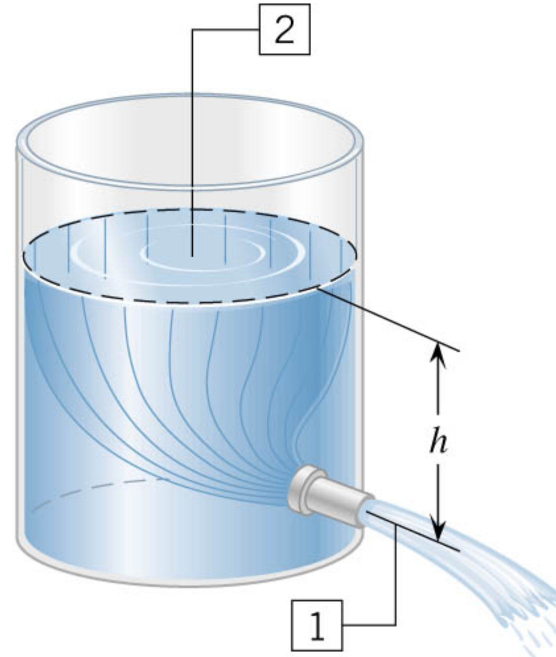
Chapter 10

Fluids

conclusion

Example: 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*)

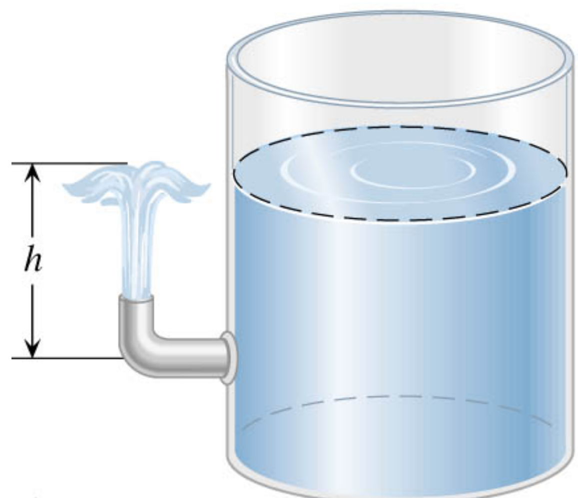
$$P_1 = P_2 = P_{atmosphere} \quad (1\times10^5 \text{ N/m}^2)$$

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

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

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

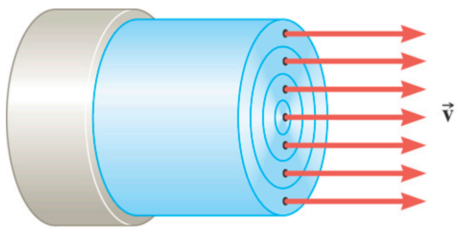
$$v_1 = \sqrt{2gh}$$



(*b*)

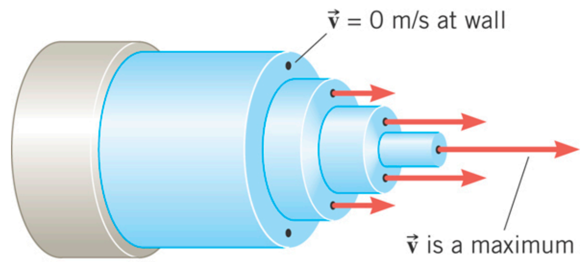
10.6 Viscous Flow

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:

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

η, is the coefficient of viscosity

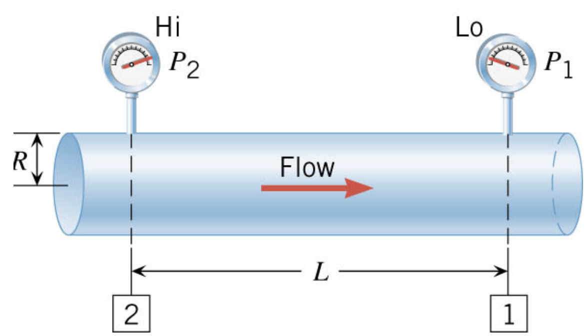
SI Unit: $\text{Pa}\cdot\text{s}$; $1 \text{ poise (P)} = 0.1 \text{ Pa}\cdot\text{s}$

POISEUILLE'S LAW (flow of viscous fluid)

The volume flow rate is given by:

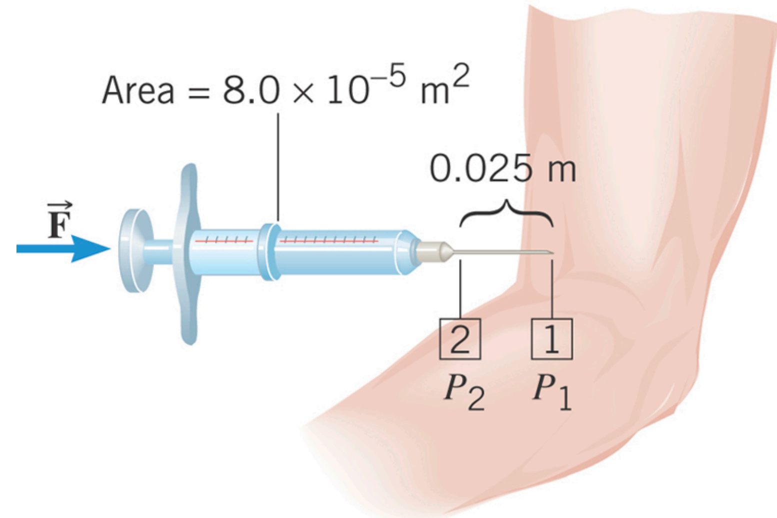
$$Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L}$$

Pressure drop in a straight uniform diamater pipe.



Example: **Giving and Injection**

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



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

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

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

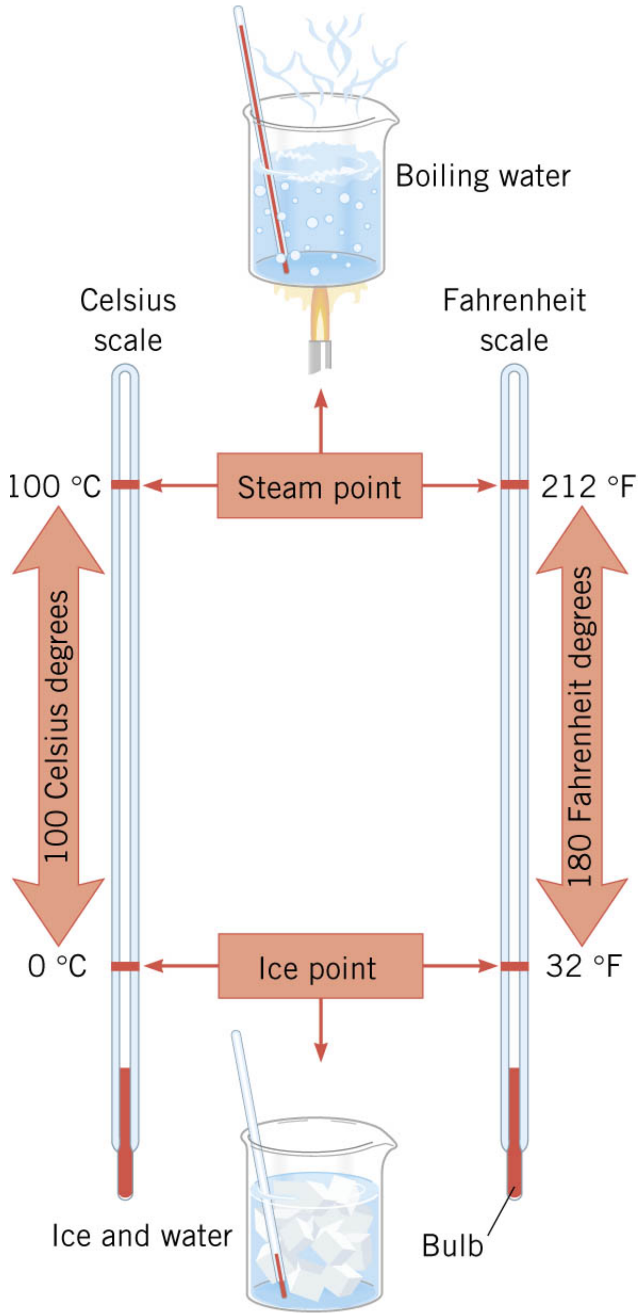
$$P_2 = \left(1200 + P_1\right)\text{Pa} = \left(1200+1900\right)\text{Pa} = 3100\text{ Pa}$$

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

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*:

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

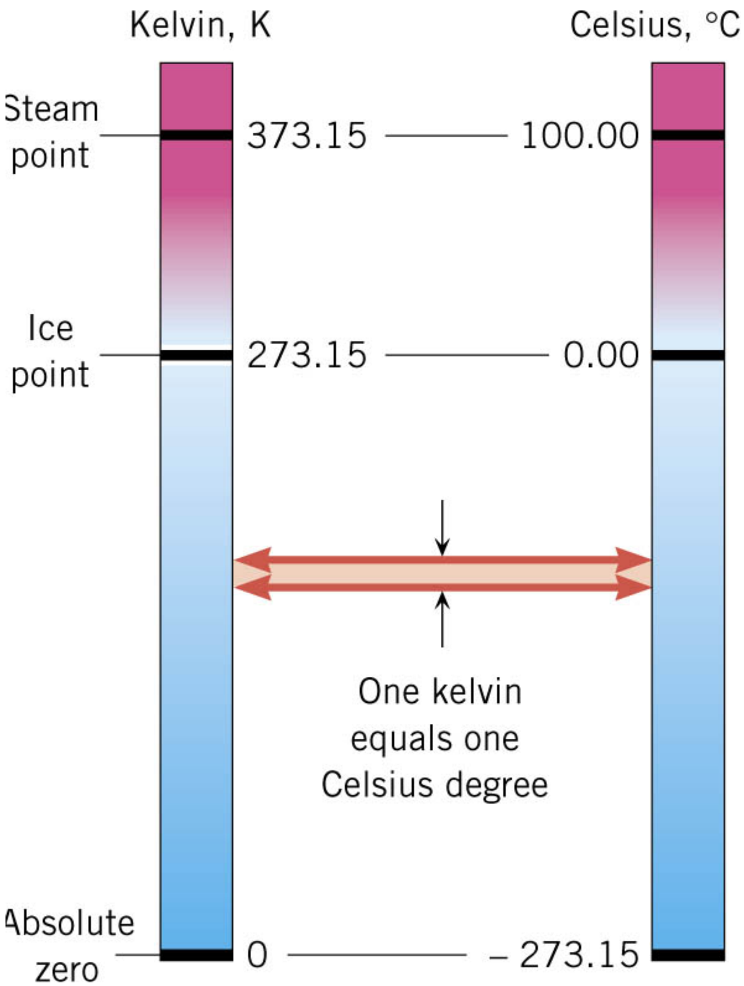
Convert F° to C°:

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

Convert C° to F°:

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

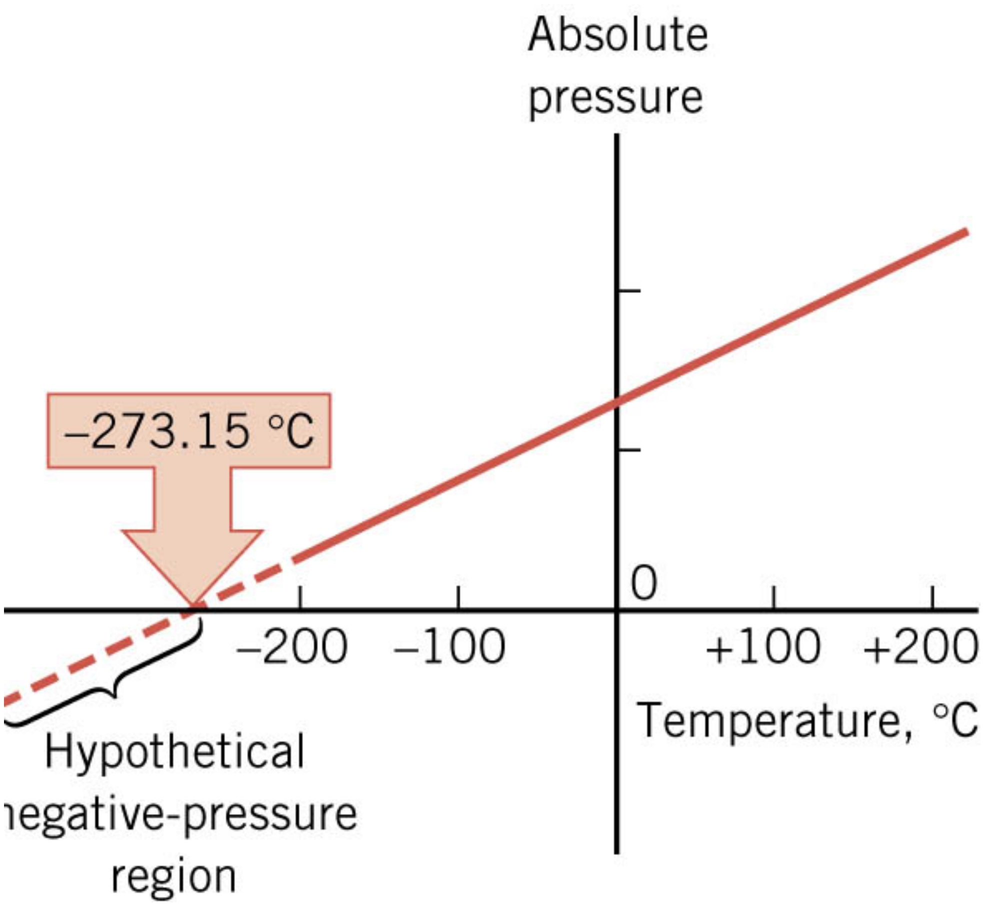
12.1 The Kelvin Temperature Scale



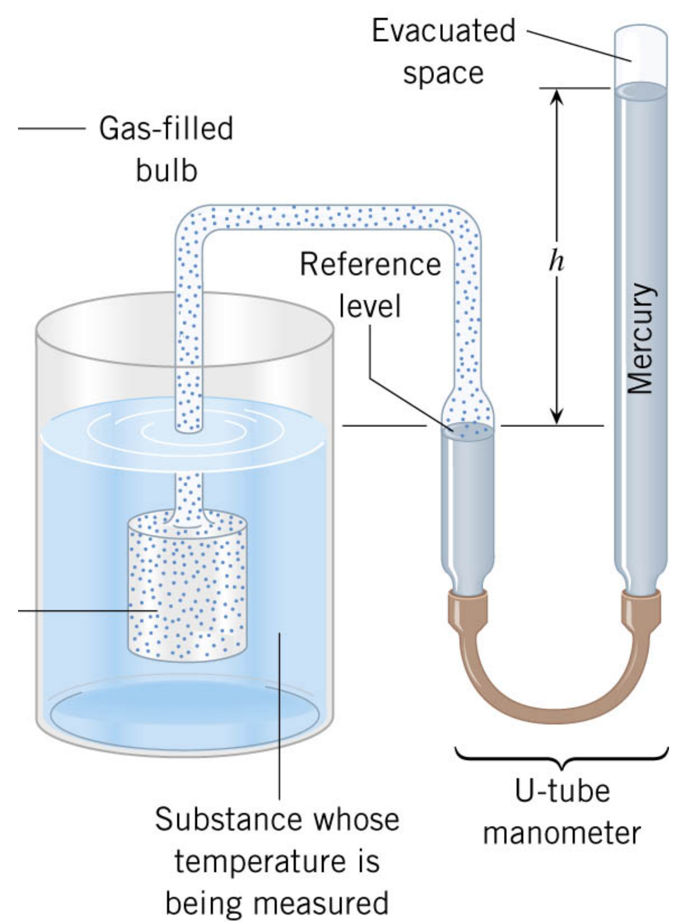
Kelvin temperature

$$T = T_c + 273.15$$

12.1 The Kelvin Temperature Scale



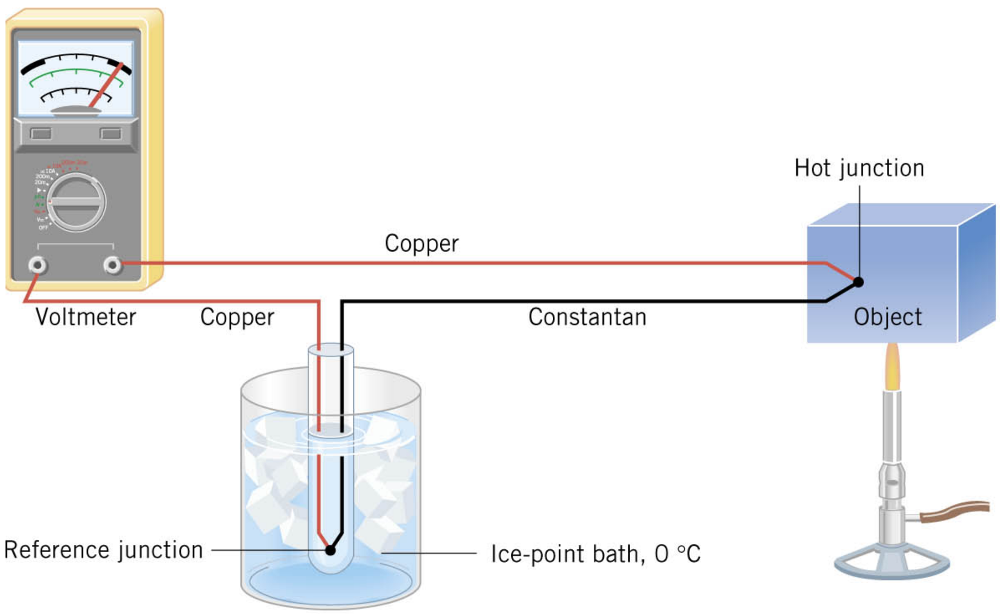
A ***constant-volume gas thermometer***.



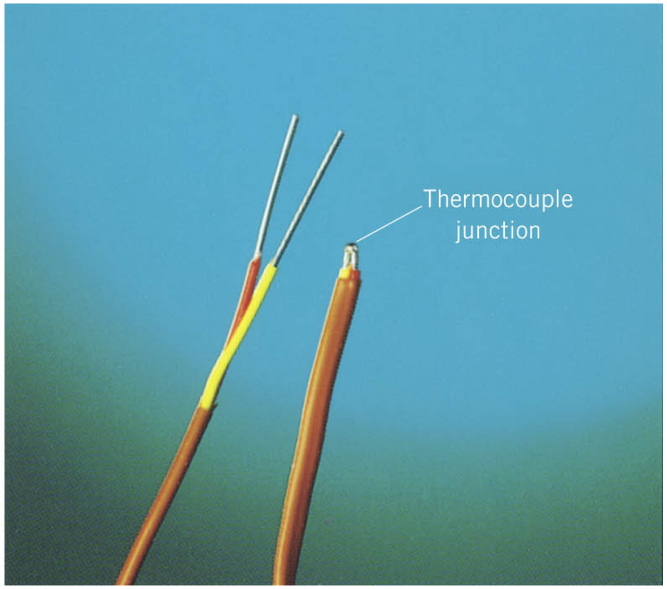
absolute zero point = -273.15°C

12.1 Thermometers

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

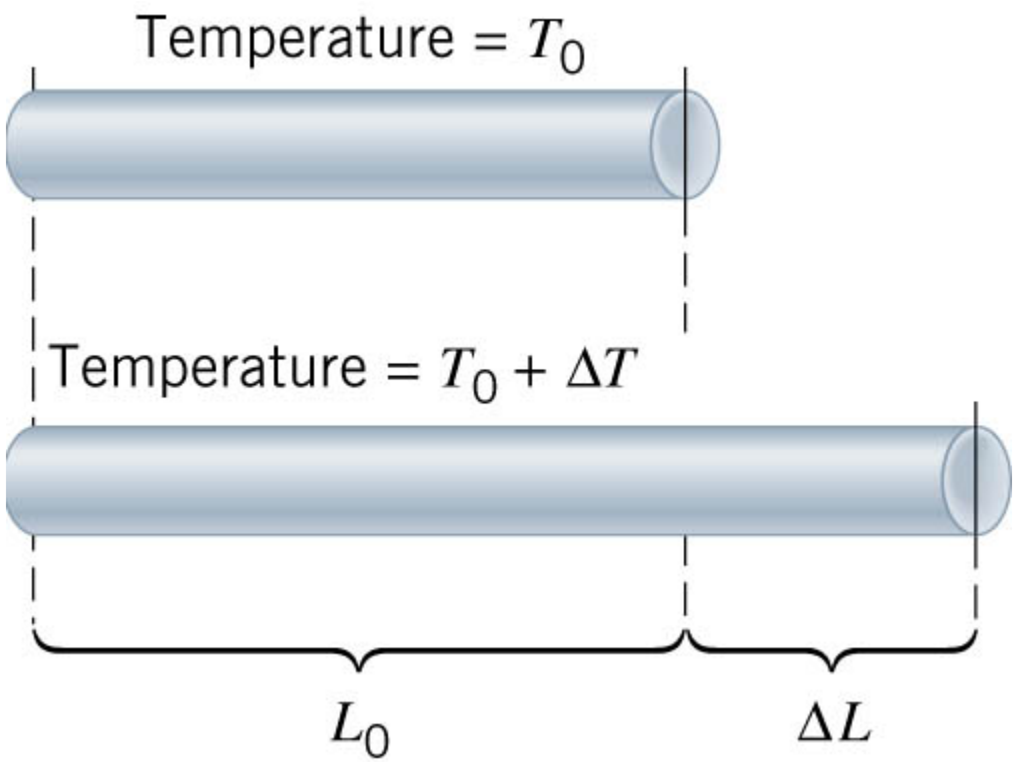


(*a*)



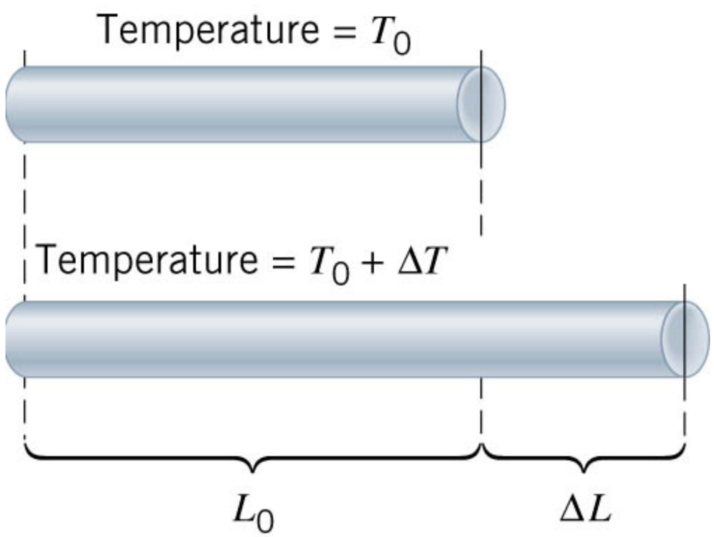
(*b*)

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.

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

coefficient of linear expansion

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

12.2 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.

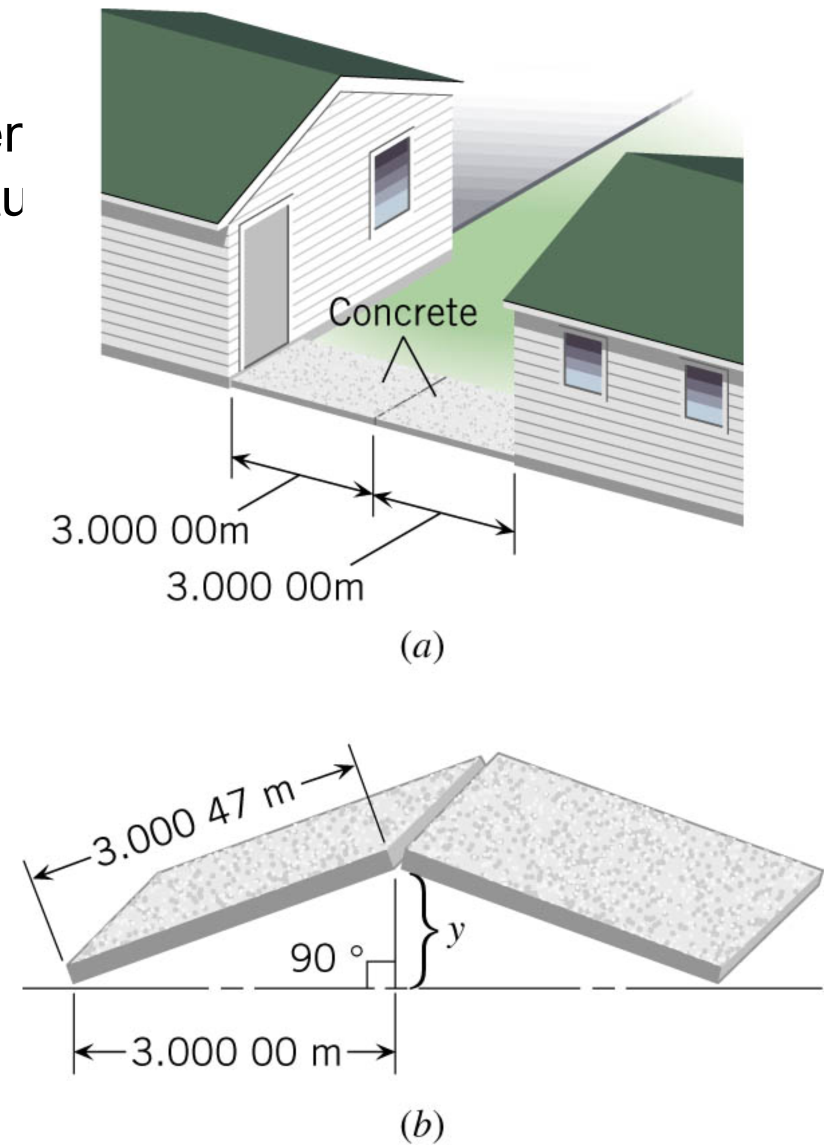
[b]Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

Example: 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.

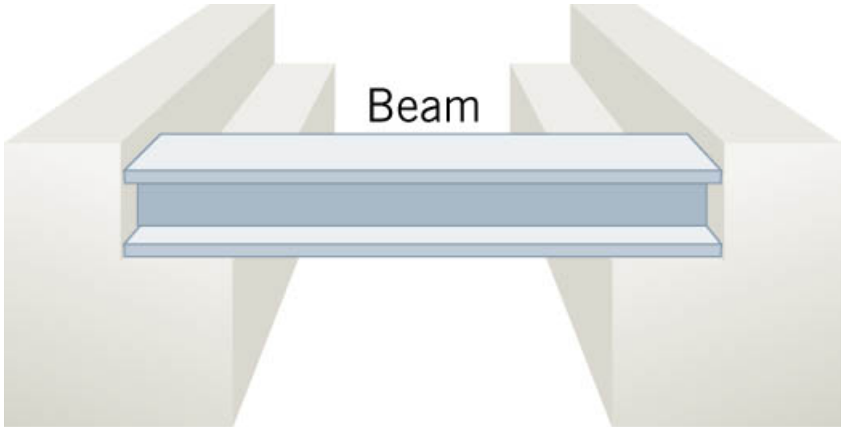
$$\Delta L = \alpha L_o \Delta T$$
$$= \left[12\times10^{-6}\left(\mathrm{C}^\circ\right)^{-1}\right](3.0\ \mathrm{m})(13\ \mathrm{C}^\circ)$$
$$= 0.00047\ \mathrm{m}$$

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



Example: 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?



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

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

$$= \left(2.0\times 10^{11}\,\text{N/m}^2\right)\left[12\times 10^{-6}\left(\text{C}^\circ\right)^{-1}\right]\left(19\text{C}^\circ\right)$$

$$= 4.7\times 10^{7}\,\text{N/m}^2$$

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

12.2 Linear Thermal Expansion

Conceptual Example: Expanding Cylinders

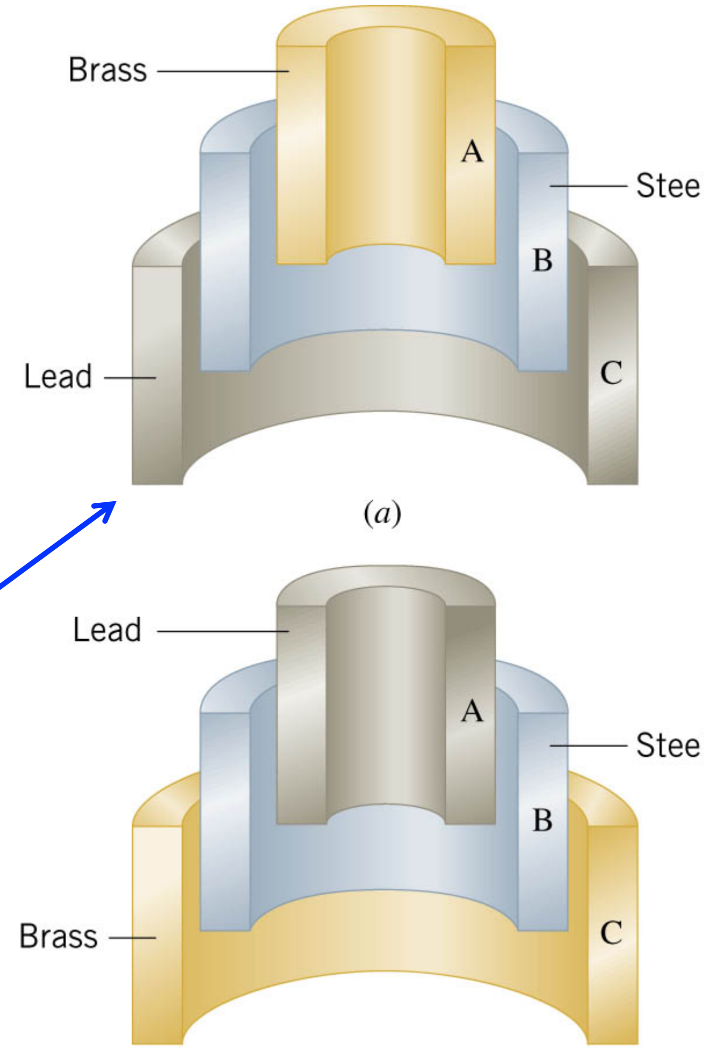
As the cylinders are heated to the same, but higher, temperature, cylinder C falls off, while cylinder A becomes tightly wedged to cylinder B.

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*)

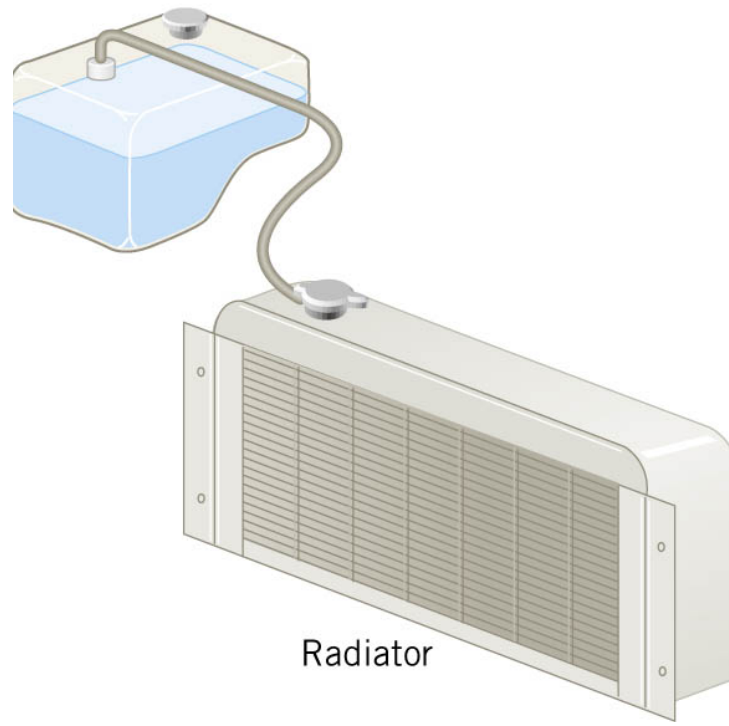
Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

Substance	Coefficient of Thermal Expansion $(C°)^{-1}$	
	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: An Automobile Radiator



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

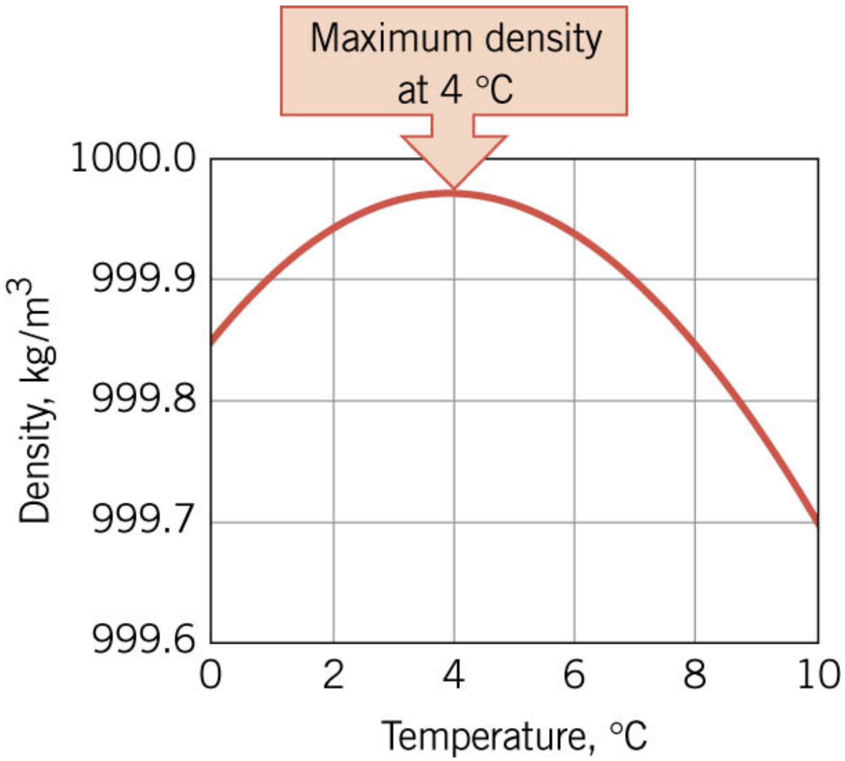
$$\Delta V_{\text{coolant}} = \left[4.10\times10^{-4}\left(\text{C}^\circ\right)^{-1}\right]\left(15\text{ liters}\right)\left(86\text{ C}^\circ\right)$$
$$= 0.53\text{ liters}$$

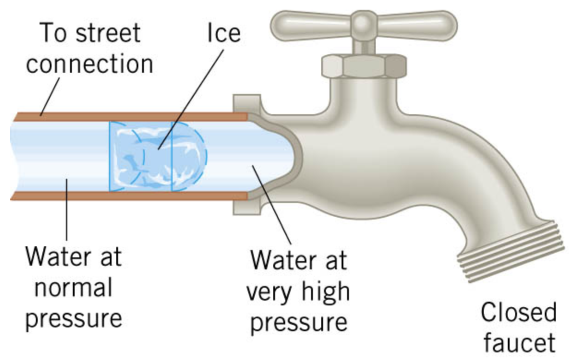
$$\Delta V_{\text{radiator}} = \left[51\times10^{-6}\left(\text{C}^\circ\right)^{-1}\right]\left(15\text{ liters}\right)\left(86\text{ C}^\circ\right)$$
$$= 0.066\text{ liters}$$

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

12.2 Volume Thermal Expansion

Expansion of water.

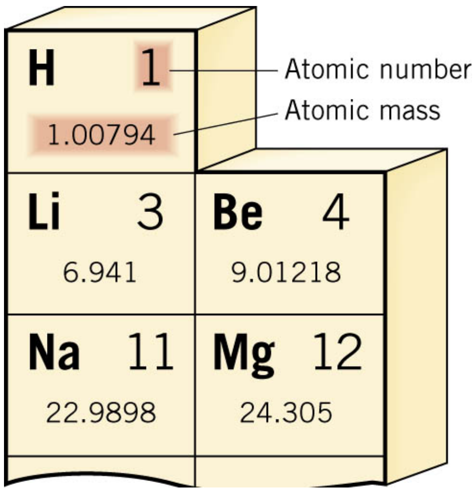




12.3 Molecular Mass, the Mole, and Avogadro's Number

The ***atomic number*** of an element is the # of protons in its nucleus.
Isotopes of an element have different # of neutrons in its nucleus.

The ***atomic mass unit*** (symbol u) is used to compare the mass of elements.
The reference is the most abundant isotope of carbon, which is called carbon-12.



$$1\ \text{u} = 1.6605\times10^{-24}\,\text{g} = 1.6605\times10^{-27}\,\text{kg}$$

The atomic mass is given in atomic mass units. For example, a Li atom has a mass of 6.941u.

One ***mole*** (mol) of a substance (element or molecule) contains as many particles as there are atoms in 12 grams of the isotope carbon-12. The number of atoms in 12 grams of carbon-12 is known as Avogadro's number, N_A.

<u>Avogadro's number</u>

$$N_A = 6.022\times10^{23}\,\text{mol}^{-1}$$

12.3 Molecular Mass, the Mole, and Avogadro's Number

The mass per mole (in g/mol) of a substance has the same numerical value as the atomic or molecular mass of the substance (in atomic mass units).

For example Hydrogen has an atomic mass of 1.00794 g/mol, while the mass of a single hydrogen atom is 1.00794 u.

$$N: \text{ \# of atoms or molecules,}$$

$$n: \text{ \# of moles of element or molecule}$$

$$m_p: \text{ atomic mass (amu)} \Rightarrow \text{also grams/mole}$$

$$\boxed{\begin{aligned} N &= nN_{\mathrm{A}} \\ m &= nm_p \end{aligned}}$$

Example: **Hope Diamond & Rosser Reeves Ruby**

$$\left[12.011\right]\text{g/mole}$$

The Hope diamond (44.5 carats) is almost pure carbon. The Rosser Reeves ruby (138 carats) is primarily aluminum oxide (Al_2O_3). One carat is equivalent to a mass of 0.200 g. Determine (a) the number of carbon atoms in the Hope diamond and (b) the number of Al_2O_3 molecules in the ruby.

$$\left[2\left(26.98\right)+3\left(15.99\right)\right]\text{g/mole}$$

(a)

$$n=\frac{m}{\text{Mass per mole}}=\frac{\left(44.5\text{ carats}\right)\left[\left(0.200\text{ g}\right)/\left(1\text{ carat}\right)\right]}{12.011\text{g}/\text{mol}}=0.741\text{ mol}$$

$$N=nN_A=\left(0.741\text{ mol}\right)\left(6.022\times10^{23}\text{mol}^{-1}\right)=4.46\times10^{23}\text{atoms}$$

(b)

$$n=\frac{m}{\text{Mass per mole}}=\frac{\left(138\text{ carats}\right)\left[\left(0.200\text{ g}\right)/\left(1\text{ carat}\right)\right]}{101.96\text{g}/\text{mol}}=0.271\text{ mol}$$

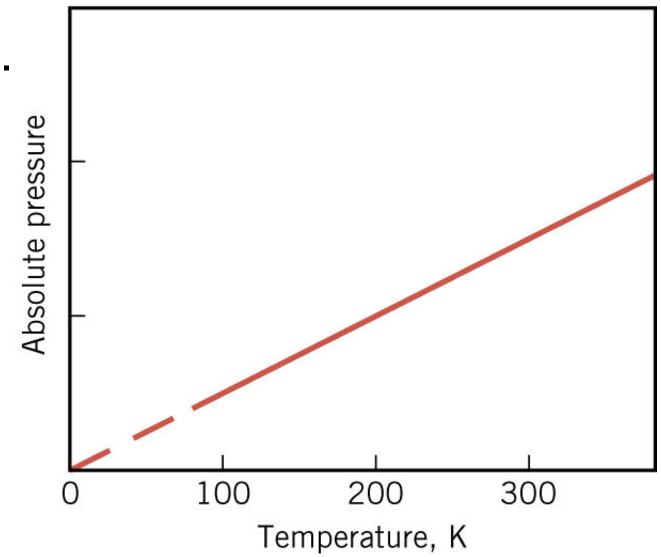
$$N=nN_A=\left(0.271\text{ mol}\right)\left(6.022\times10^{23}\text{mol}^{-1}\right)=1.63\times10^{23}\text{atoms}$$

12.3 *The Ideal Gas Law*

An ***ideal gas*** is an idealized model for real gases that have sufficiently low densities, and molecules interact only by elastic collisions with others or the walls. (Note – typical molecular speed is ~400 m/s, at 300 K)

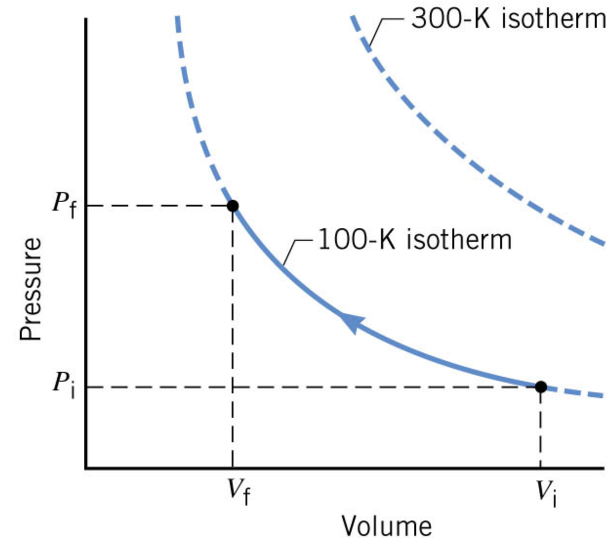
At constant volume the pressure is proportional to the temperature.

$$P \propto T$$



At constant temperature, the pressure is inversely proportional to the volume.

$$P \propto 1/V$$



The pressure is also proportional to the amount of gas.

$$P \propto n$$

THE IDEAL GAS LAW

The absolute pressure of an ideal gas is directly proportional to the Kelvin temperature and the number of moles (n) of the gas and is inversely proportional to the volume of the gas.

$$P = \frac{nRT}{V}$$

$$PV = nRT$$

$$R = 8.31\ \mathrm{J}/(\mathrm{mol}\cdot\mathrm{K})$$

Another form for the Ideal Gas Law using the number of atoms (N)

$$PV = nRT$$

$$= N\left(\frac{R}{N_A}\right)T$$

$$N = nN_A$$

$$PV = Nk_BT$$

Boltzmann's constant

$$k_B = \frac{R}{N_A} = \frac{8.31\mathrm{J}/(\mathrm{mol}\cdot\mathrm{K})}{6.022\times10^{23}\mathrm{mol}^{-1}} = 1.38\times10^{-23}\ \mathrm{J}/\mathrm{K}$$

When temperature is involved, a letter $k = k_B$, Boltzmann's constant

Example: Oxygen in the Lungs

In the lungs, the respiratory membrane separates tiny sacs of air (pressure 1.00x10^5 Pa) from the blood in the capillaries. These sacs are called alveoli. The average radius of the alveoli is 0.125 mm, and the air inside contains 14% oxygen. Assuming that the air behaves as an ideal gas at 310K, find the number of oxygen molecules in one of these sacs.

$$PV = NkT$$

$$N_{tot} = \frac{PV}{k_B T} = \frac{\left(1.00\times10^{5}\,\mathrm{Pa}\right)\left[\tfrac{4}{3}\pi\left(0.125\times10^{-3}\,\mathrm{m}\right)^{3}\right]}{\left(1.38\times10^{-23}\,\mathrm{J/K}\right)\left(310\ \mathrm{K}\right)}$$

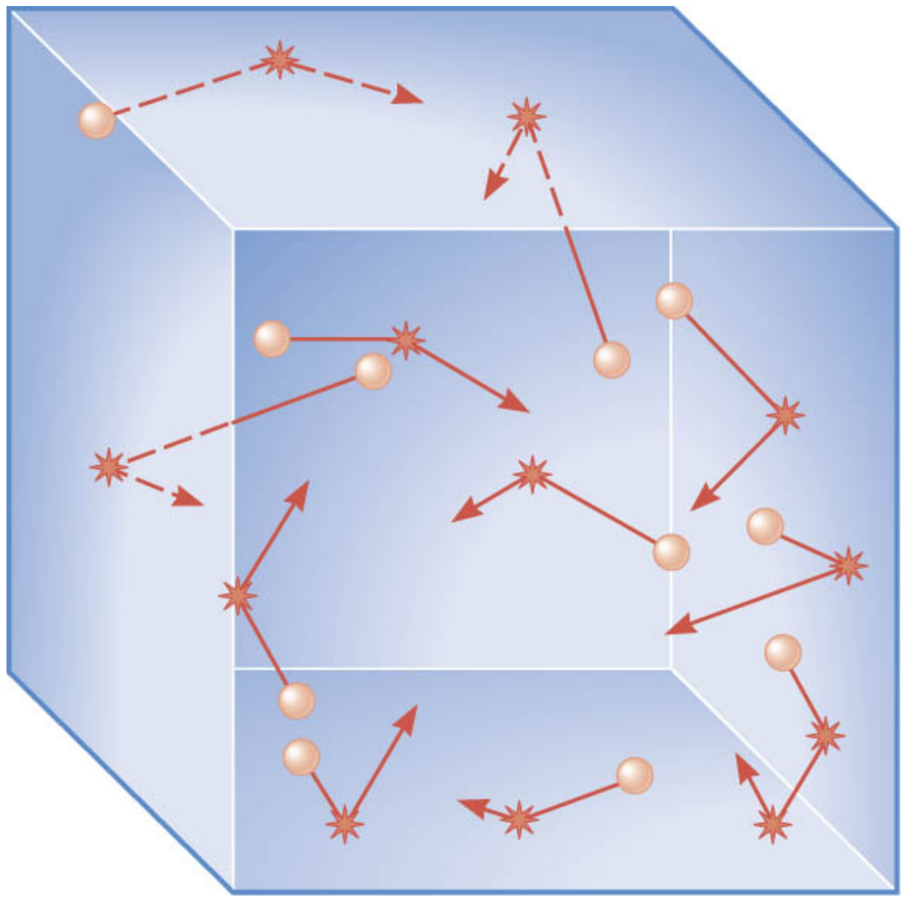
$$= 1.9\times10^{14}$$

$$N_{\mathrm{Oxy}} = \left(1.9\times10^{14}\right)\times\left(0.14\right) = 2.7\times10^{13}$$

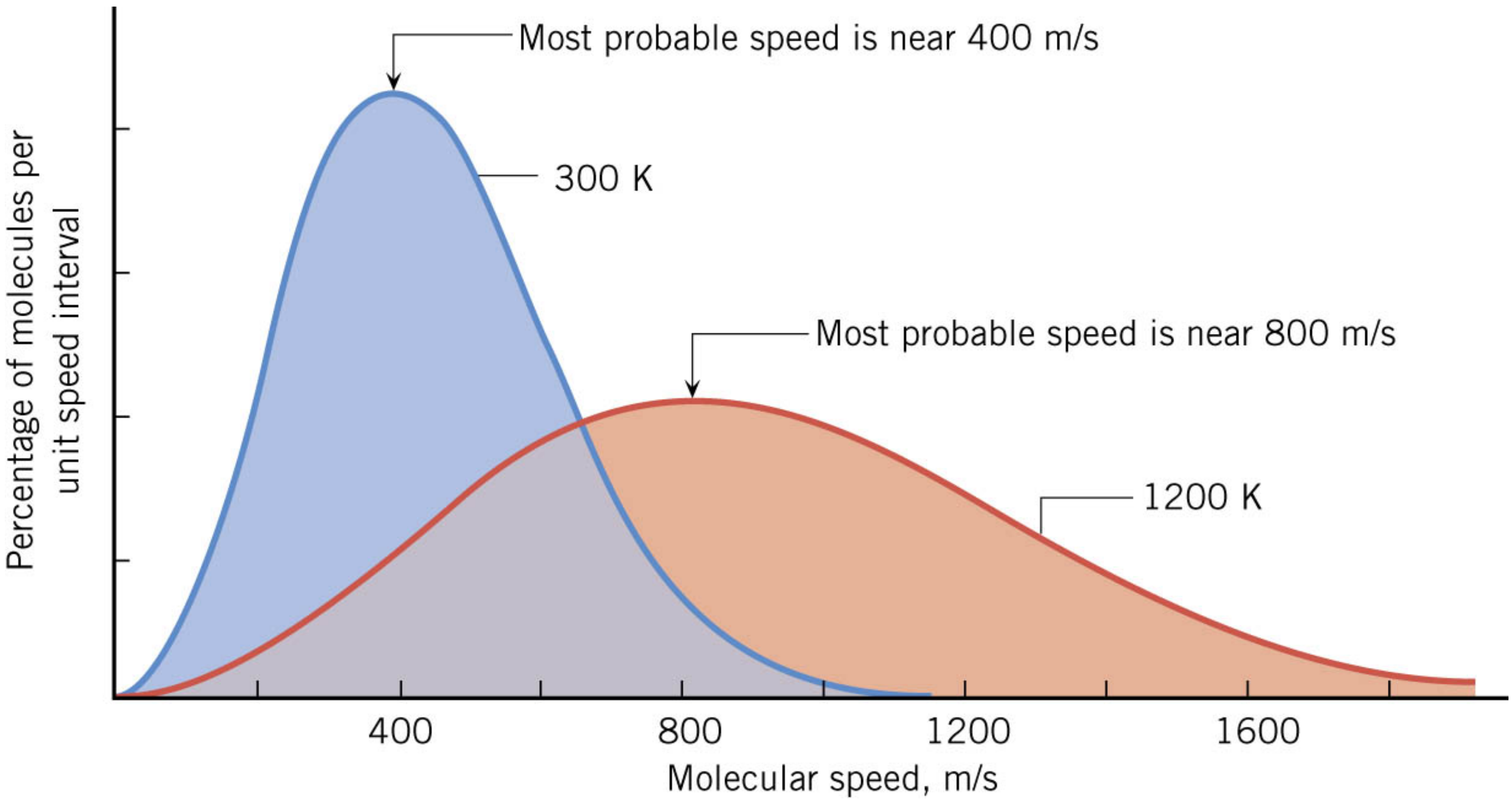
The particles are in constant, random motion, colliding with each other and with the walls of the container.

Each collision changes the particle's speed.

As a result, the atoms and molecules have different speeds.

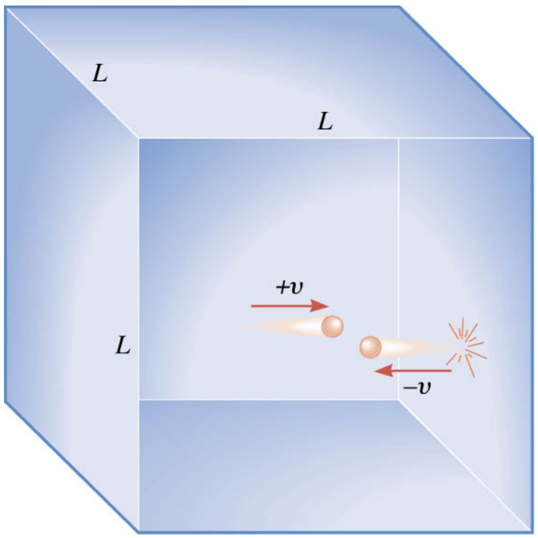


THE DISTRIBUTION OF MOLECULAR SPEEDS



12.4 Kinetic Theory of Gases

KINETIC THEORY



$$\sum F = ma = m\frac{\Delta v}{\Delta t} = \frac{\Delta(mv)}{\Delta t}$$

Average force on each gas molecule when hitting the wall $= \dfrac{\text{Final momentum-Initial momentum}}{\text{Time between successive collisions}}$

$$= \frac{(-mv)-(+mv)}{2L/v} = \frac{-mv^2}{L}$$

Average force on a wall

$$\overline{F} = \left(\frac{N}{3}\right)\left(\frac{m\overline{v^2}}{L}\right) \Rightarrow P = \frac{\overline{F}}{A} = \frac{\overline{F}}{L^2} = \left(\frac{N}{3}\right)\left(\frac{m\overline{v^2}}{L^3}\right)$$

$$PV = \left(\frac{N}{3}\right)m\overline{v^2} = \tfrac{2}{3}N\left(\tfrac{1}{2}m\overline{v^2}\right)$$

$$PV = NkT$$

$$\overline{KE} = \tfrac{1}{2}m\overline{v^2}$$

$$v_{rms} = \sqrt{\overline{v^2}}$$

root mean square speed

Temperature reflects the <u>average</u> Kinetic Energy of the molecules

$$\tfrac{3}{2}kT = \tfrac{1}{2}mv_{rms}^2 = \overline{KE}$$

$$k = 1.38\times10^{-23}\ \text{J/K}$$

Example: The Speed of Molecules in Air

Air is primarily a mixture of nitrogen N_2 molecules (molecular mass 28.0u) and oxygen O_2 molecules (molecular mass 32.0u). Assume that each behaves as an ideal gas and determine the rms speeds of the nitrogen and oxygen molecules when the temperature of the air is 293K.

$$\tfrac{1}{2} m v_{rms}^2 = \tfrac{3}{2} kT$$

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$

T must be in Kelvin
$(\mathrm{K} = \mathrm{C}^\circ + 273)$

Nitrogen molecule

$$m = \frac{28.0\,\mathrm{g/mol}}{6.022\times 10^{23}\,\mathrm{mol}^{-1}} = \underline{4.65\times 10^{-26}\,\mathrm{kg}}$$

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\left(1.38\times 10^{-23}\,\mathrm{J/K}\right)\left(293\,\mathrm{K}\right)}{4.65\times 10^{-26}\,\mathrm{kg}}} = 511\,\mathrm{m/s}$$

Molecules are moving <u>really fast</u> but do not go very far before hitting another molecule.

THE INTERNAL ENERGY OF A MONO-ATOMIC IDEAL GAS

$$\overline{\mathrm{KE}} = \tfrac{1}{2} m v_{rms}^2 = \tfrac{3}{2} kT$$

Average KE per atom

⇓ multiply by the number of atoms

$$U = N \tfrac{3}{2} kT = \tfrac{3}{2} nRT$$

Total Internal Energy

THE INTERNAL ENERGY OF A MOLECULAR GAS MUST INCLUDE MOLECULAR VIBRATIONS!

$H_2, N_2, H_2O, SO_2, CO_2,$ …(most gases except Nobel gases)

Chapter 13

Heat

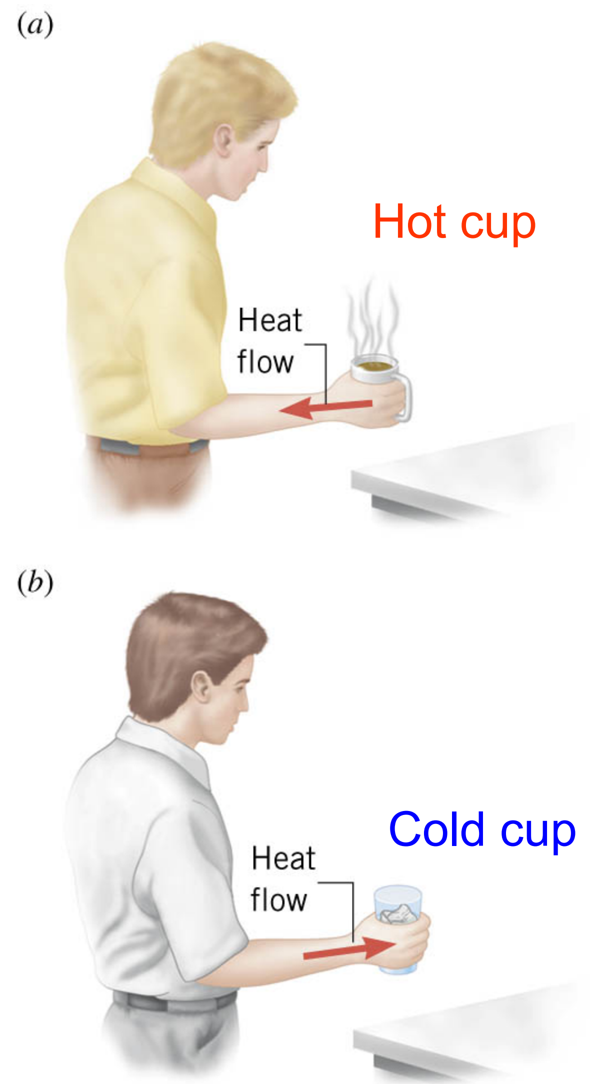
DEFINITION OF HEAT

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.



13.2 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.

Specific means per unit mass

Example: 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 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.

13.2 Specific Heat Capacities (Gases)

To relate heat and temperature change in solids and liquids (mass in kg), use:

$$Q = mc\Delta T \qquad \text{specific heat capacity, } c \ \left[\text{J/}\left(\text{kg}\cdot{}^{\circ}\text{C}\right)\right]$$

For gases, the amount of gas is given in moles, use molar heat capacities:

$$Q = nC\Delta T \qquad \text{molar heat capacity, } C \ \left[\text{J/}\left(\text{mole}\cdot{}^{\circ}\text{C}\right)\right]$$

$$C = \left(m/n\right)c = m_u c; \quad m_u = \text{mass/mole (kg)}$$

ALSO, for gases it is necessary to distinguish between the molar specific heat capacities at constant pressure and at constant volume:

$$C_P, C_V$$

Constant pressure for a monatomic ideal gas

$$Q_P = nC_P\Delta T$$

$$C_P = \tfrac{5}{2}R$$

Constant volume for a monatomic ideal gas

$$Q_V = nC_V\Delta T$$

$$C_V = \tfrac{3}{2}R$$

any ideal gas

$$C_P - C_V = R$$