Chapter 10

Fluids

conclusion

Example: Efflux Speed

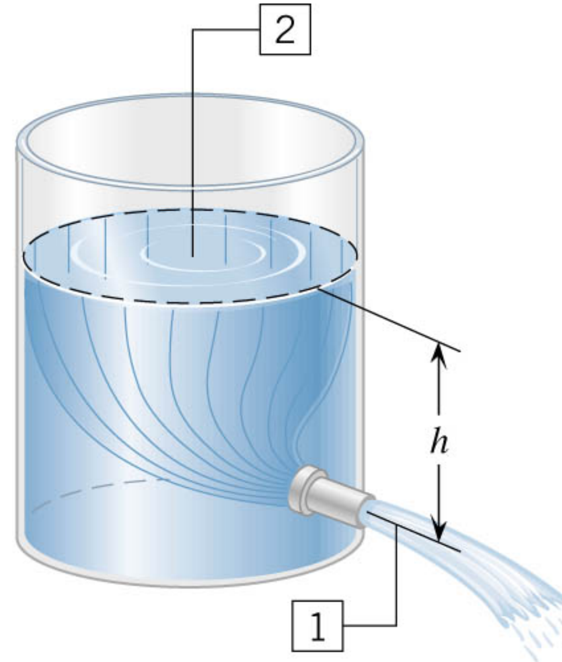
The tank is open to the atmosphere at the top. Find and expression for the speed of the liquid leaving the pipe at the bottom.

$$P_1 = P_2 = P_{atmosphere} \quad (1\times 10^5 \text{ N/m}^2)$$
$$v_2 = 0, \quad y_2 = h, \quad y_1 = 0$$

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

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

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



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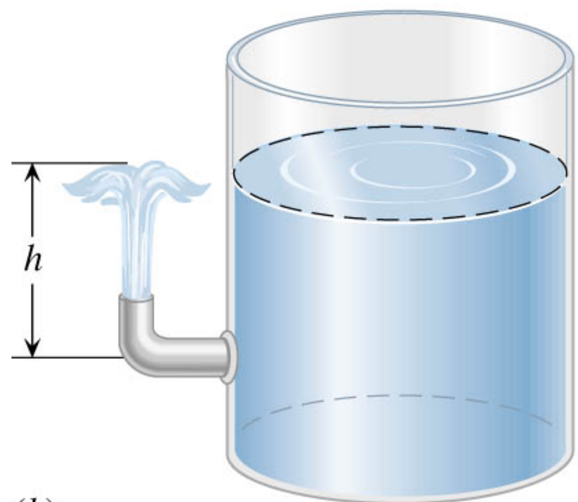


(*b*)

Clicker Question 10.6

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

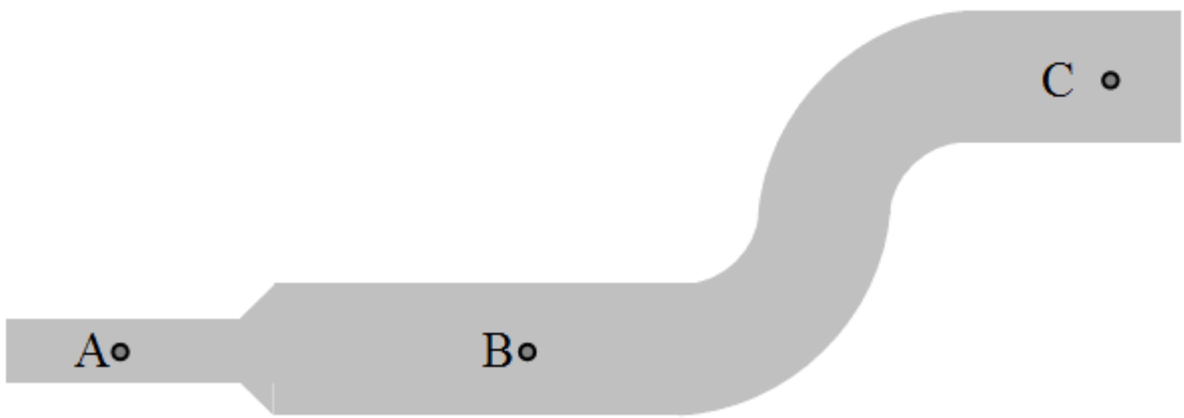
a) $P_A > P_B > P_C$

b) $P_B > P_A = P_C$

c) $P_C > P_B > P_A$

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

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



Clicker Question 10.6

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

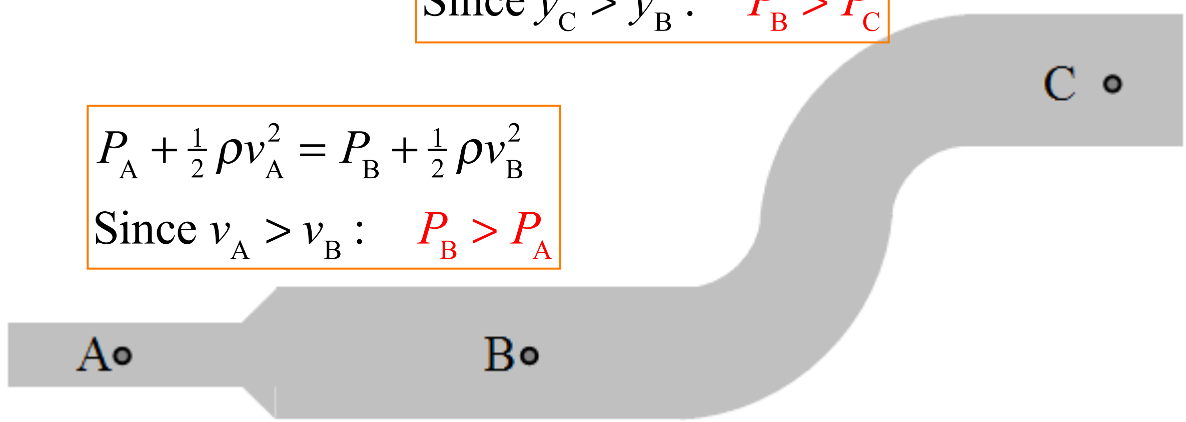
e) $P_C > P_A \quad \& \quad P_C > P_B$

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

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

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

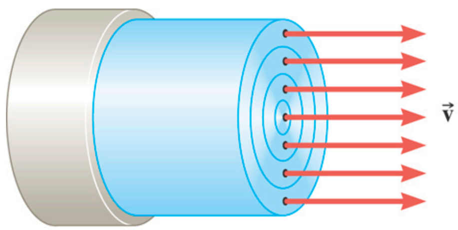
Since $v_A > v_B$: $P_B > P_A$



Pipe area grows: $v_A > v_B$

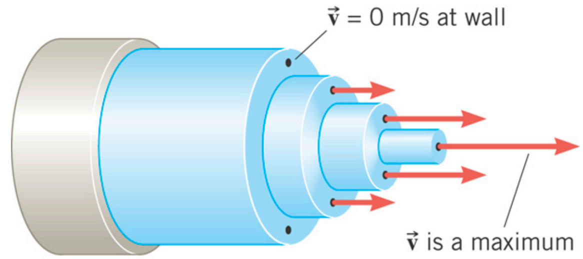
10.6 Viscous Flow

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

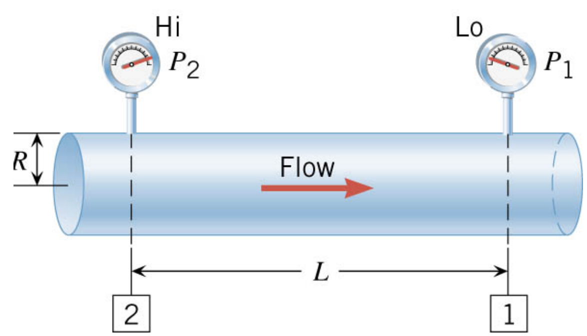
SI Unit: $\mathrm{Pa \cdot s}$; $\quad$ 1 poise (P) = 0.1 $\mathrm{Pa \cdot s}$

POISEUILLE'S LAW (flow of viscous fluid)

The volume flow rate is given by:

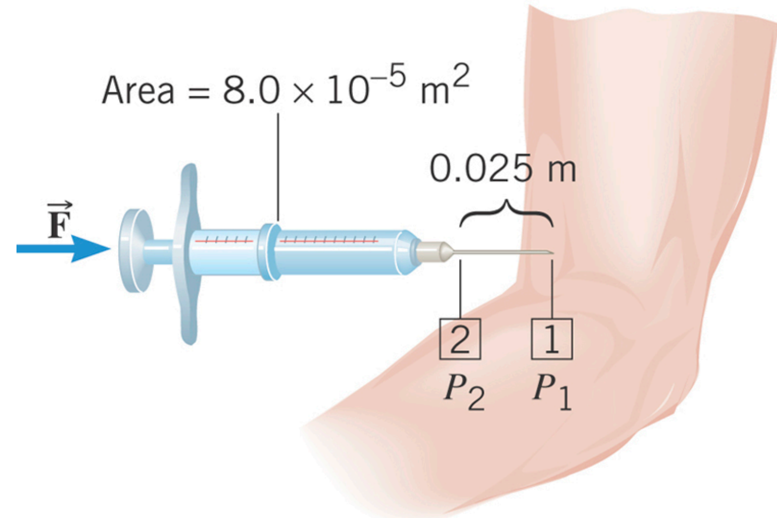
$$Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L}$$

Pressure drop in a straight uniform diamater pipe.



Example: Giving and Injection

A syringe is filled with a solution whose viscosity is $1.5\text{x}10^{-3}$ 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?

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

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

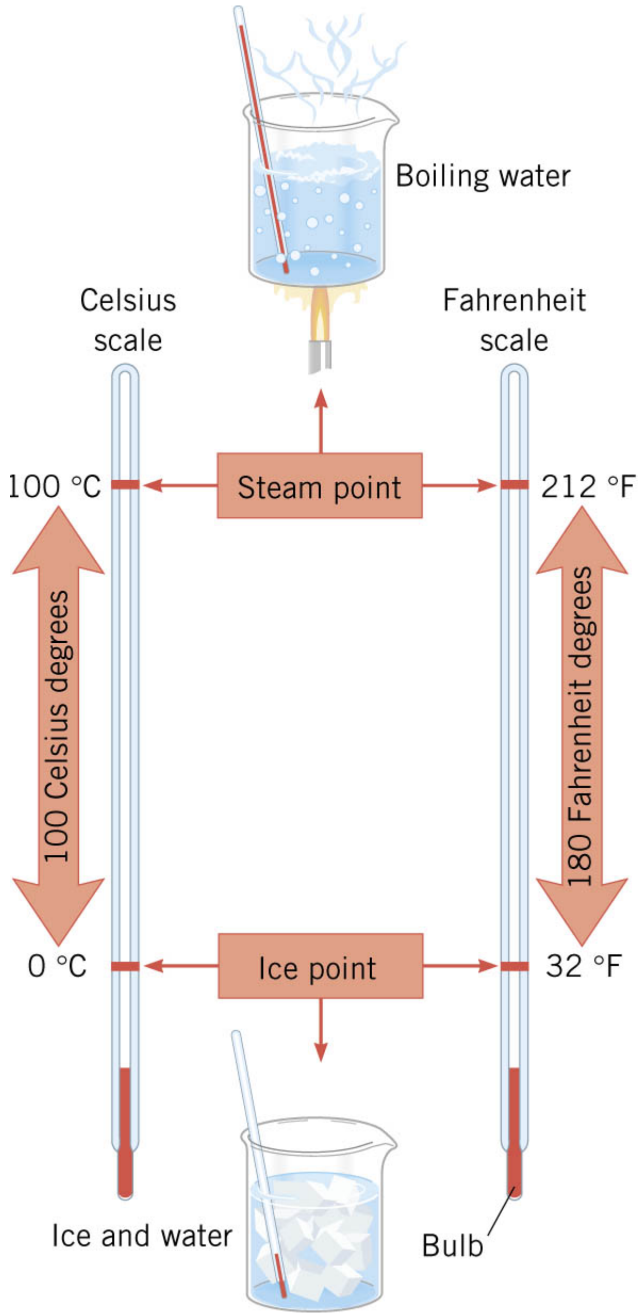
$$P_2 = \left(1200 + P_1\right)\text{Pa} = \left(1200+1900\right)\text{Pa} = 3100\text{ Pa}$$

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

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*:

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

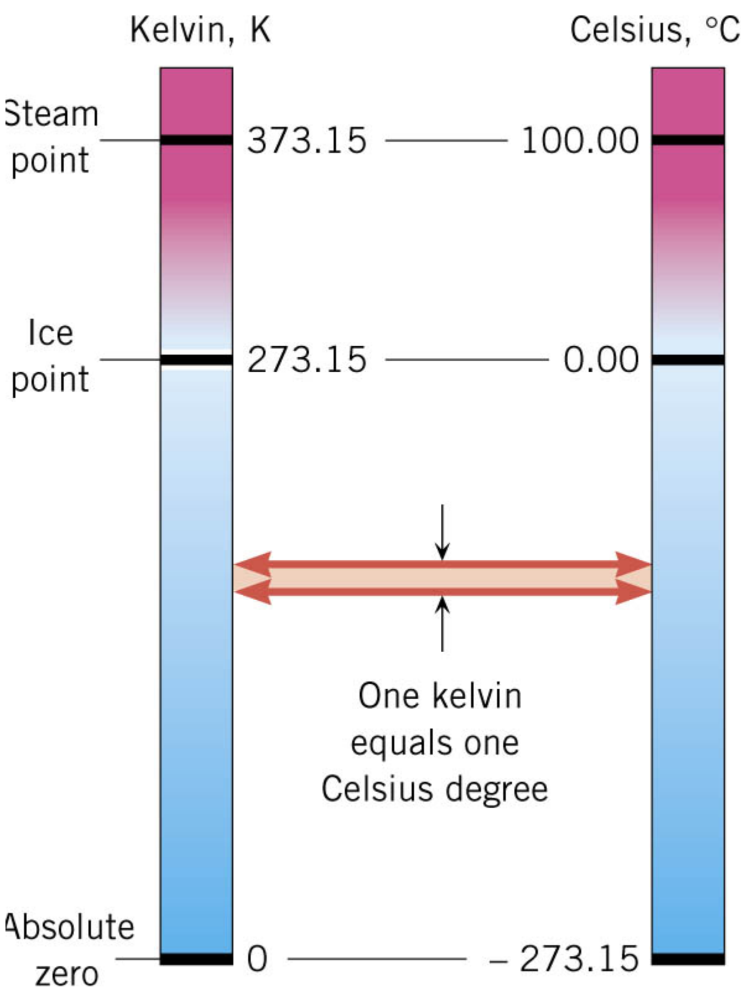
Convert F° to C°:

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

Convert C° to F°:

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

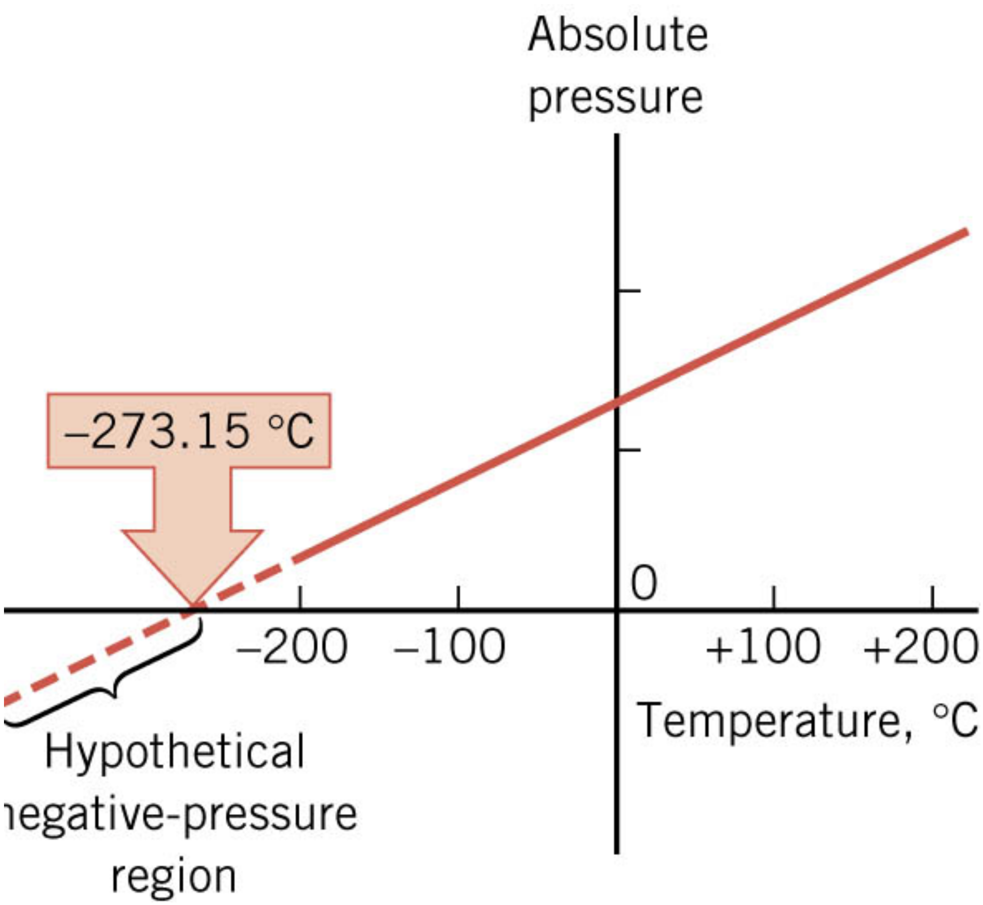
12.1 The Kelvin Temperature Scale



Kelvin temperature

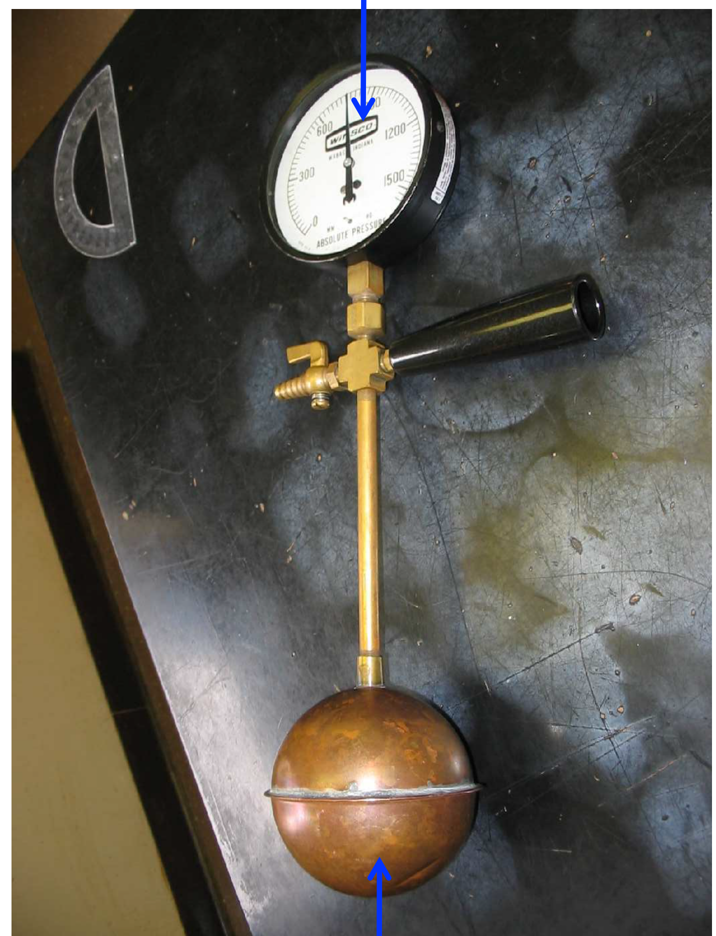
$$T = T_c + 273.15$$

12.1 The Kelvin Temperature Scale



absolute zero point = -273.15^{o}C

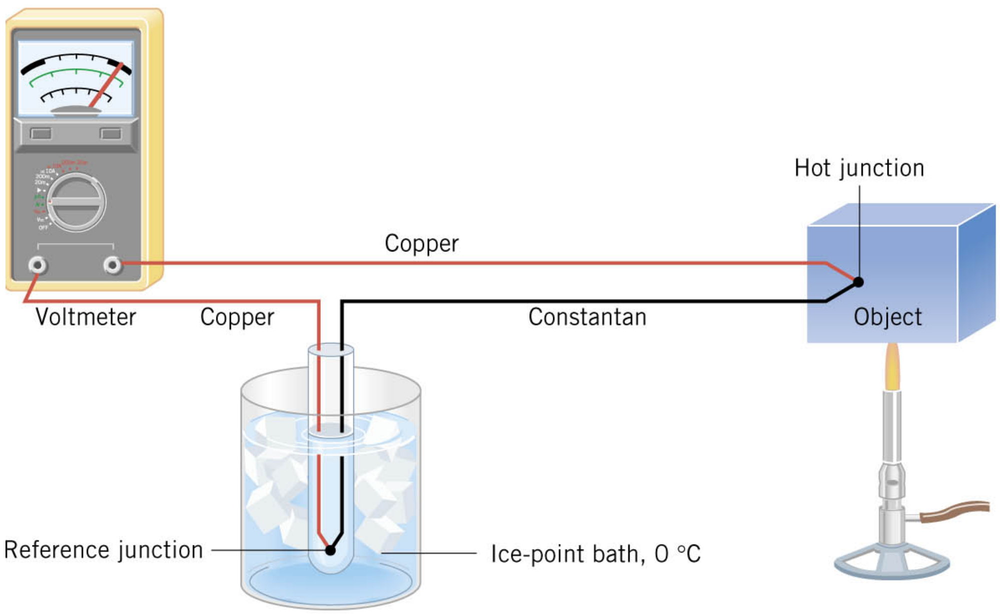
Pressure gauge



Helium gas (stays a gas)

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***.



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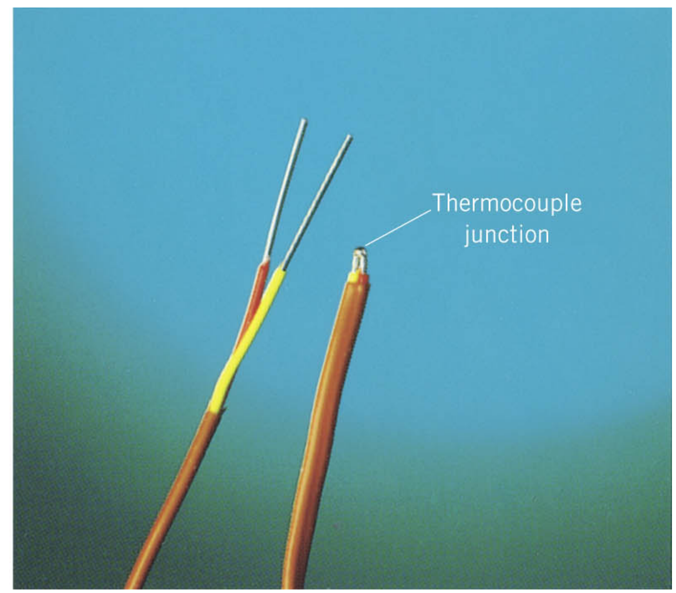
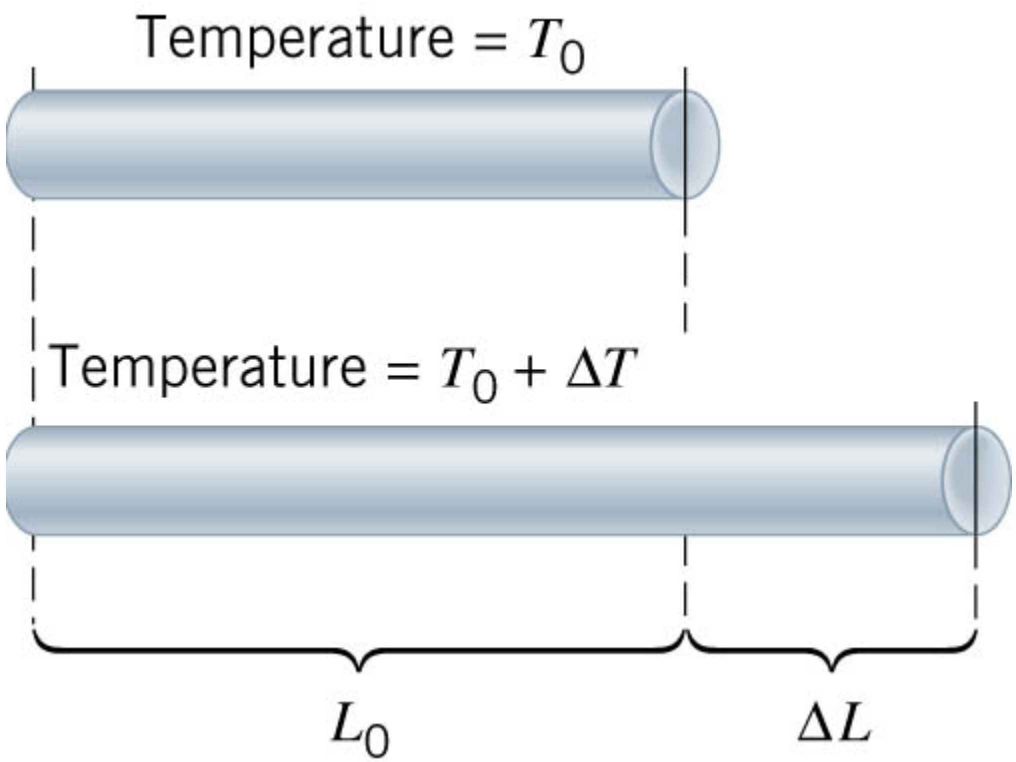


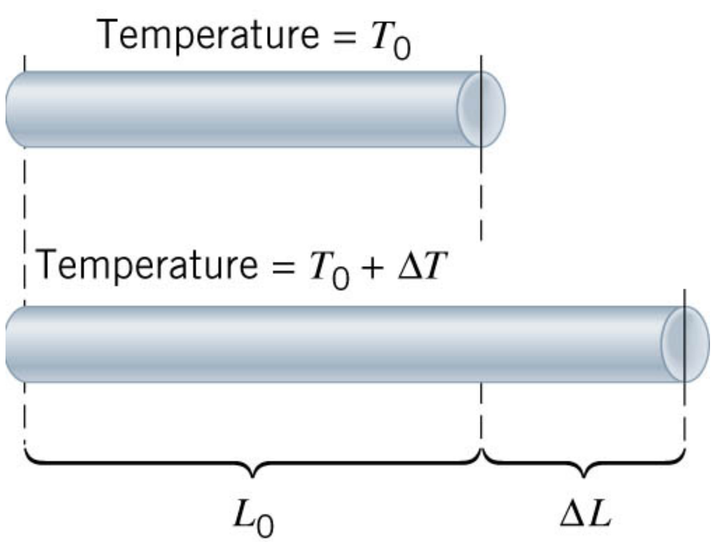
(*b*)

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}

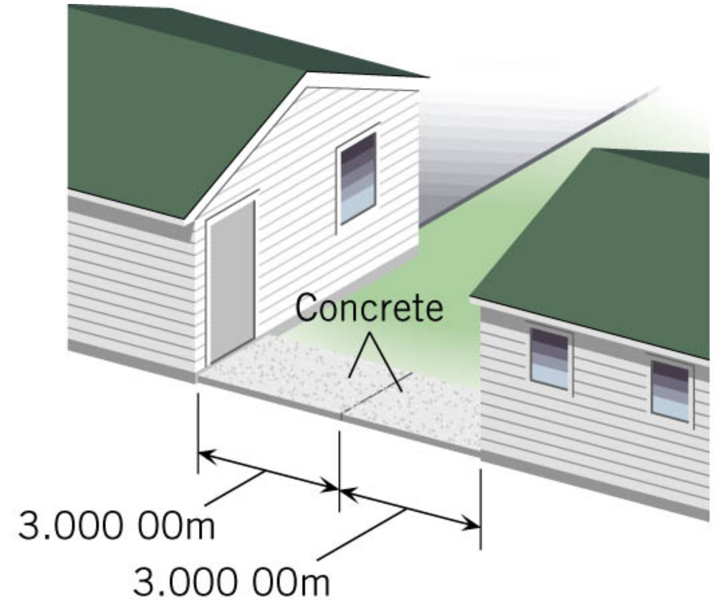
[a]The values for α and β pertain to a temperature near 20 °C.
[b]Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

Example: The Buckling of a Sidewalk

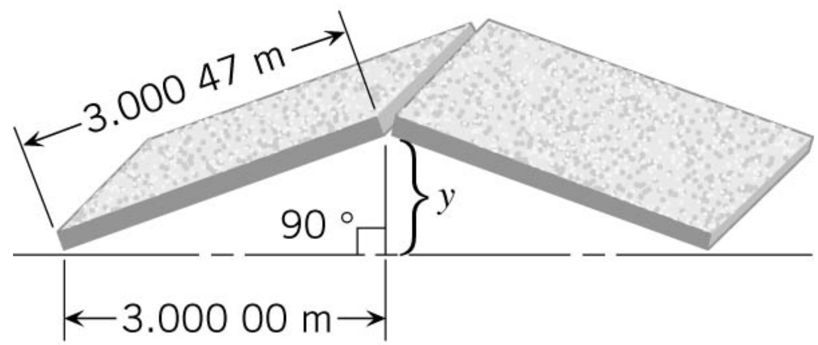
A concrete sidewalk is constructed betweer two buildings on a day when the temperatu is 25°C. As the temperature rises to 38°C, the slabs expand, but no space is provided for thermal expansion. Determine the distance *y* in part (b) of the drawing.

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

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



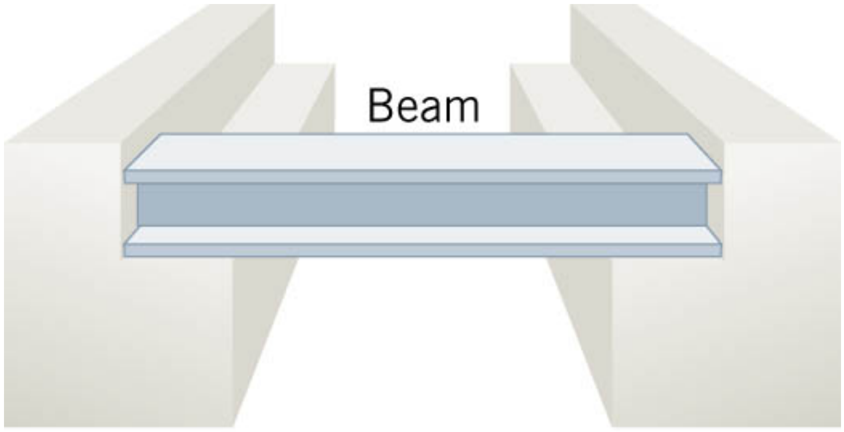
(a)



(b)

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?



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

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

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

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

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

12.2 Linear Thermal Expansion

Conceptual Example: Expanding Cylinders

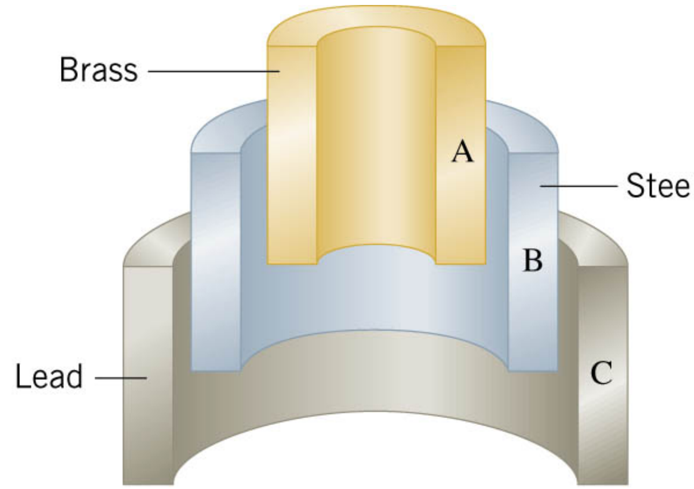
As the cylinders are heated to the same, but higher, temperature, cylinder C falls off, while cylinder A becomes tightly wedged to cylinder B.

Which cylinder is made from which material?

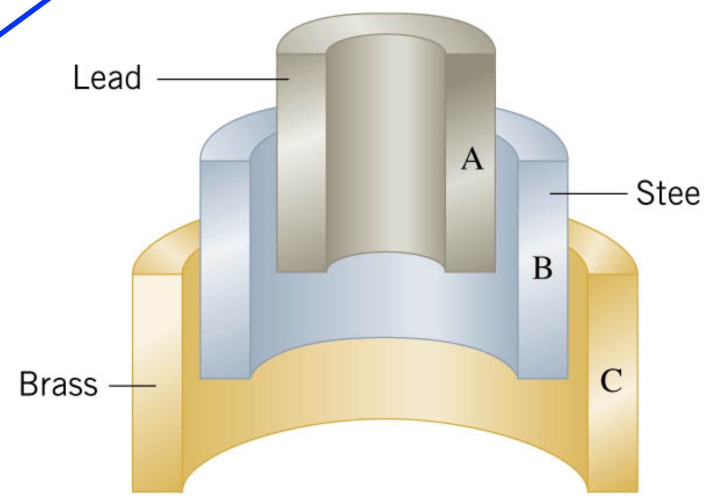
Diameter change proportional to α.

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

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		
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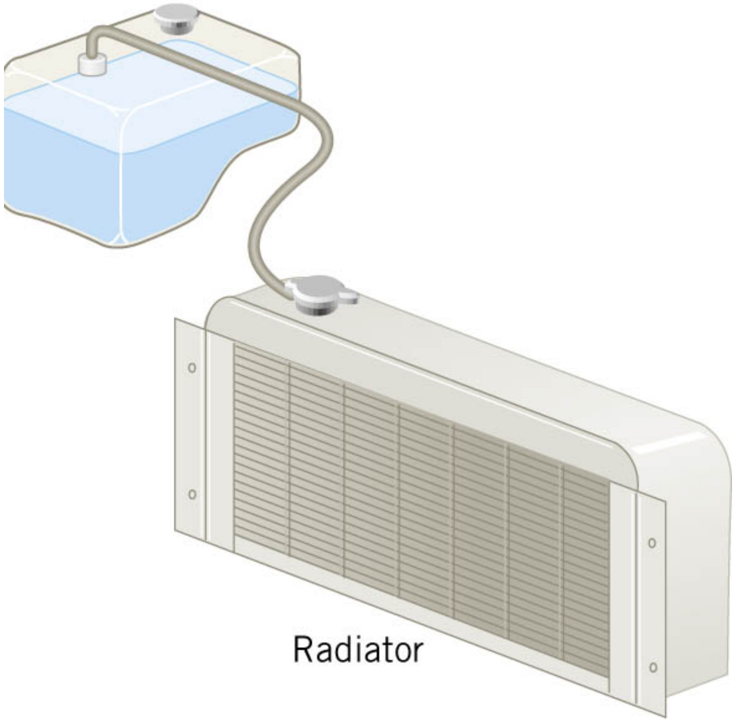
Brass	19×10^{-6}	57×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}

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

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

Example: An Automobile Radiator

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



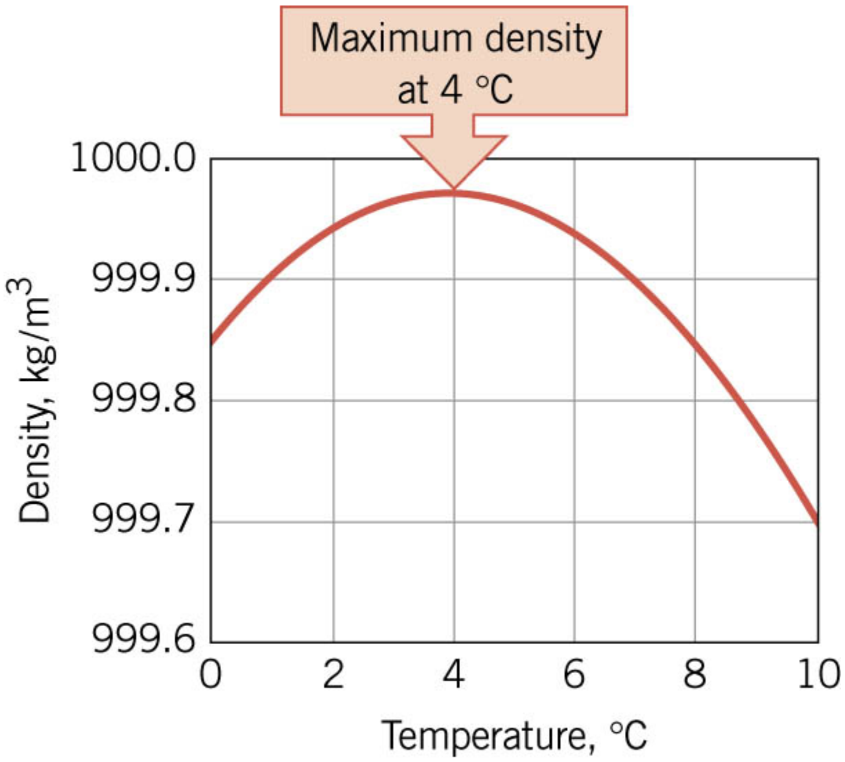
$$\Delta V_{\text{coolant}} = \left[4.10\times10^{-4}\left(\text{C}^\circ\right)^{-1}\right]\left(15\text{ liters}\right)\left(86\text{ C}^\circ\right)$$
$$= 0.53\text{ liters}$$

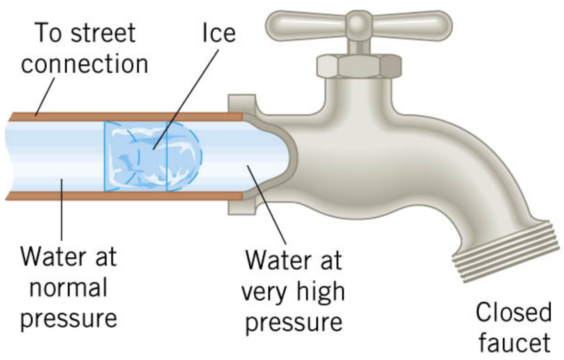
$$\Delta V_{\text{radiator}} = \left[51\times10^{-6}\left(\text{C}^\circ\right)^{-1}\right]\left(15\text{ liters}\right)\left(86\text{ C}^\circ\right)$$
$$= 0.066\text{ liters}$$

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

12.2 Volume Thermal Expansion

Expansion of water.

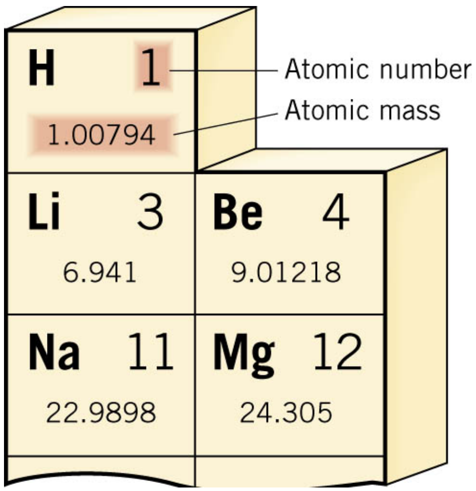




12.3 Molecular Mass, the Mole, and Avogadro's Number

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.



$$1\ \text{u} = 1.6605 \times 10^{-24}\ \text{g} = 1.6605 \times 10^{-27}\ \text{kg}$$

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.

Avogadro's number

$$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$$

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.

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

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

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

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

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)

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

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

(b)

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

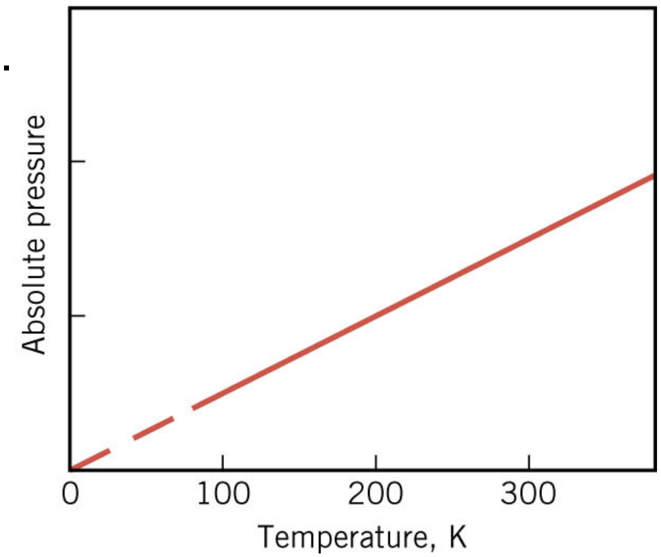
$$N=nN_A=\left(0.271\text{ mol}\right)\left(6.022\times10^{23}\text{mol}^{-1}\right)=1.63\times10^{23}\text{atoms}$$

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)

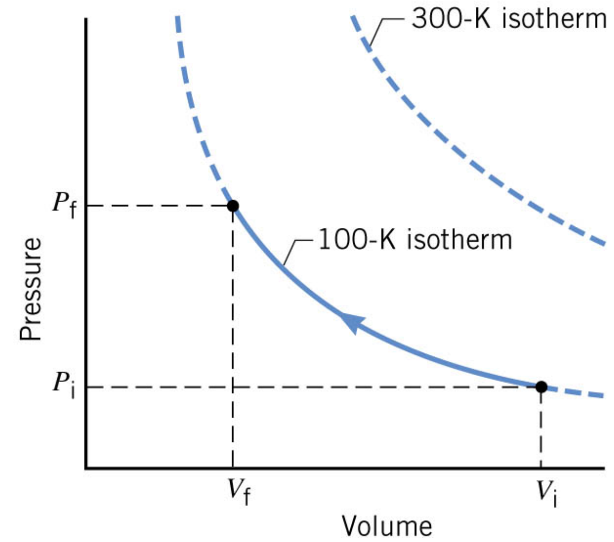
At constant volume the pressure is proportional to the temperature.

$$P \propto T$$



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.

$$P \propto n$$

Clicker Question 12.1

Under which of the following circumstances does a real gas behave like an ideal gas?

When

a) the gas particles move very slowly.

b) the gas particles do not collide with each other very often.

c) the gas particles bounce off each other without energy loss.

d) the gas particles don't hit the walls of the container.

e) there are only one kind of particles in the container.

Clicker Question 12.1

Under which of the following circumstances does a real gas behave like an ideal gas?

When

Molecules interact only by elastic collisions with others or the walls.

a) the gas particles move very slowly.

b) the gas particles do not collide with each other very often.

c) the gas particles bounce off each other without energy loss.

d) the gas particles don't hit the walls of the container.

e) there are only one kind of particles in the container.

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

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

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.

$$PV = NkT$$

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

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

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

Clicker Question 12.2

An ideal gas is enclosed within a container by a moveable piston. If the final temperature is two times the initial temperature and the volume is reduced to one-fourth of its initial value, what will the final pressure of the gas be relative to its initial pressure, P_1?

a) $8P_1$

b) $4P_1$

c) $2P_1$

d) $P_1/2$

e) $P_1/4$

Clicker Question 12.2

An ideal gas is enclosed within a container by a moveable piston. If the <u>final temperature is two times the initial temperature</u> and the <u>volume is reduced to one-fourth of its initial value</u>, what will the final pressure of the gas be relative to its initial pressure, P_1?

a) $8P_1$

b) $4P_1$

c) $2P_1$

d) $P_1/2$

e) $P_1/4$

$$P_1V_1 = nRT_1; \quad V_2 = V_1/4; \quad T_2 = 2T_1$$

$$P_2 = \frac{nRT_2}{V_2} = \frac{nR(2T_1)}{V_1/4} = 8\frac{nRT_1}{V_1} = 8P_1$$