1.4 Perform the following unit conversions:

(a) $1\,\text{L}\left|\dfrac{0.0353\,\text{ft}^3}{1\,\text{L}}\right|\left|\dfrac{12\,\text{in.}}{1\,\text{ft}}\right|^3 = 61\,\text{in.}^3 \leftarrow$

(b) $650\,\text{J}\left|\dfrac{1\,\text{kJ}}{10^3\,\text{J}}\right|\left|\dfrac{1\,\text{Btu}}{1.0551\,\text{kJ}}\right| = 0.616\,\text{Btu} \leftarrow$

(c) $0.135\,\text{kW}\left|\dfrac{3413\,\text{Btu/h}}{1\,\text{kW}}\right|\left|\dfrac{1\,\text{h}}{3600\,\text{s}}\right|\left|\dfrac{778.17\,\text{ft}\cdot\text{lbf}}{1\,\text{Btu}}\right| = 99.596\,\dfrac{\text{ft}\cdot\text{lbf}}{\text{s}} \leftarrow$

(d) $378\,\dfrac{\text{g}}{\text{s}}\left|\dfrac{1\,\text{kg}}{10^3\,\text{g}}\right|\left|\dfrac{1\,\text{lb}}{0.4536\,\text{kg}}\right|\left|\dfrac{60\,\text{s}}{1\,\text{min}}\right| = 50\,\dfrac{\text{lb}}{\text{min}} \leftarrow$

(e) $304\,\text{kPa}\left|\dfrac{1\,\text{lbf/in.}^2}{6894.8\,\text{Pa}}\right|\left|\dfrac{10^3\,\text{Pa}}{1\,\text{kPa}}\right| = 44.09\,\dfrac{\text{lbf}}{\text{in.}^2} \leftarrow$

(f) $55\,\dfrac{\text{m}^3}{\text{h}}\left|\dfrac{3.2808\,\text{ft}}{1\,\text{m}}\right|^3\left|\dfrac{1\,\text{h}}{3600\,\text{s}}\right| = 0.54\,\dfrac{\text{ft}^3}{\text{s}} \leftarrow$

(g) $50\,\dfrac{\text{km}}{\text{h}}\left|\dfrac{10^3\,\text{m}}{1\,\text{km}}\right|\left|\dfrac{3.2808\,\text{ft}}{1\,\text{m}}\right|\left|\dfrac{1\,\text{h}}{3600\,\text{s}}\right| = 45.57\,\dfrac{\text{ft}}{\text{s}} \leftarrow$

(h) $8896\,\text{N}\left|\dfrac{1\,\text{lbf}}{4.4482\,\text{N}}\right|\left|\dfrac{1\,\text{ton}}{2000\,\text{lbf}}\right| = 1\,\text{ton} \leftarrow$

1.5 Perform the following unit conversions:

$$\text{(a)}\ 122\ \text{in.}^3\left|\frac{1\ \text{cm}^3}{0.061024\ \text{in.}^3}\right|\left|\frac{1\ \text{m}}{10^2\ \text{cm}}\right|^3\left|\frac{1\ \text{L}}{10^{-3}\ \text{m}^3}\right| = 2\ \text{L} \leftarrow$$

$$\text{(b)}\ 778.17\ \text{ft}\cdot\text{lbf}\left|\frac{1\ \text{kJ}}{737.56\ \text{ft}\cdot\text{lbf}}\right| = 1.0551\ \text{kJ} \leftarrow$$

$$\text{(c)}\ 100\ \text{hp}\left|\frac{1\ \text{kW}}{1.341\ \text{hp}}\right| = 74.57\ \text{kW} \leftarrow$$

$$\text{(d)}\ 1000\ \frac{\text{lb}}{\text{h}}\left|\frac{1\ \text{h}}{3600\ \text{s}}\right|\left|\frac{1\ \text{kg}}{2.2046\ \text{lb}}\right| = 0.126\ \frac{\text{kg}}{\text{s}} \leftarrow$$

$$\text{(e)}\ 29.392\ \frac{\text{lbf}}{\text{in.}^2}\left|\frac{6894.8\ \text{Pa}}{1\ \text{lbf/in.}^2}\right|\left|\frac{1\ \text{N/m}^2}{1\ \text{Pa}}\right|\left|\frac{1\ \text{bar}}{10^5\ \text{N/m}^2}\right| = 2.027\ \text{bar} \leftarrow$$

$$\text{(f)}\ 2500\ \frac{\text{ft}^3}{\text{min}}\left|\frac{0.028317\ \text{m}^3}{1\ \text{ft}^3}\right|\left|\frac{1\ \text{min}}{60\ \text{s}}\right| = 1.18\ \frac{\text{m}^3}{\text{s}} \leftarrow$$

$$\text{(g)}\ 75\ \frac{\text{mile}}{\text{h}}\left|\frac{1.6093\ \text{km/h}}{1\ \text{mile/h}}\right| = 120.7\ \frac{\text{km}}{\text{h}} \leftarrow$$

$$\text{(h)}\ 1\ \text{ton}\left|\frac{2000\ \text{lbf}}{1\ \text{ton}}\right|\left|\frac{4.4482\ \text{N}}{1\ \text{lbf}}\right| = 8896\ \text{N} \leftarrow$$

1.6 Which of the following food items weighs approximately one newton?

a. a grain of rice
b. a small strawberry
c. a medium-sized apple
d. a large watermelon

1.7 A person whose mass is 150 lb weights 144.4 lbf. Determine (a) the *local* acceleration of gravity, in ft/s^2, and (b) the person's mass, in lb, and weight, in lbf, if g = 32.174 ft/s^2.

(a) $F_{\text{grav}} = mg \rightarrow$

$$g = \frac{F_{\text{grav}}}{m} = \frac{144.4 \text{ lbf}}{150 \text{ lb}}\left|\frac{32.174 \text{ lb}\cdot\text{ft/s}^2}{1 \text{ lbf}}\right| = \underline{\mathbf{30.97\ ft/s^2}}$$

(b) Mass value remains the same. So

$$F_{\text{grav}} = mg = (150 \text{ lb})\left(32.174\frac{\text{ft}}{\text{s}^2}\right)\left|\frac{1 \text{ lbf}}{32.174 \text{ lb}\cdot\text{ft/s}^2}\right| = \underline{\mathbf{150\ lbf}}$$

1.8 The *Phoenix* with a mass of 350 kg was a spacecraft used for exploration of Mars. Determine the weight of the *Phoenix*, in N, (a) on the surface of Mars where the acceleration of gravity is 3.73 m/s^2 and (b) on Earth where the acceleration of gravity is 9.81 m/s^2.

KNOWN: *Phoenix* spacecraft has mass of 350 kg.

FIND: (a) Weight of *Phoenix* on Mars, in N, and (b) weight of *Phoenix* on Earth, in N.

SCHEMATIC AND GIVEN DATA:

m = 350 kg
g_{Mars} = 3.73 m/s^2
g_{Earth} = 9.81 m/s^2

ENGINEERING MODEL:
1. Acceleration of gravity is constant at the surface of both Mars and Earth.

ANALYSIS: Weight is the force of gravity. Applying Newton's second law using the mass of the *Phoenix* and the local acceleration of gravity

$$F = mg$$

(a) On Mars,

$$F = (350\text{ kg})\left(3.73\frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right| = \underline{\mathbf{1305.5\text{ N}}}$$

(b) On Earth,

$$F = (350\text{ kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right| = \underline{\mathbf{3433.5\text{ N}}}$$

Although the mass of the Phoenix is constant, the weight of the Phoenix is less on Mars than on Earth since the acceleration due to gravity is less on Mars than on Earth.

PROBLEM 1.9

Eq. 1.8 is used in both parts: $n = m/M$, where M is from Tables A-1.

(a) $m = Mn$, where $n = 20\,kmol$.

Air: $m = (28.97\,kg/kmol)(20\,kmol) = 579.4\,kg$
C: $m = (12.01\,kg/kmol)(20\,kmol) = 240.2\,kg$
H_2O: $m = (18.02\,kg/kmol)(20\,kmol) = 360.4\,kg$
CO_2: $m = (44.01\,kg/kmol)(20\,kmol) = 880.2\,kg$

(b) $n = m/M$, where $m = 50\,lb$.

H_2: $n = (50\,lb)/(2.016\,lb/lbmol) = 24.802\,lbmol$
N_2: $n = (50\,lb)/(28.01\,lb/lbmol) = 1.785\,lbmol$
NH_3: $n = (50\,lb)/(17.03\,lb/lbmol) = 2.936\,lbmol$
C_3H_8: $n = (50\,lb)/(44.09\,lb/lbmol) = 1.134\,lbmol$

PROBLEM 1.10

Using magnitudes,

$$|F| = m|a| \quad , \; |a| = 60g$$

$$= m(60g) = 60mg$$

$$= 60(50\,lb)(32.2\,\tfrac{ft}{s}) \left| \frac{1\,lbf}{32.2\,lb\cdot ft/s^2} \right| = 3000\,lbf \longleftarrow$$

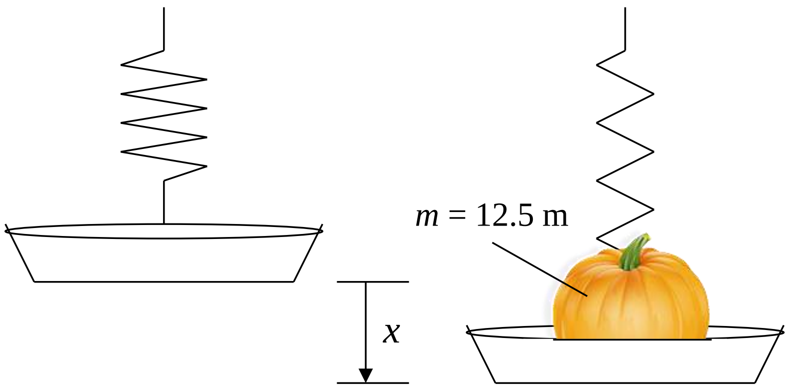
(rounded)

1.11 At the grocery store you place a pumpkin with a mass of 12.5 lb on the produce spring scale. The spring in the scale operates such that for each 4.7 lbf applied, the spring elongates one inch. If local acceleration of gravity is 32.2 ft/s^2, what distance, in inches, did the spring elongate?

KNOWN: Pumpkin placed on a spring scale causes the spring to elongate.

FIND: Distance spring elongated, in inches.

SCHEMATIC AND GIVEN DATA:



ENGINEERING MODEL:
1. Spring constant is 4.7 lbf/in.
2. Local acceleration of gravity is 32.2 ft/s^2.

ANALYSIS:
The force applied to the spring to cause it to elongate can be expressed as the spring constant, *k*, times the elongation, *x*.

$$F = kx$$

The applied force is due to the weight of the pumpkin, which can be expressed as the mass (*m*) of the pumpkin times acceleration of gravity, (*g*).

$$F = Weight = mg = kx$$

Solving for elongation, *x*, substituting values for pumpkin mass, acceleration of gravity, and spring constant, and applying the appropriate conversion factor yield

$$x = \frac{mg}{k} = \frac{(12.5\text{ lb})\left(32.2\frac{\text{ft}}{\text{s}^2}\right)}{\left(4.7\frac{\text{lbf}}{\text{in.}}\right)}\left|\frac{1\text{ lbf}}{32.174\frac{\text{lb}\cdot\text{ft}}{\text{s}^2}}\right| = \underline{\textbf{2.66 in.}}$$

The spring is known to deflect 0.14 inch for every 1 lbf of applied force. Thus, we begin by determining the weight of the object (F_{grav}) using the deflection (Δx) given as 1.8 inches.

$$\Delta x = 1.8 \text{ inches} = (0.14 \tfrac{\text{in.}}{\text{lbf}})(F_{\text{grav}})$$

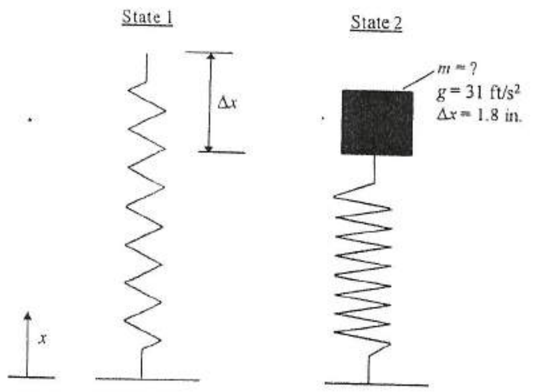
$$(F_{\text{grav}}) = \frac{1.8 \text{ inches}}{(0.14 \frac{\text{in.}}{\text{lbf}})} = 12.86 \text{ lbf}$$

The mass can be solved from the expression $F_{grav} = mg$.

rounded

$$m = \frac{(F_{\text{grav}})}{g} = \frac{12.86 \text{ lbf}}{31 \frac{\text{ft}}{\text{s}^2}} \left| \frac{32.2 \frac{\text{ft} \cdot \text{lb}}{\text{s}^2}}{1 \text{lbf}} \right| = 13.36 \text{lb}$$

$m = 13.36$ lb



PROBLEM 1.13

Weight refers to the force of gravity: $F_{grav} = mg$.

Thus, when her mass is 120 lb and weight is 119 lbf, we have

$$g = \frac{F_{grav}}{m} = \frac{119 \text{ lbf}}{120 \text{ lb}} \left| \frac{32.174 \text{ lb}\cdot\text{ft/s}^2}{1 \text{ lbf}} \right| = 31.906 \text{ ft/s}^2 \longleftarrow$$

When her mass is 120 lb and $g = 32.05 \text{ ft/s}^2$, we have

$$F_{grav} = mg = (120 \text{ lb})(32.05 \text{ ft/s}^2) \left| \frac{1 \text{ lbf}}{32.174 \text{ lb}\cdot\text{ft/s}^2} \right|$$
$$= 119.54 \text{ lbf} \longleftarrow$$

COMMENT: Her mass remains constant, but weight depends on the local acceleration of gravity.

PROBLEM 1.14

The actual forces developed when birds and aircraft collide are difficult to determine precisely, but estimates can be calculated using average values of acceleration and force magnitudes, as follows:

The goose is accelerated from a very low velocity to 150 miles/h in 10^{-3} s. Thus the averge acceleration magnitude is

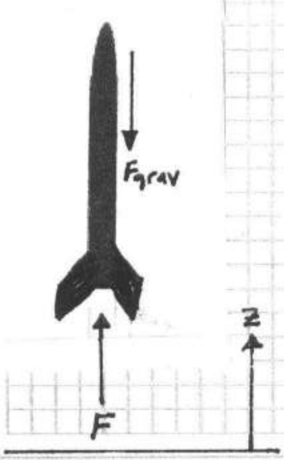
$$|a| = \left(\frac{150 \text{ miles/h} - 0}{10^{-3} \text{ s}} \right) \left| \frac{1 \text{ h}}{3600 \text{ s}} \right| \left| \frac{5280 \text{ ft}}{1 \text{ mile}} \right| = 2.2 \times 10^5 \frac{\text{ft}}{\text{s}^2}$$

The magnitude of the average force applied is

$$|F| = m|a| = (12 \text{ lb})\left(2.2 \times 10^5 \frac{\text{ft}}{\text{s}^2}\right) \left| \frac{1 \text{ lbf}}{32.2 \text{ lb}\cdot\text{ft/s}^2} \right| = 82{,}000 \text{ lbf} \longleftarrow$$

rounded

PROBLEM 1.15



$m = 4.5 \text{ lb}$

$a = 3g$, where $g = 32.2 \text{ ft/s}^2$

$\Sigma F_z = ma$

Neglecting air resistance,

$$F - F_{grav} = ma$$

$$\Rightarrow F = ma + F_{grav}$$
$$= ma + mg = m(3g) + mg$$
$$= m(4g)$$
$$= (4.5 \text{ lb})(4 \times 32.2 \text{ ft/s}^2) \left| \frac{1 \text{ lbf}}{32.2 \text{ lb}\cdot\text{ft/s}^2} \right| = 18 \text{ lbf} \longleftarrow$$

rounded

PROBLEM 1.16

The FBD of the object is as shown with an upward applied force of 10 lbf and the force downward due to gravity where $F_{grav} = mg$ and g is given as 32.2 ft/s^2. Summing forces yields the following equation that can be rearranged to solve for acceleration. It is assumed that up is positive.

$F_{\text{applied}} = 10 \text{ lbf}$

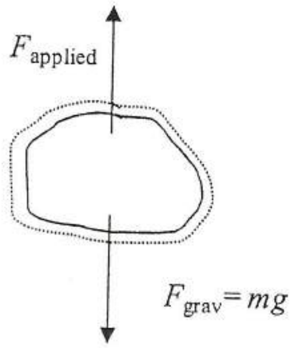
$m = 50 \text{ lb}$

$g = 32.2 \dfrac{\text{ft}}{\text{s}^2}$

$a = ? \dfrac{\text{ft}}{\text{s}^2}$

$F_{\text{applied}} - F_{\text{grav}} = ma$

$F_{\text{grav}} = mg$



$$a = \frac{F_{\text{applied}} - F_{\text{grav}}}{m} = \frac{F_{\text{applied}} - mg}{m} = \frac{F_{\text{applied}}}{m} - g$$

$$a = \frac{10 \text{ lbf}}{50 \text{ lb}} \left| \frac{32.2 \text{ ft} \cdot \text{lb}/\text{s}^2}{1 \text{lbf}} \right| - 32.2 \frac{\text{ft}}{\text{s}^2}$$

$$a = -25.8 \frac{\text{ft}}{\text{s}^2} \quad \text{downward}$$

1.17 A communications satellite weighs 4400 N on Earth where $g = 9.81$ m/s^2. What is the weight of the satellite, in N, as it orbits Earth where the acceleration of gravity is 0.224 m/s^2? Express each weight in lbf.

KNOWN: Weight of communications satellite on Earth.

FIND: Determine weight of the satellite, in N, as it orbits Earth where the acceleration of gravity is 0.224 m/s^2. Express the satellite weight, in lbf, on Earth and in orbit.

SCHEMATIC AND GIVEN DATA:

$W_{\text{Sat(Earth)}} = 4400$ N
$g_{\text{Earth}} = 9.81$ m/s^2
$g_{\text{orbit}} = 0.224$ m/s^2

ENGINEERING MODEL:
1. Gravitational acceleration on Earth is constant at 9.81 m/s^2.
2. Gravitational acceleration at orbital altitude is constant at 0.224 m/s^2.

ANALYSIS: Weight of the satellite is the force of gravity and varies with altitude. Mass of the satellite remains constant. Applying Newton's second law to solve for the mass of the satellite yields

$$W = mg \rightarrow m = W/g$$

On Earth,

$$m = W_{\text{Sat(Earth)}}/g_{\text{Earth}}$$

$$m = \frac{(4400\ \text{N})}{\left(9.81\frac{\text{m}}{\text{s}^2}\right)}\left|\frac{1\ \text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right| = 448.5\ \text{kg}$$

Solving for the satellite weight in orbit,

$$W_{\text{Sat(orbit)}} = mg_{\text{orbit}}$$

$$W_{\text{Sat(orbit)}} = (448.5\ \text{kg})\left(0.224\frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right| = \underline{\mathbf{100.5\ N}}$$

Although the mass of the communications satellite is constant, the weight of the satellite is less at orbital altitude than on Earth since the acceleration due to gravity is less at orbital altitude than on Earth.

To determine the corresponding weights in lbf, apply the conversion factor, 1 lbf = 4.4482 N.

$$W_{\text{Sat(Earth)}} = (4400\ \text{N})\left|\frac{1\ \text{lbf}}{4.4482\ \text{N}}\right| = \underline{\mathbf{989.2\ lbf}}$$

$$W_{\text{Sat(orbit)}} = (100.5\ \text{N})\left|\frac{1\ \text{lbf}}{4.4482\ \text{N}}\right| = \underline{\mathbf{22.6\ lbf}}$$

PROBLEM 1.18

(a) Mexico City, $g = 9.779 \text{ m/s}^2$

$$F_{rav} = mg = (80\text{ kg})(9.779 \tfrac{m}{s^2})\left|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right|$$

$$= 782.32 \text{ N} \longleftarrow$$

(b) Cape Town, $g = 9.796 \text{ m/s}^2$

$$F_{grav} = mg = (80\text{ kg})(9.796 \tfrac{m}{s^2})\left|\frac{1\text{N}}{1\text{ kg}\cdot\text{m/s}^2}\right|$$

$$= 783.68 \text{ N} \longleftarrow$$

(c) Tokyo, $g = 9.798 \text{ m/s}^2$

$$F_{grav} = mg = (80\text{kg})(9.798 \tfrac{m}{s^2})\left|\frac{1\text{N}}{1\text{ kg}\cdot\text{m/s}^2}\right|$$

$$= 783.84 \text{ N} \longleftarrow$$

(d) Chicago, $g = 9.803 \text{ m/s}^2$

$$F_{grav} = mg = (80\text{kg})(9.803 \tfrac{m}{s^2})\left|\frac{1\text{N}}{1\text{ kg}\cdot\text{m/s}^2}\right|$$

$$= 784.24 \text{ N} \longleftarrow$$

(e) Copenhagen, $g = 9.815 \text{ m/s}^2$

$$F_{grav} = mg = (80\text{kg})(9.815 \text{ m/s}^2)\left|\frac{1\text{N}}{1\text{ kg}\cdot\text{m/s}^2}\right|$$

$$= 785.2 \text{ N} \longleftarrow$$

PROBLEM 1.19

1. The weight of the tower itself is ignored.
2. Local acceleration of gravity is 32.1 ft/s^2.
3. $\rho_{water} = 62.4\ \text{lb/ft}^3$

The structure must exert a minimum force equivalent to the weight of the water, which can be expressed as the mass (m) of the water times acceleration of gravity, g.

$$F = Weight = mg$$

The mass of the water can be determined from its density times the volume the water occupies

$$m = \rho V = \left(62.4 \frac{\text{lb}}{\text{ft}^3}\right)(1{,}000{,}000\ \text{gal})\left|\frac{0.13368\ \text{ft}^3}{1\ \text{gal}}\right| = 8{,}341{,}632\ \text{lb}$$

Substituting for mass and acceleration of gravity and applying the appropriate conversion factor yield

$$F = mg = (8{,}341{,}632\ \text{lb})\left(32.1 \frac{\text{ft}}{\text{s}^2}\right)\left|\frac{1\ \text{lbf}}{32.174 \frac{\text{lb}\cdot\text{ft}}{\text{s}^2}}\right| = \underline{\mathbf{8{,}322{,}446\ lbf}} \longleftarrow$$

PROBLEM 1.20

0.5 kmol NH_3
$V = 6\ m^3$
$g = 9.81\ m/s^2$

(a) $F_{grav} = m\,g$

Using Eq. 1.8, $m = n\,M = 0.5\ \text{kmol}\left(17.03 \frac{\text{kg}}{\text{kmol}}\right) = 8.52\ \text{kg}$ ← Table A-1

$\therefore\ F_{grav} = (8.52\ \text{kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right| = 83.58\ \text{N} \longleftarrow F_{grav}$

(b) $\bar{v} = \dfrac{V}{n} = \dfrac{6\ \text{m}^3}{0.5\ \text{kmol}} = 12 \dfrac{\text{m}^3}{\text{kmol}}$, $v = \dfrac{V}{m} = \dfrac{6\ \text{m}^3}{8.52\ \text{kg}} = 0.704 \dfrac{\text{m}^3}{\text{kg}} \longleftarrow \bar{v}, v$

1.21 A 2-lb sample of an unknown liquid occupies a volume of 62.6 in.^{3} For the liquid determine (a) the specific volume, in ft^3/lb, and (b) the density, in lb/ft^3.

KNOWN: Volume and mass of an unknown liquid sample.

FIND: Determine (a) the specific volume, in ft^3/lb, and (b) the density, in lb/ft^3.

SCHEMATIC AND GIVEN DATA:

m = 2 lb
V = 62.6 in.^{3}

ENGINEERING MODEL:
1. The liquid can be treated as continuous.

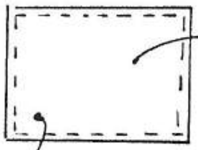
ANALYSIS:
(a) The specific volume is volume per unit mass and can be determined from the total volume and the mass of the liquid

$$v = \frac{V}{m} = \frac{62.6\text{ in.}^3}{2\text{ lb}}\left|\frac{1\text{ ft}^3}{1728\text{ in.}^3}\right| = \underline{\mathbf{0.0181\ ft^3/lb}}$$

(b) Density is the reciprocal of specific volume. Thus,

$$\rho = \frac{1}{v} = \frac{1}{0.0181\frac{\text{ft}^3}{\text{lb}}} = \underline{\mathbf{55.2\ lb/ft^3}}$$

PROBLEM 1.22



(a) From Sec. 1.5, the number of molecules in a gram mole (mol) is 6.022×10^{23} (Avogadro's number).

Thus $$n = \frac{2.5 \times 10^{22} \text{ molecules}}{6.022 \times 10^{23} \text{ molecules/mol}} = 4.15 \times 10^{-2} \text{ mols}$$

Converting to kmol,
$$n = 4.15 \times 10^{-2} \text{ mol} \left| \frac{1 \text{ kmol}}{10^3 \text{ mol}} \right| = 4.15 \times 10^{-5} \text{ kmol} \leftarrow$$

Using Eq. 1.8, $m = nM$, so
$$m = 4.15 \times 10^{-5} \text{ kmol} \left(17.03 \frac{\text{kg}}{\text{kmol}}\right) = 7.07 \times 10^{-4} \text{ kg} \leftarrow$$

Table A-1

Then
$$v = \frac{V}{m} = \frac{(1 \text{ liter})}{7.07 \times 10^{-4} \text{ kg}} \left| \frac{10^{-3} \text{m}^3}{1 \text{ liter}} \right| = 1.41 \frac{\text{m}^3}{\text{kg}} \leftarrow$$

$$\bar{v} = \frac{V}{n} = \frac{10^{-3} \text{ m}^3}{4.15 \times 10^{-5} \text{ kmol}} = 24.1 \frac{\text{m}^3}{\text{kmol}} \leftarrow$$

1.23 The specific volume of 5 kg of water vapor at 1.5 MPa, 440°C is 0.2160 m^3/kg. Determine (a) the volume, in m^3, occupied by the water vapor, (b) the amount of water vapor present, in gram moles, and (c) the number of molecules.

KNOWN: Mass, pressure, temperature, and specific volume of water vapor.

FIND: Determine (a) the volume, in m^3, occupied by the water vapor, (b) the amount of water vapor present, in gram moles, and (c) the number of molecules.

SCHEMATIC AND GIVEN DATA:

m = 5 kg
p = 1.5 MPa
T = 440°C
v = 0.2160 m^3/kg

ENGINEERING MODEL:
1. The water vapor is a closed system.

ANALYSIS:
(a) The specific volume is volume per unit mass. Thus, the volume occupied by the water vapor can be determined by multiplying its mass by its specific volume.

$$V = mv = (5\text{ kg})\left(0.2160\frac{\text{m}^3}{\text{kg}}\right) = \underline{\mathbf{1.08\ m^3}}$$

(b) Using molecular weight of water from Table A-1 and applying the appropriate relation to convert the water vapor mass to gram moles gives

$$n = \frac{m}{M} = \left(\frac{5\text{ kg}}{18.02\frac{\text{kg}}{\text{kmol}}}\right)\left|\frac{1000\text{ moles}}{1\text{ kmol}}\right| = \underline{\mathbf{277.5\ moles}}$$

(c) Using Avogadro's number to determine the number of molecules yields

$$\#\text{Molecules} = \text{Avogadro's Number} \times \#\text{moles} = \left(6.022\times10^{23}\frac{\text{molecules}}{\text{mole}}\right)(277.5\text{ moles})$$

$$\#\text{ Molecules} = \underline{\mathbf{1.671\times10^{26}\ molecules}}$$

PROBLEM 1.24

$$\underbrace{p}_{\mathrm{lbf/ft^2}} = A + \frac{B}{\underbrace{V}_{\mathrm{ft^3}}}$$

By inspection of this equation, A has units of lbf/ft². ←

Rearranging,

$$B = \underbrace{[p-A]}_{\mathrm{lbf/ft^2}}\underbrace{V}_{\mathrm{ft^3}} \Rightarrow$$ B has units of ft·lbf. ←

PROBLEM 1.25

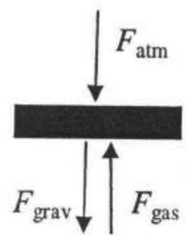
The FBD of the piston is as shown with a downward force due to the atmosphere (F_{atm}) where $F_{atm} = p_{atm} A_{piston}$ and A_{piston} is the cross sectional area of the piston. Another downward force is due to gravity (F_{grav}) where $F_{grav} = m_{piston}\, g$ and m_{piston} is the mass of the piston. The upward force (F_{gas}) is due to the pressure exerted on the bottom face of the piston by the substance where $F_{gas} = p_{gas} A_{piston}$ and p_{gas} is the pressure of the gas. Summing forces yields the following equation that can be rearranged to explore whether p_{gas} is constant. It is assumed that up is positive.

$$F_{gas} = F_{grav} + F_{atm}$$

$$F_{gas} = p_{gas} A_p \qquad F_{grav} = m_{piston}\, g \qquad F_{atm} = p_{atm} A_{piston}$$

$$p_{gas} A_{piston} = m_{piston}\, g + p_{atm} A_{piston}$$

$$p_{gas} = \frac{m_{piston}\, g}{A_{piston}} + \frac{p_{atm} A_{piston}}{A_{piston}} = \frac{m_{piston}\, g}{A_{piston}} + p_{atm}$$

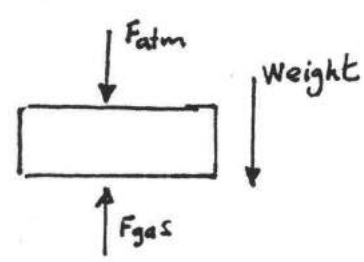


Since each of the four quantities on the right-side of the above equation is constant, it follows that the pressure acting on the bottom of the piston remains constant. ⟵
Volume change occurs as the gas is heated or cooled. ⟵

PROBLEM 1.26

Since the piston moves smoothly within the cylinder, the piston begins to rise when the force exerted by the gas exceeds the resisting force composed of the piston weight and the force exerted by the atmospheric pressure.

That is,



$$F_{gas} \geq \text{Weight} + F_{atm}$$

$$p_{gas} A \geq mg + p_{atm} A$$

$$\Rightarrow \quad p_{gas} \geq \frac{mg}{A} + p_{atm}$$

$$\geq \left[\frac{(50\ \text{kg})(9.81\ \text{m/s}^2)}{0.01\ \text{m}^2}\right] \left|\frac{1\ \text{bar}}{10^5\ \text{N/m}^2}\right| \left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right| + 1\ \text{bar}$$

$$\geq 1.49\ \text{bar} \longleftarrow$$

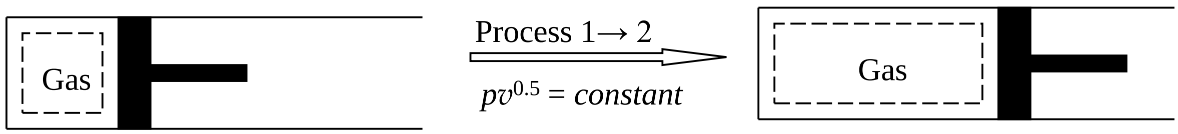
1.27 Three kg of gas in a piston-cylinder assembly undergo a process during which the relationship between pressure and specific volume is $pv^{0.5} = constant$. The process begins with $p_1 = 250$ kPa and $V_1 = 1.5$ m^3 and ends with $p_2 = 100$ kPa. Determine the final specific volume, in m^3/kg. Plot the process on a graph of pressure versus specific volume.

KNOWN: A gas of known mass undergoes a process from a known initial state to a specified final pressure. The pressure-specific volume relationship for the process is given.

FIND: Determine the final specific volume and plot the process on a pressure versus specific volume graph.

SCHEMATIC AND GIVEN DATA:

State 1 State 2



$m_1 = 3$ kg
$p_1 = 250$ kPa
$V_1 = 1.5$ m^3

$m_2 = 3$ kg
$p_2 = 100$ kPa

ENGINEERING MODEL:
1. The gas is a closed system.
2. The system undergoes a polytropic process in which $pv^{0.5} = constant$.

ANALYSIS:
The final specific volume, v_2, can be determined from the polytropic process equation

$$p_1 v_1^{0.5} = p_2 v_2^{0.5}$$

Solving for v_2 yields

$$v_2 = v_1 \left(\frac{p_1}{p_2} \right)^{\frac{1}{0.5}}$$

Specific volume at the initial state, v_1, can be determined by dividing the volume at the initial state, V_1, by the mass, m, of the system

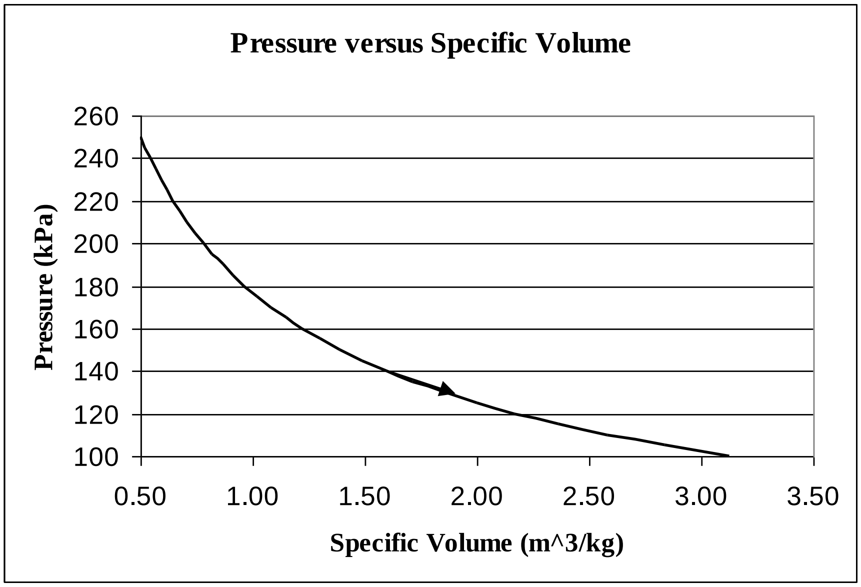
$$v_1 = \frac{V_1}{m} = \frac{1.5\,\text{m}^3}{3\,\text{kg}} = 0.5\ \text{m}^3/\text{kg}$$

Substituting values for pressures and specific volume yields

$$v_2 = \left(0.5\frac{\text{m}^3}{\text{kg}}\right)\left(\frac{250\,\text{kPa}}{100\,\text{kPa}}\right)^{\frac{1}{0.5}} = \underline{\mathbf{3.125\ m^3/kg}}$$

The volume of the system increased while pressure decreased during the process.

A plot of the process on a pressure versus specific volume graph is as follows:



1.28 A closed system consisting of 4 lb of a gas undergoes a process during which the relation between pressure and volume is $pV^n = constant$. The process begins with $p_1 = 15$ lbf/in.^{2}, $v_1 = 1.25$ ft^3/lb and ends with $p_2 = 53$ lbf/in.^{2}, $v_2 = 0.5$ ft^3/lb. Determine (a) the volume, in ft^3, occupied by the gas at states 1 and 2 and (b) the value of n. (c) Sketch Process 1-2 on pressure-volume coordinates.

KNOWN: Gas undergoes a process from a known initial pressure and specific volume to a known final pressure and specific volume.

FIND: Determine (a) the volume, in ft^3, occupied by the gas at states 1 and 2 and (b) the value of n. (c) Sketch Process 1-2 on pressure-volume coordinates.

SCHEMATIC AND GIVEN DATA:

State 1 State 2

$m = 4$ lb
$p_1 = 15$ lbf/in.^{2}
$v_1 = 1.25$ ft^3/lb

$p_2 = 53$ lbf/in.^{2}
$v_2 = 0.5$ ft^3/lb

ENGINEERING MODEL:
1. The gas is a closed system.
2. The relation between pressure and volume is $pV^n = constant$ during process 1-2.

ANALYSIS:
(a) The specific volume is volume per unit mass. Thus, the volume occupied by the gas can be determined by multiplying its mass by its specific volume.

$$V = mv$$

For state 1

$$V_1 = mv_1 = (4\text{ lb})\left(1.25\frac{\text{ft}^3}{\text{lb}}\right) = \underline{\mathbf{5\ ft^3}}$$

For state 2

$$V_2 = mv_2 = (4\text{ lb})\left(0.5\frac{\text{ft}^3}{\text{lb}}\right) = \underline{\mathbf{2\ ft^3}}$$

(b) The value of n can be determined by substituting values into the relationship:

$$p_1(V_1)^n = constant = p_2(V_2)^n$$

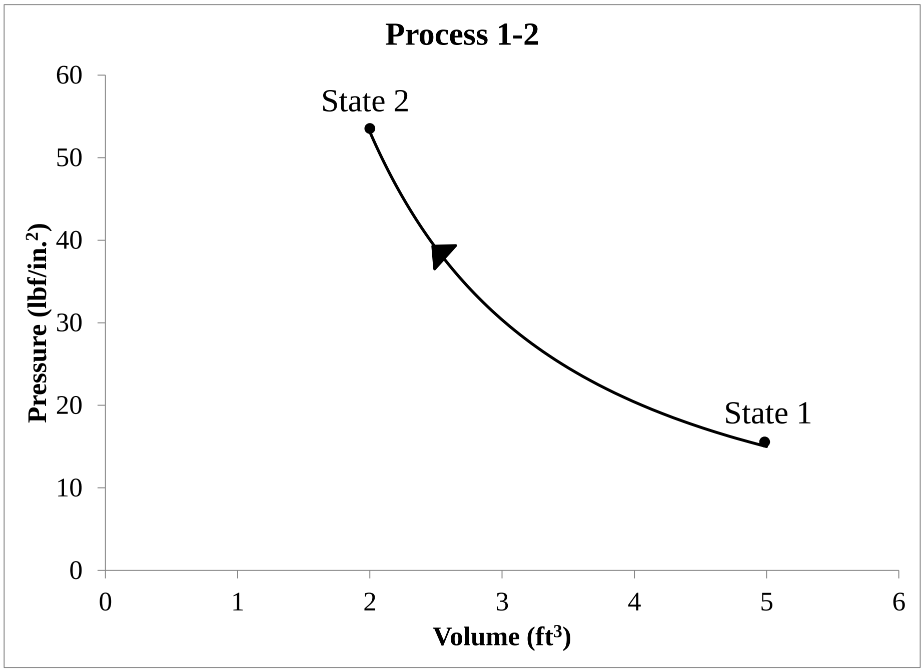
Solving for n

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n$$

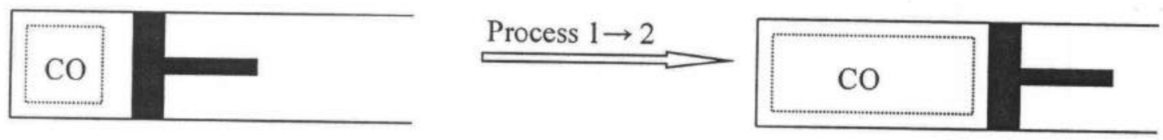
$$\ln\left(\frac{p_1}{p_2}\right) = n \ln\left(\frac{V_2}{V_1}\right)$$

$$n = \frac{\ln\left(\frac{p_1}{p_2}\right)}{\ln\left(\frac{V_2}{V_1}\right)} = \frac{\ln\left(\frac{15\ \text{lbf/in.}^2}{53\ \text{lbf/in.}^2}\right)}{\ln\left(\frac{2\ \text{ft}^3}{5\ \text{ft}^3}\right)} = \underline{\mathbf{1.38}}$$

(c) Process 1-2 is shown on pressure-volume coordinates below:



PROBLEM 1.29



$p_2 = 200$ lbf/in.^{2}
$V_2 = 2.0$ ft^3

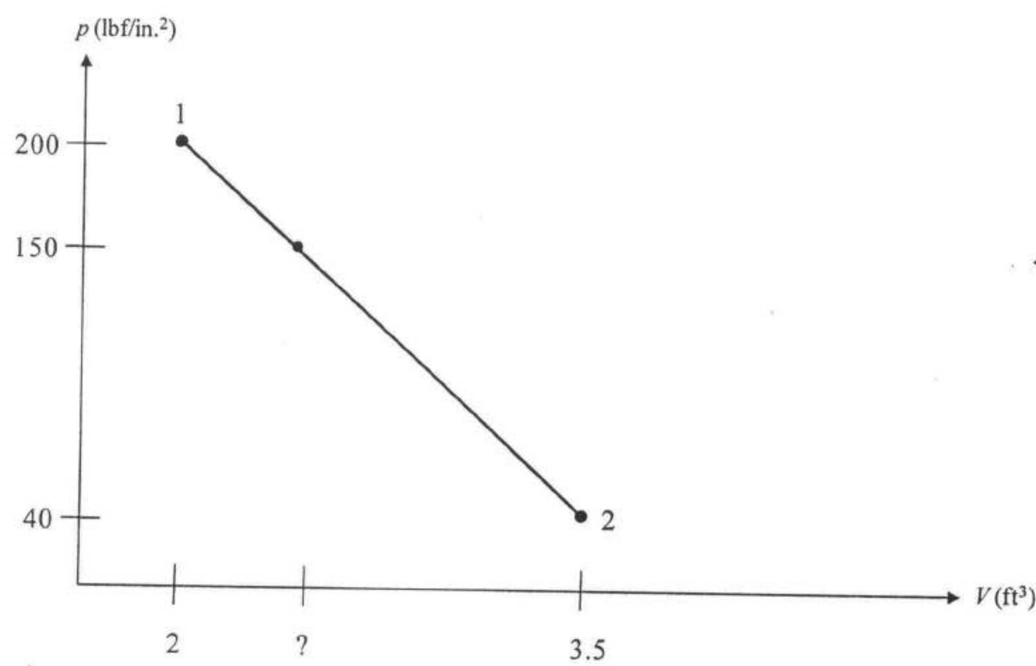
$p_1 = 40$ lbf/in.^{2}
$V_1 = 3.5$ ft^3

The pressure-volume relation is linear during the process. Therefore,

$$\frac{p - p_1}{V - V_1} = \frac{p_2 - p_1}{V_2 - V_1} \quad and \quad V = \frac{p - p_1}{p_2 - p_1}(V_2 - V_1) + V_1$$

Using given data where p =150 lbf/in.^{2}

$$V = \frac{(150 - 200)\frac{\text{lbf}}{\text{in.}^2}}{(40 - 200)\frac{\text{lbf}}{\text{in.}^2}}(3.5 - 2.0)\text{ft}^3 + 2.0\text{ ft}^3 = \frac{-50}{-160}(1.5)\text{ft}^3 + 2.0\text{ ft}^3 = 2.5\text{ ft}^3$$



PROBLEM 1.30

Since the piston moves smoothly within the cylinder, the force exerted by the gas equals the resisting force composed of the piston weight, shaft weight, force exerted by the atmospheric pressure, and the force acting on the shaft, F. That is, the sum of the forces acting vertically is zero, giving

$$F_{gas} = \begin{bmatrix}\text{Piston}\\ \text{Weight}\end{bmatrix} + \begin{bmatrix}\text{Shaft}\\ \text{Weight}\end{bmatrix} + F_{atm} + F$$

Solving

$$F = F_{gas} - \begin{bmatrix}\text{Piston}\\ \text{Weight}\end{bmatrix} - \begin{bmatrix}\text{Shaft}\\ \text{Weight}\end{bmatrix} - F_{atm} \qquad (*)$$

In this expression,

$F_{gas} = p_{gas} A_p$, where A_p is the piston face area:

$$A_p = \frac{\pi D^2}{4} = \frac{\pi (10\text{cm})^2}{4} = 78.54\text{cm}^2$$

$$\therefore \quad F_{gas} = (3\text{bar})\left|\frac{10^5 N/m^2}{1\text{bar}}\right|(78.54\text{cm}^2)\left|\frac{1\text{m}}{10^2\text{cm}}\right|^2 = 2356.2\text{ N}$$

The pressure of the atmosphere acts only on the net area at the top of the piston — namely, the piston face area less the area occupied by the shaft. The force is then

$$F_{atm} = p_{atm}[A_p - A]$$

$$= (1\text{bar})(78.54 - 0.8)\text{cm}^2\left|\frac{10^5 N/m^2}{1\text{bar}}\right|\left|\frac{1\text{m}}{10^2\text{cm}}\right|^2 = 777.4\text{N}$$

The total weight of the piston and shaft is

$$\text{Total weight} = (m_{piston} + m_{shaft})g$$

$$= (25\text{kg})(9.81\tfrac{m}{s^2})\left|\frac{1\text{ N}}{1\text{ kg}\cdot m/s^2}\right| = 245.3\text{ N}$$

Collecting results, Eq. (*) gives

$$F = 2356.2\text{N} - 245.3\text{N} - 777.4\text{N}$$

$$= 1333.5\text{ N}$$

1.31 A gas contained within a piston-cylinder assembly undergoes four processes in series:

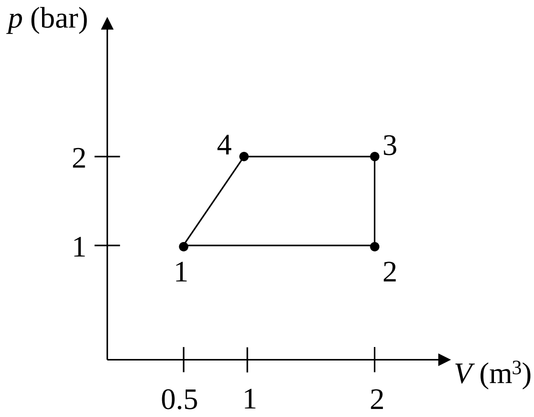
Process 1-2: Constant-pressure expansion at 1 bar from $V_1 = 0.5\ \text{m}^3$ to $V_2 = 2\ \text{m}^3$

Process 2-3: Constant volume to 2 bar

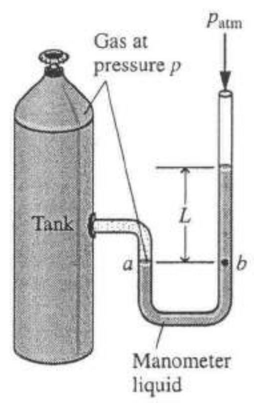
Process 3-4: Constant-pressure compression to 1 m^3

Process 4-1: Compression with $pV^{-1} = constant$

Sketch the process in series on a *p*-*V* diagram labeled with pressure and volume values at each numbered state.



PROBLEM 1.32



(a) We have $p_a = p_{gas}$ and $p_a = p_b$. p_b is evaluated using Eq. 1.11. Collecting results,

$$\Rightarrow \quad p_{gas} = p_{atm} + \rho_w g L$$

where $\rho_w = 997\ \text{kg/m}^3$ and $g = 9.81\ \text{m/s}^2$.

Solving for L

$$L = \frac{(p_{gas} - p_{atm})}{\rho_w g} = \frac{(1.5-1)\,\text{bar} \left|\frac{10^5\ \text{N/m}^2}{1\ \text{bar}}\right|}{\left(997\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right|}$$

$$= 5.11\ \text{m} \longleftarrow$$

(b) Following the approach of part (a) with $\rho_m = 13.59\ \frac{\text{g}}{\text{cm}^3}$, $p_{atm} = 750\ \text{mm Hg} = 10^5\ \text{N/m}^2$ (see "For Example" on p. 16)

$$L = \frac{p_{gas} - p_{atm}}{\rho_m g} = \frac{(1.3-1) \times 10^5\ \text{N/m}^2}{\left(13.59\ \frac{\text{g}}{\text{cm}^3}\right)\left|\frac{1\ \text{kg}}{10^3\ \text{g}}\right|\left|\frac{10^2\ \text{cm}}{1\ \text{m}}\right|^3\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right|}$$

$$= 0.225\ \text{m}\left|\frac{100\ \text{cm}}{1\ \text{m}}\right| = 22.5\ \text{cm} \longleftarrow$$

PROBLEM 1.33

Considering a manometer like that shown in Fig. 1.7 connected to the storage tank by a line filled with gas, we have $p_a = p_{gas}$ and $p_a = p_b$. p_b is evaluated using Eq. 1.11. Collecting results,

$$p_{gas} = p_{atm} + \rho g L$$

$$= 101\ \text{kPa} + \left(13.59\ \frac{\text{g}}{\text{cm}^3}\right)\left|\frac{1\ \text{kg}}{10^3\ \text{g}}\right|\left|\frac{10^2\ \text{cm}}{1\ \text{m}}\right|^3\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(1\ \text{m})\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right|\left|\frac{1\ \text{kPa}}{10^3\ \text{N/m}^2}\right|$$

$$= 101\ \text{kPa} + 133.3\ \text{kPa}$$

$$= 234.3\ \text{kPa} \longleftarrow$$

PROBLEM 1.34

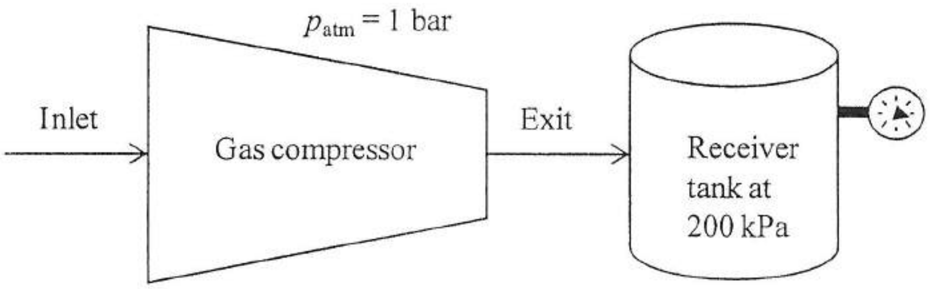


Fig. P1.34

Converting the local atmospheric pressure to kPa, we get $p_{atm} = 100$ kPa. Since the pressure in the tank, 200 kPa, is greater than the atmospheric pressure, the Bourdon reading is a *gage* pressure. Using the following relationship, $p_{gage} = p_{abs} - p_{atm}$ the Bourdon reading is 100 kPa.

PROBLEM 1.35

See Fig. P1.35. Applying the principles discussed in Sec. 1.6.1, the atmospheric pressure is

$$p_{atm} = \rho_m g L \implies L = \frac{p_{atm}}{\rho_m g} = \frac{100 \times 10^3 \text{ N/m}^2}{\left(13.59 \frac{\text{g}}{\text{cm}^3}\right)\left|\frac{1 \text{ kg}}{10^3 \text{ g}}\right|\left|\frac{10^2 \text{ cm}}{1 \text{ m}}\right|^3 \left(9.81 \frac{\text{m}}{\text{s}^2}\right)}\left|\frac{1 \text{ kg}\cdot\text{m/s}^2}{1 \text{ N}}\right|$$

$$= 0.75 \text{ m} \left|\frac{10^3 \text{ mm}}{1 \text{ m}}\right|$$

$$= 750 \text{ mm Hg}$$

Converting to in. Hg,

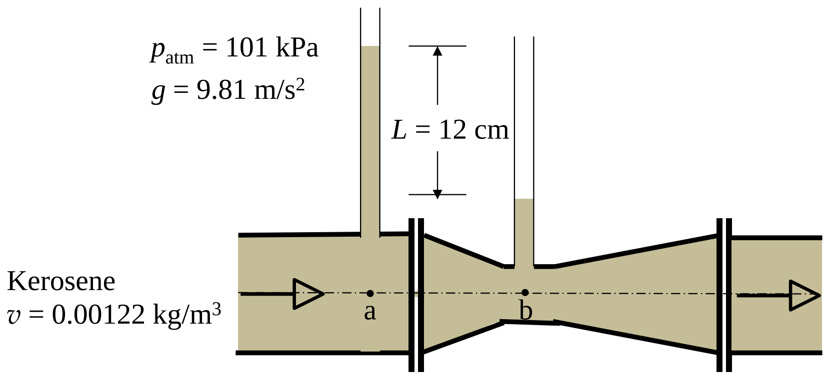
$$L = 750 \text{ mm Hg}\left|\frac{1 \text{ cm}}{10 \text{ mm}}\right|\left|\frac{1 \text{ in.}}{2.54 \text{ cm}}\right| = 29.53 \text{ in. Hg}$$

1.36 Liquid kerosene flows through a Venturi meter, as shown in Fig. P1.36. The pressure of the kerosene in the pipe supports columns of kerosene that differ in height by 12 cm. Determine the difference in pressure between points a and b, in kPa. Does the pressure increase or decrease as the kerosene flows from point a to point b as the pipe diameter decreases? The atmospheric pressure is 101 kPa, the specific volume of kerosene is 0.00122 m^3/kg, and the acceleration of gravity is $g = 9.81$ m/s^2.

KNOWN: Kerosene flows through a Venturi meter.

FIND: The pressure difference between points a and b, in kPa and whether pressure increases or decreases as the kerosene flows from point a to point b as the pipe diameter decreases.

SCHEMATIC AND GIVEN DATA:



ENGINEERING MODEL:
1. The kerosene is incompressible.
2. Atmospheric pressure is exerted at the open end of the fluid columns.

ANALYSIS:
Equation 1.11 applies to both columns of fluid (a and b). Let h_b be the height of the fluid above point b. Then $h_b + L$ is the height of the fluid above point a. Applying Eq. 1.11 to each column yields

$$p_a = p_{atm} + \rho g(h_b + L) = p_{atm} + \rho g h_b + \rho g L$$

and

$$p_b = p_{atm} + \rho g h_b$$

Thus, the difference in pressure between point a and point b is

$$\Delta p = p_b - p_a = (p_{atm} + \rho g h_b) - (p_{atm} + \rho g h_b + \rho g L)$$

$$\Delta p = -\rho g L$$