_1 = \frac{\dot{Q}}{A_s(T_s - T_{\infty 1})} = \frac{800\text{ W}}{(0.00785\text{m}^2)(120-20)\text{°C}} = \mathbf{1020\ W/m^2.°C}$$

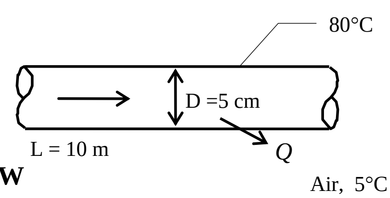
$$h_2 = \frac{\dot{Q}}{A_s(T_s - T_{\infty 2})} = \frac{800\text{ W}}{(0.00785\text{m}^2)(120-80)\text{°C}} = \mathbf{2550\ W/m^2.°C}$$

Discussion Note that a larger heat transfer coefficient is needed to dissipate heat through a smaller temperature difference for a specified heat transfer rate.

1-78 A hot water pipe at 80°C is losing heat to the surrounding air at 5°C by natural convection with a heat transfer coefficient of 25 W/ m^2.°C. The rate of heat loss from the pipe by convection is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The convection heat transfer coefficient is constant and uniform over the surface.

Analysis The heat transfer surface area is



$$A_s = \pi DL = \pi(0.05\text{ m})(10\text{ m}) = 1.571\text{ m}^2$$

Under steady conditions, the rate of heat transfer by convection is

$$\dot{Q}_{conv} = hA_s\Delta T = (25\text{W/m}^2\cdot^\circ\text{C})(1.571\text{m}^2)(80-5)^\circ\text{C} = \mathbf{2945W}$$

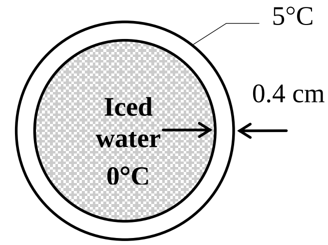
1-79 A hollow spherical iron container is filled with iced water at 0°C. The rate of heat loss from the sphere and the rate at which ice melts in the container are to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Heat transfer through the shell is one-dimensional. **3** Thermal properties of the iron shell are constant. **4** The inner surface of the shell is at the same temperature as the iced water, 0°C.

Properties The thermal conductivity of iron is k = 80.2 W/m·°C (Table A-3). The heat of fusion of water is given to be 333.7 kJ/kg.

Analysis This spherical shell can be approximated as a plate of thickness 0.4 cm and area

$$A = \pi D^2 = \pi(0.2\text{ m})^2 = 0.126\text{ m}^2$$



Then the rate of heat transfer through the shell by conduction is

$$\dot{Q}_{cond} = kA\frac{\Delta T}{L} = (80.2\text{W/m}\cdot°\text{C})(0.126\text{m}^2)\frac{(5-0)°\text{C}}{0.004\text{m}} = 12{,}632\text{W}$$

Considering that it takes 333.7 kJ of energy to melt 1 kg of ice at 0°C, the rate at which ice melts in the container can be determined from

$$\dot{m}_{ice} = \frac{\dot{Q}}{h_{if}} = \frac{12.632\text{ kJ/s}}{333.7\text{ kJ/kg}} = \mathbf{0.038\text{ kg/s}}$$

Discussion We should point out that this result is slightly in error for approximating a curved wall as a plain wall. The error in this case is very small because of the large diameter to thickness ratio. For better accuracy, we could use the inner surface area (D = 19.2 cm) or the mean surface area (D = 19.6 cm) in the calculations.

1-80

```
"GIVEN"
D=0.2 "[m]"
"L=0.4 [cm], parameter to be varied"
T_1=0 "[C]"
T_2=5 "[C]"

"PROPERTIES"
h_if=333.7 "[kJ/kg]"
k=k_('Iron', 25) "[W/m-C]"

"ANALYSIS"
A=pi*D^2
Q_dot_cond=k*A*(T_2-T_1)/(L*Convert(cm, m))
m_dot_ice=(Q_dot_cond*Convert(W, kW))/h_if
```

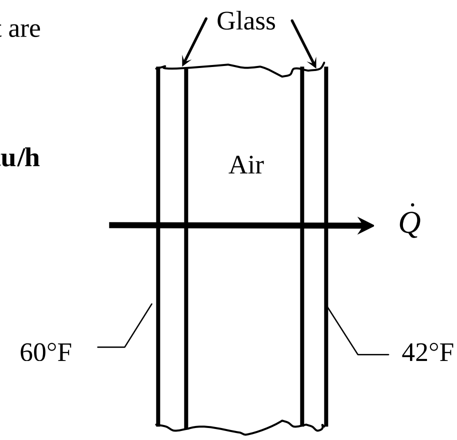
L [cm]	**m_{ice} [kg/s]**
0.2	0.07574
0.4	0.03787
0.6	0.02525
0.8	0.01894
1	0.01515
1.2	0.01262
1.4	0.01082
1.6	0.009468
1.8	0.008416
2	0.007574

1-81E The inner and outer glasses of a double pane window with a 0.5-in air space are at specified temperatures. The rate of heat transfer through the window is to be determined

Assumptions **1** Steady operating conditions exist since the surface temperatures of the glass remain constant at the specified values. **2** Heat transfer through the window is one-dimensional. **3** Thermal properties of the air are constant.

Properties The thermal conductivity of air at the average temperature of (60+42)/2 = 51°F is k = 0.01411 Btu/h.ft.°F (Table A-15).

Analysis The area of the window and the rate of heat loss through it are



$$A = (6\,\text{ft}) \times (6\,\text{ft}) = 36\,\text{m}^2$$

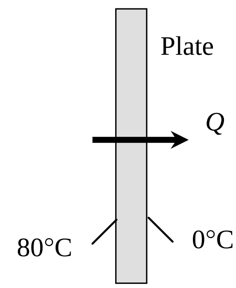
$$\dot{Q} = kA\frac{T_1 - T_2}{L} = (0.01411\,\text{Btu/h.ft.°F})(36\,\text{ft}^2)\frac{(60-42)\text{°F}}{0.25/12\,\text{ft}} = \mathbf{439\,Btu/h}$$

1-82 Two surfaces of a flat plate are maintained at specified temperatures, and the rate of heat transfer through the plate is measured. The thermal conductivity of the plate material is to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the plate remain constant at the specified values. **2** Heat transfer through the plate is one-dimensional. **3** Thermal properties of the plate are constant.

Analysis The thermal conductivity is determined directly from the steady one-dimensional heat conduction relation to be

$$\dot{Q} = kA\frac{T_1 - T_2}{L} \rightarrow k = \frac{\dot{Q}/A}{L(T_1 - T_2)} = \frac{500\,\text{W/m}^2}{(0.02\,\text{m})(80\text{-}0)°\text{C}} = \mathbf{313\,W/m.°C}$$



1-83 Four power transistors are mounted on a thin vertical aluminum plate that is cooled by a fan. The temperature of the aluminum plate is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The entire plate is nearly isothermal. **3** Thermal properties of the wall are constant. **4** The exposed surface area of the transistor can be taken to be equal to its base area. **5** Heat transfer by radiation is disregarded. **6** The convection heat transfer coefficient is constant and uniform over the surface.

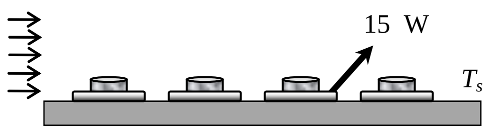
Analysis The total rate of heat dissipation from the aluminum plate and the total heat transfer area are

$$\dot{Q} = 4 \times 15\,\text{W} = 60\,\text{W}$$

$$A_s = (0.22\,\text{m})(0.22\,\text{m}) = 0.0484\,\text{m}^2$$

Disregarding any radiation effects, the temperature of the aluminum plate is determined to be

$$\dot{Q} = hA_s(T_s - T_\infty) \longrightarrow T_s = T_\infty + \frac{\dot{Q}}{hA_s} = 25°\text{C} + \frac{60\,\text{W}}{(25\,\text{W/m}^2.°\text{C})(0.0484\,\text{m}^2)} = \mathbf{74.6°C}$$



1-84 A styrofoam ice chest is initially filled with 40 kg of ice at 0°C. The time it takes for the ice in the chest to melt completely is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The inner and outer surface temperatures of the ice chest remain constant at 0°C and 8°C, respectively, at all times. **3** Thermal properties of the chest are constant. **4** Heat transfer from the base of the ice chest is negligible.

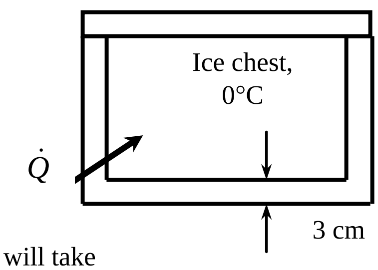
Properties The thermal conductivity of the styrofoam is given to be k = 0.033 W/m·°C. The heat of fusion of ice at 0°C is 333.7 kJ/kg.

Analysis Disregarding any heat loss through the bottom of the ice chest and using the average thicknesses, the total heat transfer area becomes

$$A = (40-3)(40-3) + 4\times(40-3)(30-3) = 5365\text{ cm}^2 = 0.5365\text{ m}^2$$

The rate of heat transfer to the ice chest becomes

$$\dot{Q} = kA\frac{\Delta T}{L} = (0.033\text{ W/m.°C})(0.5365\text{ m}^2)\frac{(8-0)\text{°C}}{0.03\text{ m}} = 4.72\text{ W}$$



The total amount of heat needed to melt the ice completely is

$$Q = mh_{if} = (40\text{ kg})(333.7\text{ kJ/kg}) = 13{,}348\text{ kJ}$$

Then transferring this much heat to the cooler to melt the ice completely will take

$$\Delta t = \frac{Q}{\dot{Q}} = \frac{13{,}348{,}000\text{ J}}{4.72\text{ J/s}} = 2{,}828{,}000\text{ s} = 785.6\text{ h} = \mathbf{32.7\ days}$$

1-85 A transistor mounted on a circuit board is cooled by air flowing over it. The transistor case temperature is not to exceed 70°C when the air temperature is 55°C. The amount of power this transistor can dissipate safely is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is disregarded. **3** The convection heat transfer coefficient is constant and uniform over the surface. **4** Heat transfer from the base of the transistor is negligible.

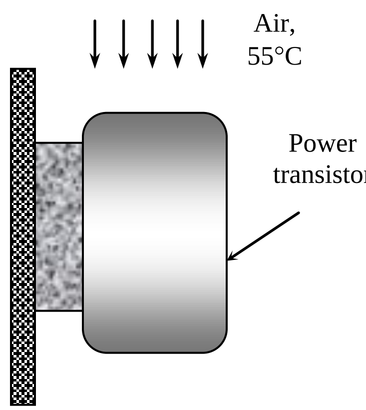
Analysis Disregarding the base area, the total heat transfer area of the transistor is

$$A_s = \pi DL + \pi D^2/4 = \pi(0.6\text{ cm})(0.4\text{cm}) + \pi(0.6\text{ cm})^2/4 = 1.037\text{ cm}^2 = 1.037\times10^{-4}\text{ m}^2$$

Then the rate of heat transfer from the power transistor at specified conditions is

$$\dot{Q} = hA_s(T_s - T_\infty) = (30\text{ W/m}^2.\text{°C})(1.037\times10^{-4}\text{ m}^2)(70-55)\text{°C} = \mathbf{0.047\ W}$$

Therefore, the amount of power this transistor can dissipate safely is 0.047 W.



1-86

```
"GIVEN"
L=0.004 "[m]"
D=0.006 "[m]"
h=30 "[W/m^2-C]"
T_infinity=55 "[C]"
"T_case_max=70 [C], parameter to be varied"

"ANALYSIS"
A=pi*D*L+pi*D^2/4
Q_dot=h*A*(T_case_max-T_infinity)
```

$T_{case, max}$ [C]	Q [W]
60	0.01555
62.5	0.02333
65	0.0311
67.5	0.03888
70	0.04665
72.5	0.05443
75	0.0622
77.5	0.06998
80	0.07775
82.5	0.08553
85	0.09331
87.5	0.1011
90	0.1089