Chapter 11

Fluids

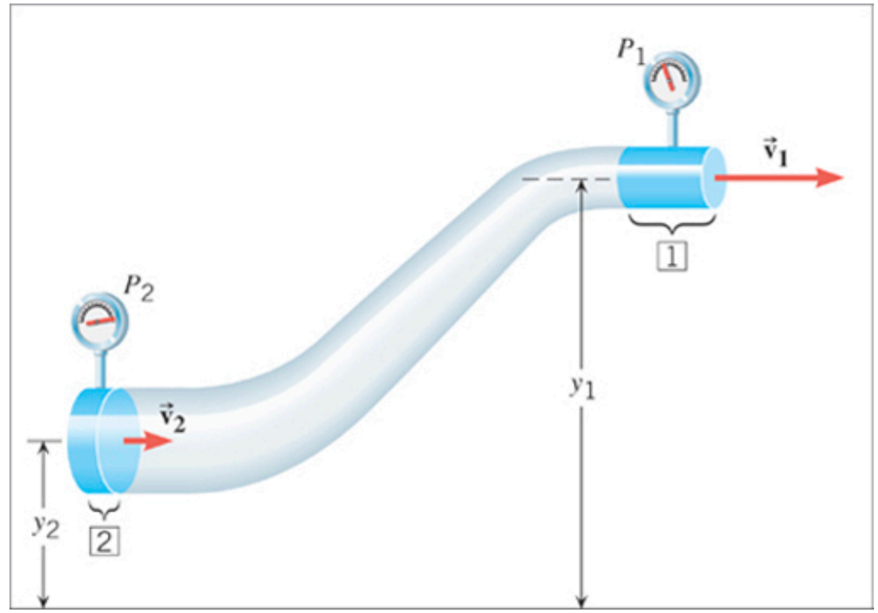
Bernoulli's equation

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,

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

$$m = \rho V$$

$$(P_2 - P_1) = \left(\tfrac{1}{2}\rho v_1^2 + \rho gy_1\right) - \left(\tfrac{1}{2}\rho v_2^2 + \rho gy_2\right)$$

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:

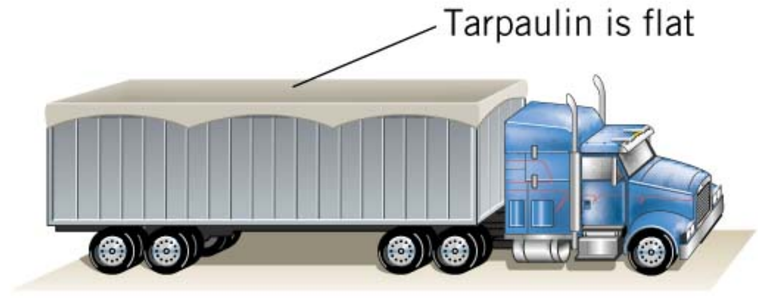
$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho gy_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho gy_2$$

11.10 Applications of Bernoulli's Equation

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.

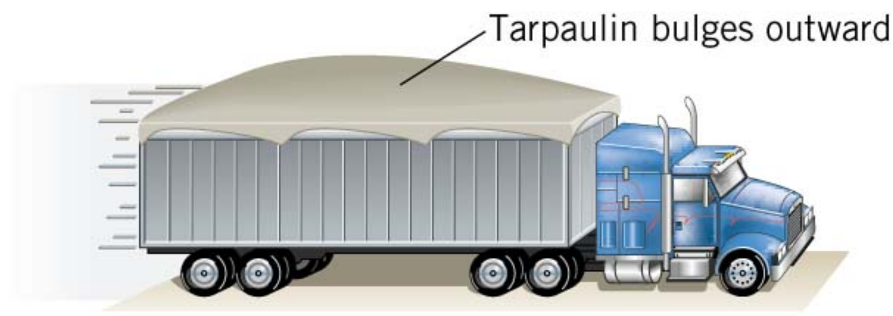


Stationary

Relative to moving truck

$v_1 = 0$ under the tarp

v_2 air flow over top



Moving

<u>Bernoulli's Equation</u>

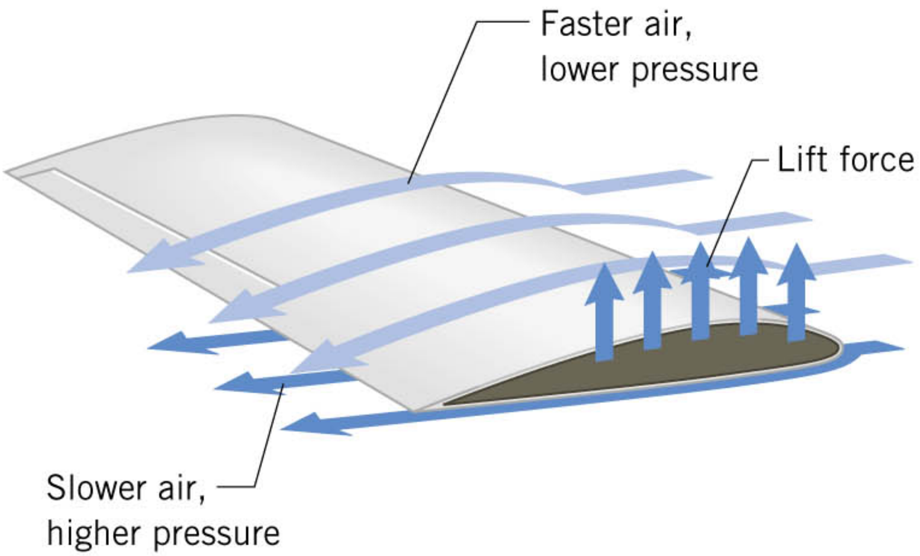
$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2$$

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

$$\boxed{P_1 > P_2}$$

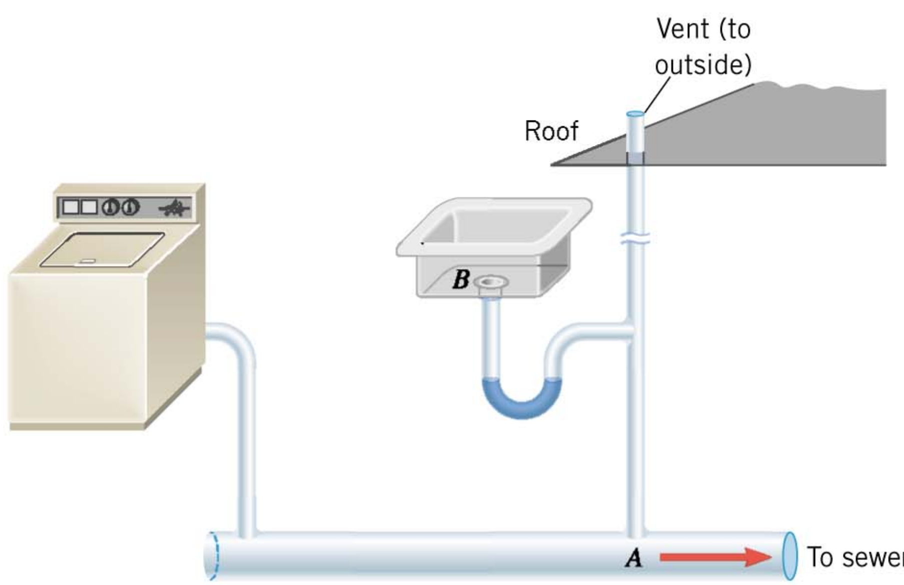
11.10 *Applications of Bernoulli's Equation*

Lift force of an airplane wing



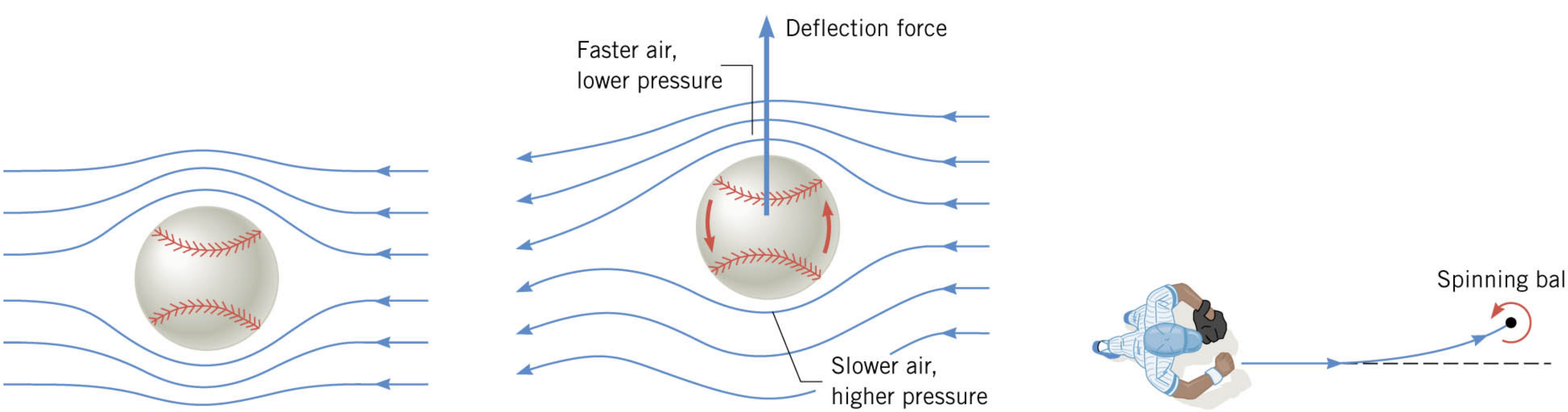
(*a*)

Venting keeps trap filled with water



(*b*) With vent

The curve ball

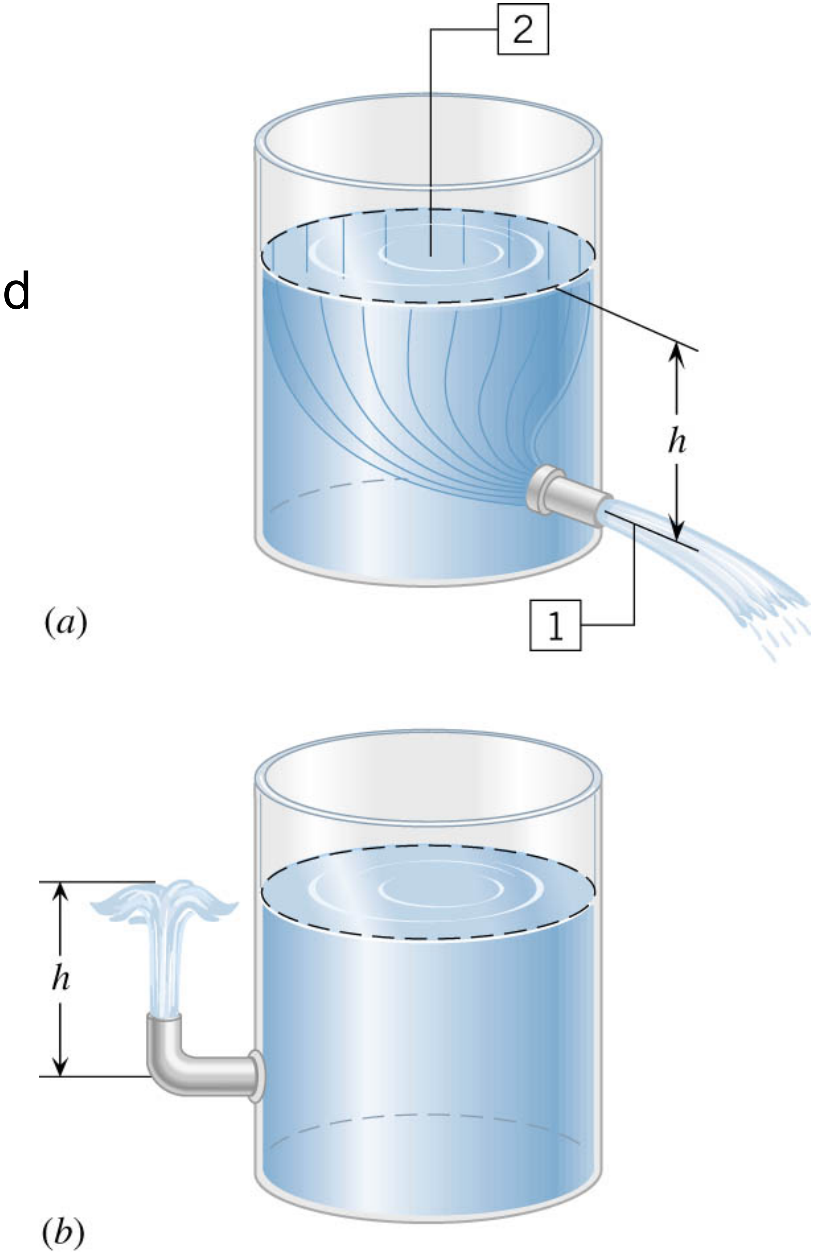


(*a*) Without spin (*b*) With spin (*c*)

11.10 Applications of Bernoulli's Equation

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.



$$P_1 = P_2 = P_{atmosphere} \quad (1\times10^5\ \mathrm{N/m^2})$$

$$v_2 = 0, \quad y_2 = h, \quad y_1 = 0$$

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

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

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

Clicker Question 11.3

Fluid flows from left to right through the pipe shown. Points A and B are at the same height, but the cross-sectional area is bigger at point B than at A. The points B and C are at two different heights, but the cross-sectional area of the pipe is the same. Rank the pressure at the three locations in order from lowest to highest.

Bernoulli's equation: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

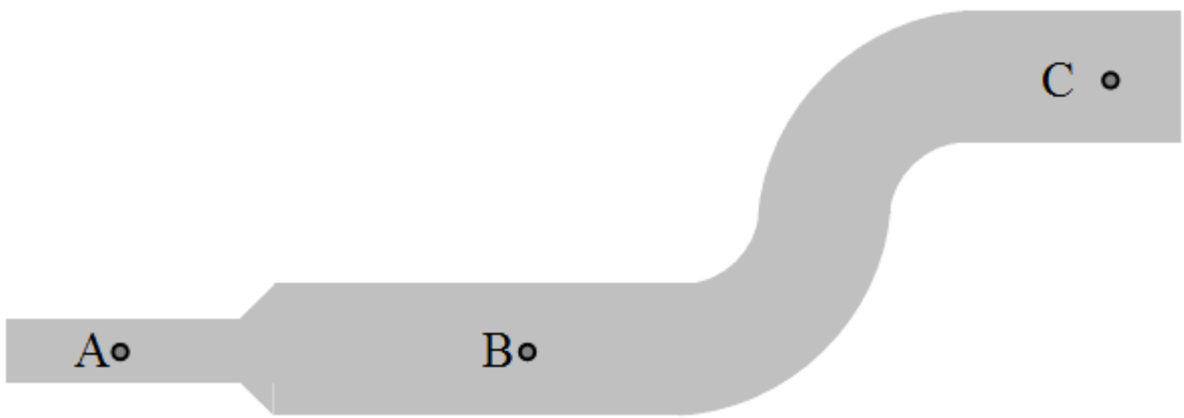
a) $P_A > P_B > P_C$

b) $P_B > P_A = P_C$

c) $P_C > P_B > P_A$

d) $P_B > P_A$ & $P_B > P_C$

e) $P_C > P_A$ & $P_C > P_B$



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Fluid flows from left to right through the pipe shown. Points A and B are at the same height, but the cross-sectional area is bigger at point B than at A. The points B and C are at two different heights, but the cross-sectional area of the pipe is the same. Rank the pressure at the three locations in order from lowest to highest.

Bernoulli's equation: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

a) $P_A > P_B > P_C$

b) $P_B > P_A = P_C$

c) $P_C > P_B > P_A$

d) $P_B > P_A \quad \& \quad P_B > P_C$

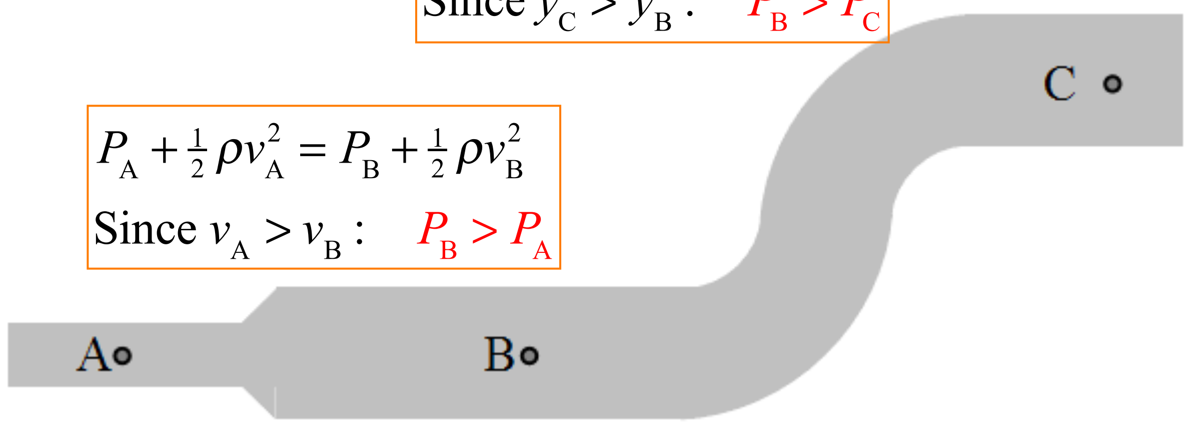
e) $P_C > P_A \quad \& \quad P_C > P_B$

$P_B + \rho g y_B = P_C + \rho g y_C$

Since $y_C > y_B$: $P_B > P_C$

$P_A + \frac{1}{2}\rho v_A^2 = P_B + \frac{1}{2}\rho v_B^2$

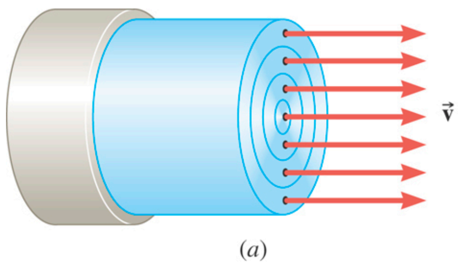
Since $v_A > v_B$: $P_B > P_A$



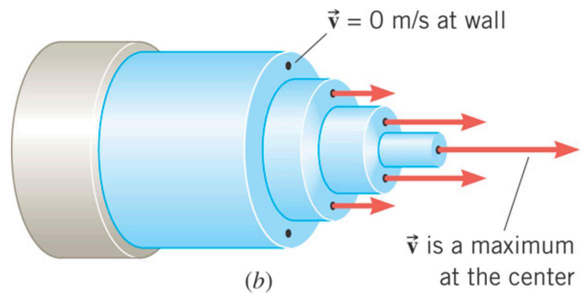
Pipe area grows: $v_A > v_B$

11.11 Viscous Flow

Flow of an ideal fluid.



Flow of a viscous fluid.



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:

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

η, is the coefficient of viscosity

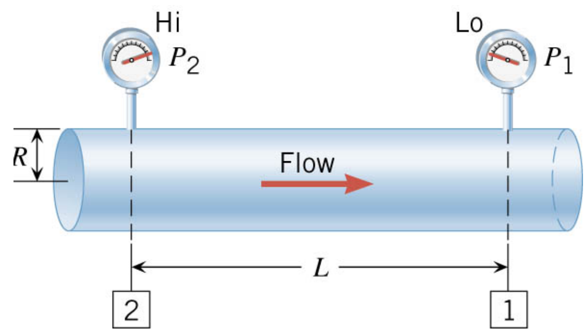
SI Unit: $\text{Pa}\cdot\text{s}$; 1 poise (P) = 0.1 $\text{Pa}\cdot\text{s}$

POISEUILLE' S LAW (flow of viscous fluid)

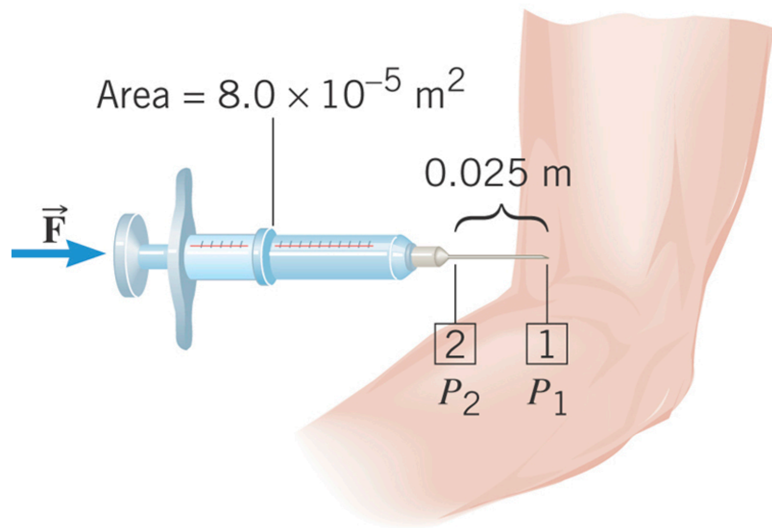
The volume flow rate is given by:

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

Pressure drop in a straight uniform diamater pipe.



Example 17 Giving and Injection



A syringe is filled with a solution whose viscosity is $1.5\text{x}10^{-3}$ Pa·s. The internal radius of the needle is $4.0\text{x}10^{-4}$m.

The gauge pressure in the vein is 1900 Pa. What force must be applied to the plunger, so that $1.0\text{x}10^{-6}\text{m}^3$ of fluid can be injected in 3.0 s?

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

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

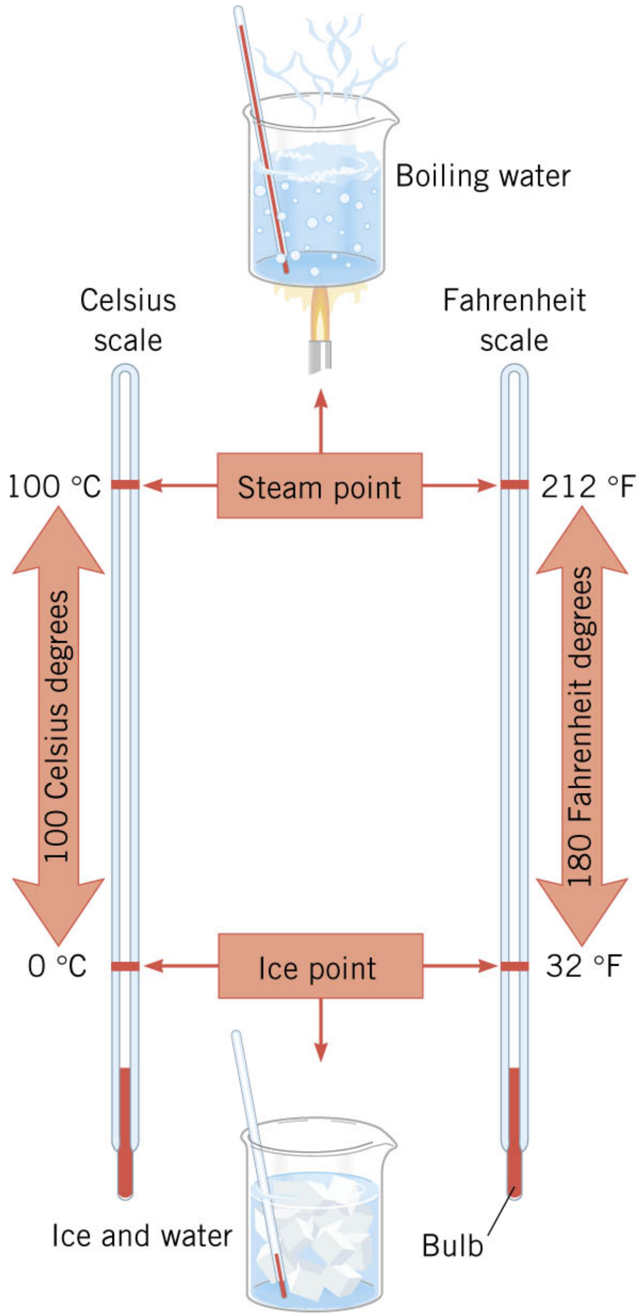
$$P_2 = \left(1200 + P_1\right)\text{Pa} = \left(1200+1900\right)\text{Pa} = 3100\text{ Pa}$$

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

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*:

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

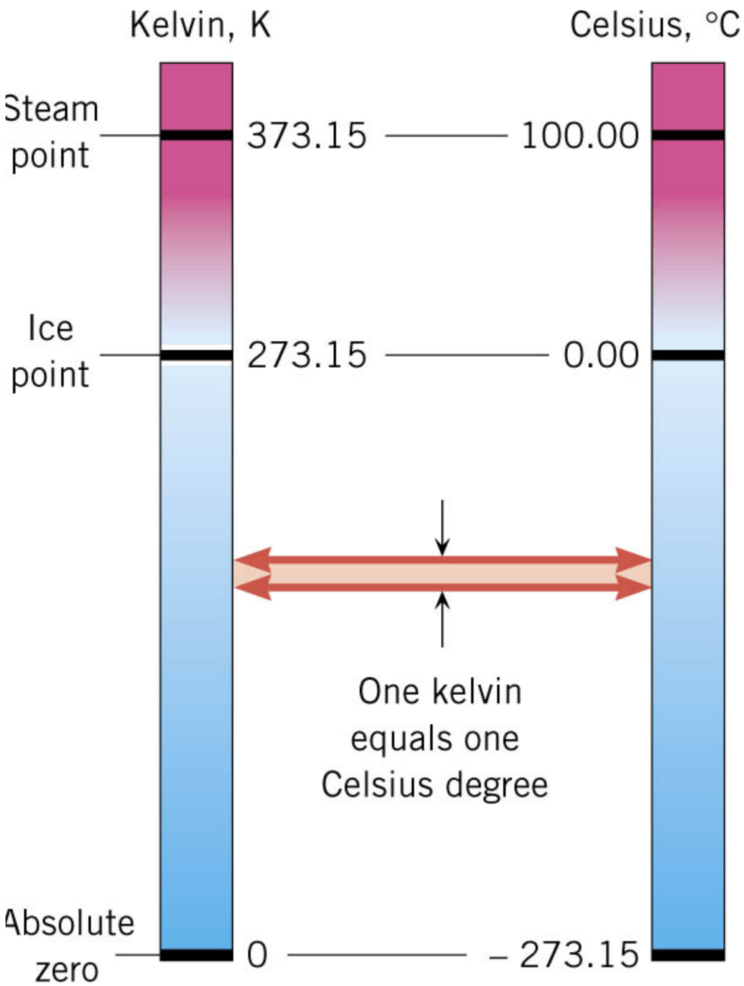
Convert F° to C°:

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

Convert C° to F°:

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

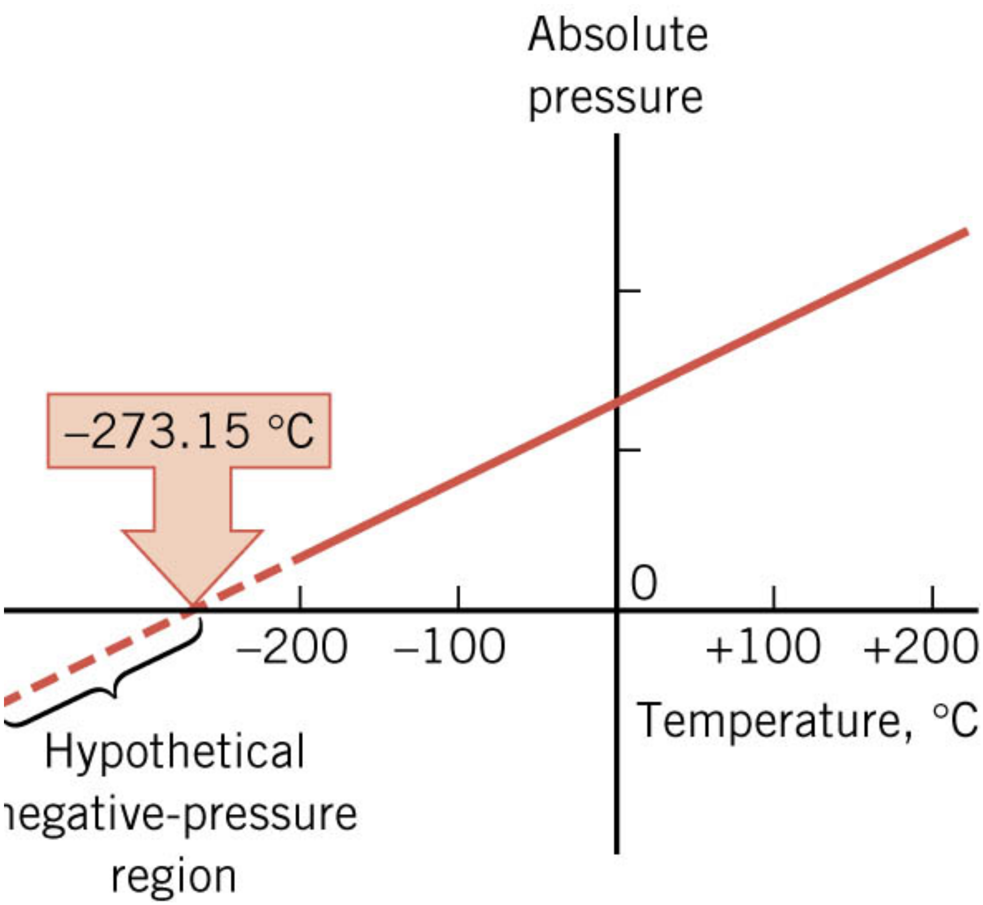
12.2 The Kelvin Temperature Scale



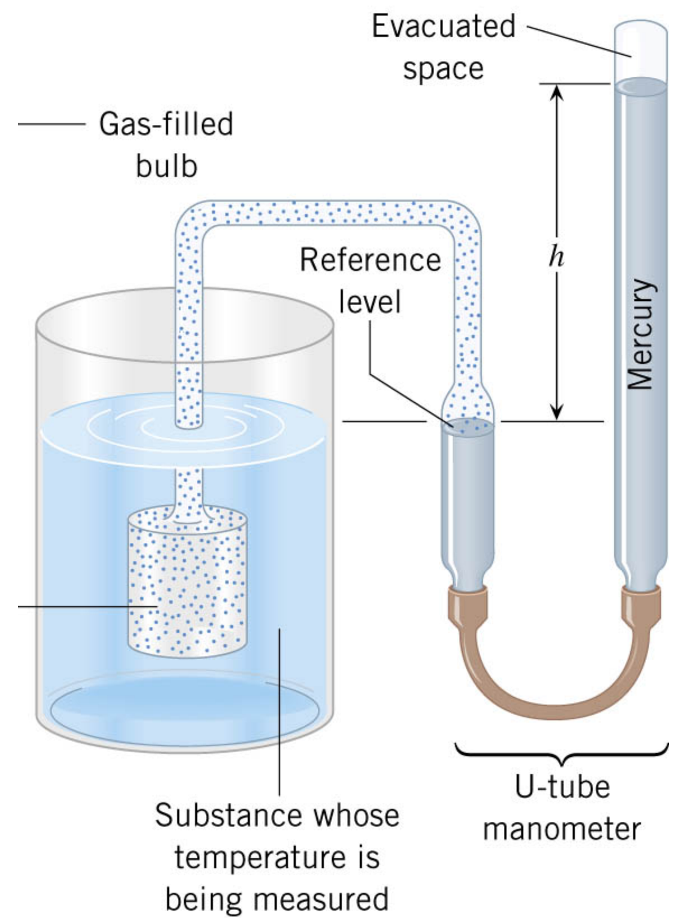
Kelvin temperature

$$T = T_c + 273.15$$

12.2 The Kelvin Temperature Scale



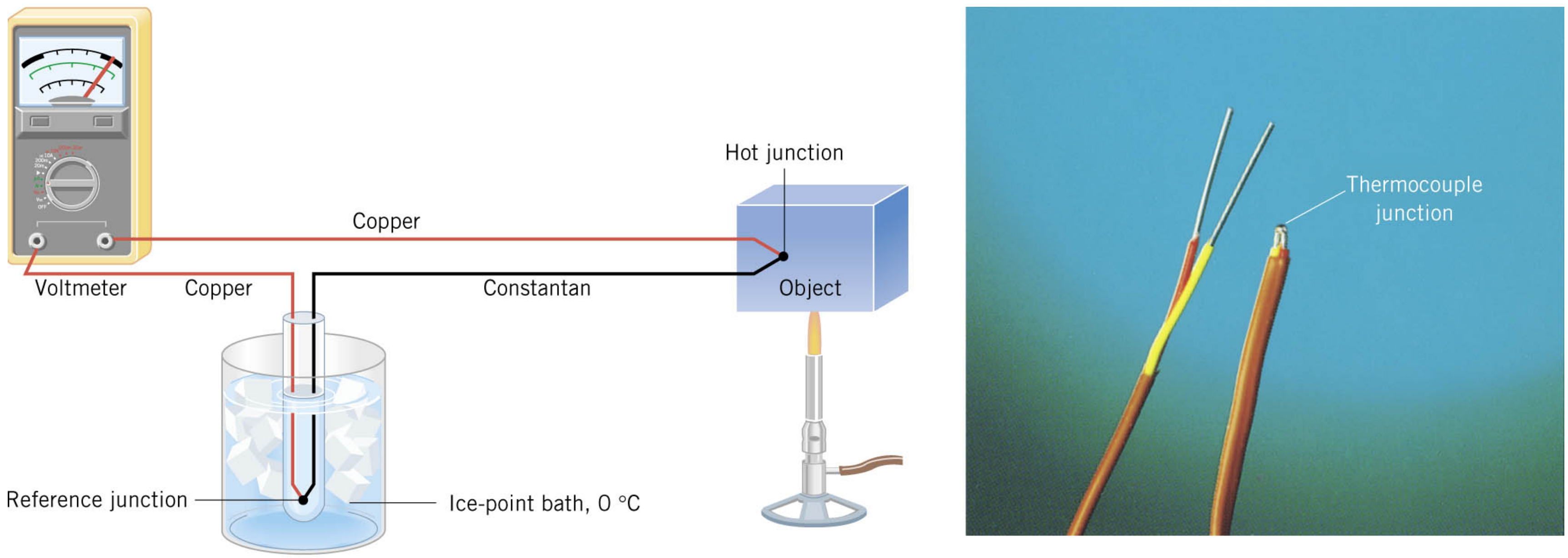
A ***constant-volume gas thermometer***.



absolute zero point = -273.15°C

12.3 Thermometers

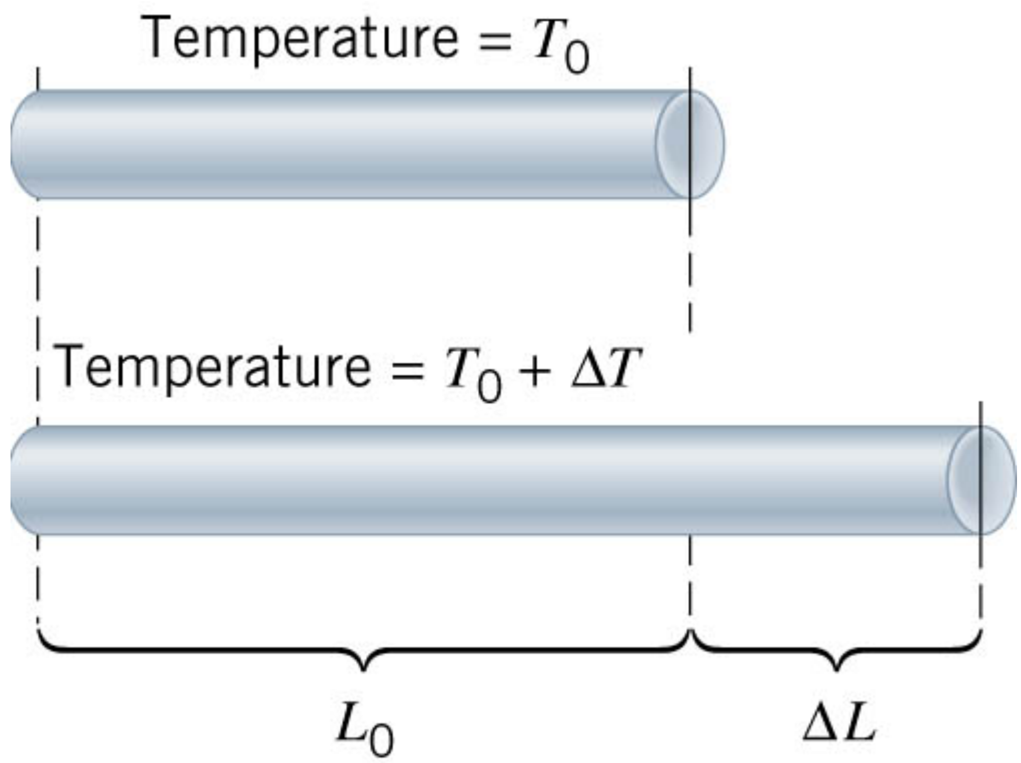
Thermometers make use of the change in some physical property with temperature. A property that changes with temperature is called a ***thermometric property***.



(a) (b)

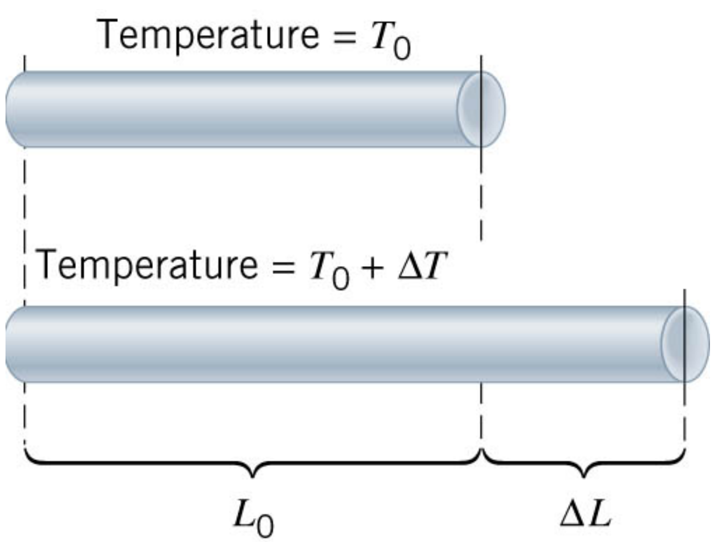
12.4 Linear Thermal Expansion

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

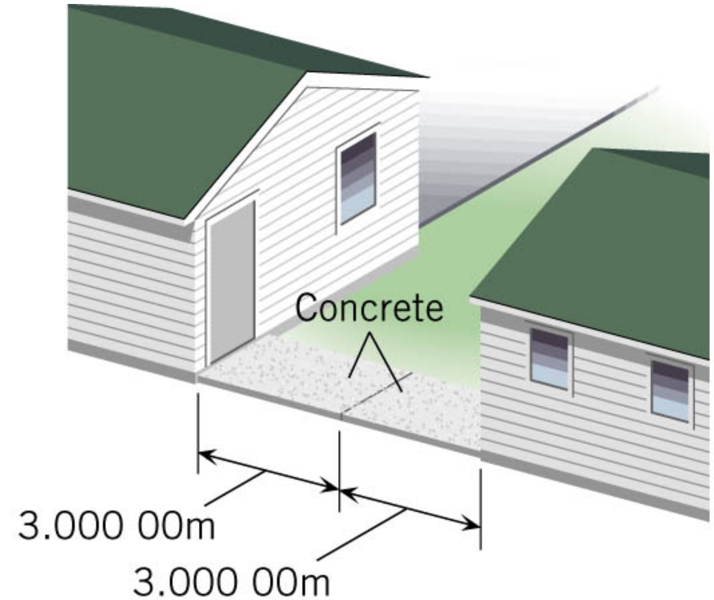
Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

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}

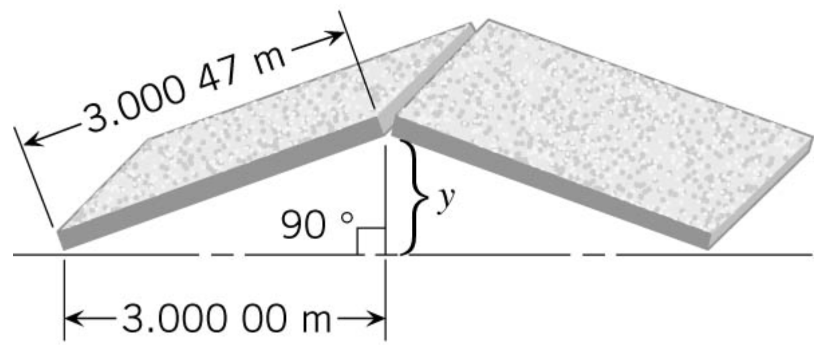
[a]The values for α and β pertain to a temperature near 20 °C.
[b]Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

Example 3 The Buckling of a Sidewalk

A concrete sidewalk is constructed betweer two buildings on a day when the temperatu 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*)



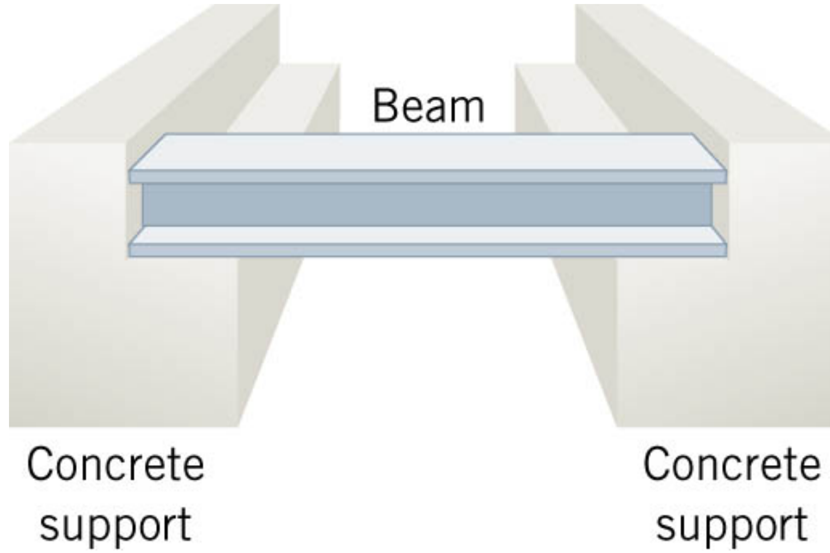
(*b*)

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

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

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?



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

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

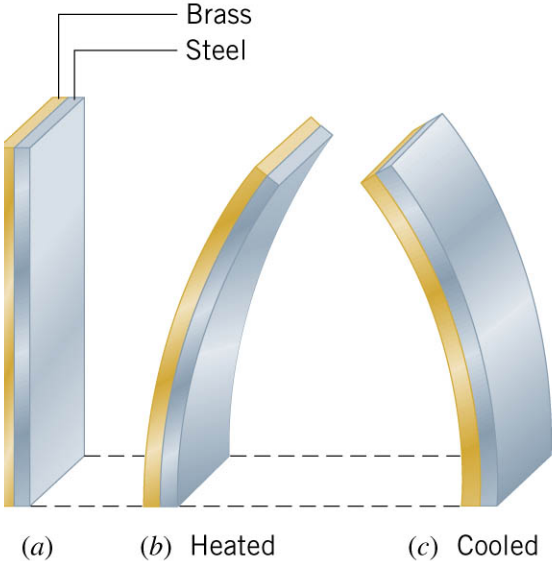
$$= \left(2.0\times10^{11}\,\text{N/m}^2\right)\left[12\times10^{-6}\left(\text{C}^\circ\right)^{-1}\right]\left(19\text{C}^\circ\right)$$

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

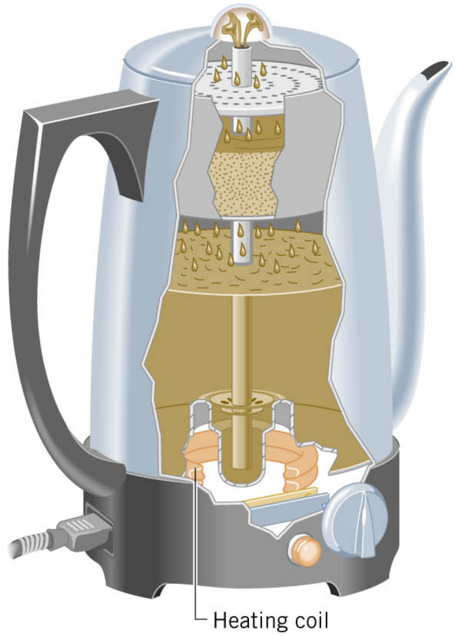
Pressure at ends of the beam, $4.7\times10^{7}\,\text{N/m}^2 \approx 170$ atmospheres (1×10^{5} N/m)

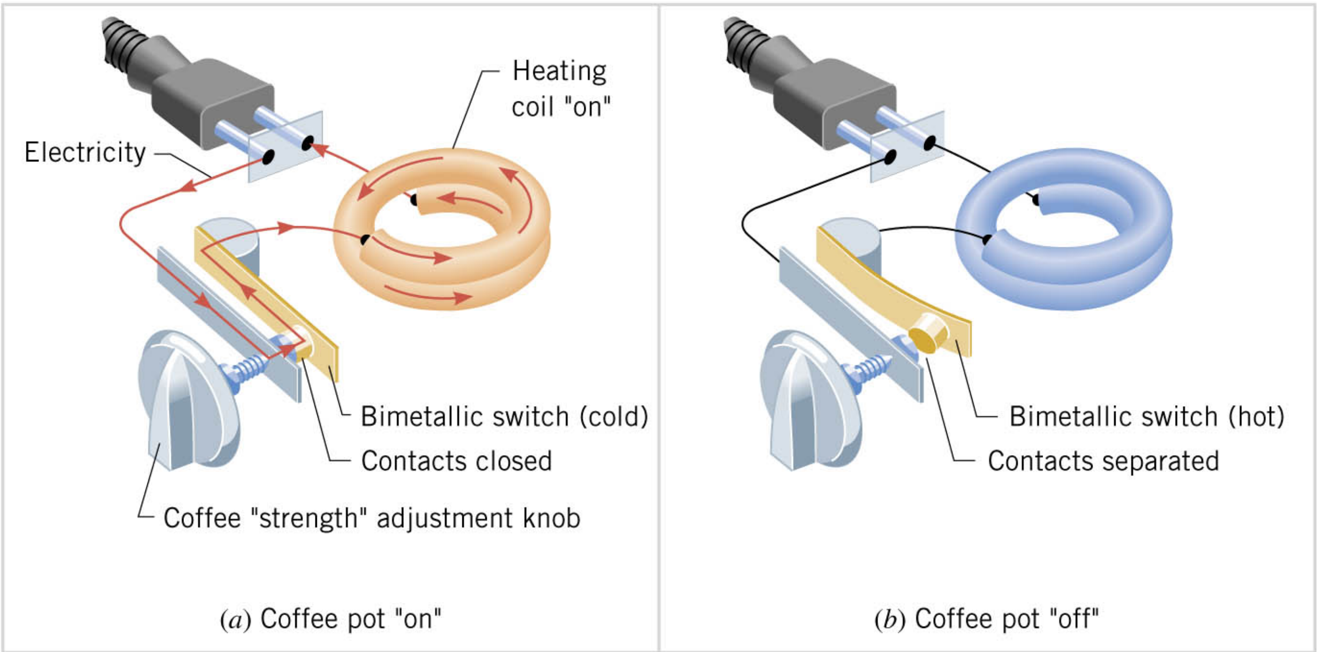
12.4 *Linear Thermal Expansion*

THE BIMETALLIC STRIP



Temperature control with bimetalic strip





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.

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

Lead ring falls off steel, brass ring sticks inside.

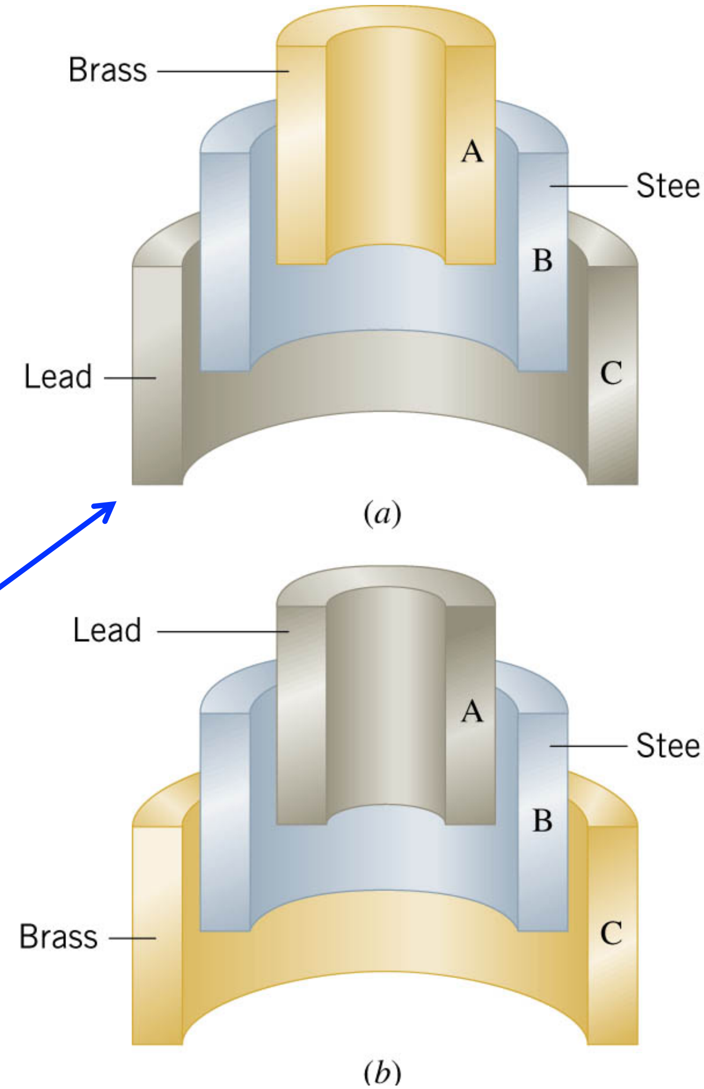


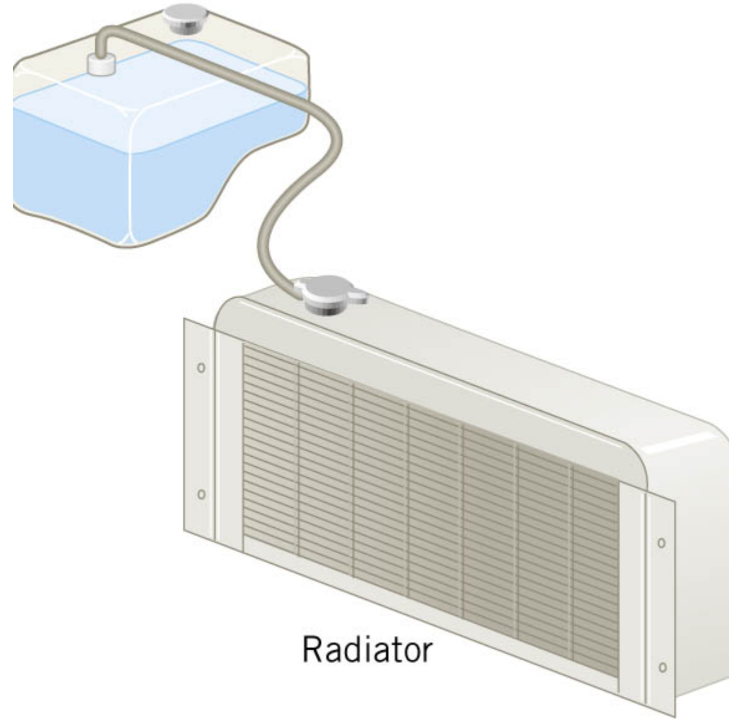
Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

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}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}

Linear themal expansion $\Delta L = \alpha L_0 \Delta T$

$\Delta V = \beta V_o \Delta T$ Volume themal expansion

Example 8 An Automobile Radiator

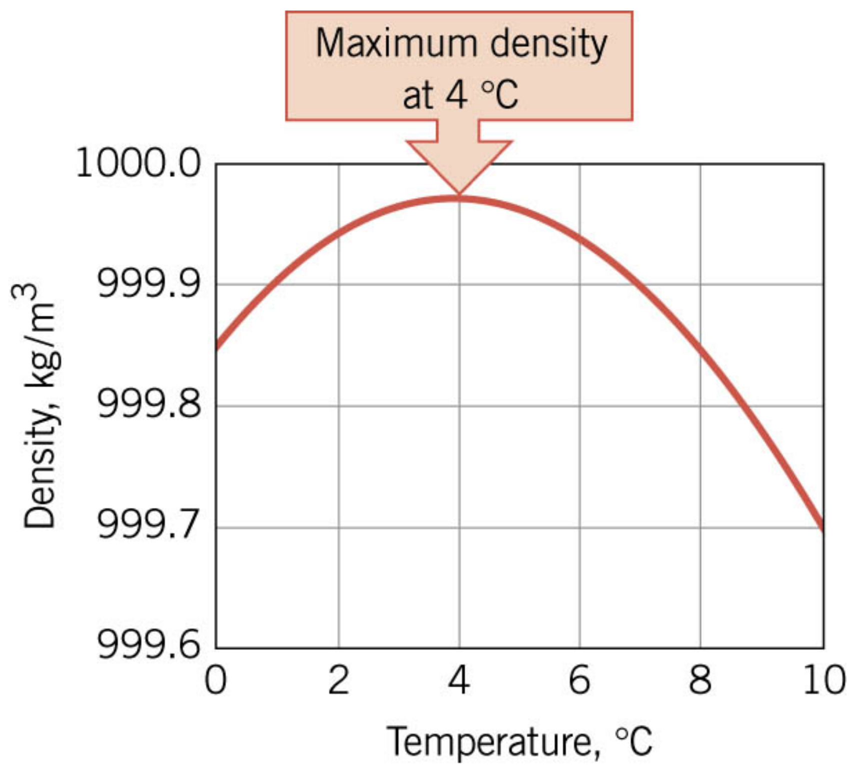


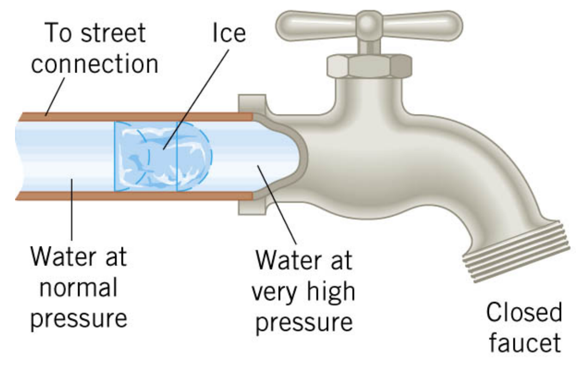
The radiator is made of copper and the coolant has an expansion coefficient of $4.0\times10^{-4}\ (C^{o})^{-1}$. If the radiator is filled to its 15-quart capacity when the engine is cold ($6^{o}C$), how much overflow will spill into the reservoir when the coolant reaches its operating temperature ($92^{o}C$)?

$$\Delta V_{\text{coolant}} = \left[4.10\times10^{-4}\left(\text{C}^{\circ}\right)^{-1}\right]\left(15\ \text{liters}\right)\left(86\ \text{C}^{\circ}\right)$$
$$= 0.53\ \text{liters}$$
$$\Delta V_{\text{radiator}} = \left[51\times10^{-6}\left(\text{C}^{\circ}\right)^{-1}\right]\left(15\ \text{liters}\right)\left(86\ \text{C}^{\circ}\right)$$
$$= 0.066\ \text{liters}$$

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

Expansion of water.



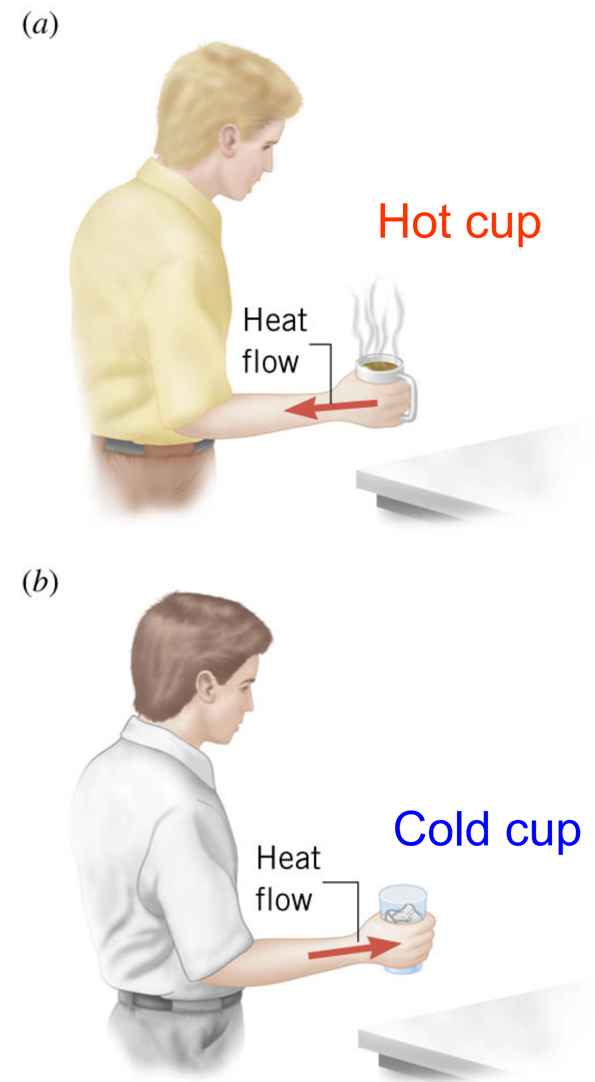


DEFINITION OF HEAT

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

$$Q = mc\Delta T$$

c, is the specific heat capacity of the substance

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

$\Delta T > 0$, Heat added

$\Delta T < 0$, 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.

12.7 Heat and Temperature Change: Specific Heat Capacity

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?

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc} = \frac{8.0 \times 10^5 \text{ J}}{(65 \text{ kg})\left[3500 \text{ J}/(\text{kg} \cdot \text{C}^\circ)\right]} = 3.5 \text{ C}^\circ$$

OTHER UNITS for heat production

1 cal = 4.186 joules (calorie)

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

Specific means per unit mass

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.

Clicker Question 12.1

Four 1-kg cylinders are heated to 100 C° and placed on top of a block of paraffin wax, which melts at 63 C°. There is one cylinder made from lead, one of copper, one of aluminum, and one of iron. After a few minutes, it is observed that the cylinders have sunk into the paraffin to differing depths. Rank the depths of the cylinders from deepest to shallowest..

$$Q = mc\Delta T$$

a) lead > iron > copper > aluminum

b) aluminum > copper > lead > iron

c) aluminum > iron > copper > lead

d) copper > aluminum > iron > lead

e) iron > copper > lead > aluminum

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Silver	235

Clicker Question 12.1

Four 1-kg cylinders are heated to 100 C° and placed on top of a block of paraffin wax, which melts at 63 C°. There is one cylinder made from lead, one of copper, one of aluminum, and one of iron. After a few minutes, it is observed that the cylinders have sunk into the paraffin to differing depths. Rank the depths of the cylinders from deepest to shallowest..

$$Q = mc\Delta T$$

a) lead > iron > copper > aluminum

b) aluminum > copper > lead > iron

c) aluminum > iron > copper > lead

d) copper > aluminum > iron > lead

e) iron > copper > lead > aluminum

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	1
Copper	387	3
Glass	840	
Human body (37 °C, average)	3500	
Ice (−15 °C)	2.00×10^3	
Iron or steel	452	2
Lead	128	4
Silver	235	