Chapter 1: 20, 23, 35, 41, 68, 71, 76, 77, 80, 85, 90, 101, 103 and 104.

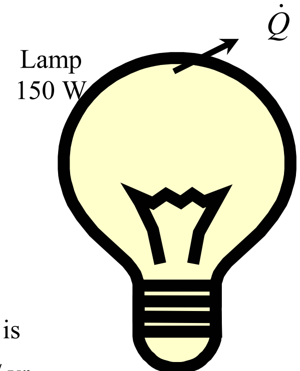
1-20 The filament of a 150 W incandescent lamp is 5 cm long and has a diameter of 0.5 mm. The heat flux on the surface of the filament, the heat flux on the surface of the glass bulb, and the annual electricity cost of the bulb are to be determined.

Assumptions Heat transfer from the surface of the filament and the bulb of the lamp is uniform .

Analysis (*a*) The heat transfer surface area and the heat flux on the surface of the filament are

$$A = \pi DL = \pi(0.05 \text{ cm})(5 \text{ cm}) = 0.785 \text{ cm}^2$$

$$\dot{q} = \frac{\dot{Q}}{A} = \frac{150 \text{ W}}{0.785 \text{ cm}^2} = 191 \text{ W/cm}^2 = \mathbf{1.91 \times 10^6 \ W/m^2}$$



(*b*) The heat flux on the surface of glass bulb is

$$A = \pi D^2 = \pi(8 \text{ cm})^2 = 201.1 \text{ cm}^2$$

$$\dot{q} = \frac{\dot{Q}}{A} = \frac{150 \text{ W}}{201.1 \text{ cm}^2} = 0.75 \text{ W/cm}^2 = \mathbf{7500 \ W/m^2}$$

(*c*) The amount and cost of electrical energy consumed during a one-year period is

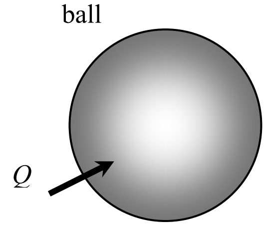
$$\text{Electricity Consumption} = \dot{Q}\Delta t = (0.15 \text{ kW})(365 \times 8 \text{ h/yr}) = 438 \text{ kWh/yr}$$

$$\text{Annual Cost} = (438 \text{ kWh/yr})(\$0.08/\text{kWh}) = \mathbf{\$35.04 / yr}$$

1-23 An aluminum ball is to be heated from 80°C to 200°C. The amount of heat that needs to be transferred to the aluminum ball is to be determined.

Assumptions The properties of the aluminum ball are constant.

Properties The average density and specific heat of aluminum are given to be ρ = 2,700 kg/m^3 and $C_p = 0.90$ kJ/kg.°C.



Analysis The amount of energy added to the ball is simply the change in its internal energy, and is determined from

$$E_{\text{transfer}} = \Delta U = mC(T_2 - T_1)$$

where

$$m = \rho V = \frac{\pi}{6}\rho D^3 = \frac{\pi}{6}(2700 \text{ kg/m}^3)(0.15 \text{ m})^3 = 4.77 \text{ kg}$$

Substituting,

$$E_{\text{transfer}} = (4.77 \text{ kg})(0.90 \text{ kJ/kg.°C})(200-80)\text{°C} = \mathbf{515 \ kJ}$$

Therefore, 515 kJ of energy (heat or work such as electrical energy) needs to be transferred to the aluminum ball to heat it to 200°C.

1-35 A resistance heater is to raise the air temperature in the room from 7 to 25°C within 15 min. The required power rating of the resistance heater is to be determined.

We observe that the pressure in the room remains constant during this process. Therefore, some air will leak out as the air expands. However, we can take the air to be a closed system by considering the air in the room to have undergone a constant pressure expansion process.

Assumptions **1** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. **4** Heat losses from the room are negligible.

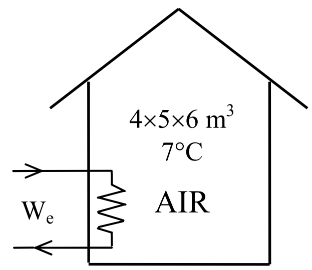
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.005 kJ/kg·K for air at room temperature (Table A-11).

Analysis The energy balance for this steady-flow system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{e,in} - W_b = \Delta U$$

$$W_{e,in} = \Delta H = m(h_2 - h_1) \cong mC_p(T_2 - T_1)$$



or,

$$\dot{W}_{e,in}\Delta t = mC_{p,ave}(T_2 - T_1)$$

The mass of air is

$$V = 4 \times 5 \times 6 = 120 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(120 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(280 \text{ K})} = 149.3 \text{ kg}$$

Using C_p value at room temperature, the power rating of the heater becomes

$$\dot{W}_{e,in} = (149.3 \text{ kg})(1.005 \text{ kJ/kg}\cdot{}^\circ\text{C})(25-7)^\circ\text{C}/(15\times 60 \text{ s}) = \mathbf{3.00\ kW}$$

1-41 An iron block at 100°C is brought into contact with an aluminum block at 200°C in an insulated enclosure. The final equilibrium temperature of the combined system is to be determined.

We take the entire contents of the enclosure iron + aluminum blocks, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process.

Assumptions **1** Both the iron and aluminum block are incompressible substances with constant specific heats. **2** The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$ and $\Delta E = \Delta U$. **3** The system is well-insulated and thus there is no heat transfer.

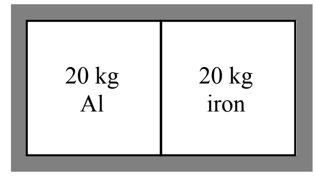
Properties The specific heats of iron and the aluminum blocks at room temperature are $C_{p,\text{ iron}}$ = 0.45 kJ/kg·°C and $C_{p,\text{ Al}}$ = 0.973 kJ/kg·°C (Table A-3).

Analysis The energy balance on the system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$0 = \Delta U$$

$$\Delta U_{\text{iron}} + \Delta U_{\text{Al}} = 0$$



or,

$$[mC(T_2 - T_1)]_{\text{iron}} + [mC(T_2 - T_1)]_{\text{Al}} = 0$$

The specific heat of iron is given in Table A-3 to be 0.45 kJ/kg.°C, which is the value at room temperature. The specific heat of aluminum at 450 K (which is somewhat below 200°C = 473 K) is 0.973 kJ/kg.°C. Substituting,

$$(20\text{ kg})(0.450\text{ kJ / kg}\cdot^\circ\text{C})(T_2-100)^\circ\text{C}+(20\text{ kg})(0.973\text{ kJ / kg}\cdot^\circ\text{C})(T_2-200)^\circ\text{C}=0$$

$$T_2 = \mathbf{168\ °C}$$

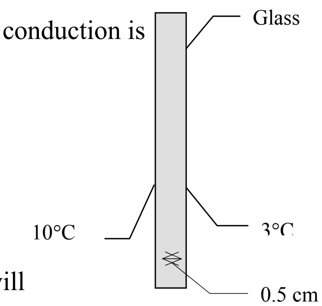
Discussion The result can be improved by using specific heat values at the average temperature of (100+168)/2 = 134°C.

1-68 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

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

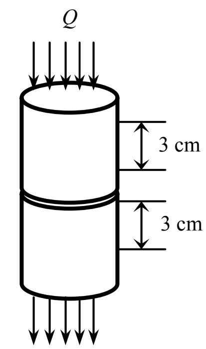
If the thickness of the glass doubled to 1 cm, then the amount of heat transfer will go down by half to **39,310 kJ**.

1-71 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

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

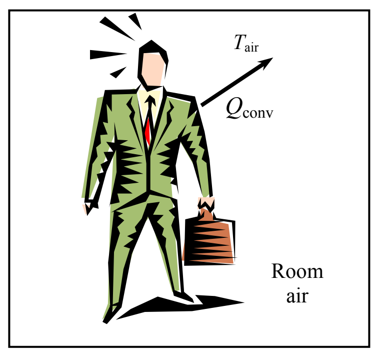
$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{Q}L}{A\Delta T} = \frac{(33 \text{ W})(0.03 \text{ m})}{(0.001257 \text{ m}^2)(10°\text{C})} = \mathbf{78.8 \text{ W / m.°C}}$$

1-76 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

$$A = (\pi D)h = \pi(0.3 \text{ m})(1.70 \text{ m}) = 1.60 \text{ m}^2$$



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

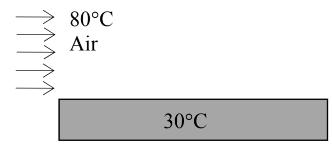
$$\dot{Q}_{conv} = hA\Delta T = (15 \text{W/m}^2\cdot°\text{C})(1.60 \text{m}^2)(34-20)°\text{C} = \mathbf{336 W}$$

1-77 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

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



1-80 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.

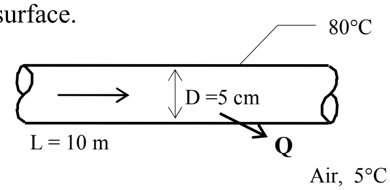
Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The convection heat transfer coefficient is constant and uniform over the surface.

Analysis The heat transfer surface area is

$$A = (\pi D)L = 3.14\text{x}(0.05\ \text{m})(10\ \text{m}) = 1.571\ \text{m}^2$$

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

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



1-85 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

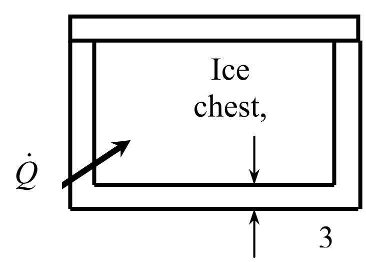
$$A = (40-3)(40-3) + 4\times(40-3)(30-3) = 5365\ \text{cm}^2 = 0.5365\ \text{m}^2$$

The rate of heat transfer to the ice chest becomes

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

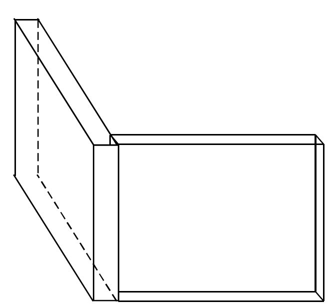
The total amount of heat needed to melt the ice completely is

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



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

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



1-90 A person with a specified surface temperature is subjected to radiation heat transfer in a room at specified wall temperatures. The rate of radiation heat loss from the person is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by convection is disregarded. **3** The emissivity of the person is constant and uniform over the exposed surface.

Properties The average emissivity of the person is given to be 0.7.

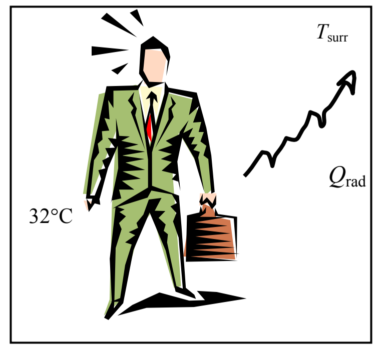
Analysis Noting that the person is completely enclosed by the surrounding surfaces, the net rates of radiation heat transfer from the body to the surrounding walls, ceiling, and the floor in both cases are

(*a*) $T_{surr} = 300$ K

$$\begin{aligned}\dot{Q}_{rad} &= \varepsilon\sigma A(T_s^4 - T_{surr}^4)\\ &= (0.7)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.7\ \text{m}^2)[(32+273)^4 - (300\ \text{K})^4]\text{K}^4\\ &= \mathbf{37.4\ W}\end{aligned}$$

(*b*) $T_{surr} = 280$ K

$$\begin{aligned}\dot{Q}_{rad} &= \varepsilon\sigma A(T_s^4 - T_{surr}^4)\\ &= (0.7)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.7\ \text{m}^2)[(32+273)^4 - (280\ \text{K})^4]\text{K}^4\\ &= \mathbf{169\ W}\end{aligned}$$

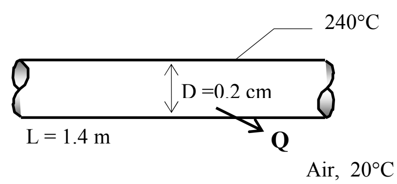


Discussion Note that the radiation heat transfer goes up by more than 4 times as the temperature of the surrounding surfaces drops from 300 K to 280 K.

1-101 The convection heat transfer coefficient for heat transfer from an electrically heated wire to air is to be determined by measuring temperatures when steady operating conditions are reached and the electric power consumed.

Assumptions 1 Steady operating conditions exist since the temperature readings do not change with time. **2** Radiation heat transfer is negligible.

Analysis In steady operation, the rate of heat loss from the wire equals the rate of heat generation in the wire as a result of resistance heating. That is,



$$\dot{Q} = \dot{E}_{generated} = VI = (110\ \text{V})(3\ \text{A}) = 330\ \text{W}$$

The surface area of the wire is

$$A = (\pi D)L = \pi(0.002\ \text{m})(1.4\ \text{m}) = 0.00880\ \text{m}^2$$

The Newton's law of cooling for convection heat transfer is expressed as

$$\dot{Q} = hA(T_s - T_\infty)$$

Disregarding any heat transfer by radiation , the convection heat transfer coefficient is determined to be

$$h = \frac{\dot{Q}}{A(T_1 - T_\infty)} = \frac{330\ \text{W}}{(0.00880\ \text{m}^2)(240-20)°\text{C}} = \mathbf{170.5\ W/m^2.°C}$$

Discussion If the temperature of the surrounding surfaces is equal to the air temperature in the room, the value obtained above actually represents the combined convection and radiation heat transfer coefficient.

1-103 A 1000-W iron is left on the iron board with its base exposed to the air at 20°C. The temperature of the base of the iron is to be determined in steady operation.

Assumptions **1** Steady operating conditions exist. **2** The thermal properties of the iron base and the convection heat transfer coefficient are constant and uniform. **3** The temperature of the surrounding surfaces is the same as the temperature of the surrounding air.

Properties The emissivity of the base surface is given to be ε = 0.6.

Analysis At steady conditions, the 1000 W energy supplied to the iron will be dissipated to the surroundings by convection and radiation heat transfer. Therefore,

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 1000 \text{ W}$$

where

$$\dot{Q}_{\text{conv}} = hA\Delta T = (35 \text{ W/m}^2\cdot\text{K})(0.02 \text{ m}^2)(T_s - 293 \text{ K}) = 0.7(T_s - 293 \text{ K}) \text{ W}$$

and

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A(T_s^4 - T_o^4) = 0.6(0.02 \text{ m}^2)(5.67\times10^{-8} \text{ W/m}^2\cdot\text{K}^4)[\text{T}_s^4 - (293 \text{ K})^4]$$
$$= 0.06804\times10^{-8}[T_s^4 - (293 \text{ K})^4] \text{ W}$$

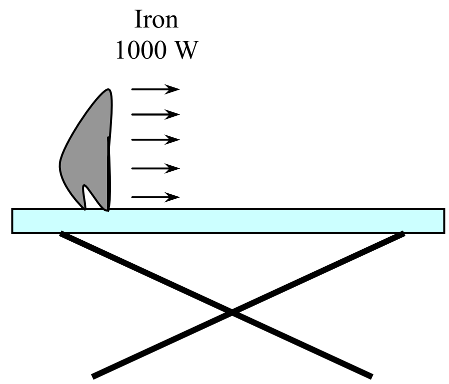
Substituting,

$$1000 \text{ W} = 0.7(T_s - 293 \text{ K}) + 0.06804\times10^{-8}[T_s^4 - (293 \text{ K})^4]$$

Solving by trial and error gives

$$T_s = \mathbf{947 \text{ K}} = \mathbf{674^\circ \text{C}}$$

Discussion We note that the iron will dissipate all the energy it receives by convection and radiation when its surface temperature reaches 947 K.



1-104 A spacecraft in space absorbs solar radiation while losing heat to deep space by thermal radiation. The surface temperature of the spacecraft is to be determined when steady conditions are reached..

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 outer surface of a spacecraft has an emissivity of 0.8 and an absorptivity of 0.3.

Analysis When the heat loss from the outer surface of the spacecraft by radiation equals the solar radiation absorbed, the surface temperature can be determined from

$$\dot{Q}_{\text{solar absorbed}} = \dot{Q}_{\text{rad}}$$
$$\alpha\dot{Q}_{\text{solar}} = \varepsilon\sigma A(T_s^4 - T_{\text{space}}^4)$$
$$0.3\times A\times(1000 \text{ W/m}^2) = 0.8\times A\times(5.67\times10^{-8} \text{ W/m}^2\cdot\text{K}^4)[\text{T}_s^4 - (0 \text{ K})^4]$$

Canceling the surface area A and solving for T_s gives

$$T_s = \mathbf{285 \text{ K}}$$