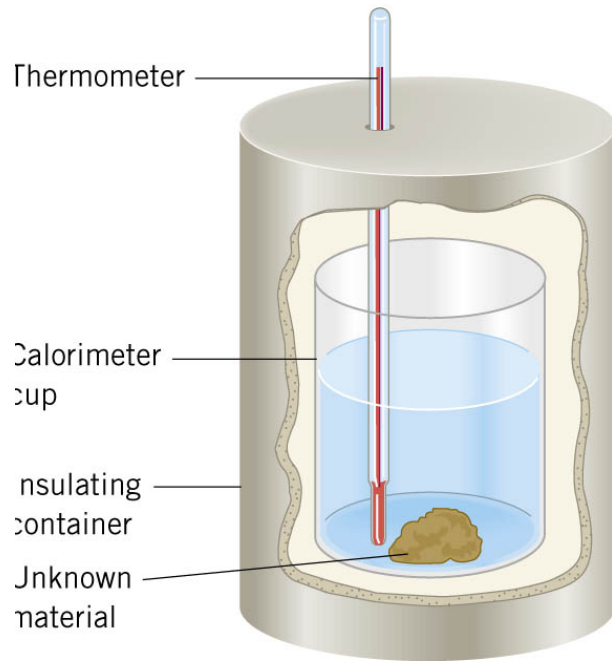


Chapter 12

Temperature and Heat

continued

12.7 Heat and Temperature Change: Specific Heat Capacity



CALORIMETRY

If there is no heat loss to the surroundings, the heat lost by the hotter object equals the heat gained by the cooler ones. **Net heat change equals zero.**

A calorimeter is made of 0.15 kg of aluminum and contains 0.20 kg of water, both at 18.0 C°. A mass, 0.040 kg at 97.0 C° is added to the water, causing the water temperature to rise to 22.0 C°. What is the specific heat capacity of the mass?

Water and Al rise in temperature ($\Delta T > 0$)

Unknown stuff drops in temperature ($\Delta T < 0$)

$$\Delta T_w = \Delta T_{Al} = +4^\circ\text{C}; \quad \Delta T_{Unk} = -75^\circ\text{C}$$

Al $\equiv$ Aluminum, W $\equiv$ water, Unk $\equiv$ unknown

Net heat change equals zero.

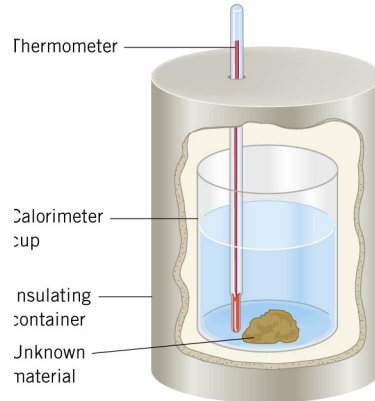
Beware, C&J take ΔT always positive and use Heat Lost by 1 = Heat gained by 2
No good, if there are 3 objects!

$$\sum Q = m_{Al} c_{Al} \Delta T_{Al} + m_w c_w \Delta T_w + m_{Unk} c_{Unk} \Delta T_{Unk} = 0$$

Three heat changes must sum to zero

12.7 Heat and Temperature Change: Specific Heat Capacity

A calorimeter is made of 0.15 kg of aluminum and contains 0.20 kg of water, both at 18.0 C°. A mass, 0.040 kg at 97.0 C° is added to the water, causing the water temperature to rise to 22.0 C°. What is the specific heat capacity of the mass?



Water and Al rise in temperature ($\Delta T > 0$)

Unknown material drops in temperature ($\Delta T < 0$)

$$\Delta T_w = \Delta T_{Al} = +4^\circ\text{C}; \quad \Delta T_{Unk} = -75^\circ\text{C}$$

Net heat change equals zero.

$$c_{Al} = 900 \text{ J/kg} \cdot \text{C}^\circ$$

$$c_w = 4190 \text{ J/kg} \cdot \text{C}^\circ$$

$$\sum Q = m_{Al} c_{Al} \Delta T_{Al} + m_w c_w \Delta T_w + m_{Unk} c_{Unk} \Delta T_{Unk} = 0$$

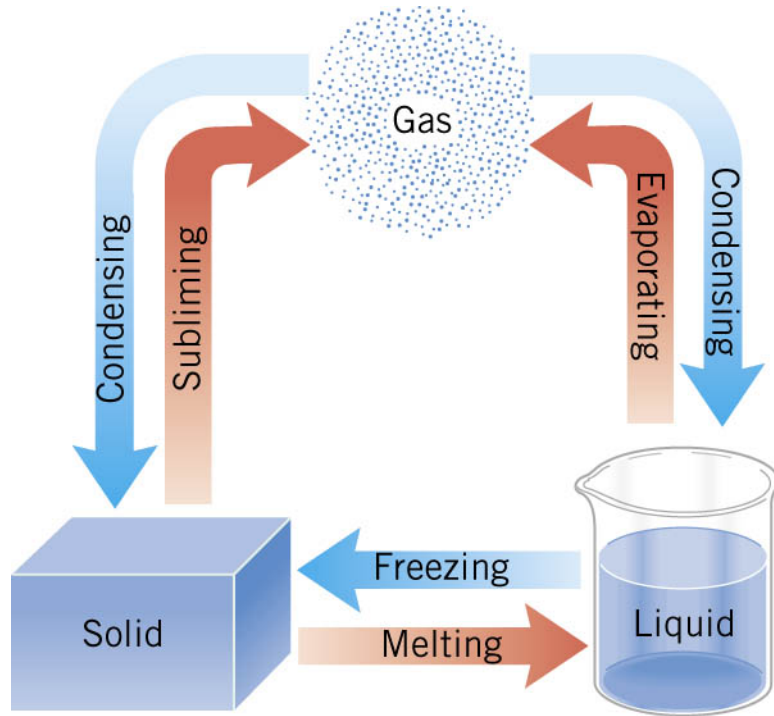
$$c_{Unk} = \frac{m_{Al} c_{Al} \Delta T_{Al} + m_w c_w \Delta T_w}{-m_{Unk} \Delta T_{Unk}};$$

$$= \frac{[(0.15\text{kg})(900 \text{ J/kg} \cdot \text{C}^\circ) + (0.20\text{kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{C}^\circ)](4\text{C}^\circ)}{-(0.04\text{kg})(-75\text{C}^\circ)}$$

$$= 1.3 \times 10^3 \text{ J/(kg} \cdot \text{C}^\circ)$$

12.8 Heat and Phase Change: Latent Heat

THE PHASES OF MATTER



There is internal energy added or removed in a change of phase.

Typically, solid $\rightarrow$ liquid (melt) or liquid $\rightarrow$ gas (evaporate) requires heat energy to be **ADDED**.

Typically, gas $\rightarrow$ liquid (condense), or liquid $\rightarrow$ solid (freeze) requires heat energy to be **REMOVED**.

HEAT ADDED OR REMOVED IN CHANGING THE PHASE OF A SUBSTANCE

The heat that must be supplied or removed to change the phase of a mass m of a substance is the “latent heat”, L :

$$Q = mL$$

SI Units of Latent Heat: J/kg

12.8 Heat and Phase Change: Latent Heat

Table 12.3 Latent Heats^a of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion, L_f (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization, L_v (J/kg)
Ammonia	-77.8	33.2×10^4	-33.4	13.7×10^5
Benzene	5.5	12.6×10^4	80.1	3.94×10^5
Copper	1083	20.7×10^4	2566	47.3×10^5
Ethyl alcohol	-114.4	10.8×10^4	78.3	8.55×10^5
Gold	1063	6.28×10^4	2808	17.2×10^5
Lead	327.3	2.32×10^4	1750	8.59×10^5
Mercury	-38.9	1.14×10^4	356.6	2.96×10^5
Nitrogen	-210.0	2.57×10^4	-195.8	2.00×10^5
Oxygen	-218.8	1.39×10^4	-183.0	2.13×10^5
Water	0.0	33.5×10^4	100.0	22.6×10^5

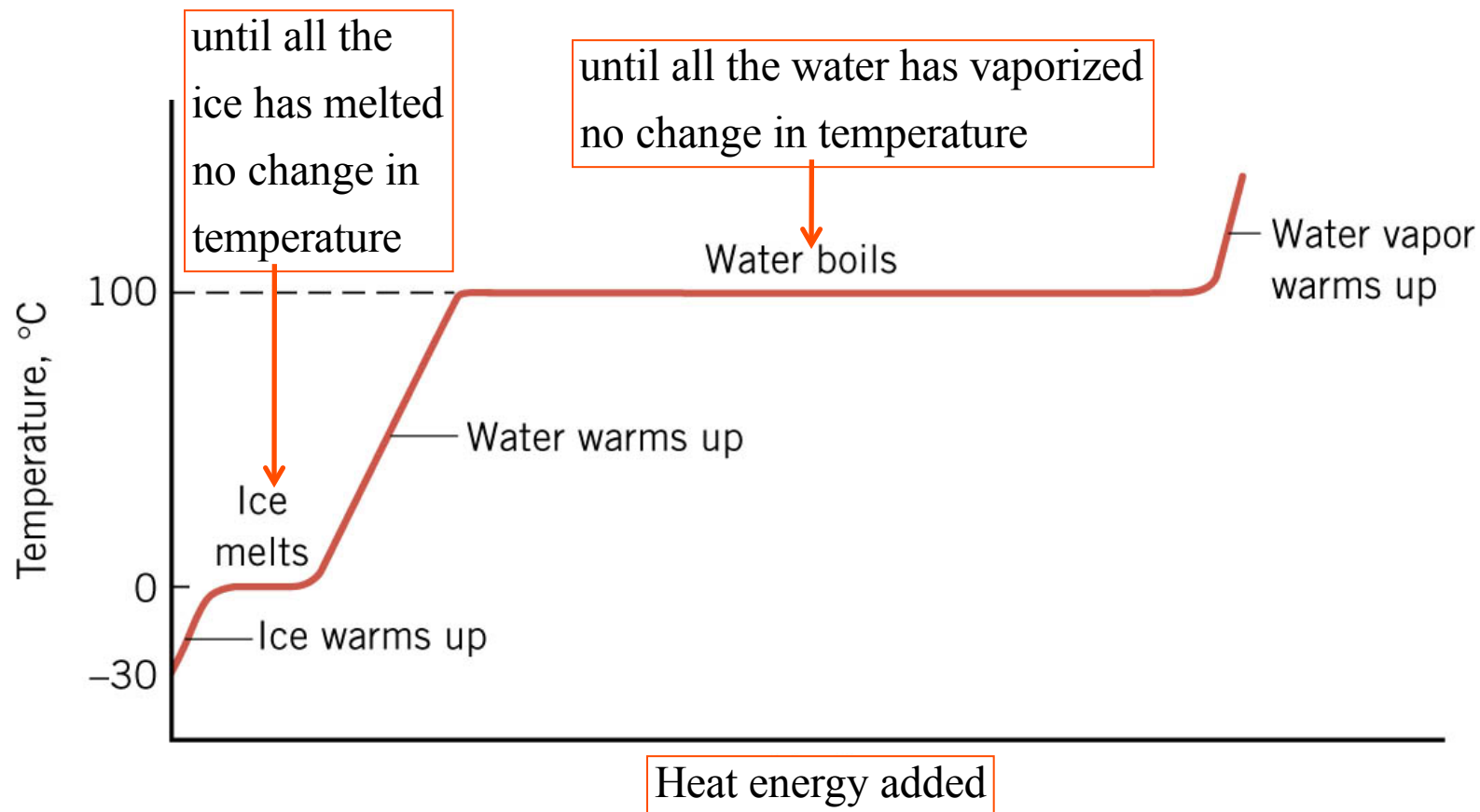
^aThe values pertain to 1 atm pressure.

Add heat: Ice $\rightarrow$ Water $L_f > 0$
Remove heat: Water $\rightarrow$ Ice $L_f < 0$

Add heat: Water $\rightarrow$ Vapor $L_v > 0$
Remove heat: Vapor $\rightarrow$ Water $L_v < 0$

12.8 Heat and Phase Change: Latent Heat

During a phase change, the temperature of the mixture does not change (provided the system is in thermal equilibrium).



12.8 Heat and Phase Change: Latent Heat

Example 14 Ice-cold Lemonade

Ice at 0°C is placed in a Styrofoam cup containing 0.32 kg of lemonade at 27°C. Assume that mass of the cup is very small and lemonade behaves like water.

After ice is added, the ice and lemonade reach an equilibrium temperature ($T = 0\text{ C}^\circ$) with some ice remaining. How much ice melted?

Heat redistributes.
No heat added or lost.

$$\sum Q = \underbrace{m_I L_I}_{\text{Heat for Ice} \rightarrow \text{Water}} + \underbrace{m_W c_W \Delta T_W}_{\text{Heat change of lemonade}} = 0$$

$$\Delta T_W = -27\text{ C}^\circ$$

$$m_I L_I + m_W c_W \Delta T_W = 0$$

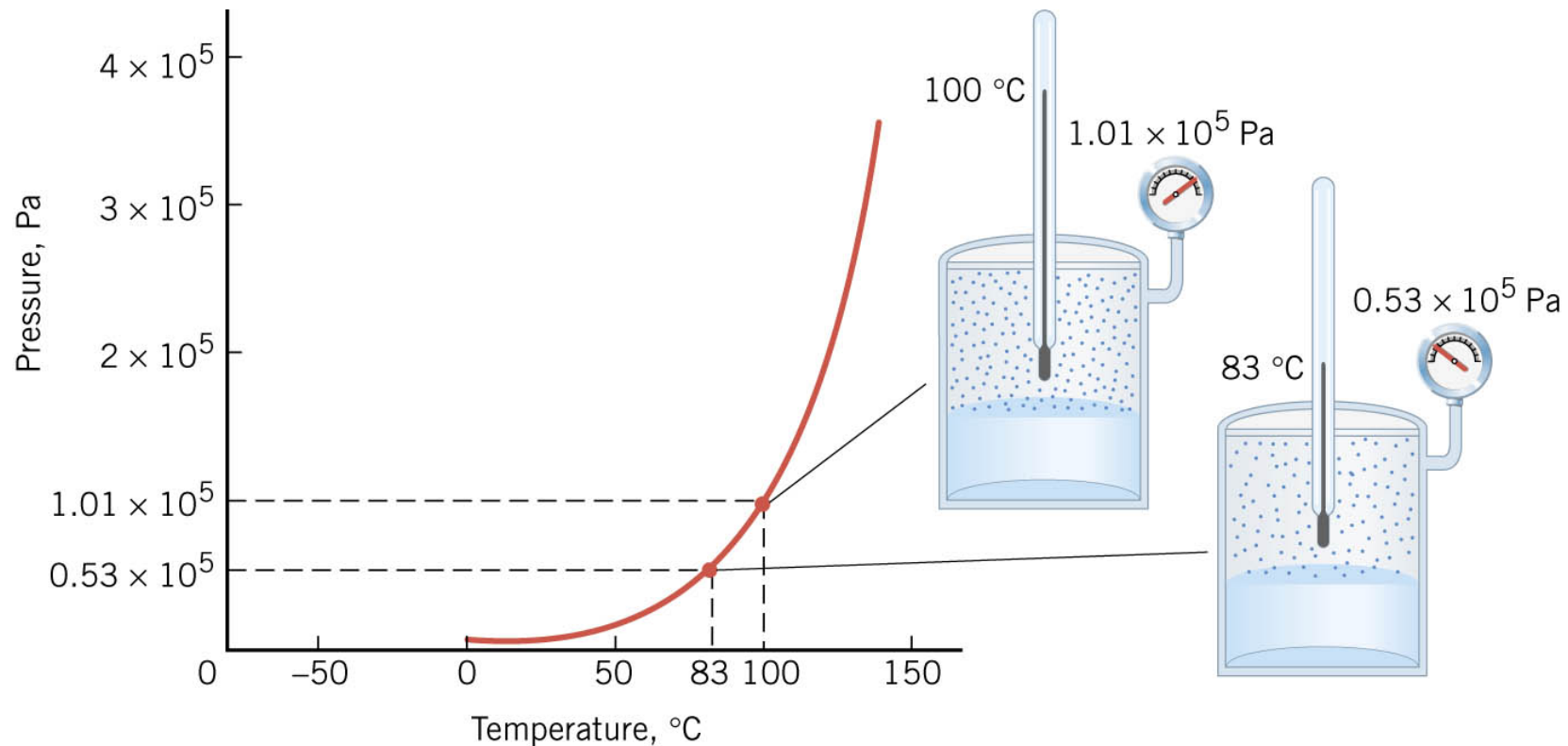
$$m_I = \frac{-m_W c_W \Delta T_W}{L_I}$$

$$= \frac{-(0.32\text{kg})(4.19 \times 10^3 \text{J/kg} \cdot \text{C}^\circ)(-27\text{C}^\circ)}{33.5 \times 10^4 \text{J/kg}} = 0.011\text{ kg}$$

In C&J, you must use $\Delta T_{\text{lemonade}} > 0$ & $(mL_f)_{\text{gained}} = (cm\Delta T)_{\text{lost}}$

12.9 Equilibrium Between Phases of Matter

Water is not "boiling". The water vaporizes and condenses at the same rate.



Only when the temperature and vapor pressure correspond to a point on the curved line do the liquid and vapor phases coexist in equilibrium.

12.9 Equilibrium Between Phases of Matter

As is the case for liquid/vapor equilibrium, a solid can be in equilibrium with its liquid phase only at specific conditions of temperature and pressure.

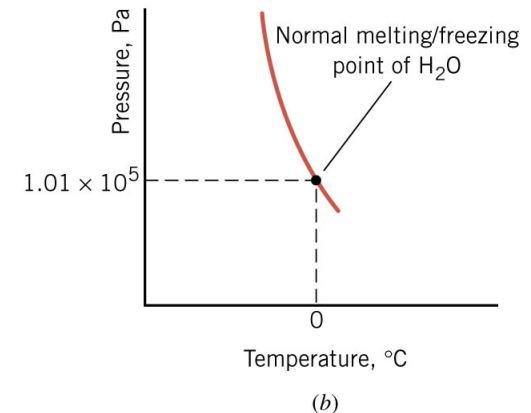
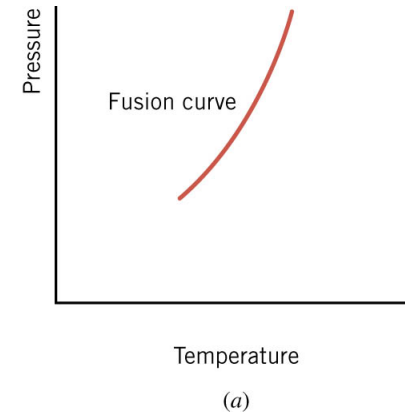
For normal liquids and solids, at higher pressures, the melting point is higher.

Water/Ice phase changes are strange.
At lower pressures, the melting point is higher.

Water boiling point behaves normally.

At lower pressure the boiling point is less than $100\text{ }^{\circ}\text{C}$

On top of Mt. Everest the boiling point of water is $69\text{ }^{\circ}\text{C}$. Not hot enough to make tea.



12.10 Humidity

Air is a mixture of gases.

The total pressure is the sum of the ***partial pressures*** of the component gases.

The partial pressure of water vapor depends on weather conditions. It can be as low as zero or as high as the vapor pressure of water at the given temperature.

To provide an indication of how much water vapor is in the air, weather forecasters usually give the ***relative humidity***:

$$(\% \text{ relative humidity}) = \frac{(\text{Partial pressure of water vapor})}{(\text{Equilibrium vapor pressure of water at current temperature})} \times 100$$

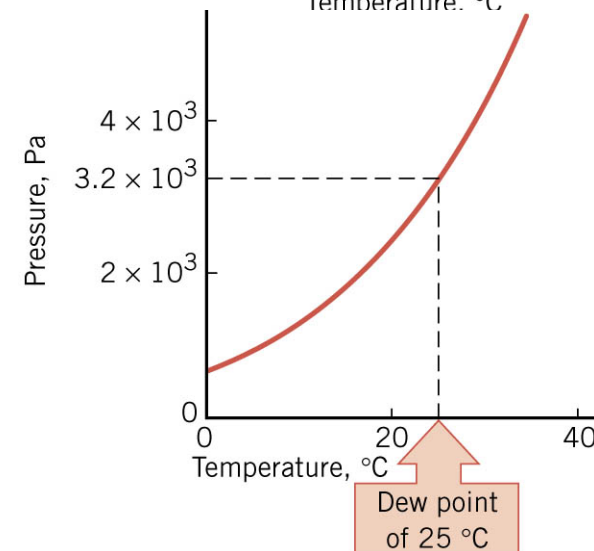
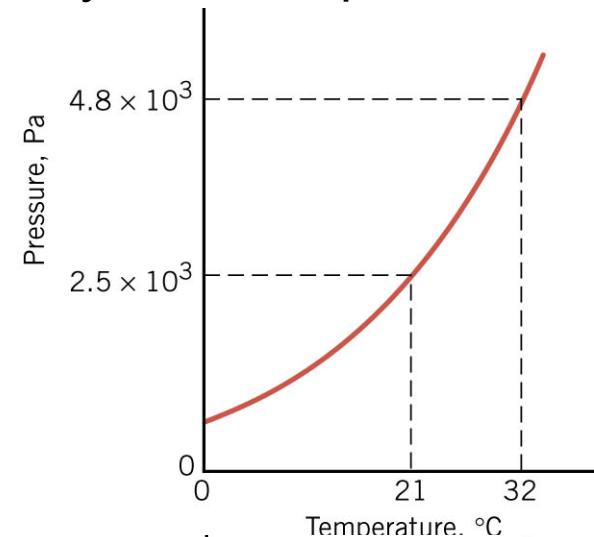
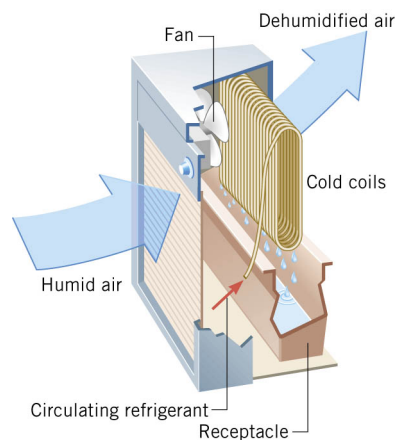
12.10 Humidity

Example 17 Relative Humidities

One day, the partial pressure of water vapor is 2.0×10^3 Pa. Using the vaporization curve, determine the relative humidity if the temperature is 32°C .

$$\text{Relative humidity} = \frac{2.0 \times 10^3 \text{ Pa}}{4.8 \times 10^3 \text{ Pa}} \times 100 = 42\%$$

The temperature at which the relative humidity is 100% is called the **dew point**.



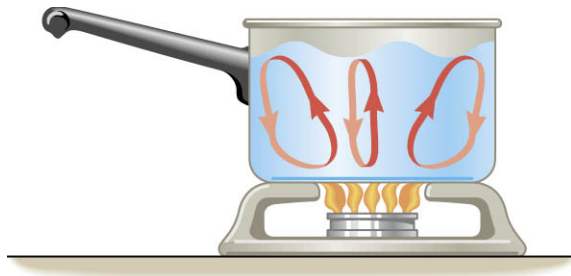
Chapter 13

The Transfer of Heat

13.1 Convection

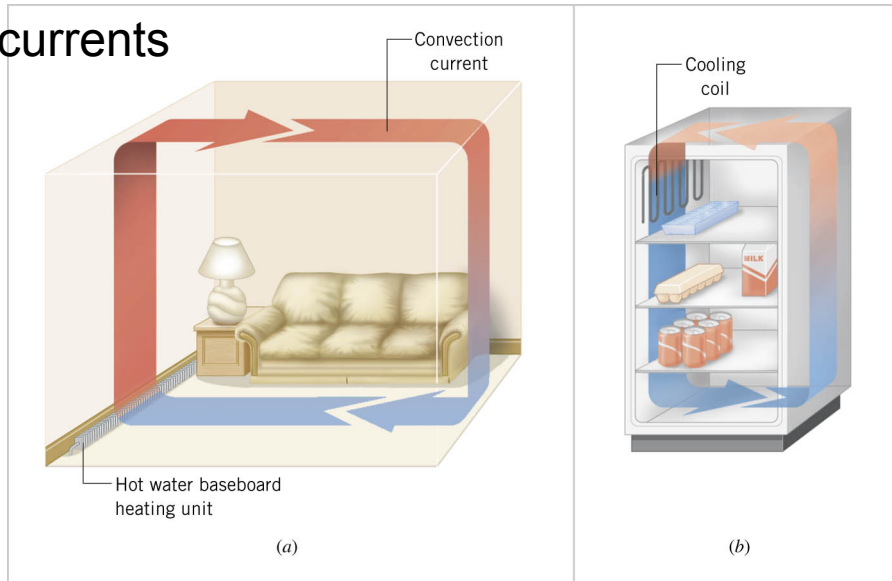
CONVECTION

Heat carried by the bulk movement of a fluid.

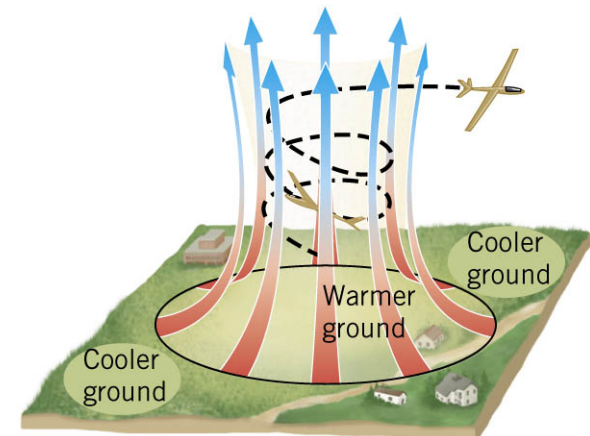


Convection
fluid currents

Convection
air currents



Convection
air currents

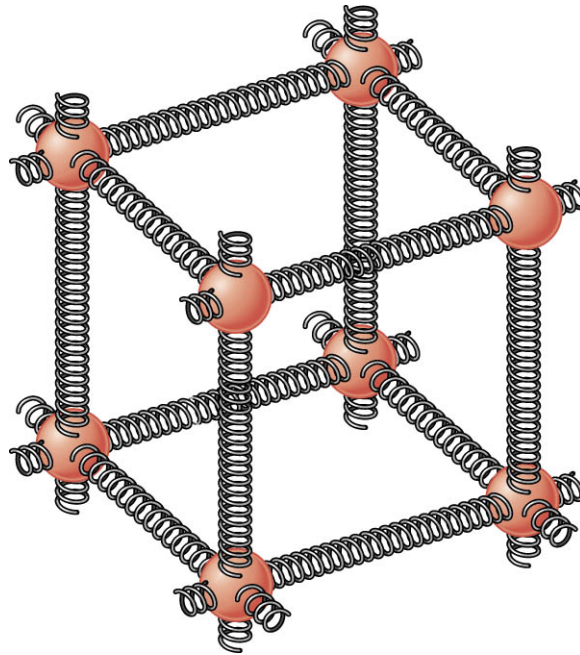


13.2 Conduction

CONDUCTION

Heat transferred directly through a material, but not via bulk motion.

One mechanism for conduction occurs when the atoms or molecules in a hotter part of the material vibrate with greater energy than those in a cooler part. Though the atomic forces, the more energetic molecules pass on some of their energy to their less energetic neighbors.

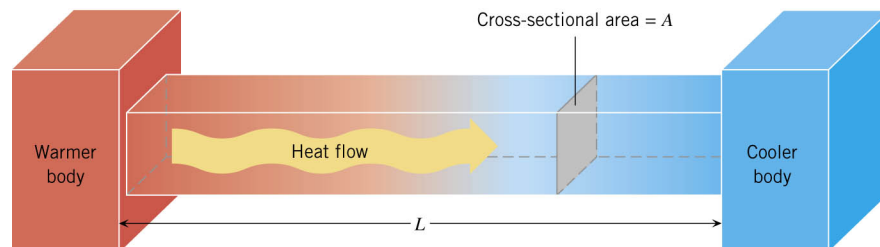


Model of solid materials.
Atoms connected by atomic
spring-like forces.

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

13.2 Conduction

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

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

k , is the thermal conductivity

SI Units of Thermal Conductivity:

$\text{J}/(\text{s} \cdot \text{m} \cdot \text{C}^\circ)$ (joule per second-meter- C°)

Table 13.1 Thermal Conductivities^a of Selected Materials

Substance	Thermal Conductivity, k [$\text{J}/(\text{s} \cdot \text{m} \cdot \text{C}^\circ)$]
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 .

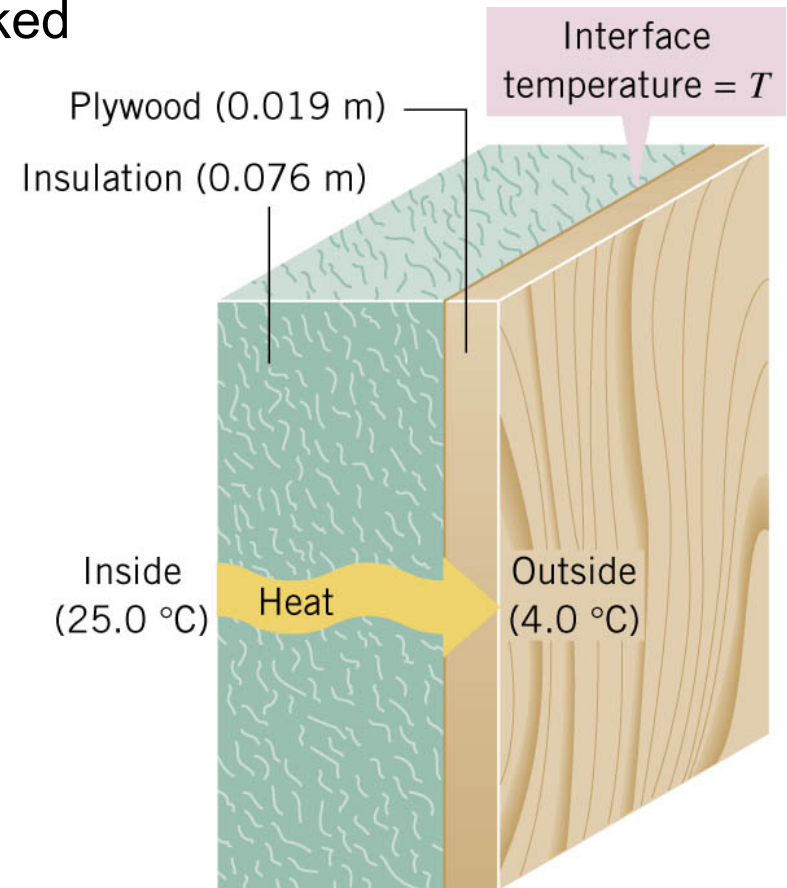
13.2 Conduction

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 $0.080 \text{ J/(s}\cdot\text{m}\cdot\text{C}^\circ)$, and the area of the wall is 35m^2 .

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

Note: Heat passing through insulation is the same heat passing through plywood.



13.2 Conduction

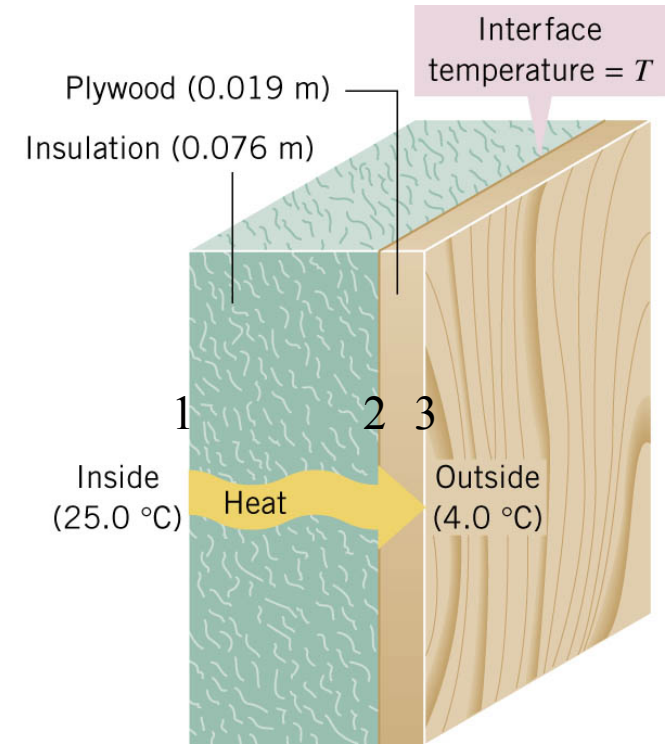
$$Q_{\text{insulation}} = Q_{12}; \quad Q_{\text{plywood}} = Q_{23}$$

$$T_1 = 25\text{C}^\circ, T_3 = 4\text{C}^\circ, T_2 \text{ is unknown}$$

First solve for the interface temperature using:

$$\begin{aligned} Q_{12} &= Q_{23} \\ \frac{k_{12}(T_1 - T_2)}{L_{12}} &= \frac{k_{23}(T_2 - T_3)}{L_{23}} \\ (T_1 - T_2) &= \frac{k_{23}L_{12}}{k_{12}L_{23}}(T_2 - T_3); \quad \frac{k_{23}L_{12}}{k_{12}L_{23}} = \frac{(.08)(.076)}{(.03)(.019)} = 10.7 \\ T_2 &= \frac{T_1 + 10.7T_3}{11.7} = \frac{25 + 42.8}{11.7}\text{C}^\circ = 5.8\text{C}^\circ \end{aligned}$$

$$\begin{aligned} Q_{12} &= \frac{(k_{12}A\Delta T_{12})t}{L_{12}} = \frac{.03(35)(19.2)3600}{.076}\text{J} \\ &= 9.5 \times 10^5 \text{J} \end{aligned}$$



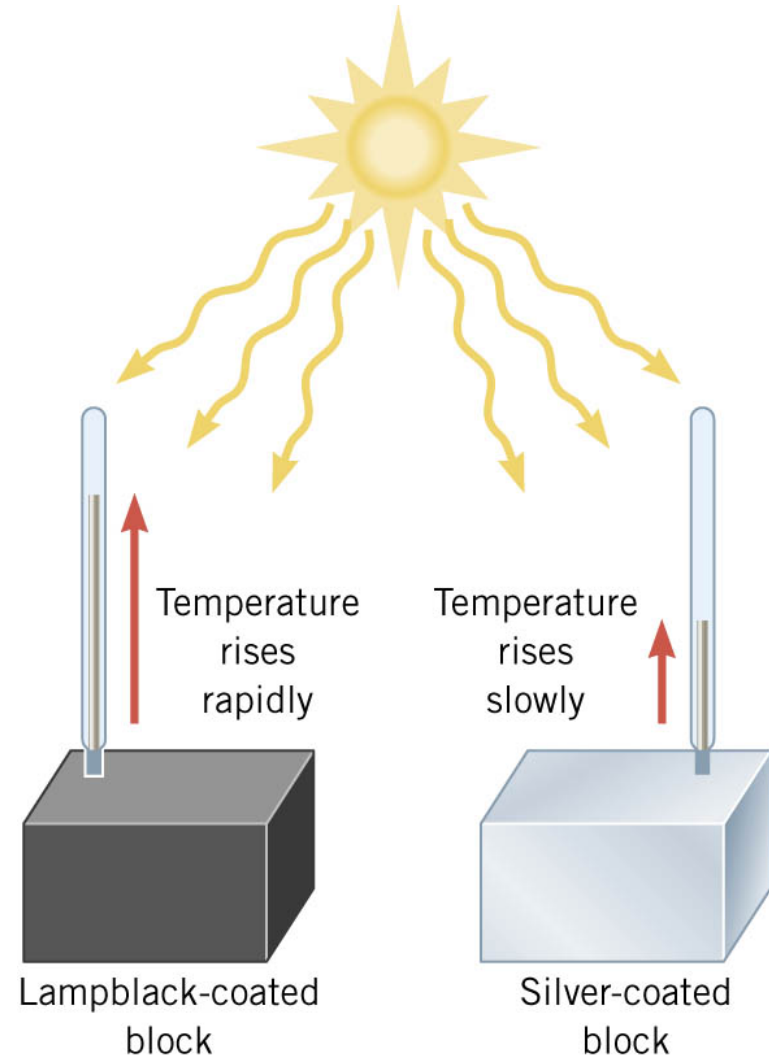
13.3 Radiation

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 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

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

emissivity $e = \text{constant between } 0 \text{ to } 1$
 $e = 1$ (perfect black body emitter)

Stefan-Boltzmann constant
 $\sigma = 5.67 \times 10^{-8} \text{ J}/(\text{s} \cdot \text{m}^2 \cdot \text{K}^4)$

Example 6 A Supergiant Star

The supergiant star Betelgeuse has a surface temperature of about 2900 K and emits a power of approximately $4 \times 10^{30} \text{ W}$. Assuming Betelgeuse is a perfect emitter and spherical, find its radius.

with $A = \pi r^2$

$$\begin{aligned} r &= \sqrt{\frac{Q/t}{4\pi e\sigma T^4}} = \sqrt{\frac{4 \times 10^{30} \text{ W}}{4\pi(1)[5.67 \times 10^{-8} \text{ J}/(\text{s} \cdot \text{m}^2 \cdot \text{K}^4)](2900 \text{ K})^4}} \\ &= 3 \times 10^{11} \text{ m} \end{aligned}$$