Chapter 11

Fluids

Bernoulli's equation

11.9 Bernoulli's Equation

NC Work yields a total Energy change.

$$W_{NC} = (P_2 - P_1)V$$

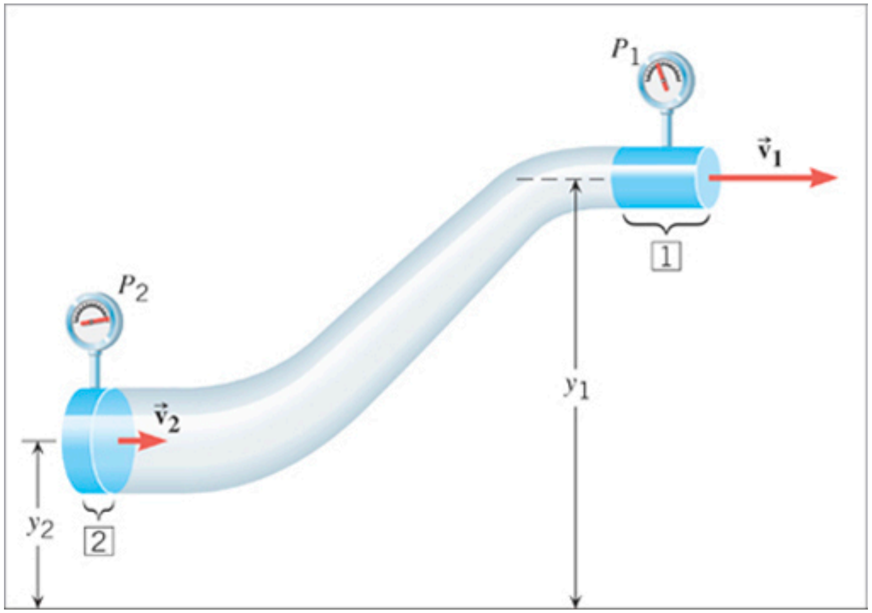
$$W_{NC} = E_1 - E_2 = \left(\tfrac{1}{2}mv_1^2 + mgy_1\right) - \left(\tfrac{1}{2}mv_2^2 + mgy_2\right)$$

Equating the two expressions for the work done,

$$(P_2 - P_1)V = \left(\tfrac{1}{2}mv_1^2 + mgy_1\right) - \left(\tfrac{1}{2}mv_2^2 + mgy_2\right)$$

$$\boxed{m = \rho V}$$

$$\boxed{(P_2 - P_1) = \left(\tfrac{1}{2}\rho v_1^2 + \rho g y_1\right) - \left(\tfrac{1}{2}\rho v_2^2 + \rho g y_2\right)}$$



Rearrange to obtain Bernoulli's Equation

BERNOULLI'S EQUATION

In steady flow of a nonviscous, incompressible fluid, the pressure, the fluid speed, and the elevation at two points are related by:

$$\boxed{P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2}$$

Conceptual Example 14 Tarpaulins and Bernoulli's Equation

When the truck is stationary, the tarpaulin lies flat, but it bulges outward when the truck is speeding down the highway.

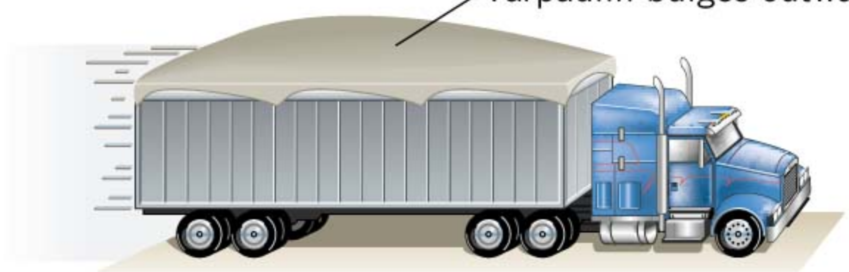
Account for this behavior.

Stationary

Relative to moving truck

$v_1 = 0$ under the tarp

v_2 air flow over top



Moving

Bernoulli's Equation

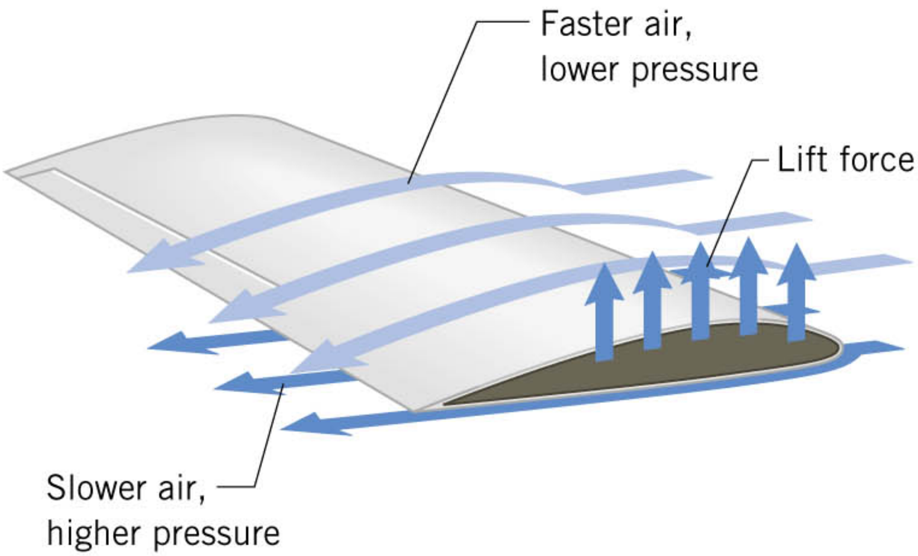
$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2$$

$$P_1 = P_2 + \tfrac{1}{2}\rho v_2^2$$

$$\boxed{P_1 > P_2}$$

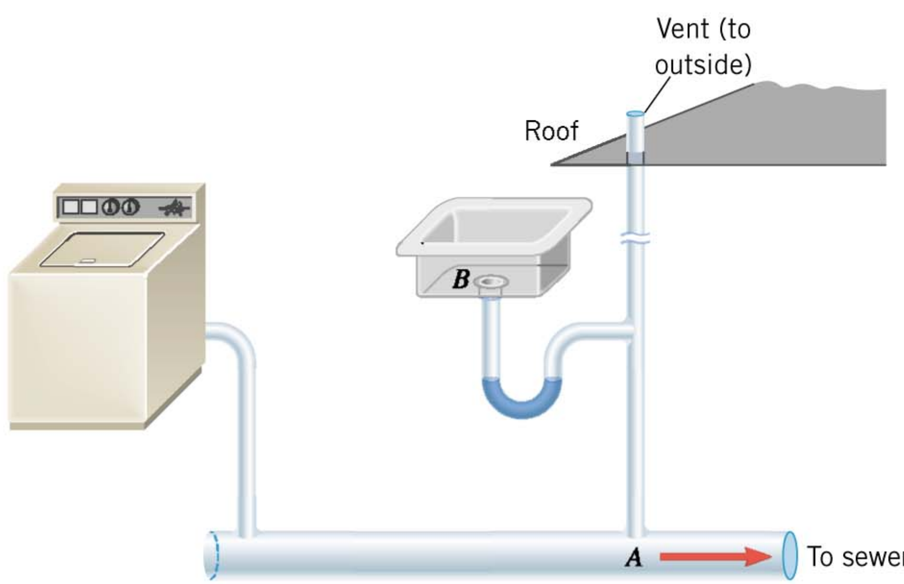
11.10 Applications of Bernoulli's Equation

Lift force of an airplane wing



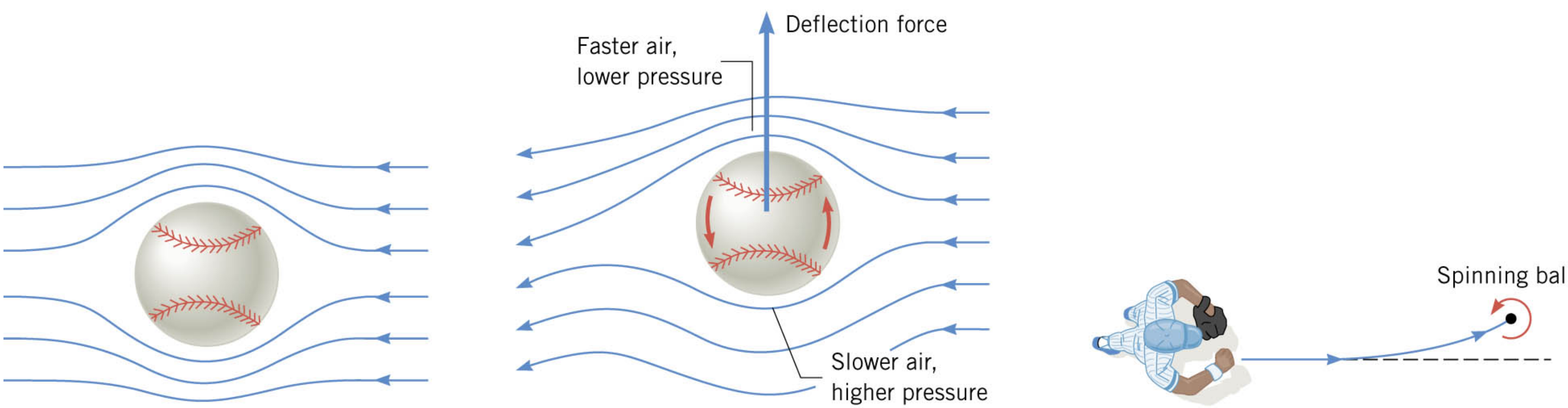
(a)

Venting keeps trap filled with water



(b) With vent

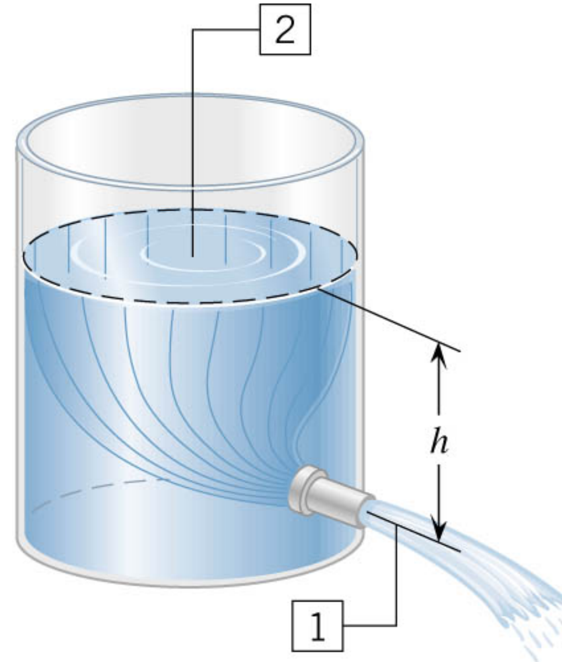
The curve ball



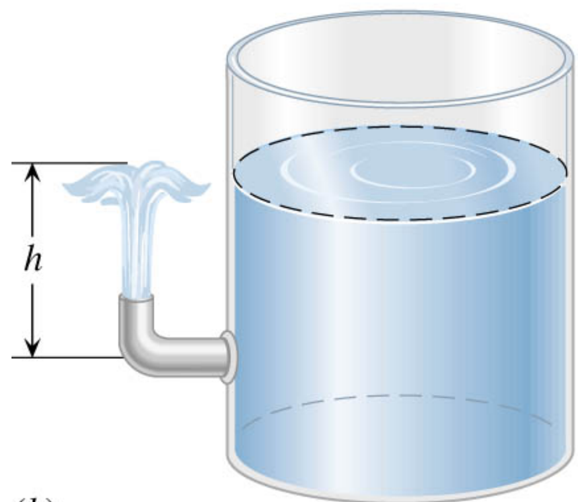
(a) Without spin (b) With spin (c)

Example 16 Efflux Speed

The tank is open to the atmosphere at the top. Find and expression for the speed of the liquid leaving the pipe at the bottom.



(a)



(b)

$$\boxed{\begin{array}{l} P_1 = P_2 = P_{atmosphere} \quad (1\times 10^5\ \mathrm{N/m^2}) \\ v_2 = 0, \quad y_2 = h, \quad y_1 = 0 \end{array}}$$

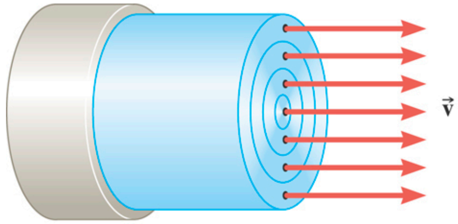
$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2$$

$$\tfrac{1}{2}\rho v_1^2 = \rho g h$$

$$\boxed{v_1 = \sqrt{2gh}}$$

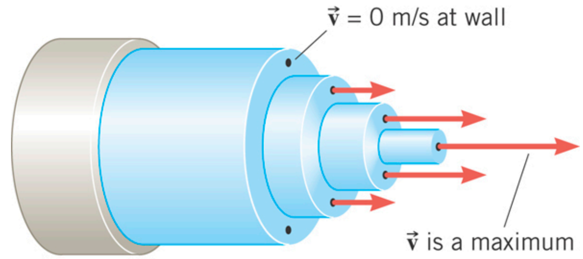
11.11 Viscous Flow

Flow of an ideal fluid.



(a)

Flow of a viscous fluid.



(b)

FORCE NEEDED TO MOVE A LAYER OF VISCOUS FLUID WITH CONSTANT VELOCITY

The magnitude of the tangential force required to move a fluid layer at a constant speed is given by:

$$\boxed{F = \frac{\eta A v}{y}}$$

η, is the coefficient of viscosity

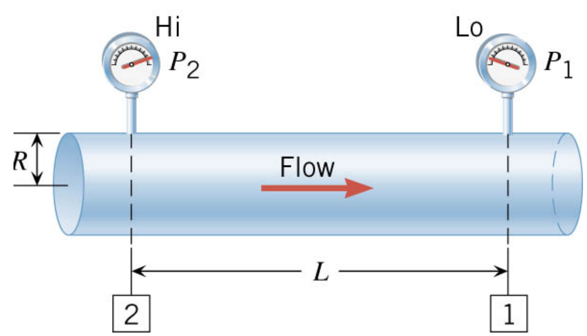
SI Unit: $\mathrm{Pa \cdot s}$; $1 \text{ poise (P)} = 0.1 \mathrm{\ Pa \cdot s}$

POISEUILLE' S LAW (flow of viscous fluid)

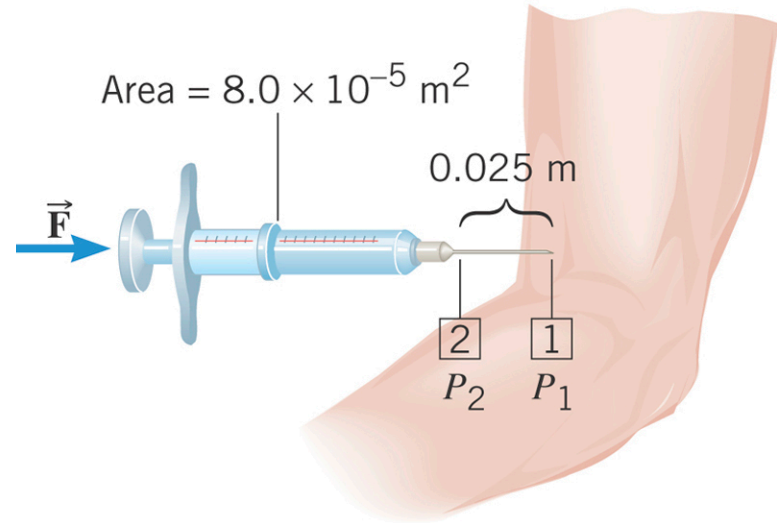
The volume flow rate is given by:

$$\boxed{Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L}}$$

Pressure drop in a straight uniform diamater pipe.



Example 17 Giving and Injection



A syringe is filled with a solution whose viscosity is 1.5x10^{-3} Pa·s. The internal radius of the needle is 4.0x10^{-4}m.

The gauge pressure in the vein is 1900 Pa. What force must be applied to the plunger, so that 1.0x10^{-6}m^3 of fluid can be injected in 3.0 s?

$$P_2 - P_1 = \frac{8\eta LQ}{\pi R^4}$$

$$= \frac{8\left(1.5\times10^{-3}\,\text{Pa}\cdot\text{s}\right)\left(0.025\text{ m}\right)\left(1.0\times10^{-6}\,\text{m}^3/3.0\text{ s}\right)}{\pi\left(4.0\times10^{-4}\text{m}\right)^4} = 1200\text{ Pa}$$

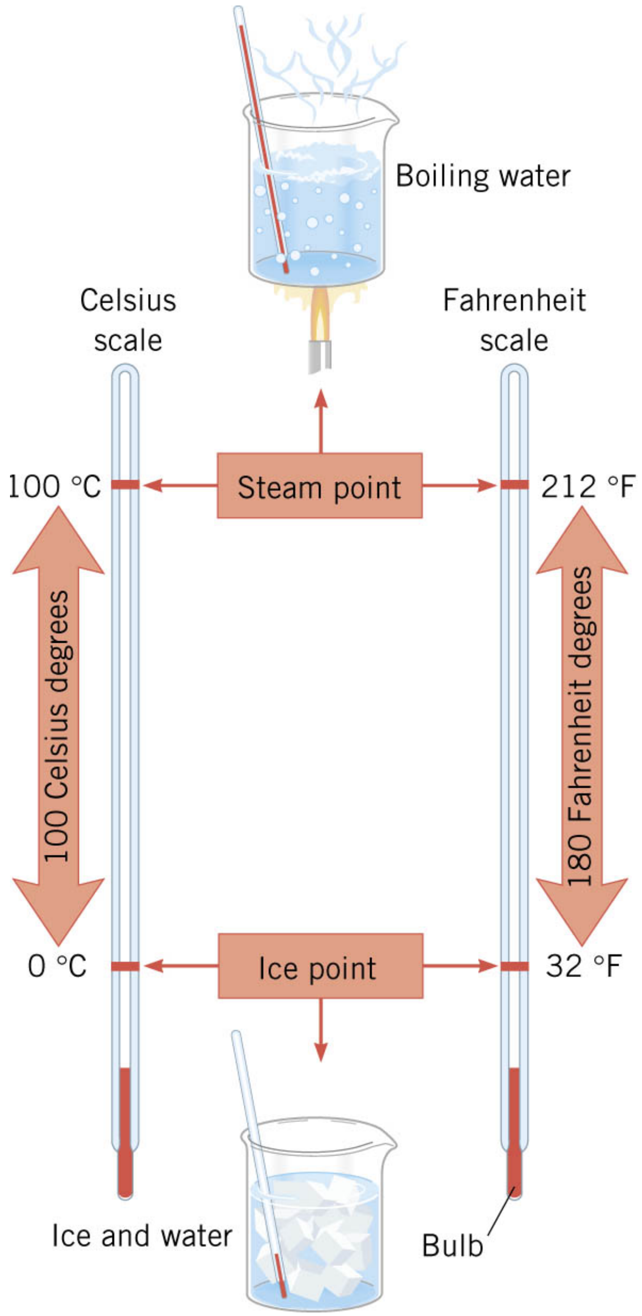
$$P_2 = \left(1200 + P_1\right)\text{Pa} = \left(1200+1900\right)\text{Pa} = 3100\text{ Pa}$$

$$\boxed{F = P_2 A = \left(3100\text{ Pa}\right)\left(8.0\times10^{-5}\text{m}^2\right) = 0.25\text{N}}$$

Chapter 12

Temperature and Heat

12.1 Common Temperature Scales



Temperatures are reported in *degrees*-**Celsius** or *degrees*-**Fahrenheit**.

Temperature changes, on the other hand, are reported in **Celsius**-*degrees* or **Fahrenheit**-*degrees*:

$$1\ \mathrm{C}^\circ = \frac{5}{9}\ \mathrm{F}^\circ \qquad \left(\frac{100}{180} = \frac{5}{9}\right)$$

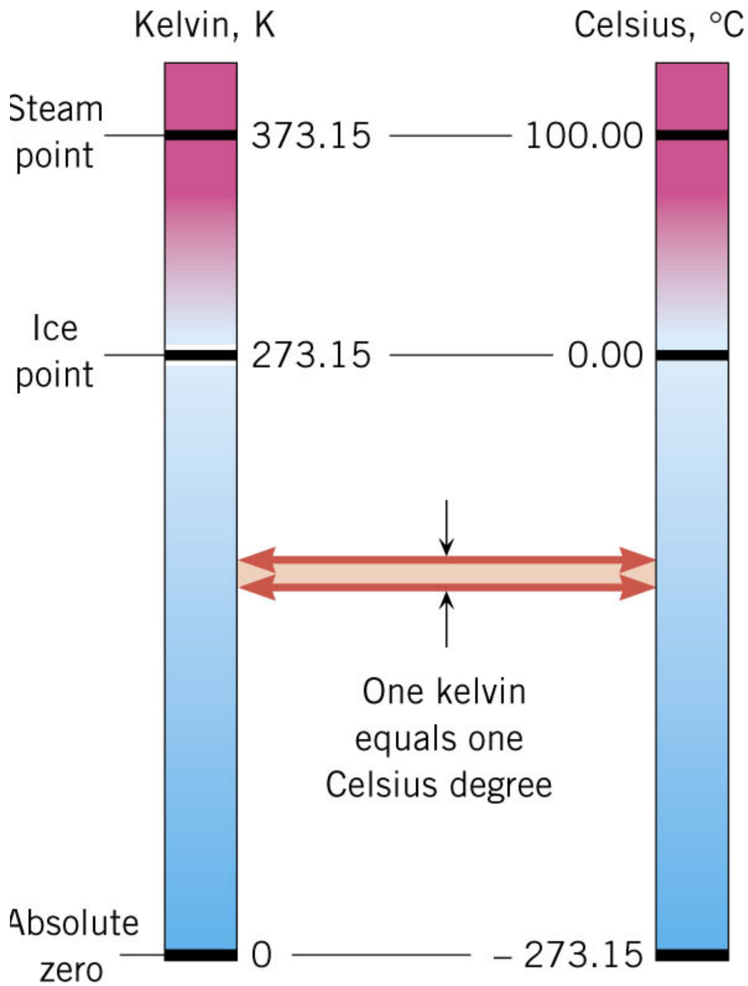
Convert F° to C°:

$$\mathrm{C}^\circ = \frac{5}{9}(\mathrm{F}^\circ - 32)$$

Convert C° to F°:

$$\mathrm{F}^\circ = \frac{9}{5}\mathrm{C}^\circ + 32$$

12.2 The Kelvin Temperature Scale

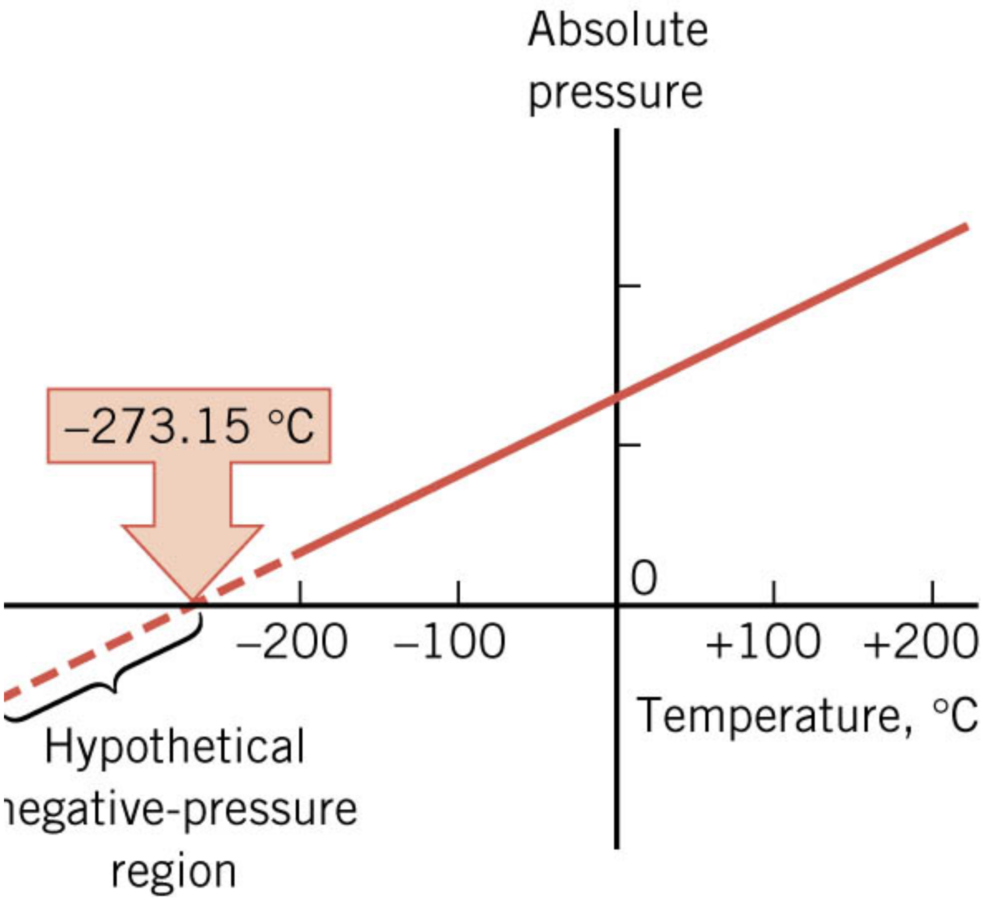


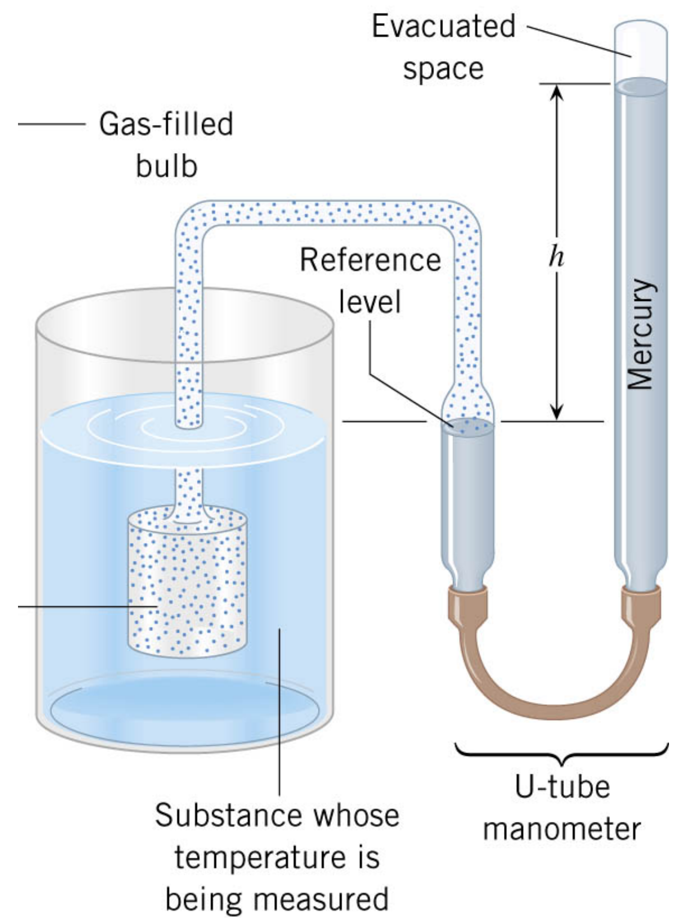
Kelvin temperature

$$T = T_c + 273.15$$

12.2 The Kelvin Temperature Scale

A ***constant-volume gas thermometer***.

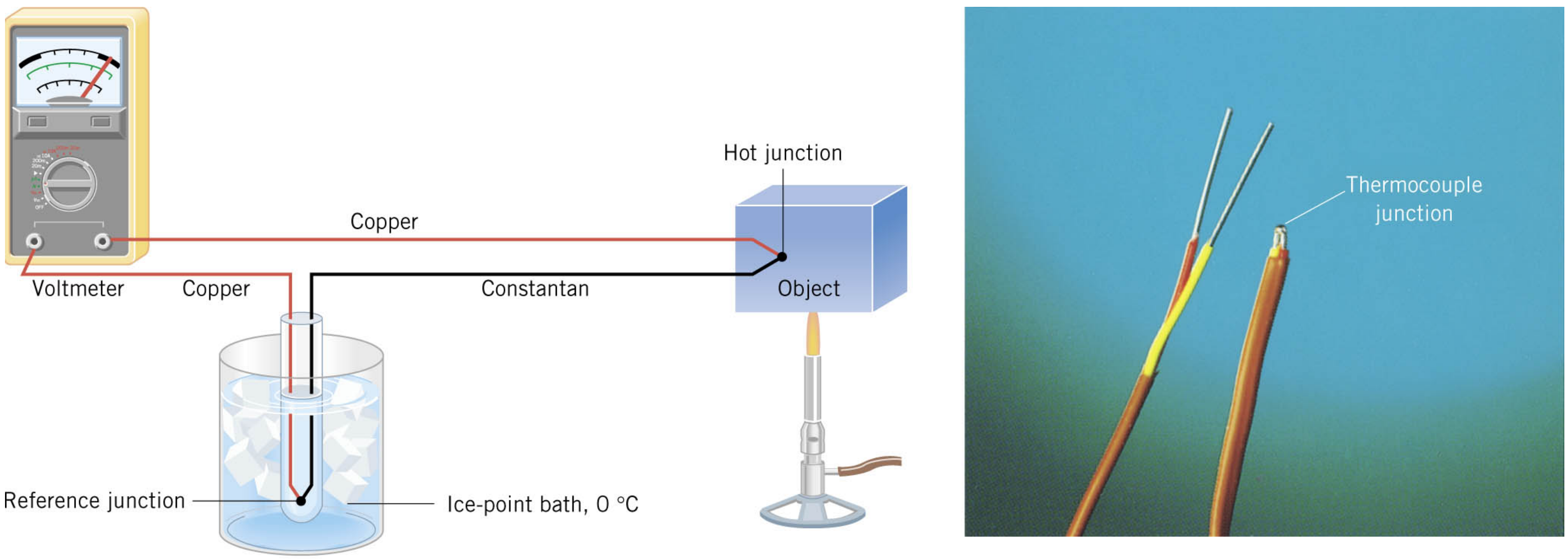




absolute zero point = -273.15^{o}C

12.3 Thermometers

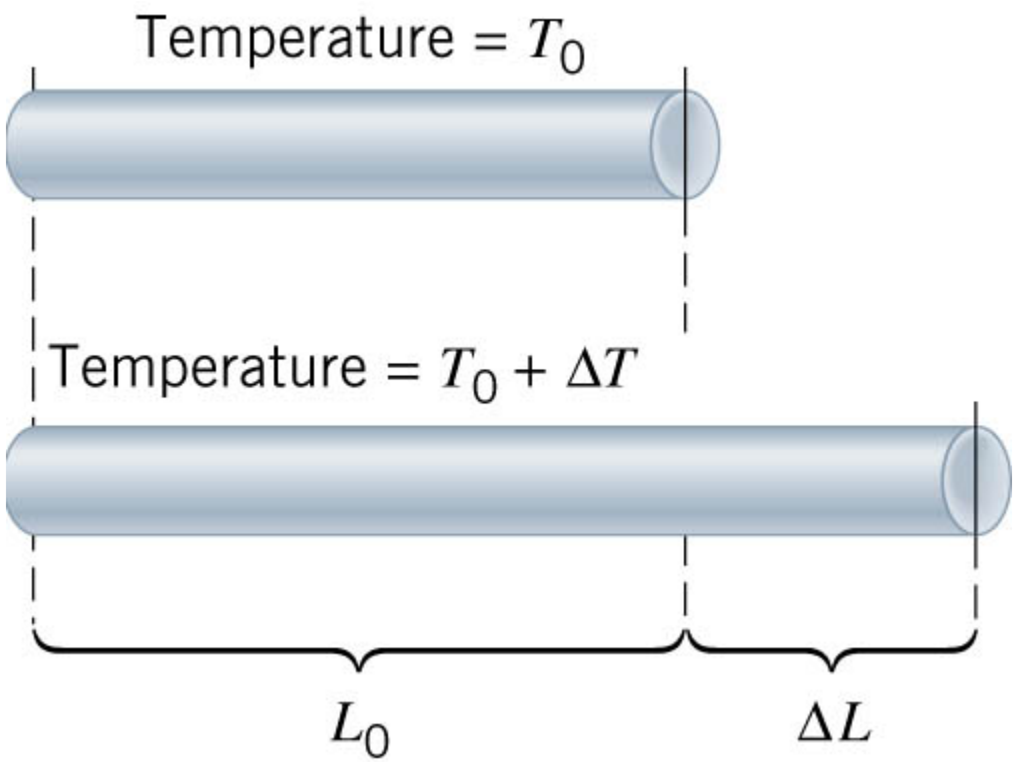
Thermometers make use of the change in some physical property with temperature. A property that changes with temperature is called a ***thermometric property***.



(*a*) (*b*)

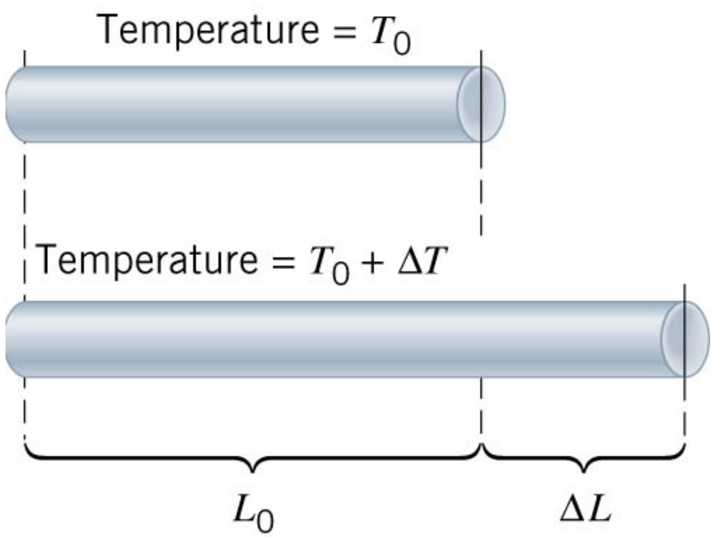
12.4 Linear Thermal Expansion

NORMAL SOLIDS



LINEAR THERMAL EXPANSION OF A SOLID

The length of an object changes when its temperature changes:



Change in length proportional to original length and temperature change.

$$\Delta L = \alpha L_0 \Delta T$$

coefficient of linear expansion

Common Unit for the Coefficient of Linear Expansion: $\frac{1}{\mathrm{C}^\circ} = \left(\mathrm{C}^\circ\right)^{-1}$

12.4 Linear Thermal Expansion

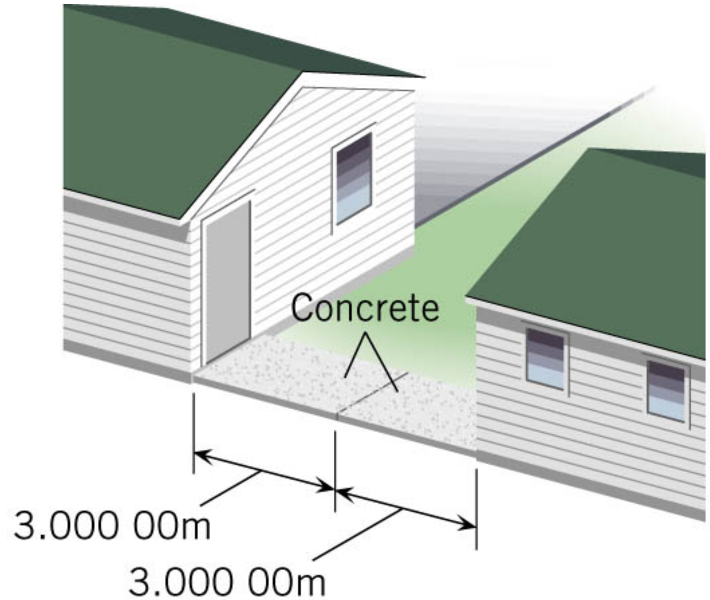
Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

Substance	Coefficient of Thermal Expansion $(C°)^{-1}$ Linear (α)	Volume (β)
Solids		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass (common)	8.5×10^{-6}	26×10^{-6}
Glass (Pyrex)	3.3×10^{-6}	9.9×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Nickel	13×10^{-6}	39×10^{-6}
Quartz (fused)	0.50×10^{-6}	1.5×10^{-6}
Silver	19×10^{-6}	57×10^{-6}
Liquids[b]		
Benzene	—	1240×10^{-6}
Carbon tetrachloride	—	1240×10^{-6}
Ethyl alcohol	—	1120×10^{-6}
Gasoline	—	950×10^{-6}
Mercury	—	182×10^{-6}
Methyl alcohol	—	1200×10^{-6}
Water	—	207×10^{-6}

[a]The values for α and β pertain to a temperature near 20 °C.
[b]Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

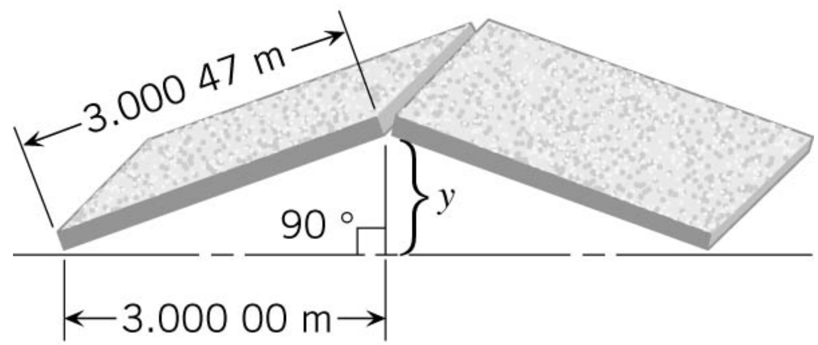
Example 3 The Buckling of a Sidewalk

A concrete sidewalk is constructed between two buildings on a day when the temperature is 25°C. As the temperature rises to 38°C, the slabs expand, but no space is provided for thermal expansion. Determine the distance *y* in part (b) of the drawing.



(a)

$$\Delta L = \alpha L_o \Delta T$$
$$= \left[12\times10^{-6}\left(\mathrm{C}^\circ\right)^{-1}\right](3.0\ \mathrm{m})(13\ \mathrm{C}^\circ)$$
$$= 0.00047\ \mathrm{m}$$

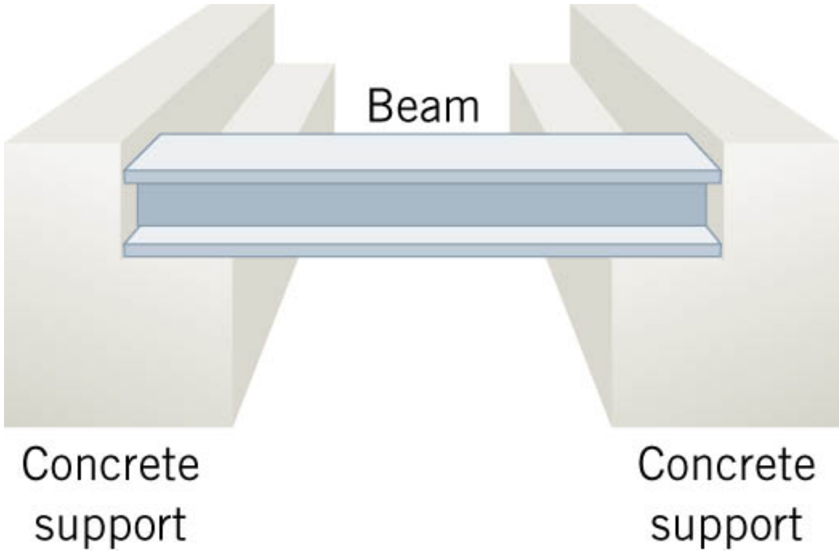


(b)

$$y = \sqrt{(3.00047\ \mathrm{m})^2 - (3.00000\ \mathrm{m})^2}$$
$$= 0.053\ \mathrm{m}$$

Example 4 The Stress on a Steel Beam

The beam is mounted between two concrete supports when the temperature is 23°C. What compressional stress must the concrete supports apply to each end of the beam, if they are to keep the beam from expanding when the temperature rises to 42°C?



$$\text{Stress} = \frac{F}{A} = Y\frac{\Delta L}{L_0} \qquad \text{with } \Delta L = \alpha L_0 \Delta T$$

$$= Y\alpha\,\Delta T$$

$$= \left(2.0\times10^{11}\,\mathrm{N/m^2}\right)\left[12\times10^{-6}\left(\mathrm{C}^\circ\right)^{-1}\right]\left(19\,\mathrm{C}^\circ\right)$$

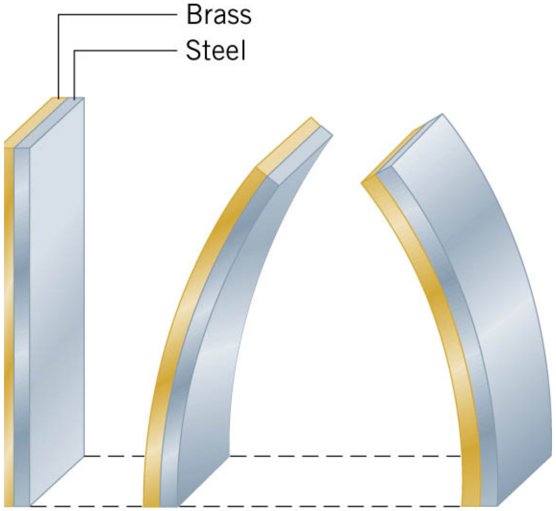
$$= 4.7\times10^{7}\,\mathrm{N/m^2}$$

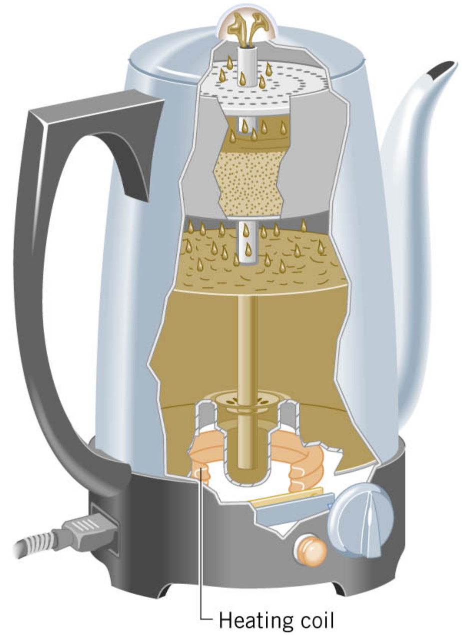
Pressure at ends of the beam, $4.7\times10^{7}\,\mathrm{N/m^2} \approx 170$ atmospheres (1×10^{5} N/m)

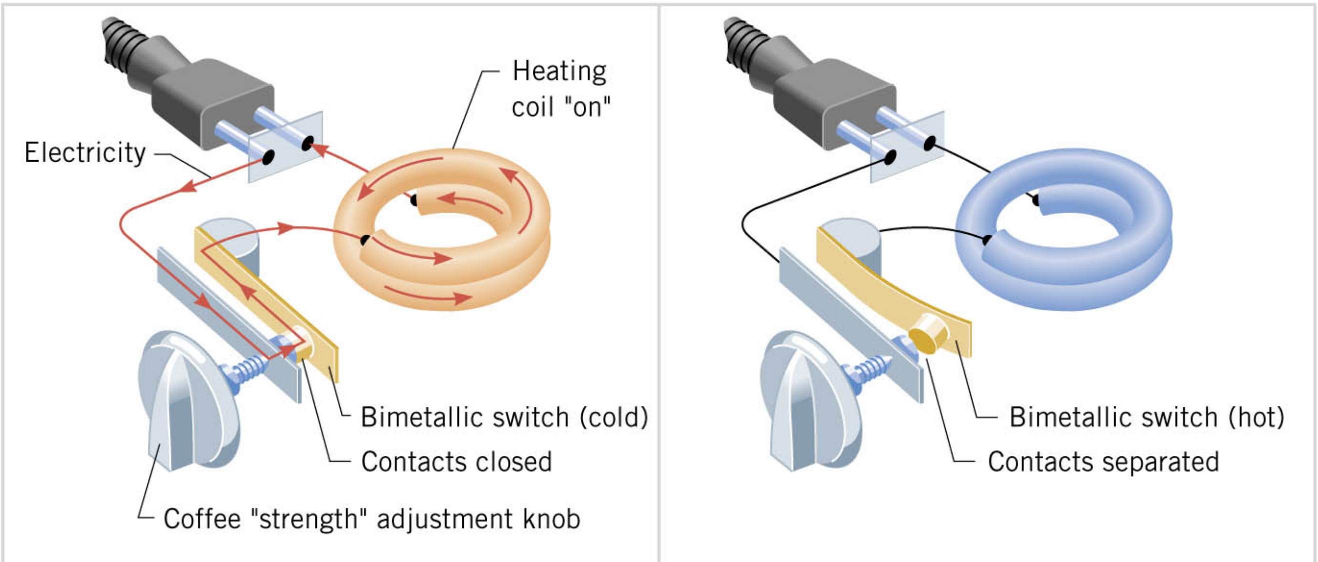
12.4 *Linear Thermal Expansion*

Temperature control with bimetalic strip

THE BIMETALLIC STRIP







(a) Coffee pot "on"

(b) Coffee pot "off"

12.4 Linear Thermal Expansion

Conceptual Example 7 Expanding Cylinders

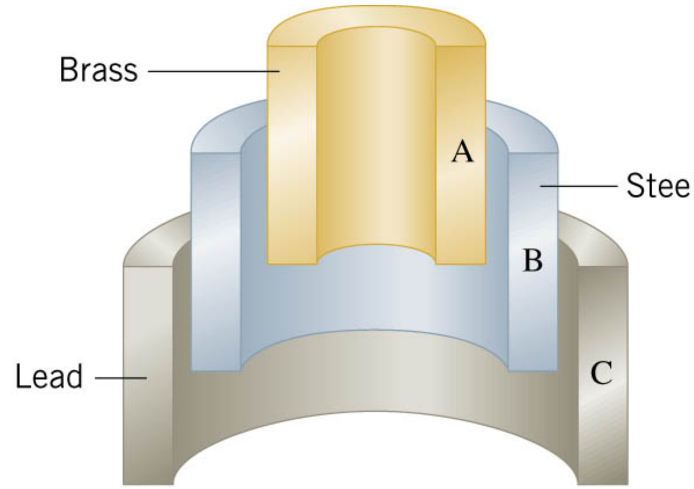
As the cylinders are heated to the same, but higher, temperature, cylinder C falls off, while cylinder A becomes tightly wedged to cylinder B.

Which cylinder is made from which material?

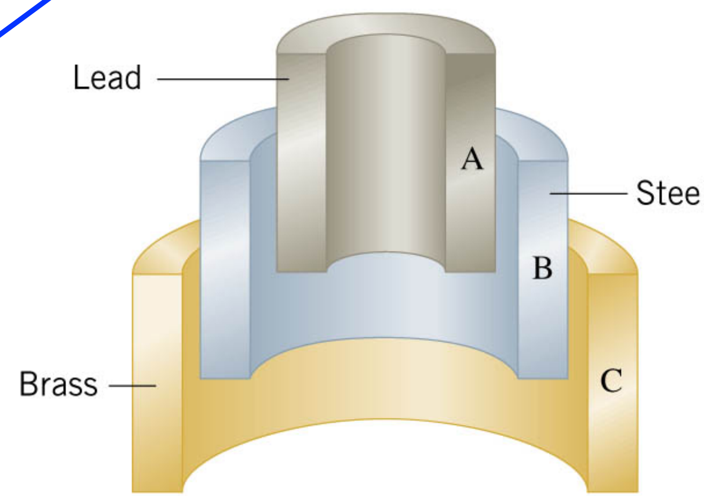
Diameter change proportional to α.

$$\alpha_{\mathrm{Pb}} > \alpha_{\mathrm{Brass}} > \alpha_{\mathrm{Fe}}$$

Lead ring falls off steel, brass ring sticks inside.



(*a*)



(*b*)

Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

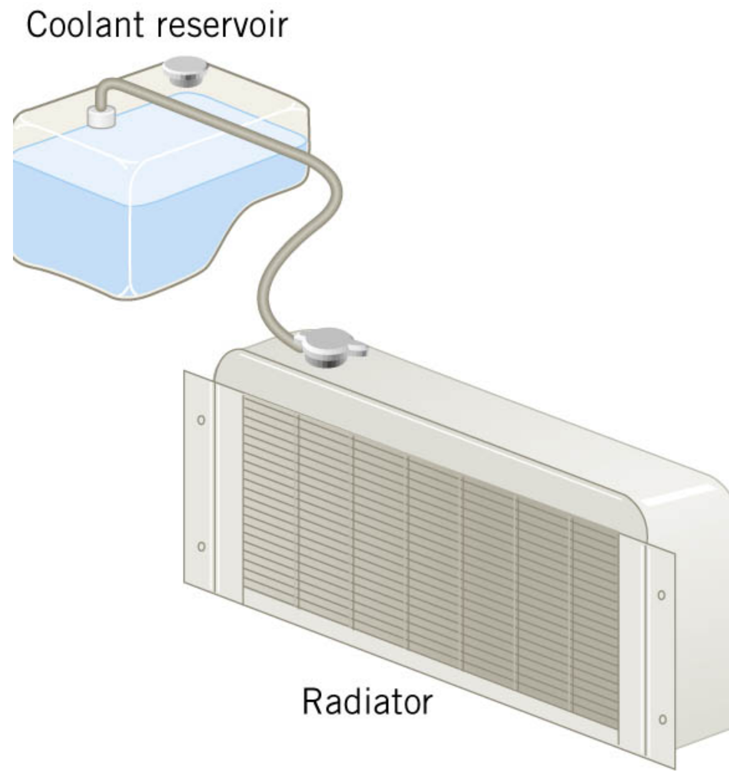
Substance	Coefficient of Thermal Expansion $(\mathrm{C}°)^{-1}$	
	Linear (α)	Volume (β)
Solids		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}

Linear themal expansion $\boxed{\Delta L = \alpha L_0 \Delta T}$

$\boxed{\Delta V = \beta V_o \Delta T}$ Volume themal expansion

Example 8 An Automobile Radiator

The radiator is made of copper and the coolant has an expansion coefficient of $4.0\text{x}10^{-4}\ (\text{C}^{\text{o}})^{-1}$. If the radiator is filled to its 15-quart capacity when the engine is cold (6^{o}C), how much overflow will spill into the reservoir when the coolant reaches its operating temperature (92^{o}C)?

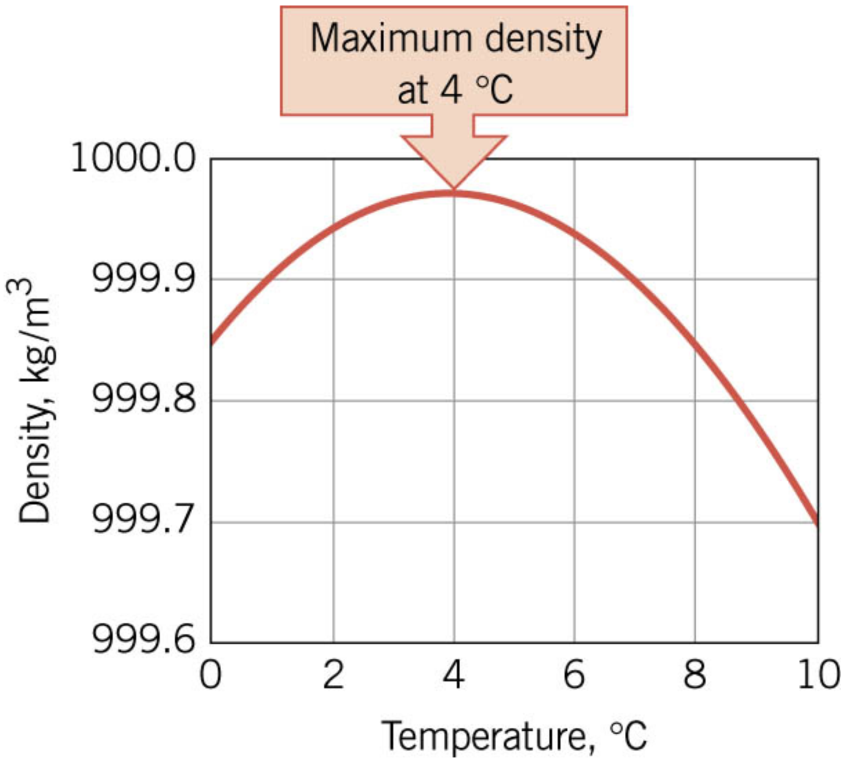


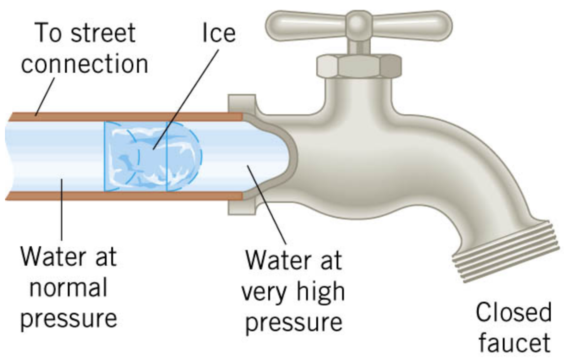
$$\Delta V_{\text{coolant}} = \left[4.10\times 10^{-4}\left(\text{C}^{\circ}\right)^{-1}\right]\left(15\ \text{liters}\right)\left(86\ \text{C}^{\circ}\right)$$
$$= 0.53\ \text{liters}$$
$$\Delta V_{\text{radiator}} = \left[51\times 10^{-6}\left(\text{C}^{\circ}\right)^{-1}\right]\left(15\ \text{liters}\right)\left(86\ \text{C}^{\circ}\right)$$
$$= 0.066\ \text{liters}$$

$$\Delta V_{\text{expansion}} = (0.53 - 0.066)\ \text{liters}$$
$$= 0.46\ \text{liters}$$

12.5 Volume Thermal Expansion

Expansion of water.



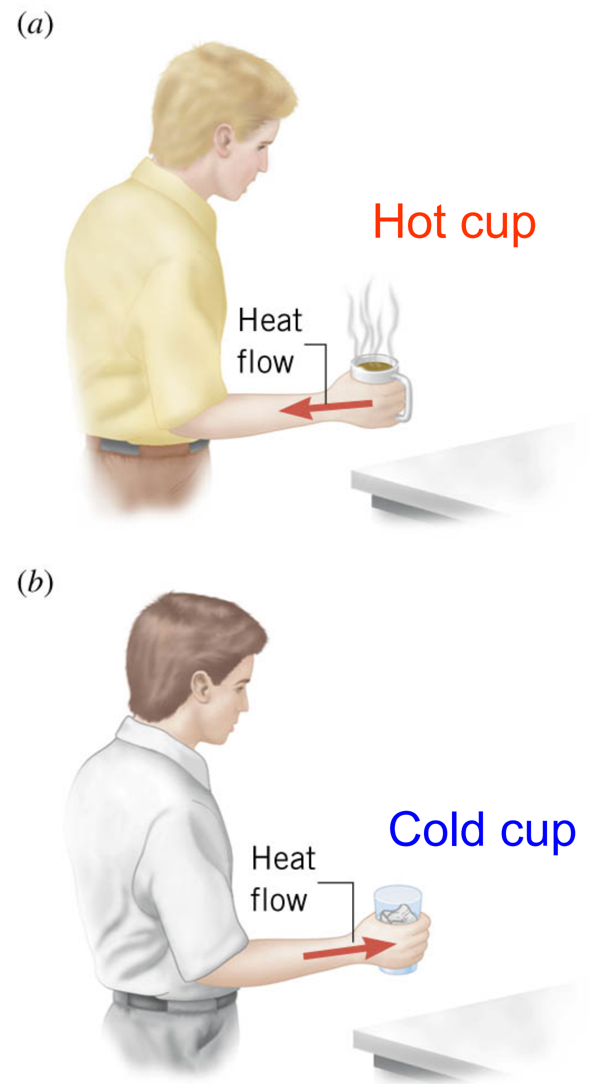


12.6 *Heat and Internal Energy*

DEFINITION OF HEAT

Heat is energy that flows from a higher-temperature object to a lower-temperature object because of a difference in temperatures.

SI Unit of Heat: joule (J)



The heat that flows from hot to cold originates in the *internal energy* of the hot substance.

It is not correct to say that a substance contains heat. You must use the word energy or internal energy.

12.7 *Heat and Temperature Change: Specific Heat Capacity*

Temperature of an object reflects the amount of internal energy within it. But objects with the same temperature and mass can have DIFFERENT amounts of internal energy!

SOLIDS AND LIQUIDS (GASES ARE DIFFERENT)

HEAT SUPPLIED OR REMOVED IN CHANGING THE TEMPERATURE OF A SUBSTANCE.

The heat that must be supplied or removed to change the temperature of a substance is

$$\boxed{Q = mc\Delta T}$$

c, is the specific heat capacity of the substance

Common Unit for Specific Heat Capacity: J/(kg·C°)

$\boxed{\Delta T > 0, \text{ Heat added}}$ $\boxed{\Delta T < 0, \text{ Heat removed}}$

GASES

The value of the specific heat of a gas depends on whether the pressure or volume is held constant.

This distinction is not important for solids.

Specific means per unit mass

Example 9 A Hot Jogger

In a half-hour, a 65-kg jogger produces 8.0×10^5 J of heat. This heat is removed from the body by a variety of means, including sweating, one of the body's own temperature-regulating mechanisms. If the heat were not removed, how much would the body temperature increase?

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc} = \frac{8.0\times10^5\,\mathrm{J}}{(65\ \mathrm{kg})\left[3500\,\mathrm{J}/(\mathrm{kg}\cdot\mathrm{C}^\circ)\right]} = 3.5\ \mathrm{C}^\circ$$

OTHER UNITS for heat production

1 cal = 4.186 joules (calorie)

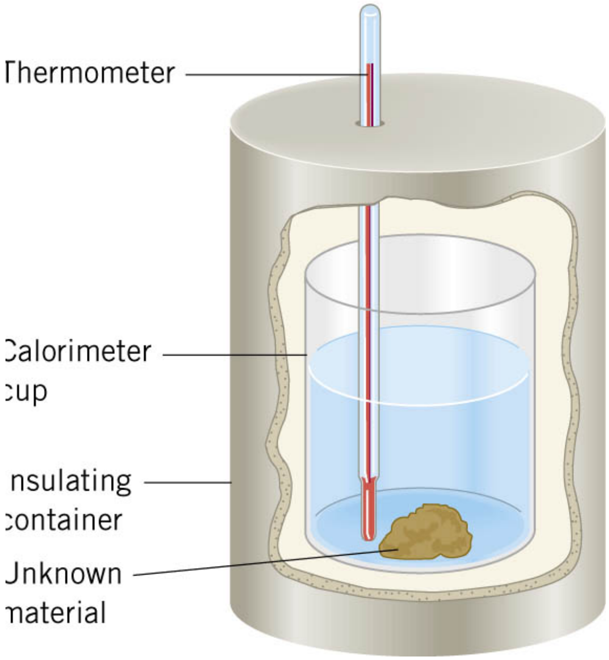
1 kcal = 4186 joules ([kilo]calories for food)

Table 12.2 Specific Heat Capacities[a] of Some Solids and Liquids

Substance	Specific Heat Capacity, *c* J/(kg·C°)
Solids	
Aluminum	9.00×10^2
Copper	387
Glass	840
Human body (37 °C, average)	3500
Ice (−15 °C)	2.00×10^3
Iron or steel	452
Lead	128
Silver	235
Liquids	
Benzene	1740
Ethyl alcohol	2450
Glycerin	2410
Mercury	139
Water (15 °C)	4186

[a]Except as noted, the values are for 25 °C and 1 atm of pressure.

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 ($\Delta T < 0$)

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

Al ≡ Aluminum, W ≡ water, Unk ≡ unknown

Net heat change equals zero.

$$\sum Q = m_{\text{Al}} c_{\text{Al}} \Delta T_{\text{Al}} + m_{\text{W}} c_{\text{W}} \Delta T_{\text{W}} + m_{\text{Unk}} c_{\text{Unk}} \Delta T_{\text{Unk}} = 0$$

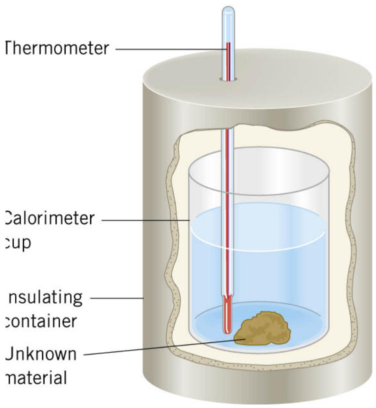
Beware, C&J take ΔT always positive and use Heat Lost by 1 = Heat gained by 2

No good, if there are 3 objects!

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 ($\Delta T < 0$)

$$\Delta T_{\mathrm{w}} = \Delta T_{\mathrm{Al}} = +4\,°\mathrm{C}; \quad \Delta T_{\mathrm{Unk}} = -75\,°\mathrm{C}$$

$$c_{\mathrm{Al}} = 900\ \mathrm{J/kg \cdot C°}$$

$$c_{\mathrm{W}} = 4190\ \mathrm{J/kg \cdot C°}$$

Net heat change equals zero.

$$\sum Q = m_{\mathrm{Al}} c_{\mathrm{Al}} \Delta T_{\mathrm{Al}} + m_{\mathrm{W}} c_{\mathrm{W}} \Delta T_{\mathrm{W}} + m_{\mathrm{Unk}} c_{\mathrm{Unk}} \Delta T_{\mathrm{Unk}} = 0$$

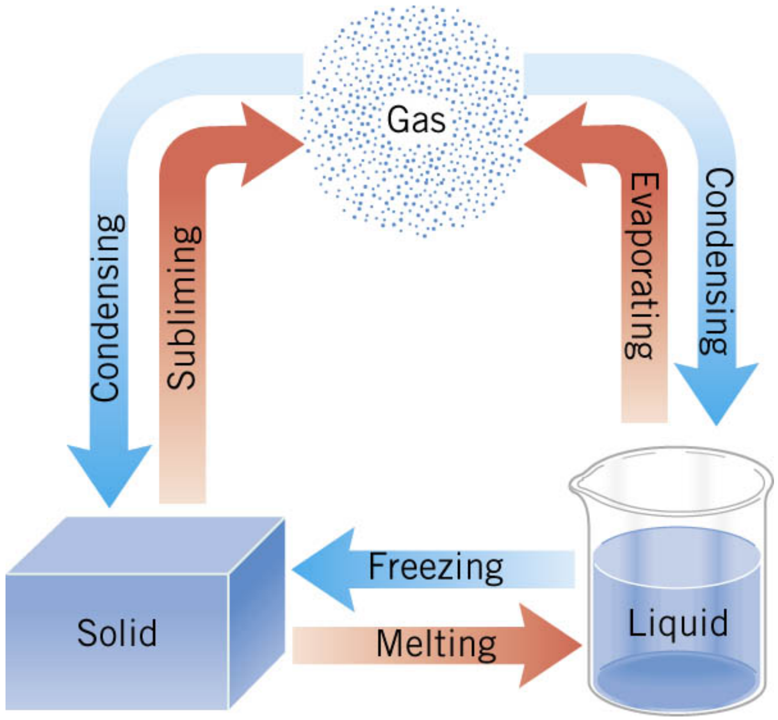
$$c_{\mathrm{Unk}} = \frac{m_{\mathrm{Al}} c_{\mathrm{Al}} \Delta T_{\mathrm{Al}} + m_{\mathrm{W}} c_{\mathrm{W}} \Delta T_{\mathrm{W}}}{-m_{\mathrm{Unk}} \Delta T_{\mathrm{Unk}}};$$

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

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

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 —> liquid (melt) or liquid —> gas (evaporate) requires heat energy to be ADDED.

Typically, gas—>liquid (condense), or liquid —> 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* :

$$\boxed{Q = mL}$$

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

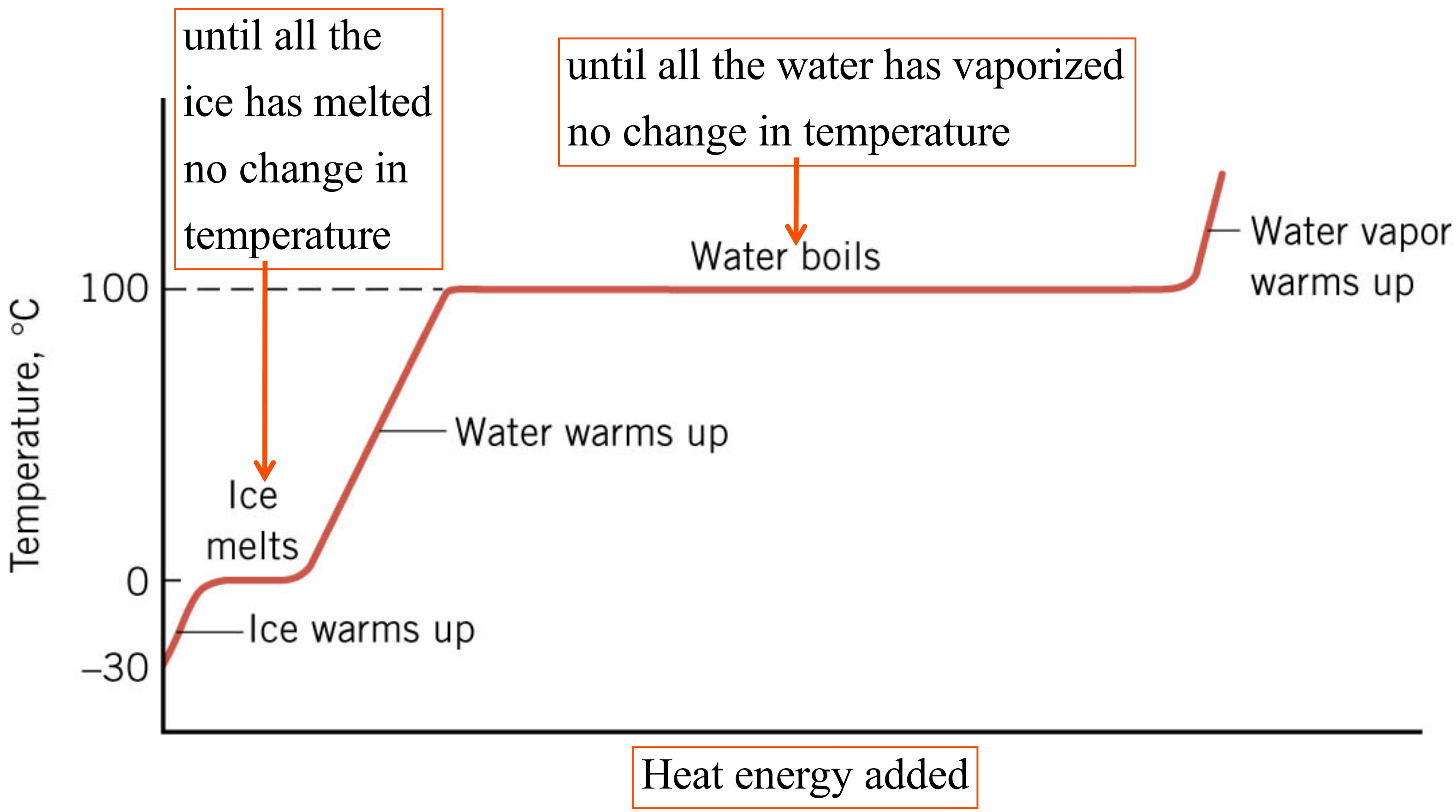
Substance	Melting Point (°C)	Latent Heat of Fusion, L_f (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization, L_v (J/kg)
Ammonia	−77.8	33.2×10^4	−33.4	13.7×10^5
Benzene	5.5	12.6×10^4	80.1	3.94×10^5
Copper	1083	20.7×10^4	2566	47.3×10^5
Ethyl alcohol	−114.4	10.8×10^4	78.3	8.55×10^5
Gold	1063	6.28×10^4	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

[a]The values pertain to 1 atm pressure.

$$\boxed{\begin{array}{ll} \text{Add heat: Ice} \rightarrow \text{Water} & L_f > 0 \\ \text{Remove heat: Water} \rightarrow \text{Ice} & L_f < 0 \end{array}}$$

$$\boxed{\begin{array}{ll} \text{Add heat: Water} \rightarrow \text{Vapor} & L_v > 0 \\ \text{Remove heat: Vapor} \rightarrow \text{Water} & L_v < 0 \end{array}}$$

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 C°) with some ice remaining. How much ice melted?

Heat redistributes.
No heat added or lost.

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

$$\Delta T_W = -27\ \text{C}°$$

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

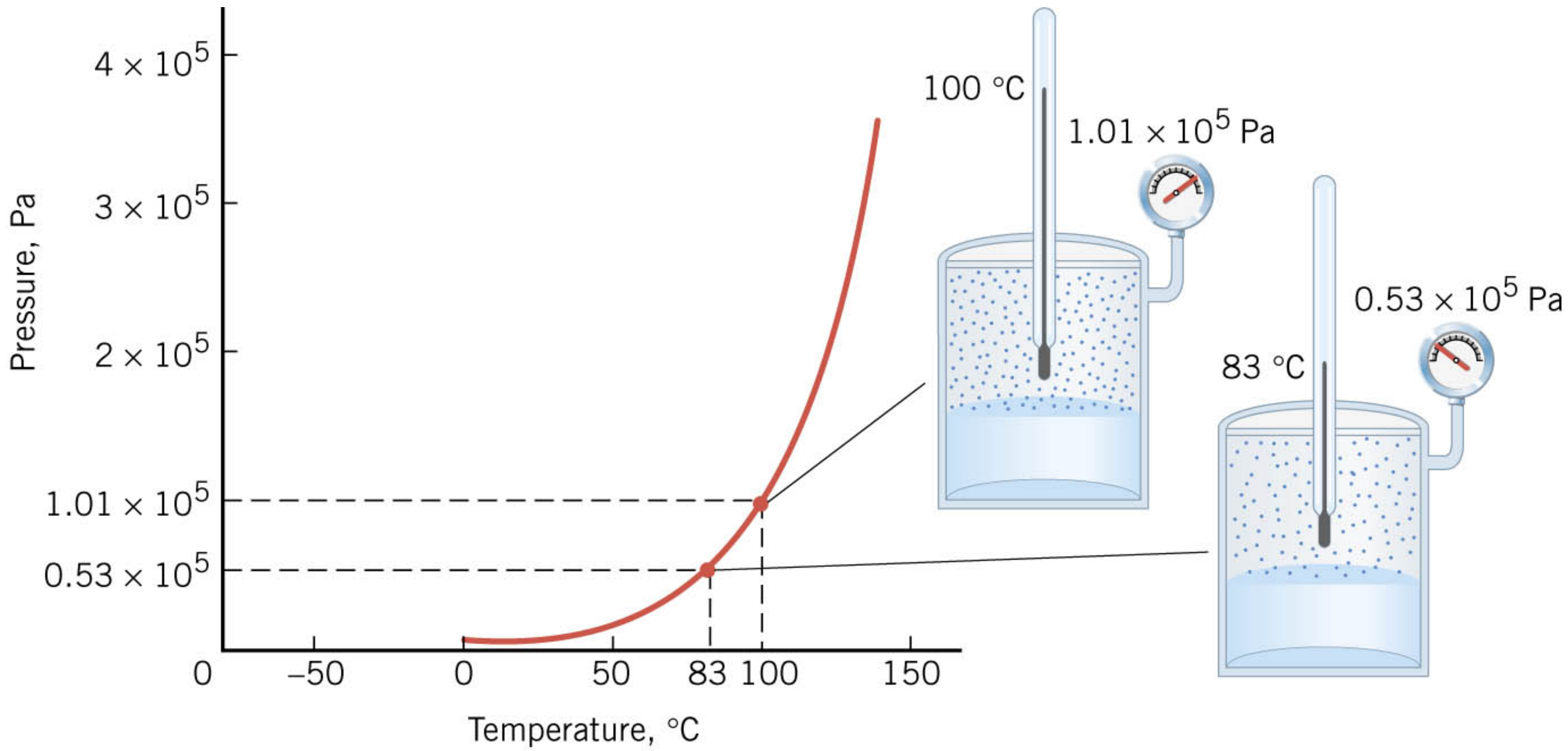
$$m_I = \frac{-m_W c_W \Delta T_W}{L_I}$$

$$= \frac{-(0.32\text{kg})(4.19\times10^3\text{J/kg}\cdot\text{C}°)(-27\text{C}°)}{33.5\times10^4\text{J/kg}} = 0.011\ \text{kg}$$

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

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.

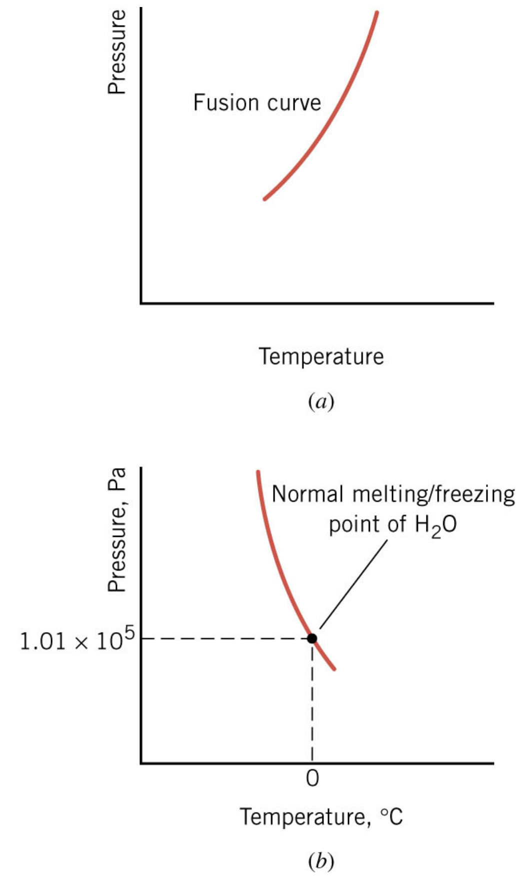
For normal liquids and solids,
at higher pressures, the melting point is higher.

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

Water boiling point behaves normally.

At at lower pressure the boiling point is less than 100 C°

On top of Mt. Everest the boiling point of water is 69 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.

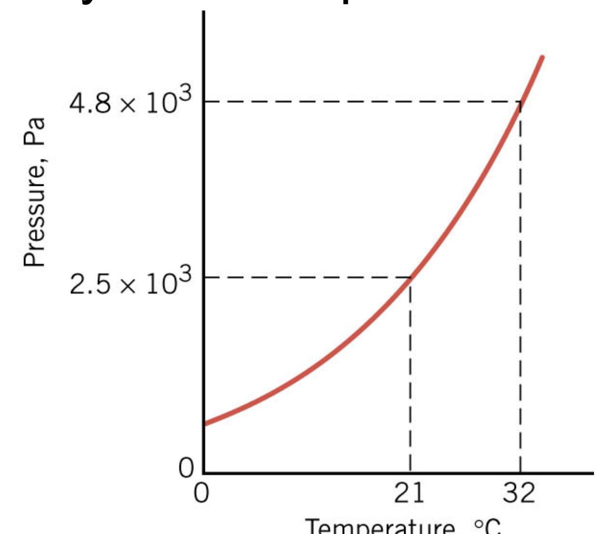
To provide an indication of how much water vapor is in the air, weather forecasters usually give the ***relative humidity:***

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

12.10 *Humidity*

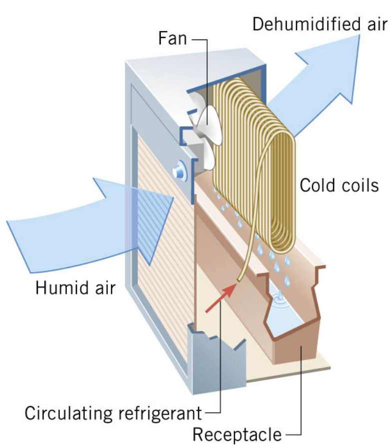
Example 17 Relative Humidities

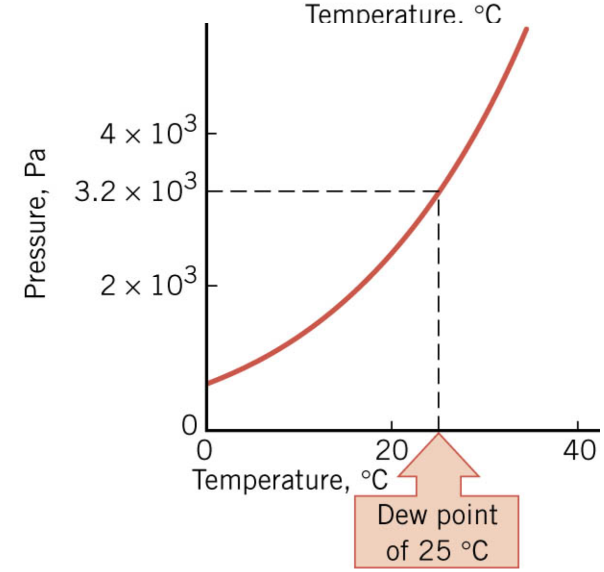
One day, the partial pressure of water vapor is $2.0\text{x}10^3$ Pa. Using the vaporization curve, determine the relative humidity if the temperature is 32°C.



$$\text{Relative humidity} = \frac{2.0\times10^3\ \text{Pa}}{4.8\times10^3\ \text{Pa}}\times100 = 42\%$$

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



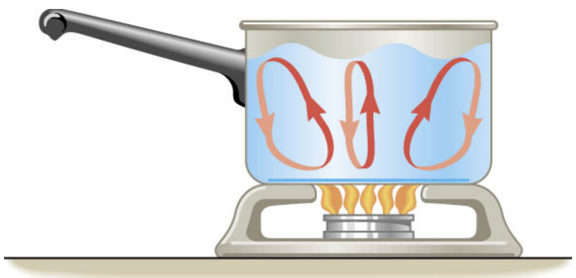


Chapter 13

The Transfer of Heat

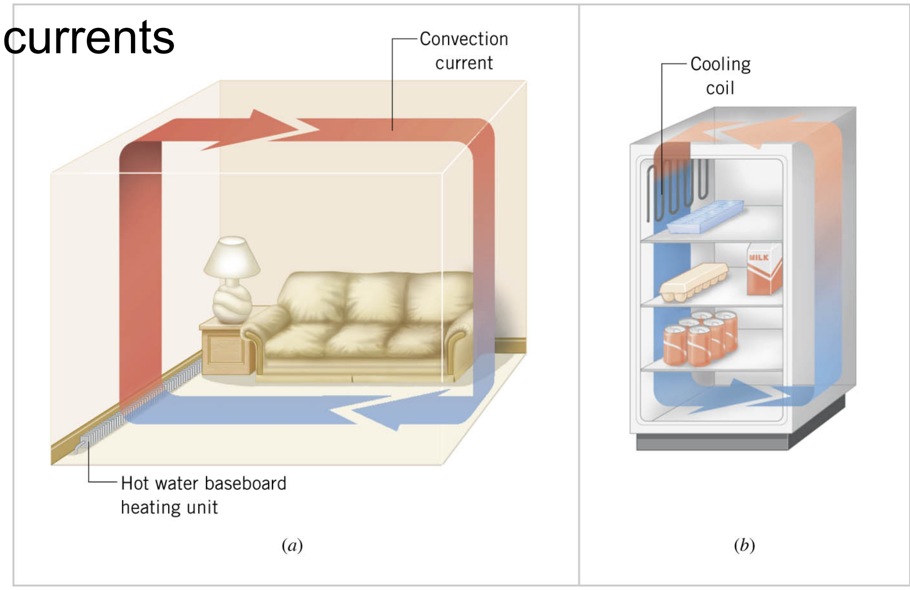
CONVECTION

Heat carried by the bulk movement of a fluid.

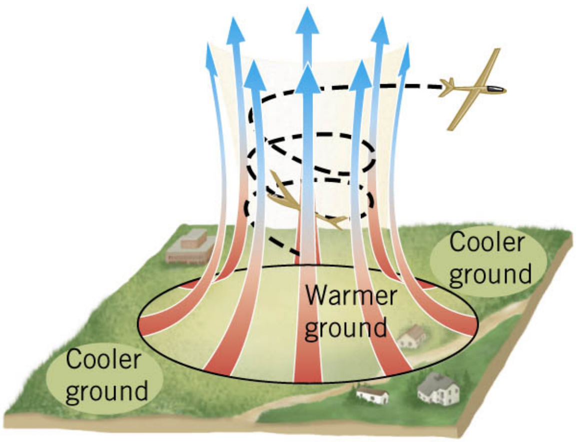


Convection fluid currents

Convection air currents



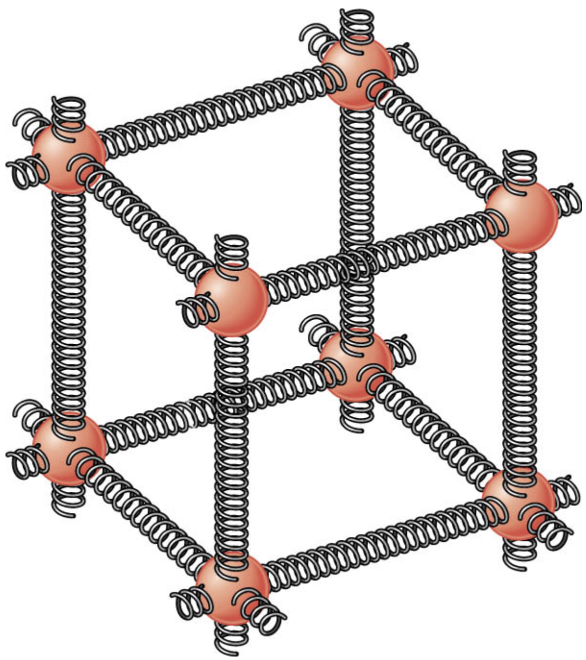
Convection air currents



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.

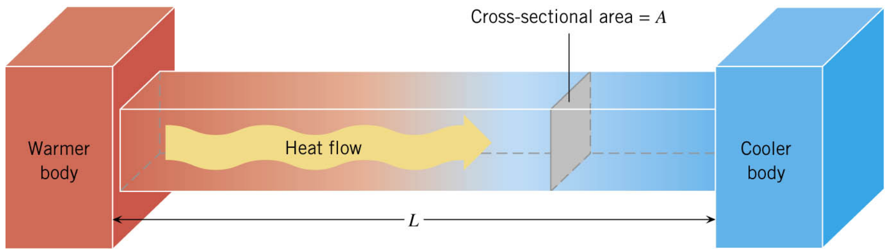


Model of solid materials. Atoms connected by atomic spring-like forces.

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

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

k, is the thermal conductivity

SI Units of Thermal Conductivity:
J/(s·m·C°) (joule per second-meter-C°)

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

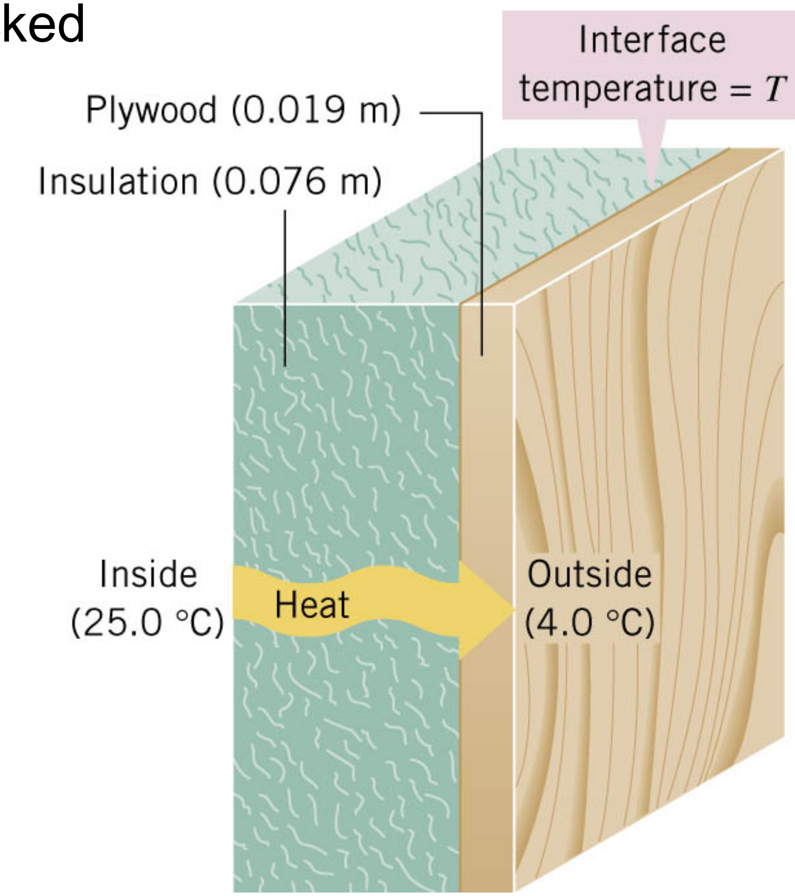
[a] Except as noted, the values pertain to temperatures near 20 °C.

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.

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

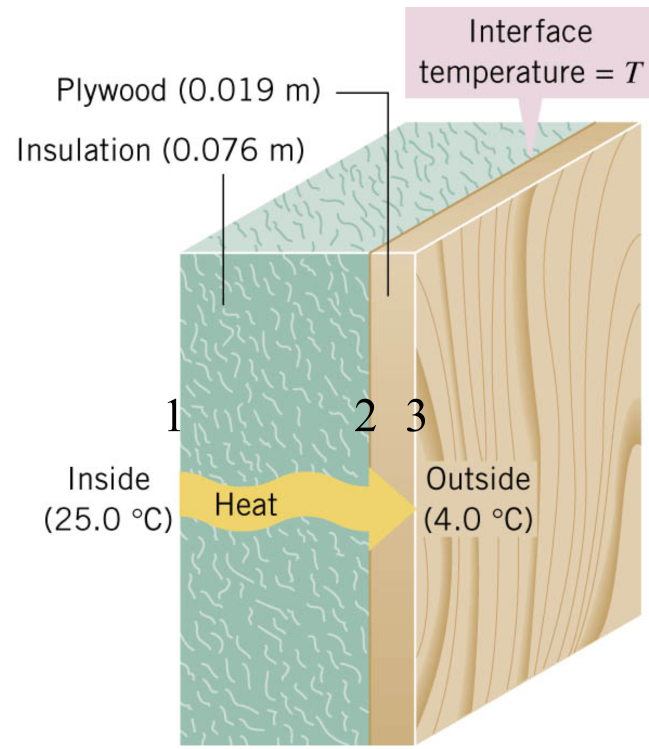


13.2 **Conduction**

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

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

First solve for the interface temperature using:



$$Q_{12} = Q_{23}$$

$$\frac{k_{12}\left(T_1 - T_2\right)}{L_{12}} = \frac{k_{23}\left(T_2 - T_3\right)}{L_{23}}$$

$$\left(T_1 - T_2\right) = \frac{k_{23}L_{12}}{k_{12}L_{23}}\left(T_2 - T_3\right); \quad \frac{k_{23}L_{12}}{k_{12}L_{23}} = \frac{(.08)(.076)}{(.03)(.019)} = 10.7$$

$$T_2 = \frac{T_1 + 10.7T_3}{11.7} = \frac{25 + 42.8}{11.7}\text{C}° = 5.8\text{C}°$$

$$Q_{12} = \frac{\left(k_{12}A\Delta T_{12}\right)t}{L_{12}} = \frac{.03(35)(19.2)3600}{.076}\text{J}$$

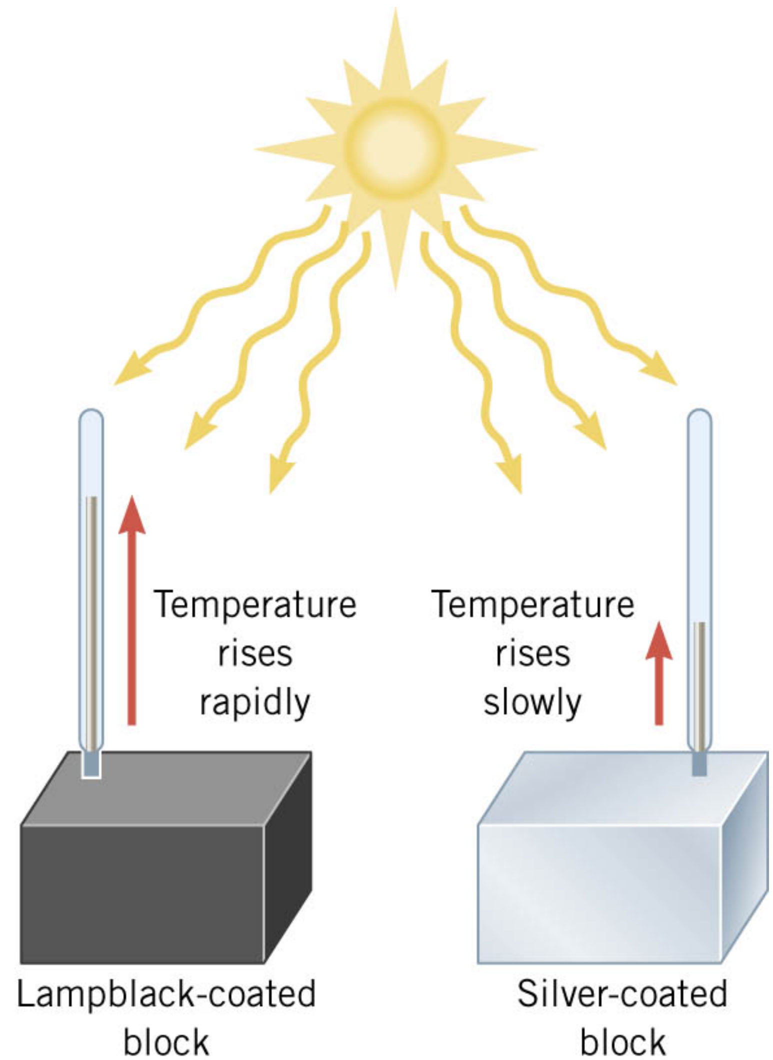
$$= 9.5 \times 10^5 \text{J}$$

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***.



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

$$\boxed{Q = e\sigma T^4 At}$$

emissivity $e =$ constant between 0 to 1
$e = 1$ (perfect black body emitter)

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 $4\mathrm{x}10^{30}$ W. Assuming Betelgeuse is a perfect emitter and spherical, find its radius.

with $A = \pi r^2$

$$r = \sqrt{\frac{Q/t}{4\pi e\sigma T^4}} = \sqrt{\frac{4\times 10^{30}\ \mathrm{W}}{4\pi(1)\left[5.67\times 10^{-8}\ \mathrm{J}/\left(\mathrm{s}\cdot \mathrm{m}^2\cdot \mathrm{K}^4\right)\right](2900\ \mathrm{K})^4}}$$

$$= 3\times 10^{11}\ \mathrm{m}$$