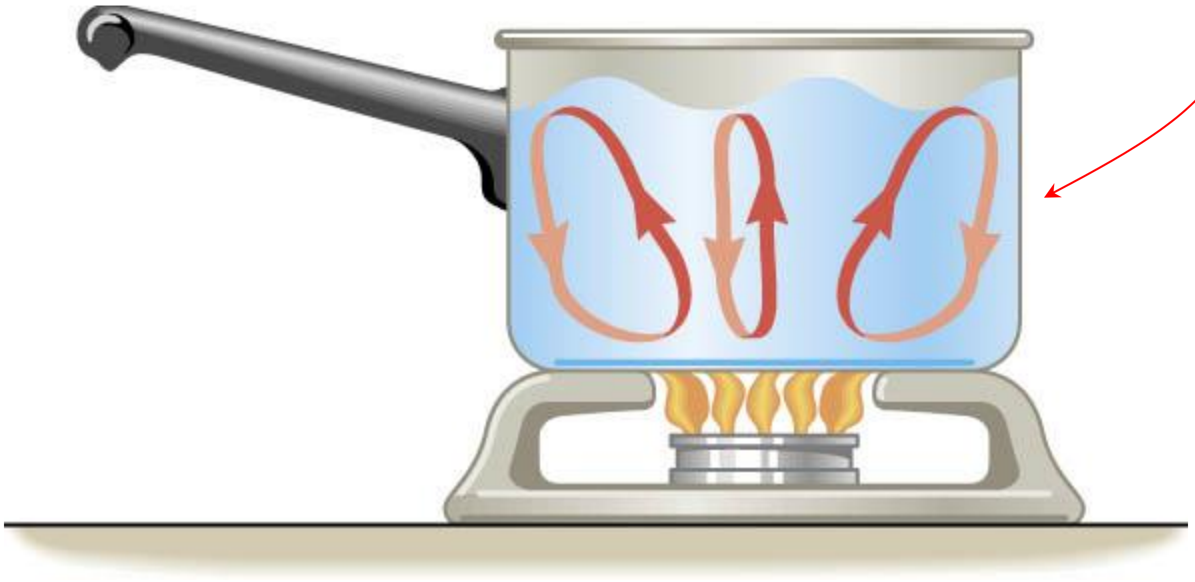
Chapter 13

The Transfer of Heat

CONVECTION

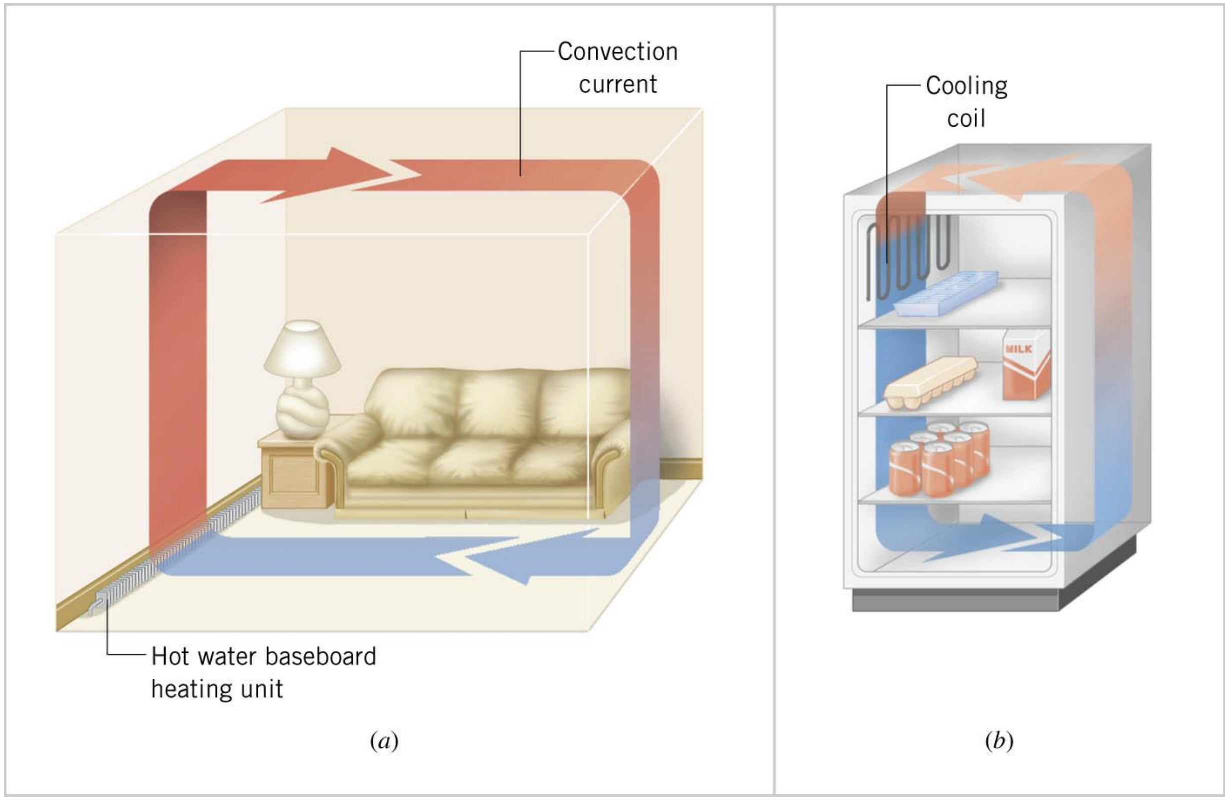
Convection is the process in which heat is carried from one place to another by the bulk movement of a fluid.



convection currents

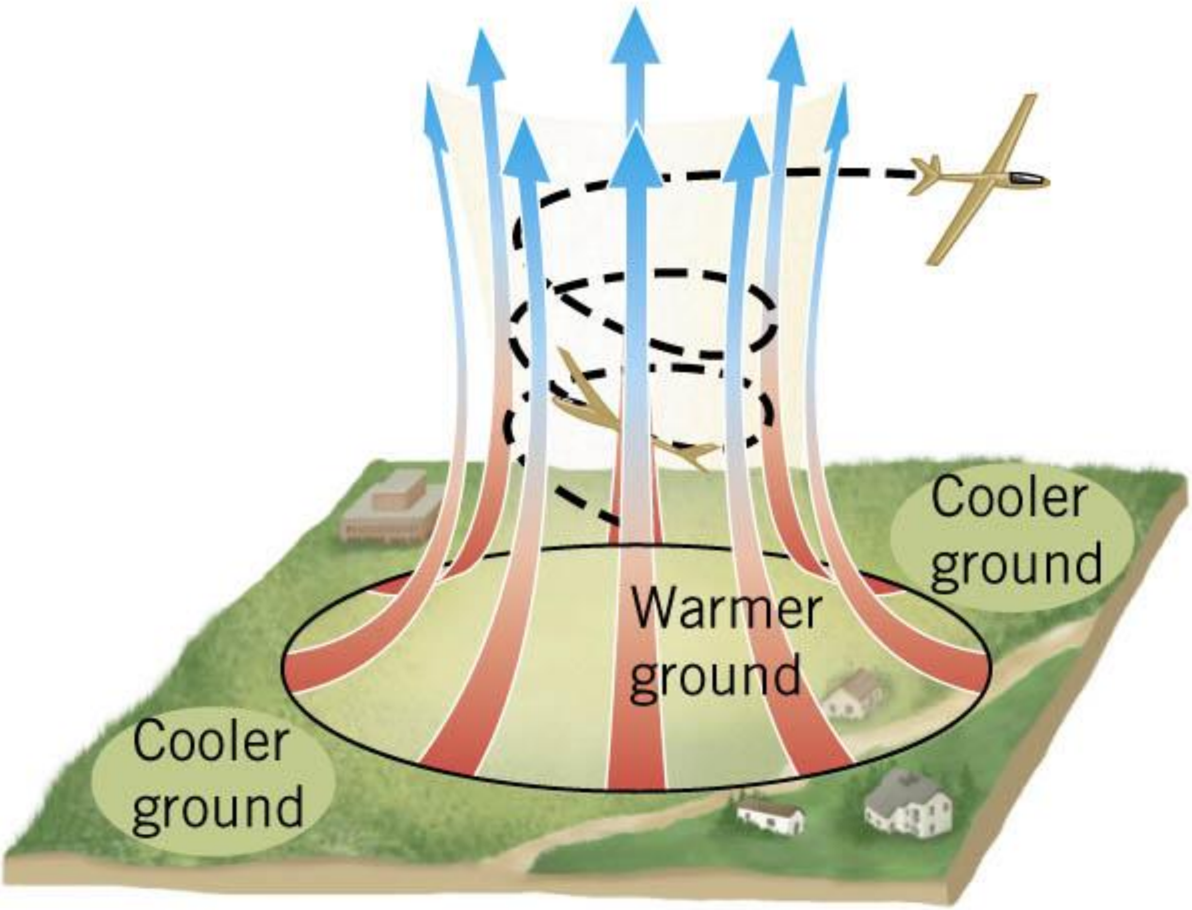
Conceptual Example 1 **Hot Water Baseboard Heating and Refrigerators**

Hot water baseboard heating units are mounted on the wall next to the floor. The cooling coil in a refrigerator is mounted near the top of the refrigerator. Each location is designed to maximize the production of convection currents. Explain how.

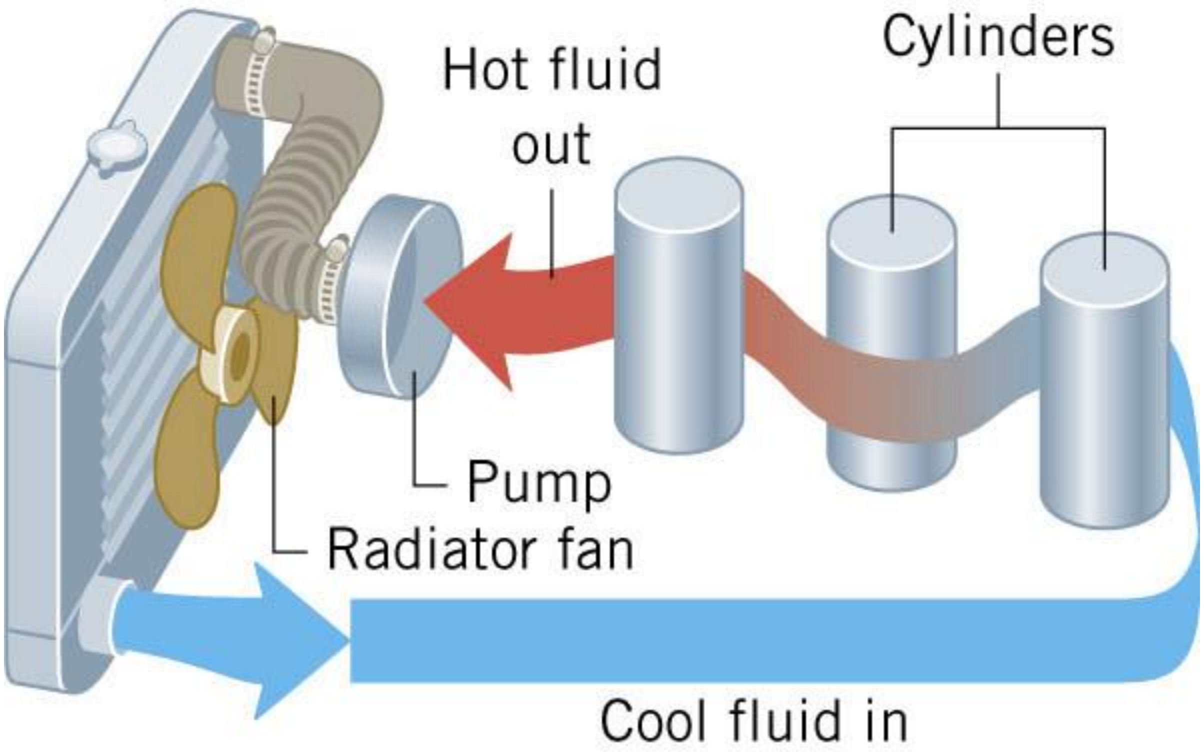


13.1 *Convection*

“Thermals” can be used by glider pilots to gain considerable altitude.



Forced Convection



CONDUCTION

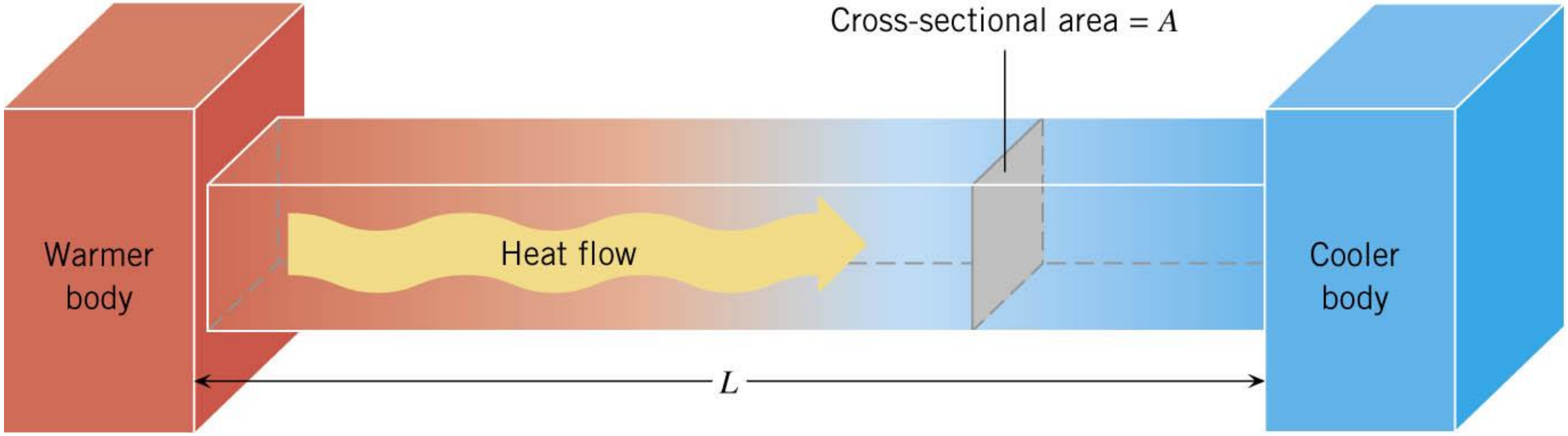
Conduction is the process whereby heat is transferred directly through a material, with any bulk motion of the material playing no role in the transfer.

One mechanism for conduction occurs when the atoms or molecules in a hotter part of the material vibrate or move with greater energy than those in a cooler part.

By means of collisions, the more energetic molecules pass on some of their energy to their less energetic neighbors.

Materials that conduct heat well are called ***thermal conductors***, and those that conduct heat poorly are called ***thermal insulators.***

13.2 Conduction



The amount of heat Q that is conducted through the bar depends on a number of factors:

1. The time during which conduction takes place.
2. The temperature difference between the ends of the bar.
3. The cross sectional area of the bar.
4. The length of the bar.

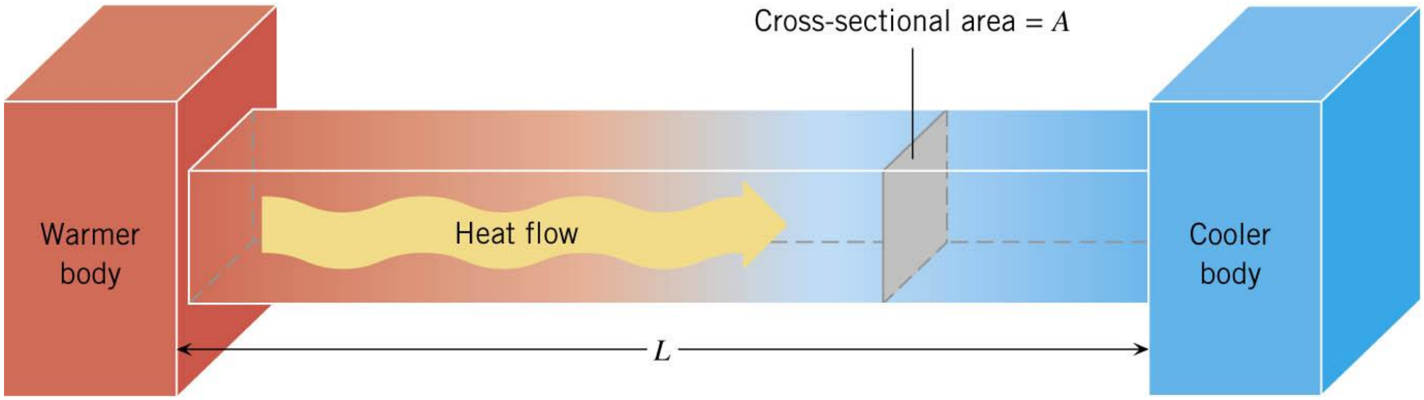
CONDUCTION OF HEAT THROUGH A MATERIAL

The heat *Q* conducted during a time *t* through a bar of length *L* and cross-sectional area *A* is

$$Q = \frac{(kA\Delta T)t}{L}$$

thermal conductivity

SI Units of Thermal Conductivity: J/(s·m·C°)



13.2 Conduction

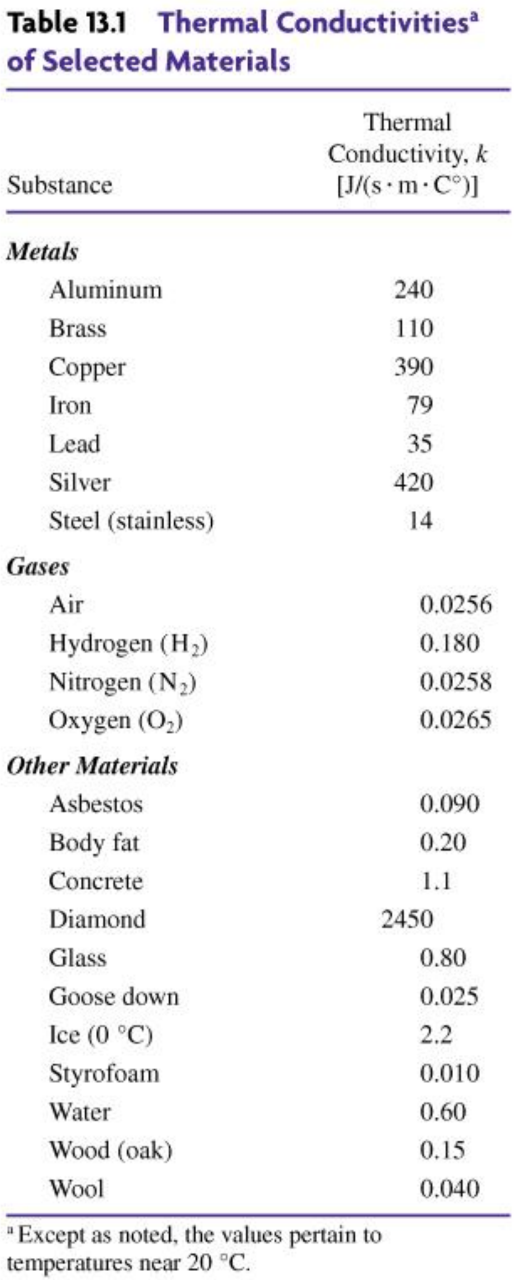
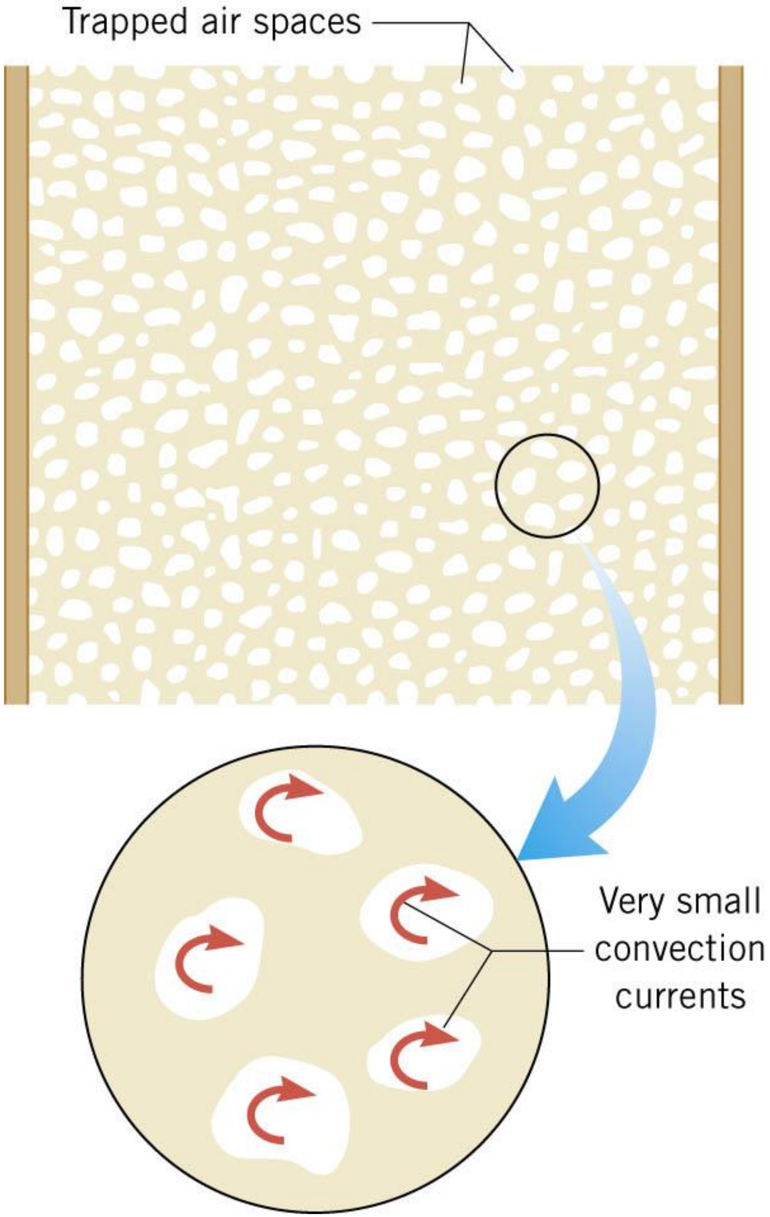


Table 13.1 Thermal Conductivities[a] of Selected Materials

Substance	Thermal Conductivity, k [J/(s·m·C°)]
Metals	
Aluminum	240
Brass	110
Copper	390
Iron	79
Lead	35
Silver	420
Steel (stainless)	14
Gases	
Air	0.0256
Hydrogen (H_2)	0.180
Nitrogen (N_2)	0.0258
Oxygen (O_2)	0.0265
Other Materials	
Asbestos	0.090
Body fat	0.20
Concrete	1.1
Diamond	2450
Glass	0.80
Goose down	0.025
Ice (0 °C)	2.2
Styrofoam	0.010
Water	0.60
Wood (oak)	0.15
Wool	0.040

[a] Except as noted, the values pertain to temperatures near 20 °C.

13.2 Conduction

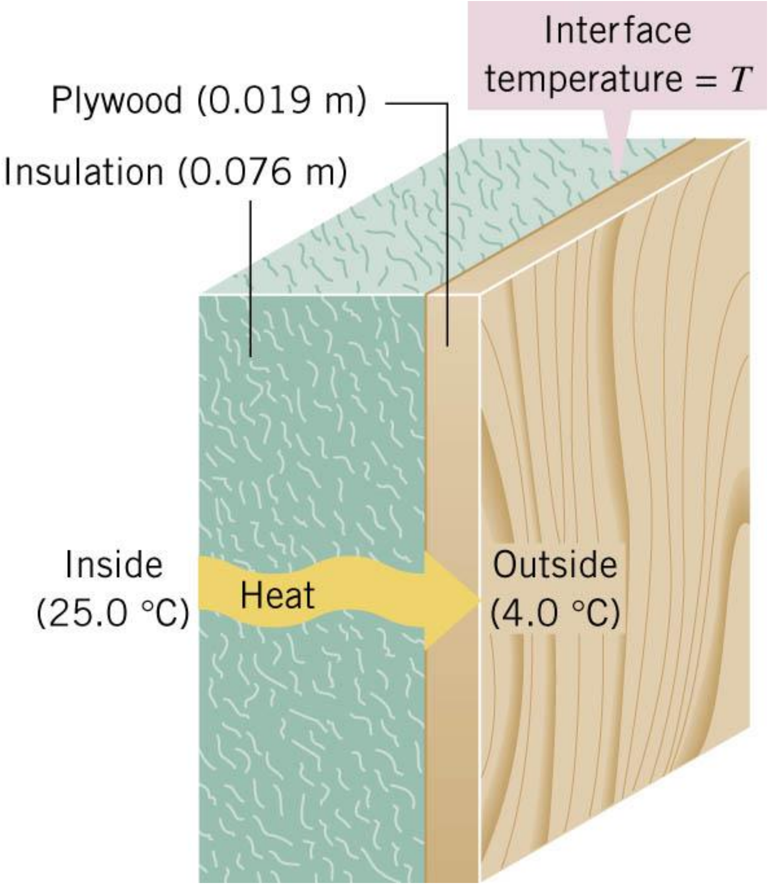


Materials with dead air spaces are usually excellent thermal insulators.

Example 4 Layered insulation

One wall of a house consists of plywood backed by insulation. The thermal conductivities of the insulation and plywood are, respectively, 0.030 and 0.080 J/(s·m·C°), and the area of the wall is 35m^2.

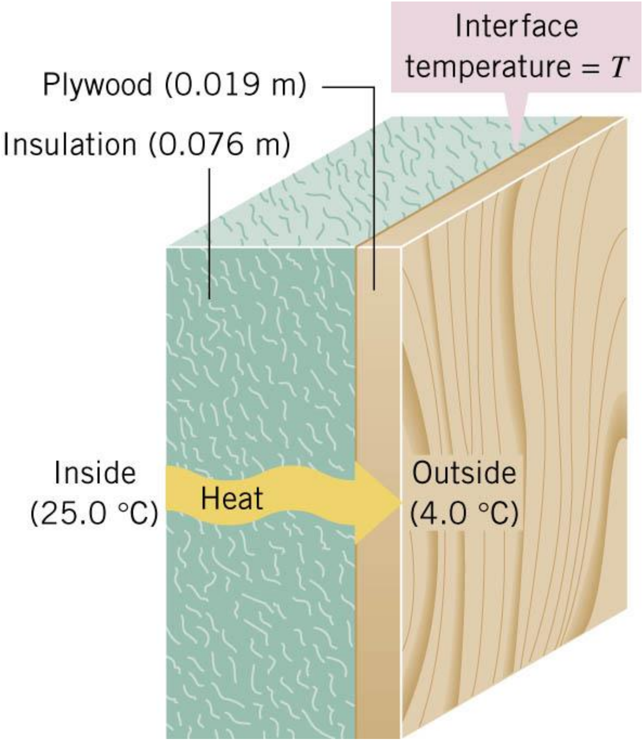
Find the amount of heat conducted through the wall in one hour.



13.2 Conduction

$$Q = Q_{\text{insulation}} = Q_{\text{plywood}}$$

But first we must solve for the interface temperature.

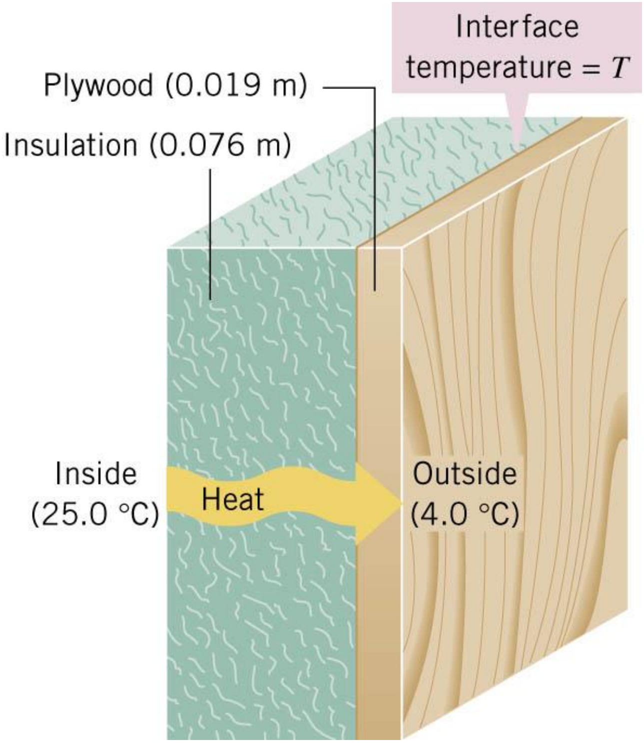


$$\left[\frac{(kA\Delta T)t}{L}\right]_{\text{insulation}} = \left[\frac{(kA\Delta T)t}{L}\right]_{\text{plywood}}$$

$$\frac{\left[0.030\,\text{J}/\left(\text{s}\cdot\text{m}\cdot\text{C}^\circ\right)\right]A\left(25.0^\circ\,\text{C} - T\right)t}{0.076\,\text{m}} = \frac{\left[0.080\,\text{J}/\left(\text{s}\cdot\text{m}\cdot\text{C}^\circ\right)\right]A\left(T - 4.0^\circ\,\text{C}\right)t}{0.019\,\text{m}}$$

⇨ $$T = 5.8^\circ\,\text{C}$$

13.2 Conduction

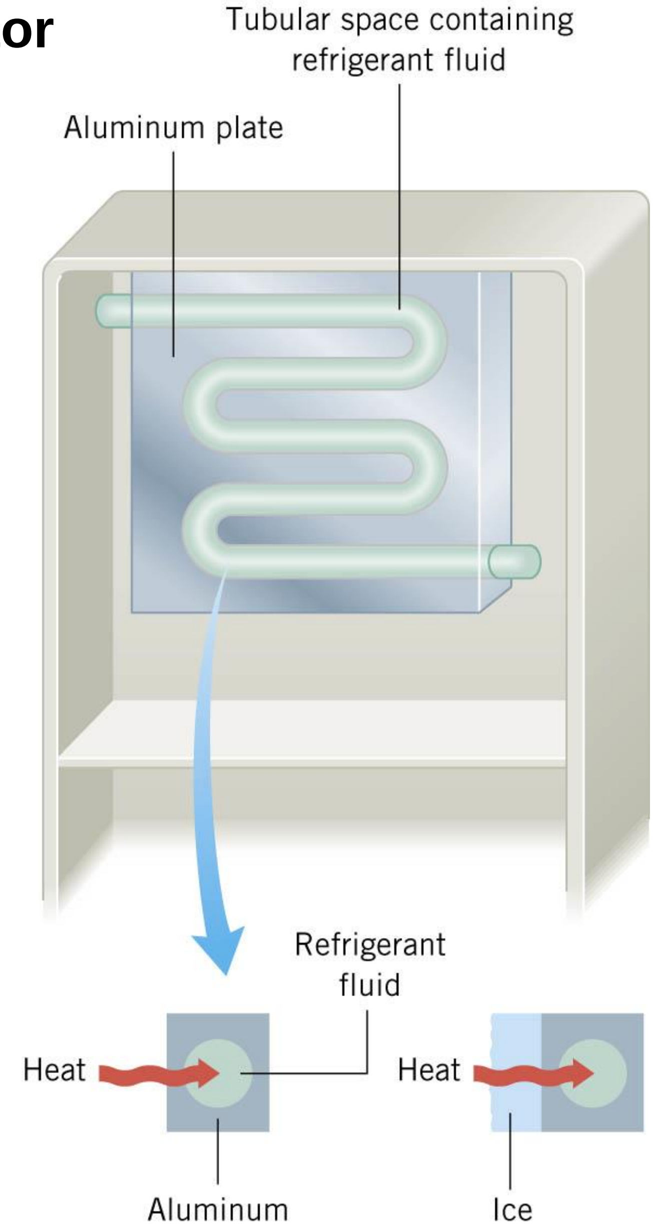


$$Q_{\text{insulation}} = \frac{\left[0.030\,\text{J}/\left(\text{s}\cdot\text{m}\cdot\text{C}^\circ\right)\right]\left(35\,\text{m}^2\right)\left(25.0^\circ\text{C} - 5.8^\circ\text{C}\right)\left(3600\,\text{s}\right)}{0.076\,\text{m}}$$

$$= 9.5\times 10^5\,\text{J}$$

Conceptual Example 5 An Iced-Up Refrigerator

In a refrigerator, heat is removed by a cold refrigerant fluid that circulates within a tubular space embedded within a metal plate. Decide whether the plate should be made from aluminum or stainless steel and whether the arrangement works better or worse when it becomes coated with a layer of ice.

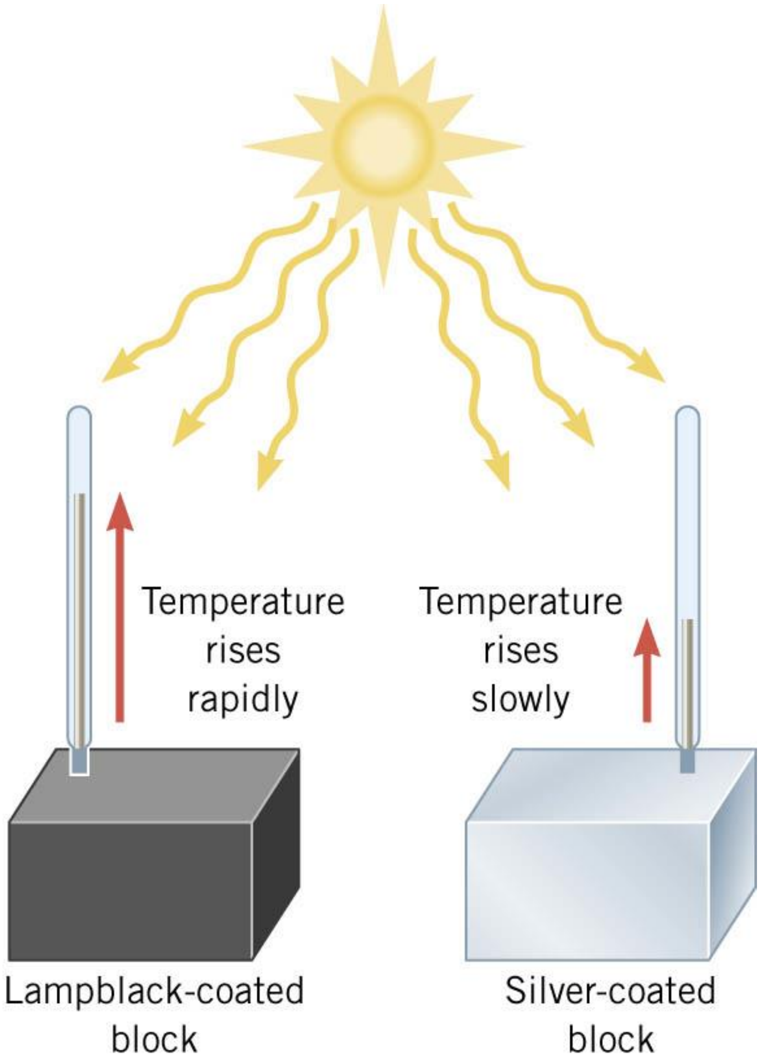


RADIATION

Radiation is the process in which energy is transferred by means of electromagnetic waves.

A material that is a good absorber is also a good emitter.

A material that absorbs completely is called a ***perfect blackbody***.



13.3 Radiation

The emissivity *e* is a dimensionless number between zero and one. It is the ratio of what an object radiates to what the object would radiate if it were a perfect emitter.

THE STEFAN-BOLTZMANN LAW OF RADIATION

The radiant energy *Q*, emitted in a time *t* by an object that has a Kelvin temperature *T*, a surface area *A*, and an emissivity *e*, is given by

$$Q = e\sigma T^4 At$$

Stefan-Boltzmann constant

$$\sigma = 5.67\times 10^{-8}\ \mathrm{J}/\left(\mathrm{s}\cdot\mathrm{m}^2\cdot\mathrm{K}^4\right)$$

Example 6 **A Supergiant Star**

The supergiant star Betelgeuse has a surface temperature of about 2900 K and emits a power of approximately 4×10^{30}W.

Assuming that Betelgeuse is a perfect emitter and spherical, find its radius.

$$Q = e\sigma T^4 \underset{4\pi r^2}{\underset{\uparrow}{A}} t$$

13.3 Radiation

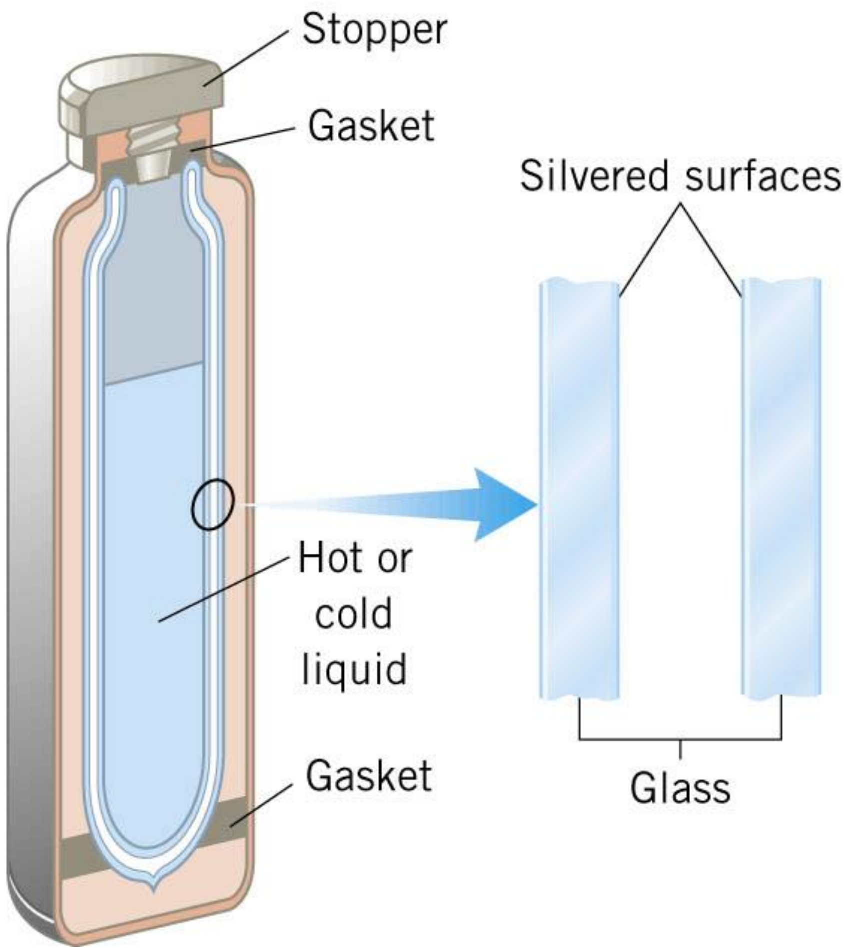
$$Q = e\sigma T^4 4\pi r^2 t$$

$$r = \sqrt{\frac{Q/t}{4\pi e\sigma T^4}} = \sqrt{\frac{4\times10^{30}\,\mathrm{W}}{4\pi(1)\left[5.67\times10^{-8}\,\mathrm{J}/\left(\mathrm{s}\cdot\mathrm{m}^2\cdot\mathrm{K}^4\right)\right](2900\,\mathrm{K})^4}}$$

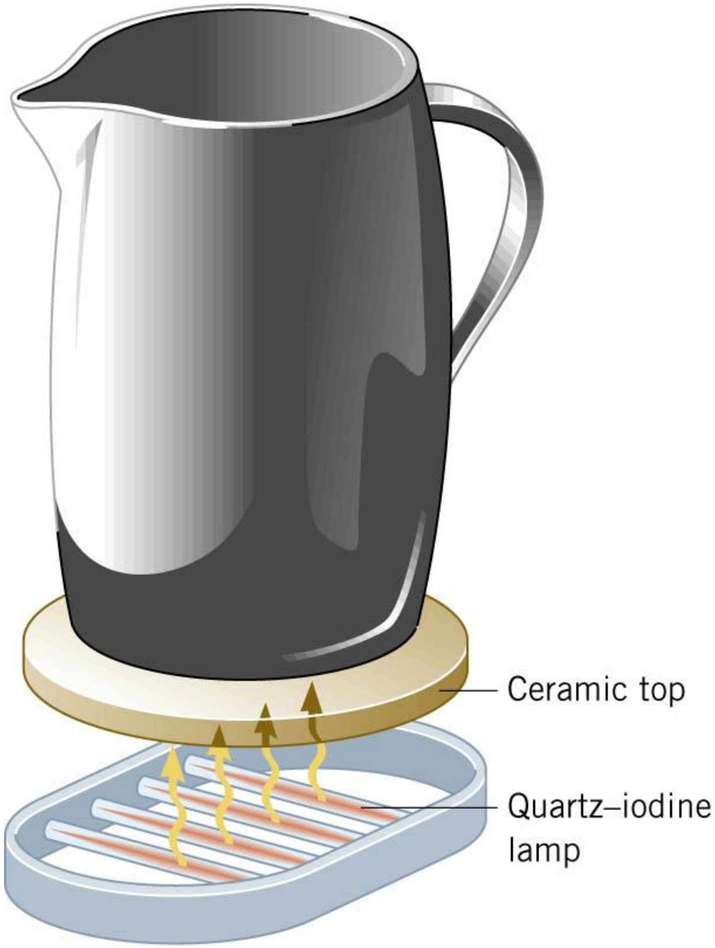
$$= 3\times10^{11}\mathrm{m}$$

13.4 Applications

A thermos bottle minimizes heat transfer via conduction, convection, and radiation.



13.4 *Applications*



The halogen cooktop stove creates electromagnetic energy that passes through the ceramic top and is absorbed directly by the bottom of the pot.