

# SOLUTIONS MANUAL

## Thermodynamics: An Engineering Approach

10th Edition

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## Chapter 1

## INTRODUCTION AND BASIC CONCEPTS

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## CYU - Check Your Understanding

### CYU 1-1 ■ Check Your Understanding

**CYU 1-1.1** Choose the wrong statement about the first law of thermodynamics.

- (a) During an interaction, energy can change from one form to another.
- (b) During an interaction, the total amount of energy remains constant.
- (c) Energy can be destroyed but it cannot be created.
- (d) Energy is a thermodynamic property.
- (e) A system with more energy input than output will gain energy.

*Answer:* (c) Energy can be destroyed but it cannot be created.

**CYU 1-1.2** Which statement best expresses the second law of thermodynamics?

- (a) The temperature of a well-sealed room increases when a fan in the room is turned on.
- (b) A cup of cool coffee in a warm room never gets hot by itself.
- (c) Heat is generated when there is friction between two surfaces.
- (d) A household refrigerator supplies heat to the kitchen when operating.
- (e) A person who has a smaller energy input than output will lose weight.

*Answer:* (b) A cup of cool coffee in a warm room never gets hot by itself.

### CYU 1-2 ■ Check Your Understanding

**CYU 1-2.1** Which of the following is not a correct unit for work?

- (a)  $\text{kg} \cdot \text{m}/\text{s}^2$
- (b)  $\text{N} \cdot \text{m}$
- (c)  $\text{kPa} \cdot \text{m}^3$
- (d)  $\text{kJ}$
- (e)  $\text{kWh}$

*Answer:* (a)  $\text{kg} \cdot \text{m}/\text{s}^2$

**CYU 1-2.2** Using unit considerations, select the correct equations.

- I.  $\text{Mass} = \text{Force} \times \text{Acceleration}$
  - II.  $\text{Work} = \text{Force} \times \text{Distance}$
  - III.  $\text{Work} = \text{Power} \times \text{Time}$
  - IV.  $\text{Density} = \text{Mass} \times \text{Volume}$
- (a) I and II
  - (b) I and III
  - (c) II and III
  - (d) I, II, and III
  - (e) II, III, and IV

*Answer:* (c) II and III

**CYU 1-2.3** What is the weight of 10 kg?

- (a) 10 N
- (b) 10 lbf
- (c) 9.8 N
- (d) 98 N
- (e) 322 lbf

*Answer:* (d) 98 N

$$W = mg = (10 \text{ kg})(9.8 \text{ m/s}^2) = 98 \text{ kg} \cdot \text{m/s}^2 = 98 \text{ N}$$

since  $1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$

### **CYU 1-3 . Check Your Understanding**

**CYU 1-3.1** Choose the wrong statement regarding systems and control volumes.

- (a) The mass or region outside the system is called the surroundings.
- (b) The real or imaginary surface that separates the system from its surroundings is called the boundary.
- (c) The boundary has zero thickness.
- (d) The boundary can neither contain any mass nor occupy any volume in space.
- (e) The boundary of a system is fixed; it cannot move.

*Answer:* (e) The boundary of a system is fixed; it cannot move.

**CYU 1-3.2** Choose the wrong statement regarding systems and control volumes.

- (a) Both mass and energy can cross the boundary of a control volume.
- (b) Mass cannot enter or leave a closed system but energy can.
- (c) Mass can enter or leave an isolated system but energy cannot.
- (d) The boundaries of a control volume can be real or imaginary.
- (e) The volume of a closed system does not have to be fixed.

*Answer:* (c) Mass can enter or leave an isolated system but energy cannot.

### **CYU 1-4 . Check Your Understanding**

**CYU 1-4.1** Which properties are intensive?

- I. Volume,  $m^3$
  - II. Density,  $\text{kg}/m^3$
  - III. Temperature,  $^\circ\text{C}$
  - IV. Pressure, kPa
- (a) II and III
  - (b) III and IV
  - (c) I, II and III
  - (d) II, III, and IV
  - (e) I, II, III, and IV

*Answer:* (d) II, III, and IV

**CYU 1-5 . Check Your Understanding**

**CYU 1-5.1** A  $1 - m^3$  tank contains 0.5 kg of a gas. What is the density (in  $kg/m^3$ ) and specific volume (in  $m^3/kg$ ) of the fluid, respectively?

- (a) 1, 0.5
- (b) 0.5, 1
- (c) 0.5, 2
- (d) 2, 0.5
- (e) 0.5, 0.5

Answer: (c) 0.5, 2

$$\rho = m/V = (0.5 \text{ kg})/(1 \text{ m}^3) = 0.5 \text{ kg/m}^3$$

$$v = V/m = (1 \text{ m}^3)/(0.5 \text{ kg}) = 2 \text{ m}^3/\text{kg}$$

**CYU 1-5.2** What is the specific volume of a fluid whose specific gravity is 1.25?

- (a)  $1.25 \text{ m}^3/\text{kg}$
- (b)  $1250 \text{ m}^3/\text{kg}$
- (c)  $1/1.25 \text{ m}^3/\text{kg}$
- (d)  $1/1250 \text{ m}^3/\text{kg}$
- (e)  $1.25 \text{ m}^3/\text{kg}$

Answer: (d)  $1/1250 \text{ m}^3/\text{kg}$

$$\rho = SG \rho_{\text{H}_2\text{O}} = (1.25)(1000 \text{ kg/m}^3) = 1250 \text{ kg/m}^3$$

$$v = 1/\rho = 1/(1250 \text{ kg/m}^3) = 1/1250 \text{ m}^3/\text{kg}$$

**CYU 1-5.3** What is the specific weight of a fluid whose specific gravity is 1?

- (a)  $1 \text{ N/m}^3$
- (b)  $9.8 \text{ N/m}^3$
- (c)  $10 \text{ N/m}^3$
- (d)  $980 \text{ N/m}^3$
- (e)  $9800 \text{ N/m}^3$

Answer: (e)  $9800 \text{ N/m}^3$

$$SW = \rho g = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2) = 9800 \text{ kg} \cdot \text{m/m}^3 \cdot \text{s}^2 = 9800 \text{ N/m}^3$$

$$\text{since } 1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$$

**CYU 1-6 . Check Your Understanding**

**CYU 1-6.1** Choose the wrong statement regarding state and equilibrium.

- (a) A set of properties completely describes the state of a system.
- (b) At a given state, all the properties of a system have fixed values.
- (c) The state of a system only changes if the values of at least two properties change.
- (d) In an equilibrium state there are no driving forces within the system.
- (e) A system in equilibrium experiences no changes when it is isolated from its surroundings.

Answer: (c) The state of a system only changes if the values of at least two properties change.

**CYU 1-8 . Check Your Understanding**

**CYU 1-8.1** The initial and final temperatures of an object are  $20^{\circ}\text{C}$  and  $300\text{ K}$ . The temperature change of the object is

- (a)  $27^{\circ}\text{C}$
- (b)  $20^{\circ}\text{C}$
- (c)  $7^{\circ}\text{C}$
- (d)  $300\text{ K}$
- (e)  $280\text{ K}$

*Answer:* (c)  $7^{\circ}\text{C}$

$$T_1 = 20^{\circ}\text{C}$$

$$T_2 = 300\text{ K} = 27^{\circ}\text{C}$$

$$dT = 27 - 20 = 7^{\circ}\text{C}$$

**CYU 1-8.2** A temperature change of  $10^{\circ}\text{C}$  is equal to

- I.  $18^{\circ}\text{F}$
- II.  $18\text{ R}$
- III.  $10\text{ K}$
- (a) Only I
- (b) Only II
- (c) I and II
- (d) I and III
- (e) I, II, and III

*Answer:* (e) I, II, and III

$$dT(\text{K}) = dT(\text{C}) \rightarrow dT = 10\text{ C} = 10\text{ K}$$

$$dT(\text{F}) = 1.8 dT(\text{C}) \rightarrow dT = 10\text{ C} = 18\text{ F}$$

$$dT(\text{R}) = 1.8 dT(\text{C}) \rightarrow dT = 10\text{ C} = 18\text{ R}$$

**CYU 1-8.3** A temperature change of  $36^{\circ}\text{F}$  is equal to

- I.  $20^{\circ}\text{C}$
- II.  $36\text{ K}$
- III.  $36\text{ R}$
- (a) Only I
- (b) Only II
- (c) I and II
- (d) I and III
- (e) I, II, and III

*Answer:* (d) I and III

$$dT(\text{F}) = 1.8 dT(\text{C}) \rightarrow dT = 36\text{ F} = 20\text{ C}$$

$$dT(\text{F}) = 1.8 dT(\text{K}) \rightarrow dT = 36\text{ F} = 20\text{ K}$$

$$dT(\text{R}) = dT(\text{F}) \rightarrow dT = 36\text{ F} = 36\text{ R}$$

## CYU 1-9 . Check Your Understanding

**CYU 1-9.1** Select all of the pressure units.

- I.  $\text{N}/\text{cm}^3$
- II. bar
- III. MPa
- IV.  $\text{kJ}/\text{m}^3$

- (a) I, II, III, and IV    (b) II, III, and IV    (c) II and III    (d) III and IV    (e) I and II

Answer: (b) II, III, and IV

**CYU 1-9.2** The pressure units Pa and psi are equivalent to

- (a) Pa = kgf/m<sup>2</sup>, psi = lbf/in<sup>2</sup>  
 (b) Pa = kgf/cm<sup>2</sup>, psi = lbf/ft<sup>2</sup>  
 (c) Pa = N/m<sup>2</sup>, psi = lbf/ft<sup>2</sup>  
 (d) Pa = N/m<sup>2</sup>, psi = lbf/in<sup>2</sup>  
 (e) Pa = N/cm<sup>2</sup>, psi = lbf/in<sup>2</sup>

Answer: (d) Pa = N/m<sup>2</sup>, psi = lbf/in<sup>2</sup>

**CYU 1-9.3** The gage pressure of a gas in a tank is 230 kPa. If the atmospheric pressure is 100 kPa, what is the absolute pressure of the gas?

- I. 330 kPa  
 II. 33 bar  
 III. 130 kPa  
 IV. 0.13 MPa  
 V. 0.23 MPa  
 (a) Only I  
 (b) Only III  
 (c) Only V  
 (d) III and IV  
 (e) I and II

Answer: (a) Only I

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} = 230 + 100 = 330 \text{ kPa} = 0.33 \text{ MPa} = 3.3 \text{ bar}$$

**CYU 1-9.4** A tank whose surface is open to the atmosphere is filled with water with a depth of 10 m. If the atmospheric pressure is 100 kPa, what is the absolute pressure at the bottom of the tank?

- (a) 98,100 kPa    (b) 98,000 kPa    (c) 100 kPa    (d) 110 kPa    (e) 198 kPa

Answer: (e) 198 kPa

$$P = P_{\text{atm}} + \rho gh = (100 \text{ kPa}) + \left(\frac{1000 \text{ kg}}{\text{m}^3}\right) \left(\frac{9.8 \text{ m}}{\text{s}^2}\right) (10 \text{ m}) \left(\frac{1}{1000}\right) = 198 \text{ kPa}$$

since  $1 \text{ N} = 1 \text{ kg} \cdot \text{m}/\text{s}^2$  and  $1 \text{ kPa} = 1000 \text{ N}/\text{m}^2$

### CYU 1-10 . Check Your Understanding

**CYU 1-9.1** The pressure at the top of a mountain is 95 kPa. If the atmospheric pressure is 100 kPa, what is the height of the mountain? Take the average density of air and the gravitational acceleration to be  $1 \text{ kg}/\text{m}^3$  and  $10 \text{ m}/\text{s}^2$ .

- (a) 50 m  
 (b) 100 m  
 (c) 500 m  
 (d) 1000 m  
 (e) 5000 m

Answer: (c) 500 m

$$P = P_{\text{atm}} - \rho gh \rightarrow 95 \text{ kPa} = (100 \text{ kPa}) - \left(\frac{1 \text{ kg}}{\text{m}^3}\right) \left(\frac{10 \text{ m}}{\text{s}^2}\right) h \left(\frac{1}{1000}\right) \rightarrow h = 500 \text{ kPa}$$

since  $1 \text{ N} = 1 \text{ kg} \cdot \text{m}/\text{s}^2$  and  $1 \text{ kPa} = 1000 \text{ N}/\text{m}^2$

**CYU 1-11 . Check Your Understanding**

**CYU 1-11.1** Which numbers have three significant digits?

- I. 0.005
  - II. 0.050
  - III. 0.500
  - IV. 50.0
- (a) I and II
  - (b) III and IV
  - (c) I, III, and IV
  - (d) II, III, and IV
  - (e) I, II, III, and IV

*Answer:* (b) III and IV

## PROBLEMS

### Thermodynamics

**1-1C** On a downhill road the potential energy of the bicyclist is being converted to kinetic energy, and thus the bicyclist picks up speed. There is no creation of energy, and thus no violation of the conservation of energy principle.

**1-2C** A car going uphill without the engine running would increase the energy of the car, and thus it would be a violation of the first law of thermodynamics. Therefore, this cannot happen. Using a level meter (a device with an air bubble between two marks of a horizontal water tube) it can be shown that the road that looks uphill to the eye is actually downhill.

**1-3C** There is no truth to his claim. It violates the second law of thermodynamics.

**1-4C** Classical thermodynamics is based on experimental observations whereas statistical thermodynamics is based on the average behavior of large groups of particles.

## Mass, Force, and Units

**1-5C** In this unit, the word *light* refers to the speed of light. The light-year unit is then the product of a velocity and time. Hence, this product forms a distance dimension and unit.

**1-6C** Pound-mass lbm is the mass unit in English system whereas pound-force lbf is the force unit. One pound-force is the force required to accelerate a mass of 32.174 lbm by  $1 \text{ ft/s}^2$ . In other words, the weight of a 1-lbm mass at sea level is 1 lbf.

**1-7C** There is no acceleration, thus the net force is zero in both cases.

**1-8** The mass of an object is given. Its weight is to be determined.

**Analysis** Applying Newton's second law, the weight is determined to be

$$W = mg = (200 \text{ kg})(9.6 \text{ m/s}^2) = 1920 \text{ N}$$

*Solution with appropriate Software*

"Given"

$m=200 \text{ [kg]}$

$g=9.6 \text{ [m/s}^2\text{]}$

"Analysis"

$W=m \cdot g$

**1-9E** The mass of an object is given. Its weight is to be determined.

**Analysis** Applying Newton's second law, the weight is determined to be

$$W = mg = (10 \text{ lbm})(32.0 \text{ ft/s}^2) \left( \frac{1 \text{ lbf}}{32.174 \text{ lbm} \cdot \text{ft/s}^2} \right) = 9.95 \text{ lbf}$$

*Solution with Appropriate Software*

"Given"

$m=10 \text{ [lbm]}$

$g=32.0 \text{ [ft/s}^2\text{]}$

"Analysis"

$W=m \cdot g \cdot \text{Convert}(\text{lbm} \cdot \text{ft/s}^2, \text{lbf})$

**1-10** The acceleration of an aircraft is given in  $g$ 's. The net upward force acting on a man in the aircraft is to be determined.

**Analysis** From the Newton's second law, the force applied is

$$F = ma = m(6g) = (90 \text{ kg})(6 \times 9.81 \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 5297 \text{ N}$$

*Solution with Appropriate Software***"Given"**

$m=90 \text{ [kg]}$

$a=6 \cdot g$

**"Analysis"**

$g=9.81 \text{ [m/s}^2\text{]}$

$W=m \cdot a$

**1-11** Gravitational acceleration  $g$  and thus the weight of bodies decreases with increasing elevation. The percent reduction in the weight of an airplane cruising at 13,000 m is to be determined.

**Properties** The gravitational acceleration  $g$  is given to be  $9.807 \text{ m/s}^2$  at sea level and  $9.767 \text{ m/s}^2$  at an altitude of 13,000 m.

**Analysis** Weight is proportional to the gravitational acceleration  $g$ , and thus the percent reduction in weight is equivalent to the percent reduction in the gravitational acceleration, which is determined from

$$\begin{aligned} \text{\%Reduction in weight} &= \text{\%Reduction in } g \\ &= \frac{\Delta g}{g} \times 100 = \frac{9.807 - 9.767}{9.807} \times 100 = \mathbf{0.41\%} \end{aligned}$$

Therefore, the airplane and the people in it will weight 0.41% less at 13,000 m altitude.

**Discussion** Note that the weight loss at cruising altitudes is negligible.

*Solution with Appropriate Software***"Given"**

$g_{\text{sea}}=9.807 \text{ [m/s}^2\text{]}$

$g_{\text{plane}}=9.767 \text{ [m/s}^2\text{]}$

$\text{altitude}=13000 \text{ [m]}$

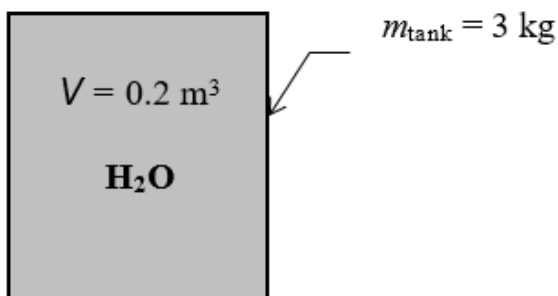
**"Analysis"**

$$\text{Reduction\%}=(g_{\text{sea}}-g_{\text{plane}})/g_{\text{sea}} \cdot \text{Convert}(\%) \text{ "since weight is proportional to the } g \text{"}$$

**1-12** A plastic tank is filled with water. The weight of the combined system is to be determined.

**Assumptions** The density of water is constant throughout.

**Properties** The density of water is given to be  $\rho = 1000 \text{ kg/m}^3$ .



**Analysis** The mass of the water in the tank and the total mass are

$$m_w = \rho V = (1000 \text{ kg/m}^3)(0.2 \text{ m}^3) = 200 \text{ kg}$$

$$m_{\text{total}} = m_w + m_{\text{tank}} = 200 + 3 = 203 \text{ kg}$$

Thus,

$$W = mg = (203 \text{ kg})(9.81 \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 1991 \text{ N}$$

*Solution with Appropriate Software*

"Given"

$$m_{\text{tank}} = 3 \text{ [kg]}$$

$$V = 0.2 \text{ [m}^3\text{]}$$

$$\rho = 1000 \text{ [kg/m}^3\text{]}$$

"Analysis"

$$m_{\text{water}} = \rho \cdot V$$

$$m_{\text{total}} = m_{\text{water}} + m_{\text{tank}}$$

$$g = 9.81 \text{ [m/s}^2\text{]}$$

$$W = m_{\text{total}} \cdot g$$

1-13 A rock is thrown upward with a specified force. The acceleration of the rock is to be determined.



*Analysis* The weight of the rock is

$$W = mg = (2 \text{ kg})(9.79 \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 19.58 \text{ N}$$

Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 200 - 19.58 = 180.4 \text{ N}$$

From the Newton's second law, the acceleration of the rock becomes

$$a = \frac{F}{m} = \frac{180.4 \text{ N}}{2 \text{ kg}} \left( \frac{1 \text{ kg} \cdot \text{m/s}^2}{1 \text{ N}} \right) = 90.2 \text{ m/s}^2$$

*Solution with Appropriate Software*

"Given"

$$m = 2 \text{ [kg]}$$

$$g = 9.79 \text{ [m/s}^2\text{]}$$

$$F_{\text{up}} = 200 \text{ [N]}$$

"The weight of the rock is"

$$W = m \cdot g$$

"The force balance on the rock yields the net force acting on the rock as"

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}}$$

$$F_{\text{down}} = W$$

"The acceleration of the rock is determined from Newton's second law."

$$F_{\text{net}} = a \cdot m$$



**1-14** Problem 1-13 is reconsidered. The entire solution by appropriate software is to be printed out, including the numerical results with proper units.

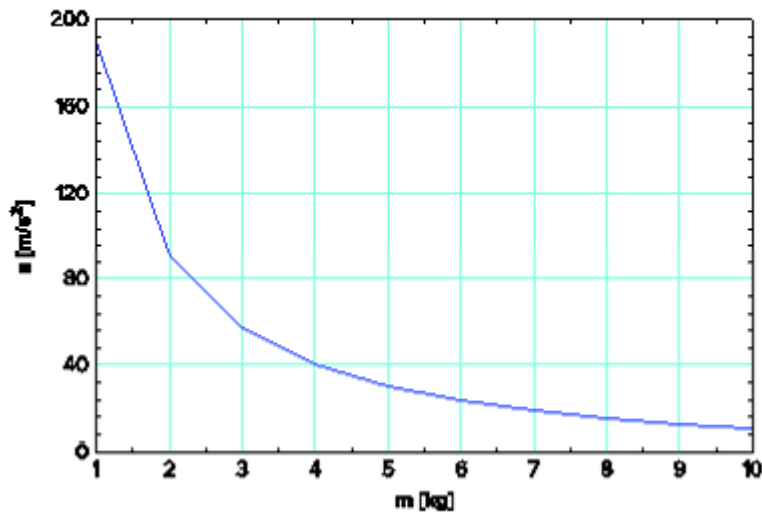
**Analysis** The problem is solved using appropriate software, and the solution is given below.

```

m=2 [kg]
F_up=200 [N]
g=9.79 [m/s^2]
W=m*g
F_net=F_up-F_down
F_down=W
F_net=m*a
a=90.21 [m/s^2]
F_down=19.58 [N]
F_net=180.4 [N]
F_up=200 [N]
g=9.79 [m/s^2]
m=2 [kg]
W=19.58 [N]

```

m[kg]	a [m/s <sup>2</sup> ]
1	190.2
2	90.21
3	56.88
4	40.21
5	30.21
6	23.54
7	18.78
8	15.21
9	12.43
10	10.21



**1-15** A resistance heater is used to heat water to desired temperature. The amount of electric energy used in kWh and kJ are to be determined.

**Analysis** The resistance heater consumes electric energy at a rate of 4 kW or 4 kJ/s. Then the total amount of electric energy used in 3 hours becomes

$$\begin{aligned}\text{Total energy} &= (\text{Energy per unit time})(\text{Time interval}) \\ &= (4 \text{ kW})(3 \text{ h}) \\ &= 12 \text{ kWh}\end{aligned}$$

$$\text{Noting that } 1 \text{ kWh} = (1 \text{ kJ/s})(3600 \text{ s}) = 3600 \text{ kJ}$$

$$\begin{aligned}\text{Total energy} &= (12 \text{ kWh})(3600 \text{ kJ/kWh}) \\ &= \mathbf{43,200 \text{ kJ}}\end{aligned}$$

**Discussion** Note that kW is a unit for power whereas kWh is a unit for energy.

*Solution with Appropriate Software*

"Given"

$$W_{\text{dot}_e} = 4 \text{ [kW]}$$

$$\text{time} = 3 \text{ [h]}$$

"Analysis"

$$\text{Energy} = W_{\text{dot}_e} \cdot \text{time}$$

$$\text{Energy}_{\text{kJ}} = \text{Energy} \cdot \text{Convert}(\text{kWh}, \text{kJ})$$

**1-16E** An astronaut took his scales with him to space. It is to be determined how much he will weigh on the spring and beam scales in space.

**Analysis** (a) A spring scale measures weight, which is the local gravitational force applied on a body:

$$W = mg = (150 \text{ lbm})(5.48 \text{ ft/s}^2) \left( \frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) = 25.5 \text{ lbf}$$

(b) A beam scale compares masses and thus is not affected by the variations in gravitational acceleration. The beam scale will read what it reads on earth,

$$W = \mathbf{150 \text{ lbf}}$$

*Solution with Appropriate Software*

"Given"

$$m = 150 \text{ [lbm]}$$

$$g_{\text{moon}} = 5.48 \text{ [ft/s}^2\text{]}$$

"Analysis"

$$W_{\text{spring}} = m \cdot g_{\text{moon}} \cdot \text{Convert}(\text{lbm} \cdot \text{ft/s}^2, \text{lbf})$$

$$g_{\text{earth}} = 32.174 \text{ [ft/s}^2\text{]}$$

$$W_{\text{beam}} = m \cdot g_{\text{earth}} \cdot \text{Convert}(\text{lbm} \cdot \text{ft/s}^2, \text{lbf})$$

**1-17** During an analysis, a relation with inconsistent units is obtained. A correction is to be found, and the probable cause of the error is to be determined.

**Analysis** The two terms on the right-hand side of the equation

$$E = 25 \text{ kJ} + 7 \text{ kJ/kg}$$

do not have the same units, and therefore they cannot be added to obtain the total energy. Multiplying the last term by mass will eliminate the kilograms in the denominator, and the whole equation will become dimensionally homogeneous; that is, every term in the equation will have the same unit.

**Discussion** Obviously this error was caused by forgetting to multiply the last term by mass at an earlier stage.

**1-18** A gas tank is being filled with gasoline at a specified flow rate. Based on unit considerations alone, a relation is to be obtained for the filling time.

**Assumptions** Gasoline is an incompressible substance and the flow rate is constant.

**Analysis** The filling time depends on the volume of the tank and the discharge rate of gasoline. Also, we know that the unit of time is ‘seconds’. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$$t [s] \leftrightarrow V [L], \quad \text{and} \quad \dot{V} [L/s]$$

It is obvious that the only way to end up with the unit “s” for time is to divide the tank volume by the discharge rate. Therefore, the desired relation is

$$t = \frac{V}{\dot{V}}$$

**Discussion** Note that this approach may not work for cases that involve dimensionless (and thus unitless) quantities.

## Systems, Properties, State, and Processes

**1-19C** Carbon dioxide is generated by the combustion of fuel in the engine. Any system selected for this analysis must include the fuel and air while it is undergoing combustion. The volume that contains this air-fuel mixture within piston-cylinder device can be used for this purpose. One can also place the entire engine in a control boundary and trace the system-surroundings interactions to determine the rate at which the engine generates carbon dioxide.

**1-20C** The radiator should be analyzed as an open system since mass is crossing the boundaries of the system.

**1-21C** A can of soft drink should be analyzed as a closed system since no mass is crossing the boundaries of the system.

**1-22C** When analyzing the control volume selected, we must account for all forms of water entering and leaving the control volume. This includes all streams entering or leaving the lake, any rain falling on the lake, any water evaporated to the air above the lake, any seepage to the underground earth, and any springs that may be feeding water to the lake.

**1-23C** In order to describe the state of the air, we need to know the value of all its properties. Pressure, temperature, and water content (i.e., relative humidity or dew point temperature) are commonly cited by weather forecasters. But, other properties like wind speed and chemical composition (i.e., pollen count and smog index, for example) are also important under certain circumstances.

Assuming that the air composition and velocity do not change and that no pressure front motion occurs during the day, the warming process is one of constant pressure (i.e., isobaric).

**1-24C** Intensive properties do not depend on the size (extent) of the system but extensive properties do.

**1-25C** The original specific weight is

$$\gamma_1 = \frac{W}{V}$$

If we were to divide the system into two halves, each half weighs  $W/2$  and occupies a volume of  $V/2$ . The specific weight of one of these halves is

$$\gamma = \frac{W/2}{V/2} = \gamma_1$$

which is the same as the original specific weight. Hence, specific weight is an *intensive property*.

**1-26C** The number of moles of a substance in a system is directly proportional to the number of atomic particles contained in the system. If we divide a system into smaller portions, each portion will contain fewer atomic particles than the original system. The number of moles is therefore an *extensive property*.

**1-27C** The state of a simple compressible system is completely specified by two independent, intensive properties.

**1-28C** Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

**1-29C** A process during which a system remains almost in equilibrium at all times is called a quasi-equilibrium process. Many engineering processes can be approximated as being quasi-equilibrium. The work output of a device is maximum and the work input to a device is minimum when quasi-equilibrium processes are used instead of nonquasi-equilibrium processes.

**1-30C** A process during which the temperature remains constant is called isothermal; a process during which the pressure remains constant is called isobaric; and a process during which the volume remains constant is called isochoric.

**1-31C** The **specific gravity**, or **relative density**, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at  $4^\circ\text{C}$ , for which  $\rho_{\text{H}_2\text{O}} = 1000 \text{ kg/m}^3$ ). That is,  $\text{SG} = \rho/\rho_{\text{H}_2\text{O}}$ . When specific gravity is known, density is determined from  $\rho = \text{SG} \times \rho_{\text{H}_2\text{O}}$ .



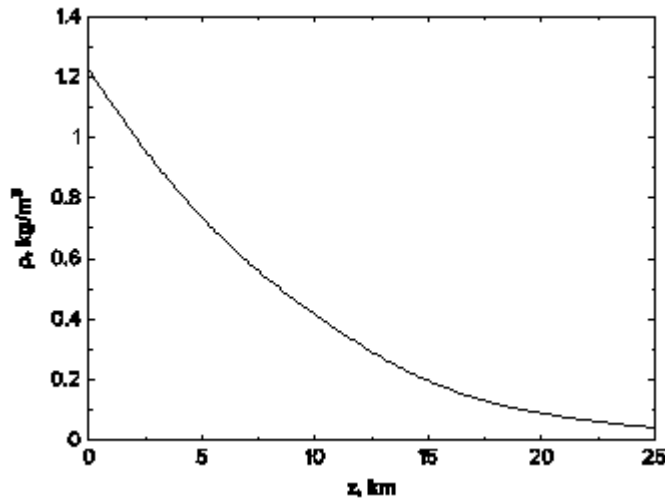
**1-32** The variation of density of atmospheric air with elevation is given in tabular form. A relation for the variation of density with elevation is to be obtained, the density at 7 km elevation is to be calculated, and the mass of the atmosphere using the correlation is to be estimated.

**Assumptions 1** Atmospheric air behaves as an ideal gas. **2** The earth is perfectly sphere with a radius of 6377 km, and the thickness of the atmosphere is 25 km.

**Properties** The density data are given in tabular form as

$r$ , km	$z$ , km	$\rho$ , $\text{kg/m}^3$
6377	0	1.225
6378	1	1.112
6379	2	1.007
6380	3	0.9093

6381	4	0.8194
6382	5	0.7364
6383	6	0.6601
6385	8	0.5258
6387	10	0.4135
6392	15	0.1948
6397	20	0.08891
6402	25	0.04008



**Analysis** Using appropriate software, (1) Define a trivial function  $\rho = a + bz + cz^2$  in equation window, (2) select new parametric table from Tables, and type the data in a two-column table, (3) select Plot and plot the data, and (4) select plot and click on “curve fit” to get curve fit window. Then specify 2<sup>nd</sup> order polynomial and enter/edit equation. The results are:

$$\rho(z) = a + bz + cz^2 = 1.20252 - 0.101674z + 0.0022375z^2 \quad \text{for the unit of kg/m}^3,$$

$$\text{(or, } \rho(z) = (1.20252 - 0.101674z + 0.0022375z^2)\rho 10^9 \quad \text{for the unit of kg/m}^3)$$

where  $z$  is the vertical distance from the earth surface at sea level. At  $z = 7$  km, the equation would give  $\rho = 0.60 \text{ kg/m}^3$ .

(b) The mass of atmosphere can be evaluated by integration to be

$$\begin{aligned} m &= \int_V \rho dV = \int_{z=0}^h (a + bz + cz^2) 4\pi(r_0 + z)^2 dz = 4\pi \int_{z=0}^h (a + bz + cz^2)(r_0^2 + 2r_0z + z^2) dz \\ &= 4\pi [ar_0^2h + r_0(2a + br_0)h^2/2 + (a + 2br_0 + cr_0^2)h^3/3 + (b + 2cr_0)h^4/4 + ch^5/5] \end{aligned}$$

where  $r_0 = 6377$  km is the radius of the earth,  $h = 25$  km is the thickness of the atmosphere, and  $a = 1.20252$ ,  $b = -0.101674$ , and  $c = 0.0022375$  are the constants in the density function. Substituting and multiplying by the factor  $10^9$  for the density unity  $\text{kg/km}^3$ , the mass of the atmosphere is determined to be

$$m = 5.092 \times 10^{18} \text{ kg}$$

Performing the analysis with excel would yield exactly the same results.

"Using linear regression feature based on the data on parametric table, we obtain"

$\rho = 1.20251659E+00 - 0.101669722E-01 * z + 2.23747073E-03 * z^2$

$z = 7$  [km]

"The mass of the atmosphere is obtained by integration to be"

$m = 4 * \pi * (a * r_0^2 * h + r_0 * (2 * a + b * r_0) * h^2 / 2 + (a + 2 * b * r_0 + c * r_0^2) * h^3 / 3 + (b + 2 * c * r_0) * h^4 / 4 + c * h^5 / 5) * 1E9$

$a = 1.20252$

$b = -0.101670$

$c = 0.0022375$

$r_0 = 6377$  [km]

$h=25$  [km]

## Temperature

**1-33C** They are Celsius ( $^{\circ}\text{C}$ ) and kelvin (K) in the SI, and fahrenheit ( $^{\circ}\text{F}$ ) and rankine (R) in the English system.

**1-34C** Probably, but not necessarily. The operation of these two thermometers is based on the thermal expansion of a fluid. If the thermal expansion coefficients of both fluids vary linearly with temperature, then both fluids will expand at the same rate with temperature, and both thermometers will always give identical readings. Otherwise, the two readings may deviate.

**1-35C** Two systems having different temperatures and energy contents are brought in contact. The direction of heat transfer is to be determined.

*Analysis* Heat transfer occurs from warmer to cooler objects. Therefore, heat will be transferred from system B to system A until both systems reach the same temperature.

**1-36C** The zeroth law of thermodynamics states that two bodies are in thermal equilibrium if both have the same temperature reading, even if they are not in contact.

**1-37E** A temperature is given in  $^{\circ}\text{C}$ . It is to be expressed in  $^{\circ}\text{F}$ , K, and R.

*Analysis* Using the conversion relations between the various temperature scales,

$$T(\text{K}) = T(^{\circ}\text{C}) + 273 = 18^{\circ}\text{C} + 273 = \mathbf{291\text{ K}}$$

$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32 = (1.8)(18) + 32 = \mathbf{64.4^{\circ}\text{F}}$$

$$T(\text{R}) = T(^{\circ}\text{F}) + 460 = 64.4 + 460 = \mathbf{524.4\text{ R}}$$

*Solution with Appropriate Software*

"Given"

$$T_{\text{C}}=18\text{ [C]}$$

"Analysis"

$$T_{\text{K}}=T_{\text{C}}+273$$

$$T_{\text{F}}=1.8 \cdot T_{\text{C}}+32$$

$$T_{\text{R}}=T_{\text{F}}+460$$

**1-38E** The temperature of steam given in K unit is to be converted to  $^{\circ}\text{F}$  unit.

*Analysis* Using the conversion relations between the various temperature scales,

$$T(^{\circ}\text{C}) = T(\text{K}) - 273 = 300 - 273 = 27^{\circ}\text{C}$$

$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32 = (1.8)(27) + 32 = 80.6^{\circ}\text{F}$$

*Solution with Appropriate Software*

"Given"

$$T_{\text{K}}=300\text{ [K]}$$

"Analysis"

$$T_C = T_K - 273$$

$$T_F = 1.8 \cdot T_C + 32$$

**1-39** A temperature change is given in °C. It is to be expressed in K.

**Analysis** This problem deals with temperature changes, which are identical in Kelvin and Celsius scales. Thus,

$$\Delta T(K) = \Delta T(^{\circ}C) = \mathbf{130\ K}$$

*Solution with Appropriate Software*

"Given"

$$\text{DELTA } T_C = 130 \text{ [C]}$$

"Analysis"

$$\text{DELTA } T_K = \text{DELTA } T_C$$

**1-40E** A temperature change is given in °F. It is to be expressed in °C, K, and R.

**Analysis** This problem deals with temperature changes, which are identical in Rankine and Fahrenheit scales. Thus,

$$\Delta T(R) = \Delta T(^{\circ}F) = \mathbf{45\ R}$$

The temperature changes in Celsius and Kelvin scales are also identical, and are related to the changes in Fahrenheit and Rankine scales by

$$\Delta T(K) = \Delta T(R)/1.8 = 45/1.8 = \mathbf{25\ K}$$

and

$$\Delta T(^{\circ}C) = \Delta T(K) = \mathbf{25^{\circ}C}$$

*Solution with Appropriate Software*

"Given"

$$\text{DELTA } T_F = 45 \text{ [F]}$$

"Analysis"

$$\text{DELTA } T_R = \text{DELTA } T_F$$

$$\text{DELTA } T_K = \text{DELTA } T_R / 1.8$$

$$\text{DELTA } T_C = \text{DELTA } T_K$$

**1-41E** The temperature of oil given in °F unit is to be converted to °C unit.

**Analysis** Using the conversion relation between the temperature scales,

$$T(^{\circ}C) = \frac{T(^{\circ}F) - 32}{1.8} = \frac{150 - 32}{1.8} = 65.6^{\circ}C$$

*Solution with Appropriate Software*

"Given"

$$T_F = 150 \text{ [F]}$$

"Analysis"

$$T_C = (T_F - 32) / 1.8$$

**1-42E** The temperature of air given in °C unit is to be converted to °F unit.

**Analysis** Using the conversion relation between the temperature scales,

$$T(^{\circ}F) = 1.8T(^{\circ}C) + 32 = (1.8)(150) + 32 = 302^{\circ}F$$

*Solution with Appropriate Software*

"Given"

$$T_{\text{C}} = 150 \text{ [C]}$$

"Analysis"

$$T_{\text{F}} = 1.8 \cdot T_{\text{C}} + 32$$

**1-43E** During a heating process, the temperature of a system rises by 10°C. Express this rise in temperature in K, °F, and R.

**1-** The temperature rise of a system is to be expressed in different units.

**Analysis** This problem deals with temperature changes, which are identical in Kelvin and Celsius scales. Then,

$$\Delta T(\text{K}) = \Delta T(^{\circ}\text{C}) = \mathbf{10 \text{ K}}$$

The temperature changes in Fahrenheit and Rankine scales are also identical and are related to the changes in Celsius and Kelvin scales through Eqs. 1–11 and 1–14:

$$\Delta T(\text{R}) = 1.8 \Delta T(\text{K}) = (1.8)(10) = \mathbf{18 \text{ R}}$$

and

$$\Delta T(^{\circ}\text{F}) = \Delta T(\text{R}) = \mathbf{18^{\circ}\text{F}}$$

**Discussion** Note that the units °C and K are interchangeable when dealing with temperature differences.

## Pressure, Manometer, and Barometer

**1-44C** The pressure relative to the atmospheric pressure is called the *gage pressure*, and the pressure relative to an absolute vacuum is called *absolute pressure*.

**1-45C** The atmospheric pressure, which is the external pressure exerted on the skin, decreases with increasing elevation. Therefore, the pressure is lower at higher elevations. As a result, the difference between the blood pressure in the veins and the air pressure outside increases. This pressure imbalance may cause some thin-walled veins such as the ones in the nose to burst, causing bleeding. The shortness of breath is caused by the lower air density at higher elevations, and thus lower amount of oxygen per unit volume.

**1-46C** The blood vessels are more restricted when the arm is parallel to the body than when the arm is perpendicular to the body. For a constant volume of blood to be discharged by the heart, the blood pressure must increase to overcome the increased resistance to flow.

**1-47C** No, the absolute pressure in a liquid of constant density does not double when the depth is doubled. It is the *gage pressure* that doubles when the depth is doubled.

**1-48C** The density of air at sea level is higher than the density of air on top of a high mountain. Therefore, the volume flow rates of the two fans running at identical speeds will be the same, but the mass flow rate of the fan at sea level will be higher.

**1-49E** The pressure given in kPa unit is to be converted to psia.

**Analysis** Using the kPa to psia units conversion factor,

$$P = (200 \text{ kPa}) \left( \frac{1 \text{ psia}}{6.895 \text{ kPa}} \right) = 29.0 \text{ psia}$$

*Solution with Appropriate Software*

"Given"

P\_kPa=200 [kPa]

"Analysis"

P\_psia=P\_kPa/(6.895 [kPa/psia])

**1-50E** A manometer measures a pressure difference as inches of water. This is to be expressed in psia unit.

**Properties** The density of water is taken to be 62.4 lbm/ft<sup>3</sup> (Table A-3E).

**Analysis** Applying the hydrostatic equation,

$$\begin{aligned} \Delta P &= \rho g h \\ &= (62.4 \text{ lbm/ft}^3)(32.174 \text{ ft/s}^2)(40/12 \text{ ft}) \left( \frac{1 \text{ lbf}}{32.174 \text{ lbm} \cdot \text{ft/s}^2} \right) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) \\ &= 1.44 \text{ lbf/in}^2 = 1.44 \text{ psia} \end{aligned}$$

*Solution with Appropriate Software*

"Given"

h\_in=40 [in] "or 40 inWater"

"Analysis"

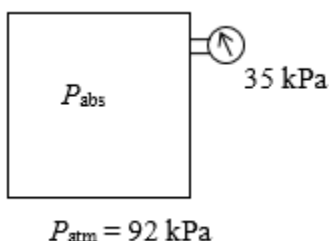
g=32.174 [ft/s^2] "acceleration of gravity"

rho\_w=62.4 [lbm/ft^3]

h=h\_in\*Convert(in, ft)

DELTAP=rho\_w\*g\*h\*Convert(lbm/ft-s^2, psia)

**1-51** The pressure in a vacuum chamber is measured by a vacuum gage. The absolute pressure in the chamber is to be determined.



**Analysis** The absolute pressure in the chamber is determined from

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$$P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}} = 92 - 35 = 57 \text{ kPa}$$

*Solution with Appropriate Software*

"Given"

$$P_{\text{vac}}=35 \text{ [kPa]}$$

$$P_{\text{atm}}=92 \text{ [kPa]}$$

"Analysis"

$$P_{\text{abs}}=P_{\text{atm}}-P_{\text{vac}}$$

**1-52E** The maximum pressure of a tire is given in English units. It is to be converted to SI units.

**Assumptions** The listed pressure is gage pressure.

**Analysis** Noting that  $1 \text{ atm} = 101.3 \text{ kPa} = 14.7 \text{ psi}$ , the listed maximum pressure can be expressed in SI units as

$$P_{35 \text{ psi}} \left( \frac{101.3 \text{ kPa}}{14.7 \text{ psi}} \right)_{\text{max}}$$

**Discussion** We could also solve this problem by using the conversion factor  $1 \text{ psi} = 6.895 \text{ kPa}$ .

*Solution with Appropriate Software*

"Given"

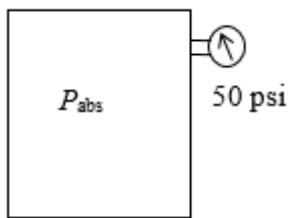
$$P_{\text{psia}}=35 \text{ [psia]}$$

"Analysis"

$$P_{\text{kPa}}=P_{\text{psia}}*(101.3 \text{ [kPa]})/(14.7 \text{ [psia]})$$

**1-53E** A pressure gage connected to a tank reads 50 psi. The absolute pressure in the tank is to be determined.

**Properties** The density of mercury is given to be  $\rho = 848.4 \text{ lbm/ft}^3$ .



**Analysis** The atmospheric (or barometric) pressure can be expressed as

$$\begin{aligned} P_{\text{atm}} &= \rho gh \\ &= (848.4 \text{ lbm/ft}^3)(32.2 \text{ ft/s}^2)(29.1/12 \text{ ft}) \left( \frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) \\ &= 14.29 \text{ psia} \end{aligned}$$

Then the absolute pressure in the tank is

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} = 50 + 14.29 = 64.3 \text{ psia}$$

*Solution with Appropriate Software*

"Given"

$$P_{\text{gage}}=50 \text{ [psi]}$$

$$h_{\text{in}}=29.1 \text{ [in]} \text{ "or } 29.1 \text{ inHg"}$$

$$\rho_{\text{mercury}}=848.4 \text{ [lbm/ft}^3\text{]}$$

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**"Analysis"**

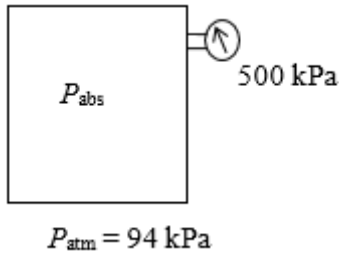
$g=32.174$  [ft/s<sup>2</sup>] "acceleration of gravity"

$h=h_{in}$ \*Convert(in, ft)

$P_{atm}=\rho_{mercury}*g*h$ \*Convert(lbm/ft-s<sup>2</sup>, psia)

$P_{abs}=P_{atm}+P_{gage}$

**1-54** A pressure gage connected to a tank reads 500 kPa. The absolute pressure in the tank is to be determined.



**Analysis** The absolute pressure in the tank is determined from

$$P_{abs} = P_{gage} + P_{atm} = 500 + 94 = 594 \text{ kPa}$$

**Solution with Appropriate Software****"Given"**

$P_{gage}=500$  [kPa]

$P_{atm}=94$  [kPa]

**"Analysis"**

$P_{abs}=P_{atm}+P_{gage}$

**1-55E** The weight and the foot imprint area of a person are given. The pressures this man exerts on the ground when he stands on one and on both feet are to be determined.

**Assumptions** The weight of the person is distributed uniformly on foot imprint area.

**Analysis** The weight of the man is given to be 200 lbf. Noting that pressure is force per unit area, the pressure this man exerts on the ground is

(a) On both feet:  $P = \frac{W}{2A} = \frac{200 \text{ lbf}}{2 \times 36 \text{ in}^2} = 2.78 \text{ lbf/in}^2 = \mathbf{2.78 \text{ psi}}$

(b) On one foot:  $P = \frac{W}{A} = \frac{200 \text{ lbf}}{36 \text{ in}^2} = 5.56 \text{ lbf/in}^2 = \mathbf{5.56 \text{ psi}}$

**Discussion** Note that the pressure exerted on the ground (and on the feet) is reduced by half when the person stands on both feet.

**Solution with Appropriate Software****"Given"**

$W=200$  [lbf]

$A=1/2*72$  [in<sup>2</sup>]

**"Analysis"**

**"(a)"**

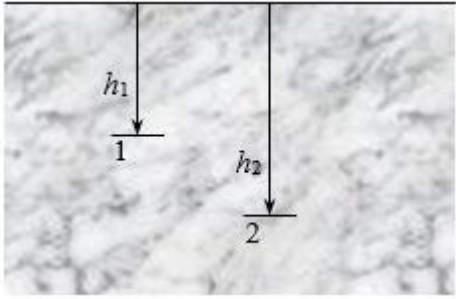
$P_a=W/A$ \*Convert(lbf/in<sup>2</sup>, psi)

**"(b)"**

$P_b=W/(2*A)$ \*Convert(lbf/in<sup>2</sup>, psi)

**1-56** The gage pressure in a liquid at a certain depth is given. The gage pressure in the same liquid at a different depth is to be determined.

**Assumptions** The variation of the density of the liquid with depth is negligible.



**Analysis** The gage pressure at two different depths of a liquid can be expressed as

$$P_1 = \rho g h_1 \quad \text{and} \quad P_2 = \rho g h_2$$

Taking their ratio,

$$\frac{P_2}{P_1} = \frac{\rho g h_2}{\rho g h_1} = \frac{h_2}{h_1}$$

Solving for  $P_2$  and substituting gives

$$P_2 = \frac{h_2}{h_1} P_1 = \frac{9 \text{ m}}{3 \text{ m}} (42 \text{ kPa}) = 126 \text{ kPa}$$

**Discussion** Note that the gage pressure in a given fluid is proportional to depth.

*Solution with Appropriate Software*

"Given"

$h_1 = 3 \text{ [m]}$

$P_{1\_gage} = 42 \text{ [kPa]}$

$h_2 = 9 \text{ [m]}$

"Analysis"

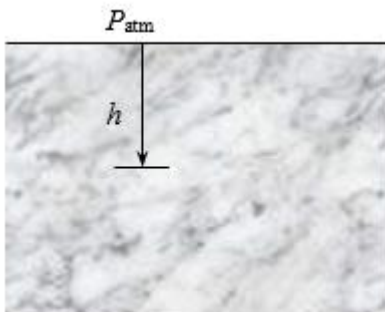
$P_{2\_gage} = (h_2/h_1) * P_{1\_gage}$

**1-57** The absolute pressure in water at a specified depth is given. The local atmospheric pressure and the absolute pressure at the same depth in a different liquid are to be determined.

**Assumptions** The liquid and water are incompressible.

**Properties** The specific gravity of the fluid is given to be  $SG = 0.85$ . We take the density of water to be  $1000 \text{ kg/m}^3$ . Then density of the liquid is obtained by multiplying its specific gravity by the density of water,

$$\rho = SG \times \rho_{H_2O} = (0.85)(1000 \text{ kg/m}^3) = 850 \text{ kg/m}^3$$



**Analysis**

(a) Knowing the absolute pressure, the atmospheric pressure can be determined from

$$P_{\text{atm}} = P - \rho gh$$

$$= (185 \text{ kPa}) - (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(9 \text{ m}) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right)$$

$$= 96.7 \text{ kPa}$$

(b) The absolute pressure at the same depth in the other liquid is

$$P = P_{\text{atm}} + \rho gh$$

$$= (96.7 \text{ kPa}) + (850 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(9 \text{ m}) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right)$$

$$= 171.8 \text{ kPa}$$

**Discussion** Note that at a given depth, the pressure in the lighter fluid is lower, as expected.

### Solution with Appropriate Software

"Given"

$h=9 \text{ [m]}$

$P=185 \text{ [kPa]}$

$\rho_s=0.85$

"Analysis"

$\rho=\rho_s*\rho_{\text{water}}$

$\rho_{\text{water}}=1000 \text{ [kg/m}^3\text{]}$  "taken"

"(a)"

$P_{\text{atm}}=P-\rho_{\text{water}}*g*h*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$

$g=9.81 \text{ [m/s}^2\text{]}$  "acceleration of gravity"

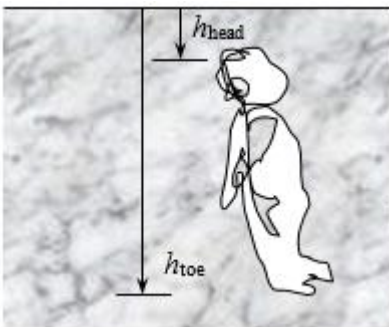
"(b)"

$P_{\text{abs}}=P_{\text{atm}}+\rho*g*h*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$

**1-58** A man is standing in water vertically while being completely submerged. The difference between the pressures acting on the head and on the toes is to be determined.

**Assumptions** Water is an incompressible substance, and thus the density does not change with depth.

**Properties** We take the density of water to be  $\rho = 1000 \text{ kg/m}^3$ .



**Analysis** The pressures at the head and toes of the person can be expressed as

$$P_{\text{head}} = P_{\text{atm}} + \rho gh_{\text{head}} \quad \text{and} \quad P_{\text{toe}} = P_{\text{atm}} + \rho gh_{\text{toe}}$$

where  $h$  is the vertical distance of the location in water from the free surface. The pressure difference between the toes and the head is determined by subtracting the first relation above from the second,

$$P_{\text{toe}} - P_{\text{head}} = \rho gh_{\text{toe}} - \rho gh_{\text{head}} = \rho g(h_{\text{toe}} - h_{\text{head}})$$

Substituting,

$$P_{\text{toe}} - P_{\text{head}} = (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(1.75 \text{ m} - 0) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) = 17.2 \text{ kPa}$$

**Discussion** This problem can also be solved by noting that the atmospheric pressure (1 atm = 101.325 kPa) is equivalent to 10.3-m of water height, and finding the pressure that corresponds to a water height of 1.75 m.

*Solution with Appropriate Software*

"Given"

$$h=1.75 \text{ [m]}$$

"Analysis"

$$g=9.81 \text{ [m/s}^2\text{]}$$

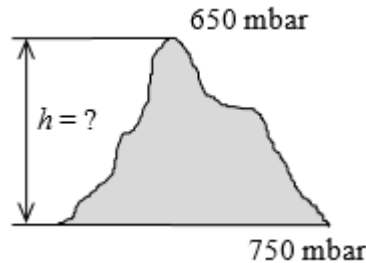
$$\text{DELTA}P=\rho_{\text{water}}*g*h*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$$

$$\rho_{\text{water}}=1000 \text{ [kg/m}^3\text{]} \text{ "taken"}$$

**1-59** A mountain hiker records the barometric reading before and after a hiking trip. The vertical distance climbed is to be determined.

**Assumptions** The variation of air density and the gravitational acceleration with altitude is negligible.

**Properties** The density of air is given to be  $\rho = 1.20 \text{ kg/m}^3$ .



**Analysis** Taking an air column between the top and the bottom of the mountain and writing a force balance per unit base area, we obtain

$$W_{\text{air}}/A = P_{\text{bottom}} - P_{\text{top}}$$

$$(\rho gh)_{\text{air}} = P_{\text{bottom}} - P_{\text{top}}$$

$$(1.20 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(h) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ bar}}{100,000 \text{ N/m}^2} \right) = (0.750 - 0.650) \text{ bar}$$

It yields

$$h = 850 \text{ m}$$

which is also the distance climbed.

*Solution with Appropriate Software*

"Given"

$$P_{\text{bottom}}=0.750 \text{ [bar]}$$

$$P_{\text{top}}=0.650 \text{ [bar]}$$

$$\rho=1.2 \text{ [kg/m}^3\text{]}$$

"Analysis"

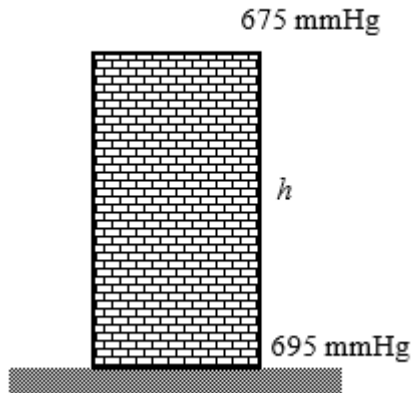
$$\rho*g*h*\text{Convert}(\text{kg/m-s}^2, \text{bar})=(P_{\text{bottom}}-P_{\text{top}})$$

$$g=9.81 \text{ [m/s}^2\text{]}$$

**1-60** A barometer is used to measure the height of a building by recording reading at the bottom and at the top of the building. The height of the building is to be determined.

**Assumptions** The variation of air density with altitude is negligible.

**Properties** The density of air is given to be  $\rho = 1.18 \text{ kg/m}^3$ . The density of mercury is  $13,600 \text{ kg/m}^3$ .



**Analysis** Atmospheric pressures at the top and at the bottom of the building are

$$\begin{aligned}
 P_{\text{top}} &= (\rho g h)_{\text{top}} \\
 &= (13,600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.675 \text{ m}) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) \\
 &= 90.06 \text{ kPa} \\
 P_{\text{bottom}} &= (\rho g h)_{\text{bottom}} \\
 &= (13,600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.695 \text{ m}) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) \\
 &= 92.72 \text{ kPa}
 \end{aligned}$$

Taking an air column between the top and the bottom of the building and writing a force balance per unit base area, we obtain

$$\begin{aligned}
 W_{\text{air}}/A &= P_{\text{bottom}} - P_{\text{top}} \\
 (\rho g h)_{\text{air}} &= P_{\text{bottom}} - P_{\text{top}} \\
 (1.18 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(h) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) &= (92.72 - 90.06) \text{ kPa}
 \end{aligned}$$

It yields

$$h = 231 \text{ m}$$

which is also the height of the building.

### *Solution with Appropriate Software*

"Given"

$h_{\text{top}}=0.675 \text{ [m]}$  "or 675 mmHg"

$h_{\text{bottom}}=0.695 \text{ [m]}$  "or 695 mmHg"

$\rho_{\text{air}}=1.18 \text{ [kg/m}^3]$

$\rho_{\text{mercury}}=13600 \text{ [kg/m}^3]$

"Analysis"

$g=9.81 \text{ [m/s}^2]$

$P_{\text{top}}=\rho_{\text{mercury}}*g*h_{\text{top}}*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$

$P_{\text{bottom}}=\rho_{\text{mercury}}*g*h_{\text{bottom}}*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$

$(P_{\text{bottom}}-P_{\text{top}})=\rho_{\text{air}}*g*h*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$



**1-61** Problem 1-60 is reconsidered. The entire software solution is to be printed out, including the numerical results with proper units.

**Analysis** The problem is solved using appropriate software, and the solution is given below.

P\_bottom=695 [mmHg]

P\_top=675 [mmHg]

g=9.81 [m/s^2]

rho=1.18 [kg/m^3]

DELTA P\_abs=(P\_bottom-P\_top)\*CONVERT(mmHg, kPa) "Delta P reading from the barometers, converted from mmHg to kPa"

DELTA P\_h=rho\*g\*h\*Convert(Pa, kPa) "Delta P due to the air fluid column height, h, between the top and bottom of the building"

DELTA P\_abs=DELTA P\_h

DELTA P\_abs=2.666 [kPa]

DELTA P\_h=2.666 [kPa]

g=9.81 [m/s^2]

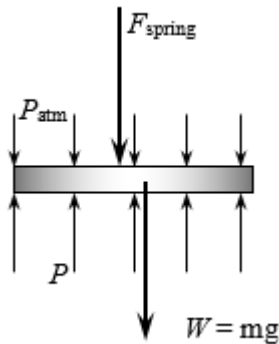
h=230.3 [m]

P\_bottom=695 [mmHg]

P\_top=675 [mmHg]

rho=1.18 [kg/m^3]

**1-62** A gas contained in a vertical piston-cylinder device is pressurized by a spring and by the weight of the piston. The pressure of the gas is to be determined.



**Analysis** Drawing the free body diagram of the piston and balancing the vertical forces yield

$$PA = P_{\text{atm}}A + W + F_{\text{spring}}$$

Thus,

$$\begin{aligned} P &= P_{\text{atm}} + \frac{mg + F_{\text{spring}}}{A} \\ &= (95 \text{ kPa}) + \frac{(3.2 \text{ kg})(9.81 \text{ m/s}^2) + 150 \text{ N}}{35 \times 10^{-4} \text{ m}^2} \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) \\ &= 147 \text{ kPa} \end{aligned}$$

*Solution with Appropriate Software*

"Given"

m\_piston=3.2 [kg]

A=35E-4 [m^2]

F\_spring=150 [N]

P\_atm=95 [kPa]

**"Analysis"**

$$g=9.807 \text{ [m/s}^2\text{]}$$

$$W=m_{\text{piston}}*g$$

$$P*A=P_{\text{atm}}*A+(W+F_{\text{spring}})*\text{Convert(N/m}^2\text{, kPa)}$$
 "force balance on the piston"



**1-63** Problem 1-62 is reconsidered. The effect of the spring force in the range of 0 to 500 N on the pressure inside the cylinder is to be investigated. The pressure against the spring force is to be plotted, and results are to be discussed.

**Analysis** The problem is solved using appropriate software, and the solution is given below.

$$P_{\text{atm}}= 95 \text{ [kPa]}$$

$$m_{\text{piston}}=3.2 \text{ [kg]}$$

$$F_{\text{spring}}=150 \text{ [N]}$$

$$A=35*\text{CONVERT(cm}^2\text{, m}^2\text{)}$$

$$g=9.81 \text{ [m/s}^2\text{]}$$

$$W_{\text{piston}}=m_{\text{piston}}*g$$

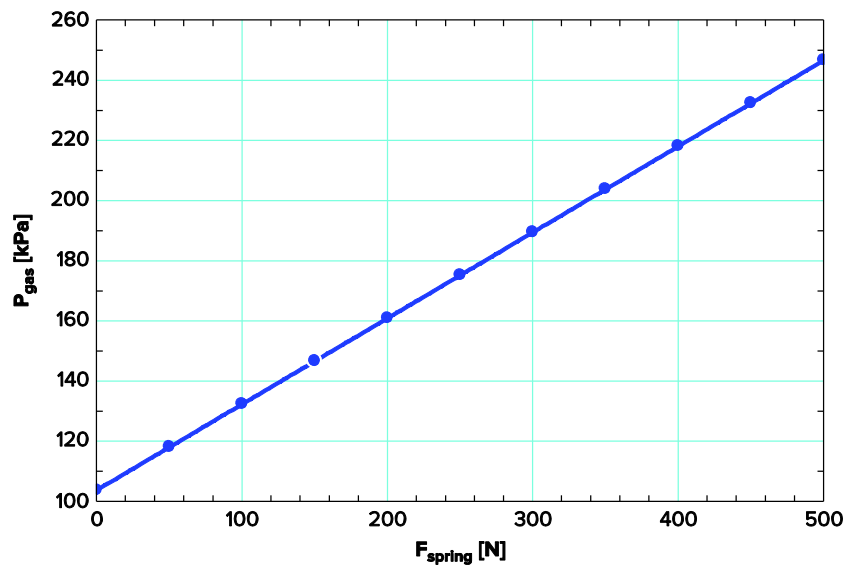
$$F_{\text{atm}}=P_{\text{atm}}*A*\text{CONVERT(kPa, N/m}^2\text{)}$$

"From the free body diagram of the piston, the balancing vertical forces yield"

$$F_{\text{gas}}= F_{\text{atm}}+F_{\text{spring}}+W_{\text{piston}}$$

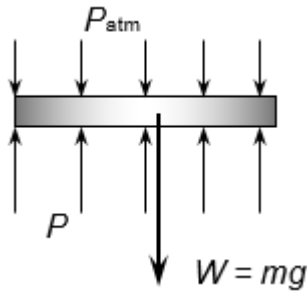
$$P_{\text{gas}}=F_{\text{gas}}/A*\text{CONVERT(N/m}^2\text{, kPa)}$$

$F_{\text{spring}} \text{ [N]}$	$P_{\text{gas}} \text{ [kPa]}$
0	104
50	118.3
100	132.5
150	146.8
200	161.1
250	175.4
300	189.7
350	204
400	218.3
450	232.5
500	246.8



**1-64** A gas is contained in a vertical cylinder with a heavy piston. The pressure inside the cylinder and the effect of volume change on pressure are to be determined.

**Assumptions** Friction between the piston and the cylinder is negligible.



**Analysis**

- (a) The gas pressure in the piston–cylinder device depends on the atmospheric pressure and the weight of the piston. Drawing the free-body diagram of the piston and balancing the vertical forces yield

$$PA = P_{\text{atm}}A + W$$

Thus,

$$\begin{aligned} P &= P_{\text{atm}} + \frac{mg}{A} \\ &= 0.97 \text{ bar} + \frac{(60 \text{ kg})(9.81 \text{ m/s}^2)}{0.04 \text{ m}^2} \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} \right) \\ &= 1.12 \text{ bar} \end{aligned}$$

- (b) The volume change will have no effect on the free-body diagram drawn in part (a), and therefore the pressure inside the cylinder will remain the same.

**Discussion** If the gas behaves as an ideal gas, the absolute temperature doubles when the volume is doubled at constant pressure.

*Solution with appropriate Software*

"Given"

m\_piston=60 [kg]

A=0.04 [m^2]

P\_atm=97 [kPa]

g=9.81 [m/s^2]

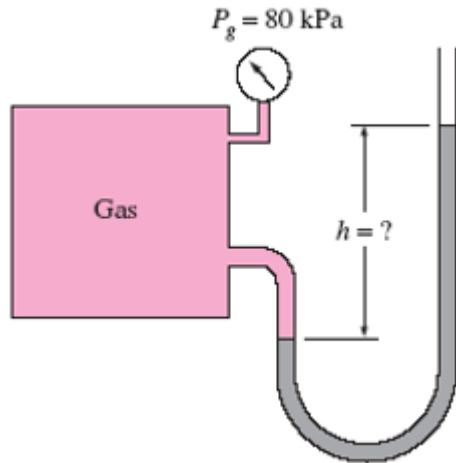
"Analysis"

W=m\_piston\*g

P\*A=P\_atm\*A+W\*Convert(N/m^2, kPa) "force balance on the piston"

**1-65** Both a gage and a manometer are attached to a gas to measure its pressure. For a specified reading of gage pressure, the difference between the fluid levels of the two arms of the manometer is to be determined for mercury and water.

**Properties** The densities of water and mercury are given to be  $\rho_{\text{water}} = 1000 \text{ kg/m}^3$  and be  $\rho_{\text{Hg}} = 13,600 \text{ kg/m}^3$ .



**Analysis** The gage pressure is related to the vertical distance  $h$  between the two fluid levels by

$$P_{\text{gage}} = \rho g h \rightarrow h = \frac{P_{\text{gage}}}{\rho g}$$

(a) For mercury,

$$h = \frac{P_{\text{gage}}}{\rho_{\text{Hg}} g} = \frac{80 \text{ kPa}}{(13,600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} \left( \frac{1 \text{ kN/m}^2}{1 \text{ kPa}} \right) \left( \frac{1000 \text{ kg/m} \cdot \text{s}^2}{1 \text{ kN}} \right) = \mathbf{0.60 \text{ m}}$$

(b) For water,

$$h = \frac{P_{\text{gage}}}{\rho_{\text{H}_2\text{O}} g} = \frac{80 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} \left( \frac{1 \text{ kN/m}^2}{1 \text{ kPa}} \right) \left( \frac{1000 \text{ kg/m} \cdot \text{s}^2}{1 \text{ kN}} \right) = \mathbf{8.16 \text{ m}}$$

### *Solution with appropriate Software*

```
Fluid$='Mercury'
```

```
P_atm = 101.325 [kPa]
```

```
DELTA P=80 [kPa] "Note how DELTAP is displayed on the Formatted Equations Window."
```

```
g=9.807 [m/s^2] "local acceleration of gravity at sea level"
```

```
rho=fluid_density(Fluid$) "Get the fluid density, either Hg or H2O, from the function."
```

```
DELTA P = rho*g*h*CONVERT(Pa, kPa) "force balance"
```

"Instead of multiplying by CONVERT('Pa', 'kPa') we could have divided by 1000 but then the Check Units option would not work on this equation since the constant 1000 does not have units. "



**1-66** Problem 1-65 is reconsidered. The effect of the manometer fluid density in the range of 800 to 13,000 kg/m<sup>3</sup> on the differential fluid height of the manometer is to be investigated. Differential fluid height against the density is to be plotted, and the results are to be discussed.

**Analysis** The problem is solved using appropriate software, and the solution is given below.

"Let's modify this problem to also calculate the absolute pressure in the tank by supplying the atmospheric pressure."

```
Function fluid_density(Fluid$)
```

```
"This function is needed since if-then-else logic can only be used in functions or procedures.
```

```
The underscore displays whatever follows as subscripts in the Formatted Equations Window."
```

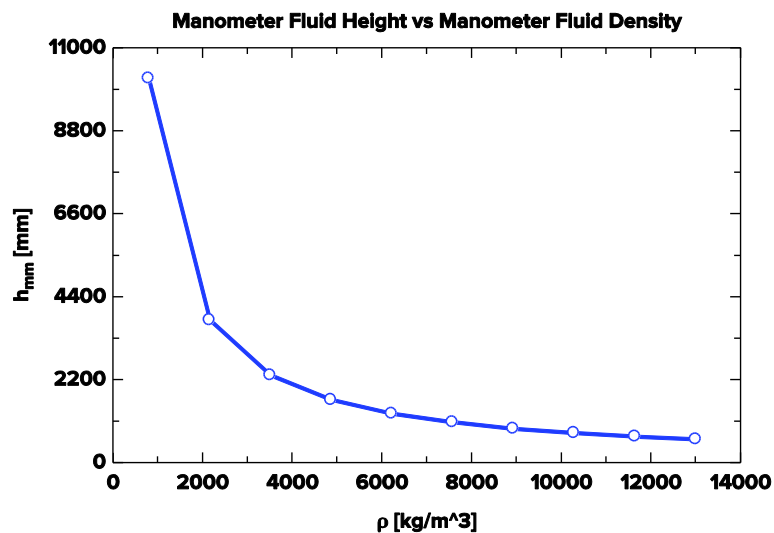
```
If fluid$='Mercury' then fluid_density=13600 else fluid_density=1000
```

```
end
```

```

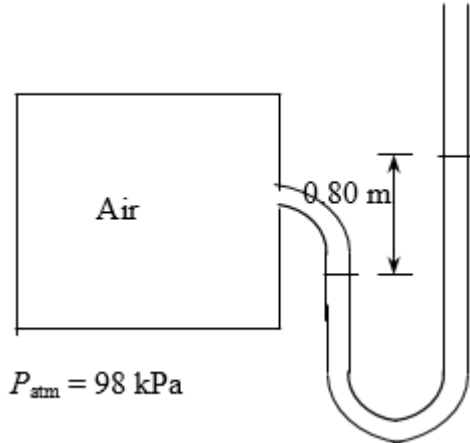
Fluid$='Mercury'
P_atm = 101.325 [kPa]
DELTAP=80 [kPa] "Note how DELTAP is displayed on the Formatted Equations Window."
g=9.807 [m/s^2] "local acceleration of gravity at sea level"
rho=Fluid_density(Fluid$) "Get the fluid density, either Hg or H2O, from the function"
DELTAP = RHO*g*h/1000 "Instead of dividing by 1000 Pa/kPa we could have multiplied by the function,
CONVERT(Pa,kPa)"
h_mm=h*convert(m, mm) "The fluid height in mm is found using the built-in CONVERT function."
P_abs= P_atm + DELTAP
    
```

$\rho$ [kg /m <sup>3</sup> ]	$h_{mm}$ [mm]
800	10197
2156	3784
3511	2323
4867	1676
6222	1311
7578	1076
8933	913.1
10289	792.8
11644	700.5
13000	627.5



**1-67** The air pressure in a tank is measured by an oil manometer. For a given oil-level difference between the two columns, the absolute pressure in the tank is to be determined.

**Properties** The density of oil is given to be  $\rho = 850 \text{ kg/m}^3$ .



**Analysis** The absolute pressure in the tank is determined from

$$\begin{aligned} P &= P_{atm} + \rho gh \\ &= (98 \text{ kPa}) + (850 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.80 \text{ m}) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) \\ &= 104.7 \text{ kPa} \end{aligned}$$

*Solution with appropriate Software*

"Given"

$$h=0.80 \text{ [m]}$$

$$P_{atm}=98 \text{ [kPa]}$$

$$\rho_{oil}=850 \text{ [kg/m}^3\text{]}$$

"Analysis"

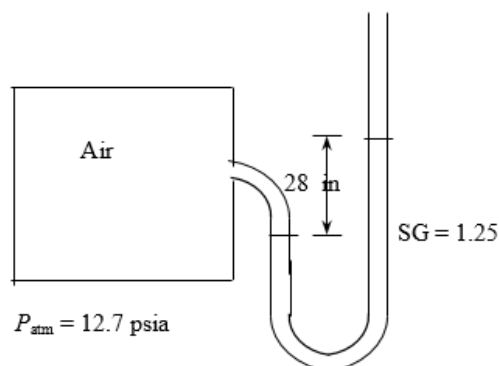
$$g=9.81 \text{ [m/s}^2\text{]}$$

$$P=P_{atm}+\rho_{oil}*g*h*\text{Convert}(\text{kg/m-s}^2, \text{kPa})$$

**1-68E** The pressure in a tank is measured with a manometer by measuring the differential height of the manometer fluid. The absolute pressure in the tank is to be determined for the cases of the manometer arm with the higher and lower fluid level being attached to the tank.

**Assumptions** The fluid in the manometer is incompressible.

**Properties** The specific gravity of the fluid is given to be  $SG = 1.25$ . The density of water at  $32^\circ\text{F}$  is  $62.4 \text{ lbm/ft}^3$  (Table A-3E)



**Analysis** The density of the fluid is obtained by multiplying its specific gravity by the density of water,

$$\rho = SG \times \rho_{H_2O} = (1.25)(62.4 \text{ lbm/ft}^3) = 78.0 \text{ lbm/ft}^3$$

The pressure difference corresponding to a differential height of 28 in between the two arms of the manometer is

$$\Delta P = \rho g h = (78 \text{ lbm/ft}^3)(32.174 \text{ ft/s}^2)(28/12 \text{ ft}) \left( \frac{1 \text{ lbf}}{32.174 \text{ lbm} \cdot \text{ft/s}^2} \right) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) = 1.26 \text{ psia}$$

Then the absolute pressures in the tank for the two cases become:

(a) The fluid level in the arm attached to the tank is higher (vacuum):

$$P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}} = 12.7 - 1.26 = \mathbf{11.44 \text{ psia}}$$

(b) The fluid level in the arm attached to the tank is lower:

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} = 12.7 + 1.26 = \mathbf{13.96 \text{ psia}}$$

**Discussion** Note that we can determine whether the pressure in a tank is above or below atmospheric pressure by simply observing the side of the manometer arm with the higher fluid level.

### Solution with appropriate Software

"Given"

rho\_s=1.25

h=28[in]\*Convert(in, ft)

P\_atm=12.7 [psia]

"Properties"

rho\_water=density(water, T=80, P=14.7)

g=32.174 [ft/s^2] "acceleration of gravity"

"Analysis"

rho=rho\_s\*rho\_water

DELTAP=rho\*g\*h\*Convert(lbm/ft-s^2, psia)

"(a)"

P\_abs\_a=P\_atm-DELTAP

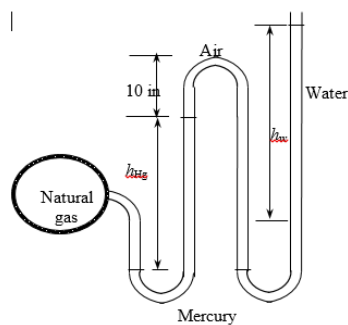
"(b)"

P\_abs\_b=P\_atm+DELTAP

**1-69E** The pressure in a natural gas pipeline is measured by a double U-tube manometer with one of the arms open to the atmosphere. The absolute pressure in the pipeline is to be determined.

**Assumptions** 1 All the liquids are incompressible. 2 The effect of air column on pressure is negligible. 3 The pressure throughout the natural gas (including the tube) is uniform since its density is low.

**Properties** We take the density of water to be  $\rho_w = 62.4 \text{ lbm/ft}^3$ . The specific gravity of mercury is given to be 13.6, and thus its density is  $\rho_{\text{Hg}} = 13.6 \times 62.4 = 848.6 \text{ lbm/ft}^3$ .



**Analysis** Starting with the pressure at point 1 in the natural gas pipeline, and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho g h$  terms until we reach the free surface of oil where the oil tube is exposed to the atmosphere, and setting the result equal to  $P_{\text{atm}}$  gives

$$P_1 - \rho_{\text{Hg}} g h_{\text{Hg}} - \rho_{\text{water}} g h_{\text{water}} = P_{\text{atm}}$$

Solving for  $P_1$ ,

$$P_1 = P_{\text{atm}} + \rho_{\text{Hg}}gh_{\text{Hg}} + \rho_{\text{water}}gh_1$$

Substituting,

$$P = 14.2 \text{ psia} + (32.2 \text{ ft/s}^2)[(848.6 \text{ lbm/ft}^3)(6/12 \text{ ft}) + (62.4 \text{ lbm/ft}^3)(27/12 \text{ ft})] \left( \frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) = 18.1 \text{ psia}$$

**Discussion** Note that jumping horizontally from one tube to the next and realizing that pressure remains the same in the same fluid simplifies the analysis greatly. Also, it can be shown that the 15-in high air column with a density of  $0.075 \text{ lbm/ft}^3$  corresponds to a pressure difference of  $0.00065 \text{ psi}$ . Therefore, its effect on the pressure difference between the two pipes is negligible.

*Solution with appropriate Software*

"Given"

$$P_{\text{atm}}=14.2 \text{ [psia]}$$

$$h_{\text{Hg}}=6[\text{in}]*\text{Convert}(\text{in},\text{ft})$$

$$h_{\text{w}}=27[\text{in}]*\text{Convert}(\text{in},\text{ft})$$

$$\rho_{\text{s}}=13.6$$

"Analysis"

$$P=P_{\text{atm}}+g*(\rho_{\text{Hg}}*h_{\text{Hg}}+\rho_{\text{w}}*h_{\text{w}})*\text{Convert}(\text{lbm/ft-s}^2, \text{psia})$$

$$\rho_{\text{w}}=62.4 \text{ [lbm/ft}^3] \text{ "taken"}$$

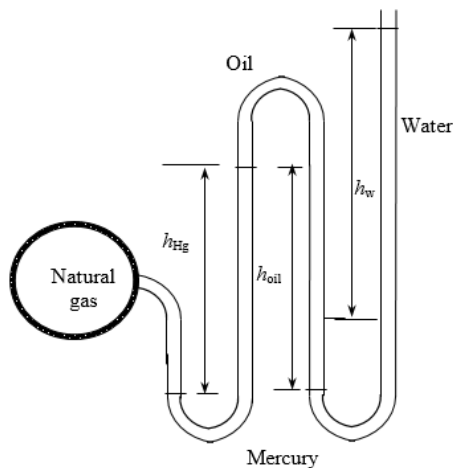
$$\rho_{\text{Hg}}=\rho_{\text{s}}*\rho_{\text{w}}$$

$$g=32.174 \text{ [ft/s}^2]$$

**1-70E** The pressure in a natural gas pipeline is measured by a double U-tube manometer with one of the arms open to the atmosphere. The absolute pressure in the pipeline is to be determined.

**Assumptions** 1 All the liquids are incompressible. 2 The pressure throughout the natural gas (including the tube) is uniform since its density is low.

**Properties** We take the density of water to be  $\rho_{\text{w}} = 62.4 \text{ lbm/ft}^3$ . The specific gravity of mercury is given to be 13.6, and thus its density is  $\rho_{\text{Hg}} = 13.6 \times 62.4 = 848.6 \text{ lbm/ft}^3$ . The specific gravity of oil is given to be 0.69, and thus its density is  $\rho_{\text{oil}} = 0.69 \times 62.4 = 43.1 \text{ lbm/ft}^3$ .



**Analysis** Starting with the pressure at point 1 in the natural gas pipeline, and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho gh$  terms until we reach the free surface of oil where the oil tube is exposed to the atmosphere, and setting the result equal to  $P_{\text{atm}}$  gives

$$P_1 - \rho_{\text{Hg}}gh_{\text{Hg}} + \rho_{\text{oil}}gh_{\text{oil}} - \rho_{\text{water}}gh_{\text{water}} = P_{\text{atm}}$$

Solving for  $P_1$ ,

$$P_1 = P_{\text{atm}} + \rho_{\text{Hg}}gh_{\text{Hg}} + \rho_{\text{water}}gh_1 - \rho_{\text{oil}}gh_{\text{oil}}$$

Substituting,

$$P_1 = 14.2 \text{ psia} + (32.2 \text{ ft/s}^2)[(848.6 \text{ lbm/ft}^3)(6/12 \text{ ft}) + (62.4 \text{ lbm/ft}^3)(27/12 \text{ ft})]$$

$$-(43.1 \text{ lbf/ft}^3)(15/12 \text{ ft}) \left( \frac{1 \text{ lbf}}{32.2 \text{ lbf} \cdot \text{ft/s}^2} \right) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) \\ = 17.7 \text{ psia}$$

**Discussion** Note that jumping horizontally from one tube to the next and realizing that pressure remains the same in the same fluid simplifies the analysis greatly.

*Solution with appropriate Software*

"Given"

$$P_{\text{atm}} = 14.2 \text{ [psia]}$$

$$h_{\text{Hg}} = 6/12 \text{ "[ft]"}$$

$$h_{\text{w}} = 27/12 \text{ "[ft]"}$$

$$h_{\text{oil}} = 15/12 \text{ "[ft]"}$$

$$\rho_{\text{s}} = 13.6$$

$$\rho_{\text{s_oil}} = 0.69$$

"Analysis"

$$P = P_{\text{atm}} + g(\rho_{\text{Hg}} h_{\text{Hg}} + \rho_{\text{w}} h_{\text{w}} - \rho_{\text{oil}} h_{\text{oil}}) \text{ Convert(lbf/ft} \cdot \text{s}^2, \text{ psia)}$$

$$\rho_{\text{w}} = 62.4 \text{ [lbf/ft}^3] \text{ "taken"}$$

$$\rho_{\text{Hg}} = \rho_{\text{s}} \rho_{\text{w}}$$

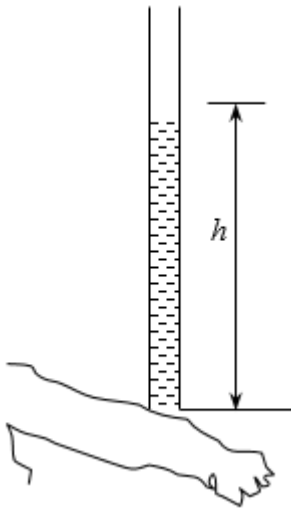
$$\rho_{\text{oil}} = \rho_{\text{s_oil}} \rho_{\text{w}}$$

$$g = 32.174 \text{ [ft/s}^2]$$

**1-71E** The systolic and diastolic pressures of a healthy person are given in mmHg. These pressures are to be expressed in kPa, psi, and meter water column.

**Assumptions** Both mercury and water are incompressible substances.

**Properties** We take the densities of water and mercury to be  $1000 \text{ kg/m}^3$  and  $13,600 \text{ kg/m}^3$ , respectively.



**Analysis** Using the relation  $P = \rho gh$  for gage pressure, the high and low pressures are expressed as

$$P_{\text{high}} = \rho gh_{\text{high}} = (13,600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.12 \text{ m}) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) = \mathbf{16.0 \text{ kPa}}$$

$$P_{\text{low}} = \rho gh_{\text{low}} = (13,600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.08 \text{ m}) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right) = \mathbf{10.7 \text{ kPa}}$$

Noting that  $1 \text{ psi} = 6.895 \text{ kPa}$ ,

$$P_{\text{high}} = (16.0 \text{ Pa}) \left( \frac{1 \text{ psi}}{6.895 \text{ kPa}} \right) = \mathbf{2.32 \text{ psi}}$$

and

$$P_{\text{low}} = (10.7 \text{ Pa}) \left( \frac{1 \text{ psi}}{6.895 \text{ kPa}} \right) = \mathbf{1.55 \text{ psi}}$$

For a given pressure, the relation  $P = \rho gh$  can be expressed for mercury and water as  $P = \rho_{\text{water}} g h_{\text{water}}$  and  $P = \rho_{\text{mercury}} g h_{\text{mercury}}$ . Setting these two relations equal to each other and solving for water height gives

$$P = \rho_{\text{water}} g h_{\text{water}} = \rho_{\text{mercury}} g h_{\text{mercury}} \rightarrow h_{\text{water}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury}}$$

Therefore,

$$h_{\text{water, high}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury, high}} = \frac{13,600 \text{ kg/m}^3}{1000 \text{ kg/m}^3} (0.12 \text{ m}) = \mathbf{1.63 \text{ m}}$$

$$h_{\text{water, low}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury, low}} = \frac{13,600 \text{ kg/m}^3}{1000 \text{ kg/m}^3} (0.08 \text{ m}) = \mathbf{1.09 \text{ m}}$$

**Discussion** Note that measuring blood pressure with a “water” monometer would involve differential fluid heights higher than the person, and thus it is impractical. This problem shows why mercury is a suitable fluid for blood pressure measurement devices.

### *Solution with appropriate Software*

"Given"

$h_{\text{high}} = 0.120 \text{ [m]}$  "or 120 mmHg"

$h_{\text{low}} = 0.080 \text{ [m]}$  "or 80 mmHg"

"Properties"

$\rho_{\text{water}} = 1000 \text{ [kg/m}^3]$  "taken"

$\rho_{\text{mercury}} = 13600 \text{ [kg/m}^3]$  "taken"

$g = 9.81 \text{ [m/s}^2]$

"Analysis"

$P_{\text{high\_kPa}} = \rho_{\text{mercury}} * g * h_{\text{high}} * \text{Convert}(\text{kg/m-s}^2, \text{kPa})$

$P_{\text{low\_kPa}} = \rho_{\text{mercury}} * g * h_{\text{low}} * \text{Convert}(\text{kg/m-s}^2, \text{kPa})$

$P_{\text{high\_psia}} = P_{\text{high\_kPa}} * \text{Convert}(\text{kPa}, \text{psia})$

$P_{\text{low\_psia}} = P_{\text{low\_kPa}} * \text{Convert}(\text{kPa}, \text{psia})$

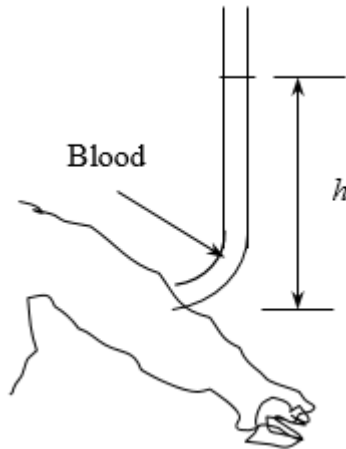
$h_{\text{water\_high}} = \rho_{\text{mercury}} / \rho_{\text{water}} * h_{\text{high}}$  "from  $P = \rho_{\text{water}} * g * h_{\text{water}} = \rho_{\text{mercury}} * g * h_{\text{mercury}}$ "

$h_{\text{water\_low}} = \rho_{\text{mercury}} / \rho_{\text{water}} * h_{\text{low}}$

**1-72** A vertical tube open to the atmosphere is connected to the vein in the arm of a person. The height that the blood will rise in the tube is to be determined.

**Assumptions** **1** The density of blood is constant. **2** The gage pressure of blood is 120 mmHg.

**Properties** The density of blood is given to be  $\rho = 1050 \text{ kg/m}^3$ .



**Analysis** For a given gage pressure, the relation  $P = \rho gh$  can be expressed for mercury and blood as  $P = \rho_{\text{blood}}gh_{\text{blood}}$  and  $P = \rho_{\text{mercury}}gh_{\text{mercury}}$ . Setting these two relations equal to each other we get

$$P = \rho_{\text{blood}}gh_{\text{blood}} = \rho_{\text{mercury}}gh_{\text{mercury}}$$

Solving for blood height and substituting gives

$$h_{\text{blood}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{blood}}} h_{\text{mercury}} = \frac{13,600 \text{ kg/m}^3}{1050 \text{ kg/m}^3} (0.12 \text{ m}) = \mathbf{1.55 \text{ m}}$$

**Discussion** Note that the blood can rise about one and a half meters in a tube connected to the vein. This explains why IV tubes must be placed high to force a fluid into the vein of a patient.

*Solution with appropriate Software*

"Given"

$h_{\text{mercury}}=0.120 \text{ [m]}$  "or 120 mmHg"

$\rho_{\text{blood}}=1050 \text{ [kg/m}^3\text{]}$

$\rho_{\text{mercury}}=13600 \text{ [kg/m}^3\text{]}$

"Analysis"

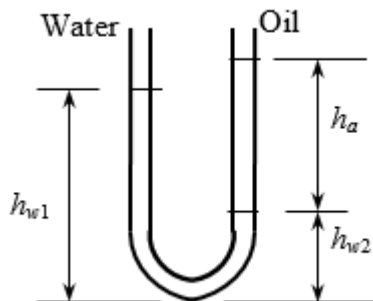
$h_{\text{blood}}=\rho_{\text{mercury}}/\rho_{\text{blood}}*h_{\text{mercury}}$

"from  $P = \rho_{\text{blood}}*g*h_{\text{blood}} = \rho_{\text{mercury}}*g*h_{\text{mercury}}$ "

**1-73** Water is poured into the U-tube from one arm and oil from the other arm. The water column height in one arm and the ratio of the heights of the two fluids in the other arm are given. The height of each fluid in that arm is to be determined.

**Assumptions** Both water and oil are incompressible substances.

**Properties** The density of oil is given to be  $\rho = 790 \text{ kg/m}^3$ . We take the density of water to be  $\rho = 1000 \text{ kg/m}^3$ .



**Analysis** The height of water column in the left arm of the manometer is given to be  $h_{w1} = 0.70\text{m}$ . We let the height of water and oil in the right arm to be  $h_{w2}$  and  $h_a$ , respectively. Then,  $h_a = 4h_{w2}$ . Noting that both arms are open to the atmosphere, the pressure at the bottom of the U-tube can be expressed as

$$P_{\text{bottom}} = P_{\text{atm}} + \rho_w g h_{w1} \quad \text{and} \quad P_{\text{bottom}} = P_{\text{atm}} + \rho_w g h_{w2} + \rho_a g h_a$$

Setting them equal to each other and simplifying,

$$\rho_w g h_{w1} = \rho_w g h_{w2} + \rho_a g h_a \rightarrow \rho_w h_{w1} = \rho_w h_{w2} + \rho_a h_a \rightarrow h_{w1} = h_{w2} + (\rho_a / \rho_w) h_a$$

Noting that  $h_a = 4h_{w2}$ , the water and oil column heights in the second arm are determined to be

$$0.7\text{ m} = h_{w2} + (790/1000) 4h_{w2} \rightarrow h_{w2} = 0.168\text{ m}$$

$$0.7\text{ m} = 0.168\text{ m} + (790/1000) h_a \rightarrow h_a = 0.673\text{ m}$$

**Discussion** Note that the fluid height in the arm that contains oil is higher. This is expected since oil is lighter than water.

*Solution with appropriate Software*

"Given"

$$h_{w1} = 0.70\text{ [m]}$$

$$h_a / h_{w2} = 4$$

$$\rho_a = 790\text{ [kg/m}^3\text{]}$$

"Analysis"

$$\rho_w = 1000\text{ [kg/m}^3\text{]} \quad \text{"taken"}$$

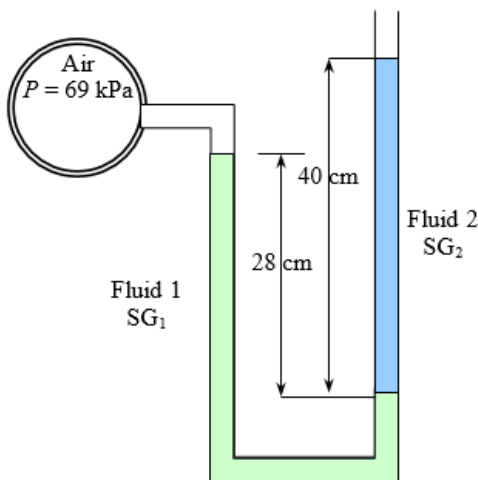
$$h_{w1} = h_{w2} + (\rho_a / \rho_w) h_a$$

$$\text{"from } P_{\text{bottom}} = P_{\text{atm}} + \rho_w g h_{w1} = P_{\text{atm}} + \rho_w g h_{w2} + \rho_a g h_a \text{"}$$

**1-74** A double-fluid manometer attached to an air pipe is considered. The specific gravity of one fluid is known, and the specific gravity of the other fluid is to be determined.

**Assumptions** 1 Densities of liquids are constant. 2 The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus the pressure at the air-water interface is the same as the indicated gage pressure.

**Properties** The specific gravity of one fluid is given to be 13.55. We take the standard density of water to be  $1000\text{ kg/m}^3$ .



**Analysis** Starting with the pressure of air in the tank, and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho g h$  terms until we reach the free surface where the oil tube is exposed to the atmosphere, and setting the result equal to  $P_{\text{atm}}$  give

$$P_{\text{air}} + \rho_1 g h_1 - \rho_2 g h_2 = P_{\text{atm}} \quad P_{\text{air}} - P_{\text{atm}} = SG_2 \rho_w g h_2 - SG_1 \rho_w g h_1$$

Rearranging and solving for  $SG_2$ ,

$$SG_2 = SG_1 \frac{h_1}{h_2} + \frac{P_{\text{air}} - P_{\text{atm}}}{\rho_w g h_2} = 13.55 \frac{0.28\text{ m}}{0.40\text{ m}} + \left( \frac{69 - 100\text{ kPa}}{(1000\text{ kg/m}^3)(9.81\text{ m/s}^2)(0.40\text{ m})} \right) \left( \frac{1000\text{ kg} \cdot \text{m/s}^2}{1\text{ kPa} \cdot \text{m}^2} \right) = 1.59$$

**Discussion** Note that the right fluid column is higher than the left, and this would imply above atmospheric pressure in the pipe for a single-fluid manometer.

*Solution with appropriate Software*

"Given"

$$SG_1=13.55$$

$$h_1=0.28 \text{ [m]}$$

$$h_2=0.40 \text{ [m]}$$

$$P_{\text{air}}=69 \text{ [kPa]}$$

$$P_{\text{atm}}=100 \text{ [kPa]}$$

"Analysis"

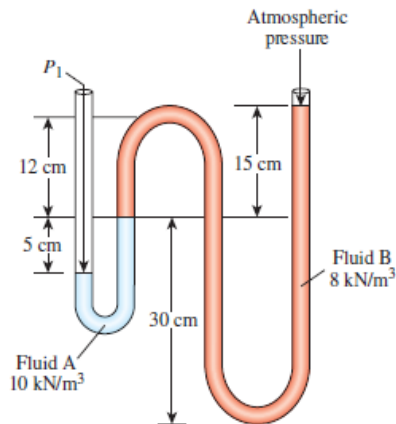
$$\rho_w=1000 \text{ [kg/m}^3\text{]} \text{ "taken"}$$

$$g=9.81 \text{ [m/s}^2\text{]}$$

$$SG_2=SG_1 \cdot h_1/h_2 + (P_{\text{air}} - P_{\text{atm}})/(\rho_w \cdot g \cdot h_2) \cdot \text{Convert}(\text{kPa} \cdot \text{m}^2, \text{kg} \cdot \text{m/s}^2)$$

**1-75** The pressure indicated by a manometer is to be determined.

**Properties** The specific weights of fluid A and fluid B are given to be  $10 \text{ kN/m}^3$  and  $8 \text{ kN/m}^3$ , respectively.



**Analysis** The absolute pressure  $P_1$  is determined from

$$\begin{aligned} P_1 &= P_{\text{atm}} + (\rho g h)_A + (\rho g h)_B \\ &= P_{\text{atm}} + \gamma_A h_A + \gamma_B h_B \\ &= (758 \text{ mm Hg}) \left( \frac{0.1333 \text{ kPa}}{1 \text{ mm Hg}} \right) \\ &\quad + (10 \text{ kN/m}^3)(0.05 \text{ m}) + (8 \text{ kN/m}^3)(0.15 \text{ m}) \\ &= 102.7 \text{ kPa} \end{aligned}$$

Note that  $1 \text{ kPa} = 1 \text{ kN/m}^2$ .

*Solution with appropriate Software*

"Given"

$$P_{\text{atm}}=758 \text{ [mmHg]}$$

$$h_A=0.05 \text{ [m]}$$

$$h_B=0.15 \text{ [m]}$$

$$\rho_{\text{og}_A}=10 \text{ [kN/m}^3\text{]}$$

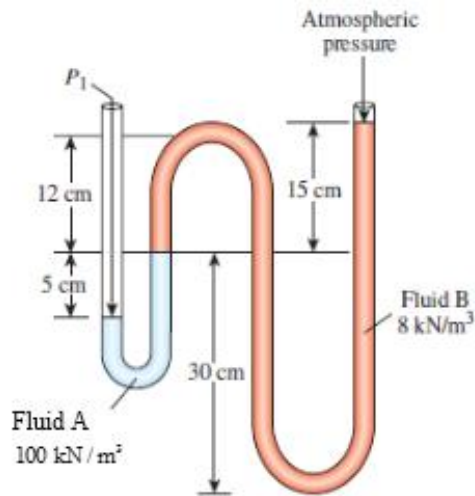
$$\rho_{\text{og}_B}=8 \text{ [kN/m}^3\text{]}$$

"Analysis"

$$P_1=P_{\text{atm}} \cdot \text{Convert}(\text{mmHg}, \text{kPa}) + \rho_{\text{og}_A} \cdot h_A + \rho_{\text{og}_B} \cdot h_B$$

1-76 The pressure indicated by a manometer is to be determined.

**Properties** The specific weights of fluid A and fluid B are given to be  $100 \text{ kN/m}^3$  and  $8 \text{ kN/m}^3$ , respectively.



**Analysis** The absolute pressure  $P_1$  is determined from

$$\begin{aligned} P_1 &= P_{\text{atm}} + (\rho gh)_A + (\rho gh)_B \\ &= P_{\text{atm}} + \gamma_A h_A + \gamma_B h_B \\ &= 90 \text{ kPa} + (100 \text{ kN/m}^3)(0.05 \text{ m}) + (8 \text{ kN/m}^3)(0.15 \text{ m}) \\ &= 96.2 \text{ kPa} \end{aligned}$$

Note that  $1 \text{ kPa} = 1 \text{ kN/m}^2$ .

*Solution with appropriate Software*

"Given"

$$P_{\text{atm}} = 90 \text{ [kPa]}$$

$$h_A = 0.05 \text{ [m]}$$

$$h_B = 0.15 \text{ [m]}$$

$$\rho_{\text{A}} = 100 \text{ [kN/m}^3\text{]}$$

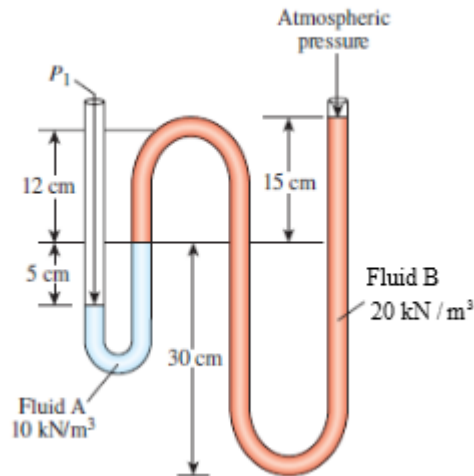
$$\rho_{\text{B}} = 8 \text{ [kN/m}^3\text{]}$$

"Analysis"

$$P_1 = P_{\text{atm}} + \rho_{\text{A}} h_A + \rho_{\text{B}} h_B$$

1-77 The pressure indicated by a manometer is to be determined.

**Properties** The specific weights of fluid A and fluid B are given to be  $10 \text{ kN/m}^3$  and  $20 \text{ kN/m}^3$ , respectively.



**Analysis** The absolute pressure  $P_1$  is determined from

$$\begin{aligned}
 P_1 &= P_{\text{atm}} + (\rho gh)_A + (\rho gh)_B \\
 &= P_{\text{atm}} + \gamma_A h_A + \gamma_B h_B \\
 &= (720 \text{ mm Hg}) \left( \frac{0.1333 \text{ kPa}}{1 \text{ mm Hg}} \right) \\
 &\quad + (10 \text{ kN/m}^3)(0.05 \text{ m}) + (20 \text{ kN/m}^3)(0.15 \text{ m}) \\
 &= 99.5 \text{ kPa}
 \end{aligned}$$

Note that  $1 \text{ kPa} = 1 \text{ kN/m}^2$ .

*Solution with appropriate Software*

"Given"

$$P_{\text{atm}} = 720 \text{ [mmHg]}$$

$$h_A = 0.05 \text{ [m]}$$

$$h_B = 0.15 \text{ [m]}$$

$$\rho_{\text{A}} = 10 \text{ [kN/m}^3\text{]}$$

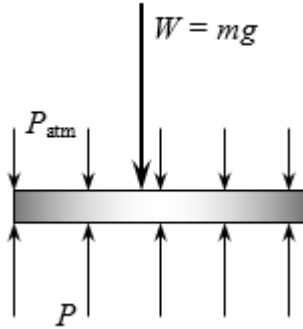
$$\rho_{\text{B}} = 20 \text{ [kN/m}^3\text{]}$$

"Analysis"

$$P_1 = P_{\text{atm}} * \text{Convert}(\text{mmHg}, \text{kPa}) + \rho_{\text{A}} * h_A + \rho_{\text{B}} * h_B$$

**1-78** The hydraulic lift in a car repair shop is to lift cars. The fluid gage pressure that must be maintained in the reservoir is to be determined.

**Assumptions** The weight of the piston of the lift is negligible.



**Analysis** Pressure is force per unit area, and thus the gage pressure required is simply the ratio of the weight of the car to the area of the lift,

$$P_{\text{gage}} = \frac{W}{A} = \frac{mg}{\pi D^2/4}$$

$$= \frac{(2500 \text{ kg})(9.81 \text{ m/s}^2)}{\pi(0.30 \text{ m})^2/4} \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) = 347 \text{ kN/m}^2 = 347 \text{ kPa}$$

**Discussion** Note that the pressure level in the reservoir can be reduced by using a piston with a larger area.

*Solution with appropriate Software*

"Given"

D=0.30 [m]

m=2500 [kg]

"Analysis"

g=9.81 [m/s<sup>2</sup>]

W=m\*g

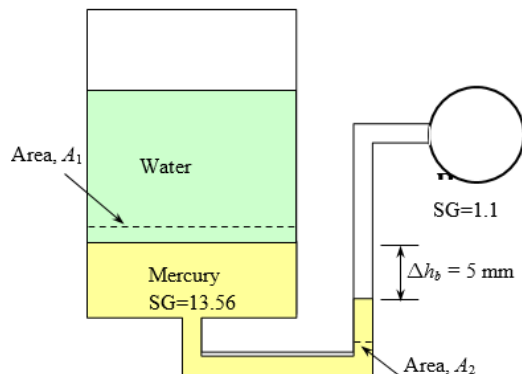
A=pi\*D<sup>2</sup>/4

P\_gage=W/A\*Convert(N/m<sup>2</sup>, kPa)

**1-79** The fluid levels in a multi-fluid U-tube manometer change as a result of a pressure drop in the trapped air space. For a given pressure drop and brine level change, the area ratio is to be determined.

**Assumptions** 1 All the liquids are incompressible. 2 Pressure in the brine pipe remains constant. 3 The variation of pressure in the trapped air space is negligible.

**Properties** The specific gravities are given to be 13.56 for mercury and 1.1 for brine. We take the standard density of water to be  $\rho_w = 1000 \text{ kg/m}^3$ .



**Analysis** It is clear from the problem statement and the figure that the brine pressure is much higher than the air pressure, and when the air pressure drops by 0.7 kPa, the pressure difference between the brine and the air space increases also by the same amount.

Starting with the air pressure (point A) and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho gh$  terms until we reach the brine pipe (point B), and setting the result equal to  $P_B$  before and after the pressure change of air give

$$\text{Before: } P_{A1} + \rho_w g h_w + \rho_{\text{Hg}} g h_{\text{Hg}, 1} - \rho_{\text{br}} g h_{\text{br}, 1} = P_B$$

$$\text{After: } P_{A2} + \rho_w g h_w + \rho_{\text{Hg}} g h_{\text{Hg}, 2} - \rho_{\text{br}} g h_{\text{br}, 2} = P_B$$

Subtracting,

$$P_{A2} - P_{A1} + \rho_{\text{Hg}} g \Delta h_{\text{Hg}} - \rho_{\text{br}} g \Delta h_{\text{br}} = 0 \quad \frac{P_{A1} - P_{A2}}{\rho_w g} = S G_{\text{Hg}} \Delta h_{\text{Hg}} - S G_{\text{br}} \Delta h_{\text{br}} = 0 \quad (1)$$

where  $\Delta h_{\text{Hg}}$  and  $\Delta h_{\text{br}}$  are the changes in the differential mercury and brine column heights, respectively, due to the drop in air pressure. Both of these are positive quantities since as the mercury-brine interface drops, the differential fluid heights for both mercury and brine increase. Noting also that the volume of mercury is constant, we have  $A_1 \Delta h_{\text{Hg}, \text{left}} = A_2 \Delta h_{\text{Hg}, \text{right}}$  and

$$P_{A2} - P_{A1} = -0.7 \text{ kPa} = -700 \text{ N/m}^2 = -700 \text{ kg/m} \cdot \text{s}^2$$

$$\Delta h_{\text{br}} = 0.005 \text{ m}$$

$$\Delta h_{\text{Hg}} = \Delta h_{\text{Hg}, \text{right}} + \Delta h_{\text{Hg}, \text{left}} = \Delta h_{\text{br}} + \Delta h_{\text{br}} A_2 / A_1 = \Delta h_{\text{br}} (1 + A_2 / A_1)$$

Substituting,

$$\frac{700 \text{ kg/m} \cdot \text{s}^2}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} = [13.56 \times 0.005(1 + A_2/A_1) - (1.1 \times 0.005)] \text{ m}$$

It gives  $A_2/A_1 = 0.134$

*Solution with appropriate Software*

"Given"

$$\text{DELTA}P=0.7 \text{ [kPa]} * \text{Convert}(\text{kPa}, \text{kg/m-s}^2)$$

$$\text{DELTA}h_{\text{br}}=0.005 \text{ [m]}$$

"Analysis"

$$\rho_w=1000 \text{ [kg/m}^3]$$

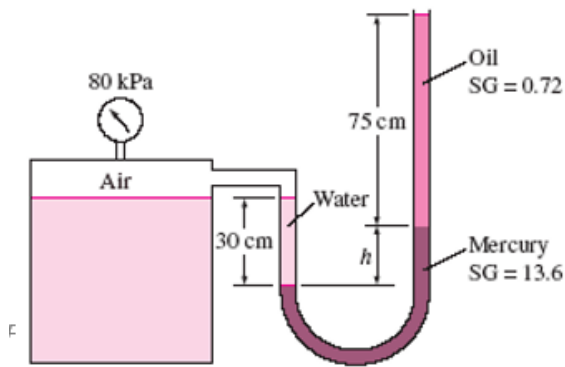
$$g=9.81 \text{ [m/s}^2]$$

$$\text{DELTA}P/(\rho_w * g)=13.56 * \text{DELTA}h_{\text{br}} * (1 + \text{Ratio}) - (1.1 * \text{DELTA}h_{\text{br}})$$

**1-80** The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height  $h$  of the mercury column is to be determined.

**Assumptions** The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus the pressure at the air-water interface is the same as the indicated gage pressure.

**Properties** We take the density of water to be  $\rho_w = 1000 \text{ kg/m}^3$ . The specific gravities of oil and mercury are given to be 0.72 and 13.6, respectively.



**Analysis** Starting with the pressure of air in the tank (point 1), and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho gh$  terms until we reach the free surface of oil where the oil tube is exposed to the atmosphere, and setting the result equal to  $P_{atm}$  gives

$$P_1 + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{oil} g h_{oil} = P_{atm}$$

Rearranging,

$$P_1 - P_{atm} = \rho_{oil} g h_{oil} + \rho_{Hg} g h_{Hg} - \rho_w g h_w$$

or,

$$\frac{P_{1,gage}}{\rho_w g} = SG_{oil} h_{oil} + SG_{Hg} h_{Hg} - h_w$$

Substituting,

$$\left( \frac{80 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} \right) \left( \frac{1000 \text{ kg} \cdot \text{m/s}^2}{1 \text{ kPa} \cdot \text{m}^2} \right) = 0.72 \times (0.75 \text{ m}) + 13.6 \times h_{Hg} - 0.3 \text{ m}$$

Solving for  $h_{Hg}$  gives

$$h_{Hg} = 0.582 \text{ m}$$

Therefore, the differential height of the mercury column must be 58.2 cm.

**Discussion** Double instrumentation like this allows one to verify the measurement of one of the instruments by the measurement of another instrument.

### *Solution with appropriate Software*

"Given"

$$P_{gage} = 80 \text{ [kPa]}$$

$$h_w = 0.3 \text{ [m]}$$

$$h_{oil} = 0.75 \text{ [m]}$$

$$\rho_{s\_oil} = 0.72$$

$$\rho_{s\_Hg} = 13.6$$

"Properties"

$$\rho_w = 1000 \text{ [kg/m}^3] \text{ "taken"}$$

$$\rho_{oil} = \rho_{s\_oil} \cdot \rho_w$$

$$\rho_{Hg} = \rho_{s\_Hg} \cdot \rho_w$$

$$g = 9.807 \text{ [m/s}^2]$$

"Analysis"

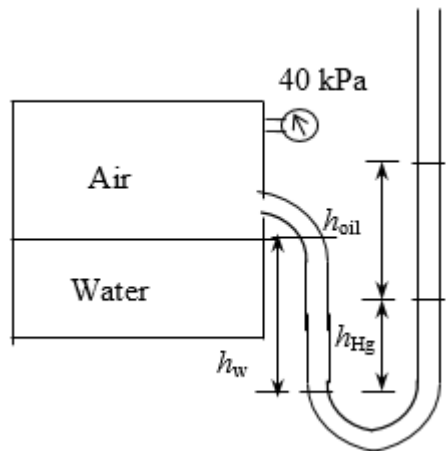
$$P_{gage} = g \cdot (\rho_{oil} \cdot h_{oil} + \rho_{Hg} \cdot h_{Hg} - \rho_w \cdot h_w) \cdot \text{Convert}(\text{kg/m} \cdot \text{s}^2, \text{kPa})$$

**1-81** The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height  $h$  of the mercury column is to be determined.

**Assumptions** The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus the pressure at the air-water interface is the same as the indicated gage pressure.

**Properties** We take the density of water to be  $\rho_w = 1000 \text{ kg/m}^3$ . The specific gravities of oil and mercury are given to be 0.72 and 13.6, respectively.

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**Analysis** Starting with the pressure of air in the tank (point 1), and moving along the tube by adding (as we go down) or subtracting (as we go up) the  $\rho gh$  terms until we reach the free surface of oil where the oil tube is exposed to the atmosphere, and setting the result equal to  $P_{atm}$  gives

$$P_1 + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{oil} g h_{oil} = P_{atm}$$

Rearranging,

$$P_1 - P_{atm} = \rho_{oil} g h_{oil} + \rho_{Hg} g h_{Hg} - \rho_w g h_w$$

$$\text{or, } \frac{P_{1,gage}}{\rho_w g} = SG_{oil} h_{oil} + SG_{Hg} h_{Hg} - h_w$$

Substituting,

$$\left[ \frac{40 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} \right] \left( \frac{1000 \text{ kg} \cdot \text{m/s}^2}{1 \text{ kPa} \cdot \text{m}^2} \right) = 0.72 \times (0.75 \text{ m}) + 13.6 \times h_{Hg} - 0.3 \text{ m}$$

Solving for  $h_{Hg}$  gives

$$h_{Hg} = 0.282 \text{ m}$$

Therefore, the differential height of the mercury column must be 28.2 cm.

**Discussion** Double instrumentation like this allows one to verify the measurement of one of the instruments by the measurement of another instrument.

*Solution with appropriate Software*

"Given"

$$P_{gage}=40 \text{ [kPa]}$$

$$h_w=0.3 \text{ [m]}$$

$$h_{oil}=0.75 \text{ [m]}$$

$$\rho_{s\_oil}=0.72$$

$$\rho_{s\_Hg}=13.6$$

"Properties"

$$\rho_w=1000 \text{ [kg/m}^3] \text{ "taken"}$$

$$\rho_{oil}=\rho_{s\_oil} \cdot \rho_w$$

$$\rho_{Hg}=\rho_{s\_Hg} \cdot \rho_w$$

$$g=9.81 \text{ [m/s}^2]$$

"Analysis"

$$P_{gage}=g \cdot (\rho_{oil} \cdot h_{oil} + \rho_{Hg} \cdot h_{Hg} - \rho_w \cdot h_w) \cdot \text{Convert}(\text{kg/m-s}^2, \text{kPa})$$

## Solving Engineering Problems and Equation Solvers

**1-82C** Despite the convenience and capability the engineering software packages offer, they are still just tools, and they will not replace the traditional engineering courses. They will simply cause a shift in emphasis in the course material from

mathematics to physics. They are of great value in engineering practice, however, as engineers today rely on software packages for solving large and complex problems in a short time, and perform optimization studies efficiently.



**1-83** Determine a positive real root of the following equation using appropriate software:

$$2x^3 - 10x^{0.5} - 3x = -3$$

**Solution** Solved by an equation solver with the following code:

$$2*x^3-10*x^{0.5}-3*x = -3$$

*Answer:*  $x = 2.063$  (using an initial guess of  $x = 2$ )



**1-84** Solve the following system of 2 equations with 2 unknowns using appropriate software:

$$x^3 - y^2 = 5.9$$

$$3xy + y = 3.5$$

**Solution** Solved by an equation solver with the following code:

$$x^3-y^2=5.9$$

$$3*x*y+y=3.5$$

*Answer*  $x=1.836$   $y=0.5378$



**1-85** Solve the following system of 3 equations with 3 unknowns using appropriate software:

$$2x - y + z = 7$$

$$3x^2 + 2y = z + 3$$

$$xy + 2z = 4$$

**Solution** Solved by an equation solver with the following code:

$$2*x-y+z=7$$

$$3*x^2+2*y=z+3$$

$$x*y+2*z=4$$

*Answer*  $x=1.609$ ,  $y = -0.9872$ ,  $z=2.794$



**1-86** Solve the following system of 3 equations with 3 unknowns using appropriate software:

$$x^2y - z = 1$$

$$x - 3y^{0.5} + xz = -2$$

$$x + y - z = 2$$

**Solution** Solved by an equation solver with the following code:

$$x^2*y-z=1$$

$$x-3*y^{0.5}+x*z = -2$$

$$x+y-z=2$$

*Answer*  $x=1$ ,  $y=1$ ,  $z=0$

## Review Problems

**1-87E** The thrust developed by the jet engine of a Boeing 777 is given to be 85,000 pounds. This thrust is to be expressed in N and kgf.

**Analysis** Noting that 1 lbf = 4.448 N and 1 kgf = 9.81 N, the thrust developed can be expressed in two other units as

$$\text{Thrust in N: } \text{Thrust} = (85,000 \text{ lbf}) \left( \frac{4.448 \text{ N}}{1 \text{ lbf}} \right) = 3.78 \times 10^5 \text{ N}$$

$$\text{Thrust in kgf: } \text{Thrust} = (3.78 \times 10^5 \text{ N}) \left( \frac{1 \text{ kgf}}{9.81 \text{ N}} \right) = 3.85 \times 10^4 \text{ kgf}$$

*Solution with appropriate Software*

"Given"

Thrust=85000 [lbf]

"Analysis"

Thrust\_N=Thrust\*Convert(lbf, N)

Thrust\_kgf=Thrust\_N\*(1/9.807) "since 1 kgf = 9.807 N"

**1-88** The gravitational acceleration changes with altitude. Accounting for this variation, the weights of a body at different locations are to be determined.

**Analysis** The weight of an 80-kg man at various locations is obtained by substituting the altitude  $z$  (values in m) into the relation

$$W = mg = (80 \text{ kg})(9.807 - 3.32 \times 10^{-6} z \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right)$$

$$\text{Sea level: } (z = 0 \text{ m}): W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 0) = 80 \times 9.807 = \mathbf{784.6 \text{ N}}$$

$$\text{Denver: } (z = 1610 \text{ m}): W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 1610) = 80 \times 9.802 = \mathbf{784.2 \text{ N}}$$

$$\text{Mt. Ev.: } (z = 8848 \text{ m}): W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 8848) = 80 \times 9.778 = \mathbf{782.2 \text{ N}}$$

*Solution with appropriate Software*

"Given"

a=9.807 [m/s^2]

b=3.32E-6 [1/s^2]

m=80 [kg]

z1=0 [m]

z2=1610 [m]

z3=8848 [m]

"Analysis"

g1=a-b\*z1

W1=m\*g1

g2=a-b\*z2

W2=m\*g2

g3=a-b\*z3

W3=m\*g3

**1-89E** A man is considering buying a 12-oz steak for \$5.50, or a 300-g steak for \$5.20. The steak that is a better buy is to be determined.

**Assumptions** The steaks are of identical quality.

**Analysis** To make a comparison possible, we need to express the cost of each steak on a common basis. Let us choose 1 kg as the basis for comparison. Using proper conversion factors, the unit cost of each steak is determined to be

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12 ounce steak:

$$\text{Unit Cost} = \left( \frac{\$5.50}{12 \text{ oz}} \right) \left( \frac{16 \text{ oz}}{1 \text{ lbm}} \right) \left( \frac{1 \text{ lbm}}{0.45359 \text{ kg}} \right) = \$16.17/\text{kg}$$

300 gram steak:

$$\text{Unit Cost} = \left( \frac{\$5.20}{300 \text{ g}} \right) \left( \frac{1000 \text{ g}}{1 \text{ kg}} \right) = \$17.33/\text{kg}$$

Therefore, the steak at the traditional market is a better buy.

*Solution with appropriate Software*

"Given"

m1=12 [oz]

price1=5.50 [\$]

m2=300 [g]

price2=5.20 [\$]

"Analysis"

UnitCost1=price1/m1\*Convert(1/oz, 1/kg)

UnitCost2=price2/m2\*Convert(1/g, 1/kg)

**1-90E** The mass of a substance is given. Its weight is to be determined in various units.

**Analysis** Applying Newton's second law, the weight is determined in various units to be

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

$$W = mg = (1 \text{ kg})(9.81 \text{ m/s}^2) \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) = 0.00981 \text{ kN}$$

$$W = mg = (1 \text{ kg})(9.81 \text{ m/s}^2) = 1 \text{ kg} \cdot \text{m/s}^2$$

$$W = mg = (1 \text{ kg})(9.81 \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) \left( \frac{1 \text{ kgf}}{9.81 \text{ N}} \right) = 1 \text{ kgf}$$

$$W = mg = (1 \text{ kg}) \left( \frac{2.205 \text{ lbm}}{1 \text{ kg}} \right) (32.2 \text{ ft/s}^2) = 71 \text{ lbm} \cdot \text{ft/s}^2$$

$$W = mg = (1 \text{ kg}) \left( \frac{2.205 \text{ lbm}}{1 \text{ kg}} \right) (32.2 \text{ ft/s}^2) \left( \frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) = 2.21 \text{ lbf}$$

*Solution with appropriate Software*

"Given"

m=1 [kg]

"Analysis"

g=9.81 [m/s^2]

W\_1=m\*g

W\_2=m\*g\*Convert(N, kN)

W\_3=m\*g\*Convert(kg-m/s^2, N)

W\_4=m\*g/9.81 "1 kgf = 9.81 N"

W\_5=m\*g\*Convert(kg-m/s^2, lbm-ft/s^2)

W\_6=m\*g\*Convert(kg-m/s^2, lbf)

**1-91E** The pressure in a steam boiler is given in kgf/cm<sup>2</sup>. It is to be expressed in psi, kPa, atm, and bars.

**Analysis** We note that  $1 \text{ atm} = 1.03323 \text{ kgf/cm}^2$ ,  $1 \text{ atm} = 14.696 \text{ psi}$ ,  $1 \text{ atm} = 101.325 \text{ kPa}$ , and  $1 \text{ atm} = 1.01325 \text{ bar}$  (inner cover page of text). Then the desired conversions become:

$$\text{In atm: } P = (92 \text{ kgf/cm}^2) \left( \frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2} \right) = 89.04 \text{ atm}$$

$$\text{In psi: } P = (92 \text{ kgf/cm}^2) \left( \frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2} \right) \left( \frac{14.696 \text{ psi}}{1 \text{ atm}} \right) = 1309 \text{ psi}$$

$$\text{In kPa: } P = (92 \text{ kgf/cm}^2) \left( \frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2} \right) \left( \frac{101.325 \text{ kPa}}{1 \text{ atm}} \right) = 9022 \text{ kPa}$$

$$\text{In bars: } P = (92 \text{ kgf/cm}^2) \left( \frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2} \right) \left( \frac{1.01325 \text{ bar}}{1 \text{ atm}} \right) = 90.22 \text{ bar}$$

**Discussion** Note that the units atm, kgf/cm<sup>2</sup>, and bar are almost identical to each other.

### Solution with appropriate Software

"Given"

$$P=92 \text{ "kgf/cm}^2\text{"}$$

"Analysis"

$$P_{\text{atm}}=P*1/1.03323 \text{ "since } 1 \text{ atm} = 1.03323 \text{ kgf/cm}^2\text{"}$$

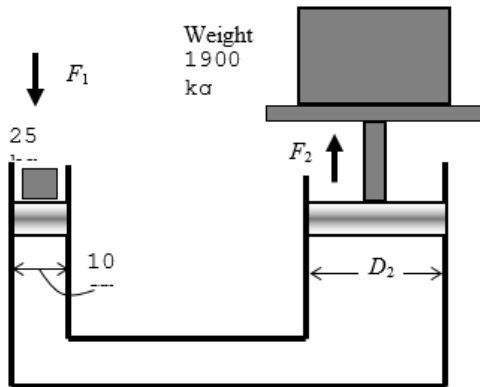
$$P_{\text{psi}}=P*1/1.03323*\text{Convert(atm, psi)}$$

$$P_{\text{kPa}}=P*1/1.03323*\text{Convert(atm, kPa)}$$

$$P_{\text{bars}}=P*1/1.03323*\text{Convert(atm, bar)}$$

**1-92** A hydraulic lift is used to lift a weight. The diameter of the piston on which the weight to be placed is to be determined.

**Assumptions** 1 The cylinders of the lift are vertical. 2 There are no leaks. 3 Atmospheric pressure act on both sides, and thus it can be disregarded.



**Analysis** Noting that pressure is force per unit area, the pressure on the smaller piston is determined from

$$P_1 = \frac{F_1}{A_1} = \frac{m_1 g}{\pi D_1^2 / 4} = \frac{(25 \text{ kg})(9.81 \text{ m/s}^2)}{\pi (0.10 \text{ m})^2 / 4} \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) = 31.23 \text{ kN/m}^2 = 31.23 \text{ kPa}$$

From Pascal's principle, the pressure on the greater piston is equal to that in the smaller piston. Then, the needed diameter is determined from

$$P_1 = P_2 = \frac{F_2}{A_2} = \frac{m_2 g}{\pi D_2^2 / 4} \rightarrow 31.23 \text{ kN/m}^2 = \frac{(1900 \text{ kg})(9.81 \text{ m/s}^2)}{\pi D_2^2 / 4} \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) \rightarrow D_2 = 0.872 \text{ m}$$

**Discussion** Note that large weights can be raised by little effort in hydraulic lift by making use of Pascal's principle.

### Solution with appropriate Software

"GIVEN"

$$m_2=1900 \text{ [kg]}$$

$$m_1=25 \text{ [kg]}$$

$D_1=0.10$  [m]  
 "ANALYSIS"  
 $g=9.81$  [m/s<sup>2</sup>]  
 $F_1=m_1 \cdot g$   
 $A_1=\pi \cdot D_1^2/4$   
 $P_1=F_1/A_1$   
 $P_2=P_1$   
 $F_2=m_2 \cdot g$   
 $A_2=F_2/P_2$   
 $A_2=\pi \cdot D_2^2/4$

**1-93** The average atmospheric pressure is given as  $P_{\text{atm}} = 101.325(1 - 0.02256z)^{5.256}$  where  $z$  is the altitude in km. The atmospheric pressures at various locations are to be determined.

**Analysis** The atmospheric pressures at various locations are obtained by substituting the altitude  $z$  values in km into the relation

$$P_{\text{atm}} = 101.325(1 - 0.02256z)^{5.256}$$

Atlanta: ( $z = 0.306$  km):  $P_{\text{atm}} = 101.325(1 - 0.02256 \times 0.306)^{5.256} = \mathbf{97.7kPa}$   
 Denver: ( $z = 1.610$  km):  $P_{\text{atm}} = 101.325(1 - 0.02256 \times 1.610)^{5.256} = \mathbf{83.4kPa}$   
 M. City: ( $z = 2.309$  km):  $P_{\text{atm}} = 101.325(1 - 0.02256 \times 2.309)^{5.256} = \mathbf{76.5kPa}$   
 Mt. Ev.: ( $z = 8.848$  km):  $P_{\text{atm}} = 101.325(1 - 0.02256 \times 8.848)^{5.256} = \mathbf{31.4kPa}$

*Solution with appropriate Software*

"Given"

$z_{\text{Atlanta}}=0.306$  [km]  
 $z_{\text{Denver}}=1.610$  [km]  
 $z_{\text{MexicoCity}}=2.309$  [km]  
 $z_{\text{Everest}}=8.848$  [km]

"Analysis"

$P_{\text{atm\_Atlanta}}=101.325 \cdot (1-0.02256 \cdot z_{\text{Atlanta}})^{5.256}$   
 $P_{\text{atm\_Denver}}=101.325 \cdot (1-0.02256 \cdot z_{\text{Denver}})^{5.256}$   
 $P_{\text{atm\_MexicoCity}}=101.325 \cdot (1-0.02256 \cdot z_{\text{MexicoCity}})^{5.256}$   
 $P_{\text{atm\_Everest}}=101.325 \cdot (1-0.02256 \cdot z_{\text{Everest}})^{5.256}$

**1-94E** Hyperthermia of 5°C is considered fatal. This fatal level temperature change of body temperature is to be expressed in °F, K, and R.

**Analysis** The magnitudes of 1 K and 1°C are identical, so are the magnitudes of 1 R and 1°F. Also, a change of 1 K or 1°C in temperature corresponds to a change of 1.8 R or 1.8°F. Therefore, the fatal level of hypothermia is

- (a) **5 K**
- (b)  $5 \times 1.8 = \mathbf{9^\circ F}$
- (c)  $5 \times 1.8 = \mathbf{9 R}$

*Solution with appropriate Software*

"Given"

DELTA\_T\_C=5 [C]

"Analysis"

"(a)"

DELTA\_T\_K=DELTA\_T\_C\*Convert(C, K)

"(b)"

$$\text{DELTA}_F = \text{DELTA}_C * \text{Convert}(C, F)$$

"(c)"

$$\text{DELTA}_R = \text{DELTA}_C * \text{Convert}(C, R)$$

**1-95E** The boiling temperature of water decreases by  $3^\circ\text{C}$  for each 1000 m rise in altitude. This decrease in temperature is to be expressed in  $^\circ\text{F}$ , K, and R.

**Analysis** The magnitudes of 1 K and  $1^\circ\text{C}$  are identical, so are the magnitudes of 1 R and  $1^\circ\text{F}$ . Also, a change of 1 K or  $1^\circ\text{C}$  in temperature corresponds to a change of 1.8 R or  $1.8^\circ\text{F}$ . Therefore, the decrease in the boiling temperature is

(a) **3 K** for each 1000 m rise in altitude, and

(b)

(c)  $3 \times 1.8 = 5.4^\circ\text{F} = 5.4 \text{ R}$  for each 1000 m rise in altitude.

*Solution with appropriate Software*

"Given"

$$\text{DELTA}_C = 3 \text{ [C]}$$

"Analysis"

"(a)"

$$\text{DELTA}_K = \text{DELTA}_C * \text{Convert}(C, K)$$

"(b)"

$$\text{DELTA}_F = \text{DELTA}_C * \text{Convert}(C, F)$$

"(c)"

$$\text{DELTA}_R = \text{DELTA}_C * \text{Convert}(C, R)$$

**1-96E** A house is losing heat at a rate of  $1800 \text{ kJ/h}$  per  $^\circ\text{C}$  temperature difference between the indoor and the outdoor temperatures. The rate of heat loss is to be expressed per  $^\circ\text{F}$ , K, and R of temperature difference between the indoor and the outdoor temperatures.

**Analysis** The magnitudes of 1 K and  $1^\circ\text{C}$  are identical, so are the magnitudes of 1 R and  $1^\circ\text{F}$ . Also, a change of 1 K or  $1^\circ\text{C}$  in temperature corresponds to a change of 1.8 R or  $1.8^\circ\text{F}$ . Therefore, the rate of heat loss from the house is

(a) **1800 kJ/h** per K difference in temperature, and

(b)

(c)  $1800/1.8 = 1000 \text{ kJ/h}$  per R or  $^\circ\text{F}$  rise in temperature.

*Solution with appropriate Software*

"Given"

$$Q_{\text{dot\_loss\_C}} = 1800 \text{ [kJ/h-C]}$$

"Analysis"

"(a)"

$$Q_{\text{dot\_loss\_K}} = Q_{\text{dot\_loss\_C}} * \text{Convert}(C, K)$$

"(b)"

$$Q_{\text{dot\_loss\_F}} = Q_{\text{dot\_loss\_C}} * \text{Convert}(1/C, 1/F)$$

"(c)"

$$Q_{\text{dot\_loss\_R}} = Q_{\text{dot\_loss\_C}} * \text{Convert}(1/C, 1/R)$$

**1-97E** The average body temperature of a person rises by about  $2^{\circ}\text{C}$  during strenuous exercise. This increase in temperature is to be expressed in  $^{\circ}\text{F}$ ,  $\text{K}$ , and  $\text{R}$ .

**Analysis** The magnitudes of  $1\text{ K}$  and  $1^{\circ}\text{C}$  are identical, so are the magnitudes of  $1\text{ R}$  and  $1^{\circ}\text{F}$ . Also, a change of  $1\text{ K}$  or  $1^{\circ}\text{C}$  in temperature corresponds to a change of  $1.8\text{ R}$  or  $1.8^{\circ}\text{F}$ . Therefore, the rise in the body temperature during strenuous exercise is

- (a)  $2\text{ K}$
- (b)  $2 \times 1.8 = 3.6^{\circ}\text{F}$
- (c)  $2 \times 1.8 = 3.6\text{ R}$

*Solution with appropriate Software*

"Given"

DELTA\_T\_C=2 [C]

"Analysis"

"(a)"

DELTA\_T\_K=DELTA\_T\_C\*Convert(C, K)

"(b)"

DELTA\_T\_F=DELTA\_T\_C\*Convert(C, F)

"(c)"

DELTA\_T\_R=DELTA\_T\_C\*Convert(C, R)

**1-98** The average temperature of the atmosphere is expressed as  $T_{\text{atm}} = 288.15 - 6.5z$  where  $z$  is altitude in km. The temperature outside an airplane cruising at 12,000 m is to be determined.

**Analysis** Using the relation given, the average temperature of the atmosphere at an altitude of 12,000 m is determined to be

$$\begin{aligned} T_{\text{atm}} &= 288.15 - 6.5z \\ &= 288.15 - 6.5 \times 12 \\ &= \mathbf{210.15\text{K}} = \mathbf{-63^{\circ}\text{C}} \end{aligned}$$

**Discussion** This is the "average" temperature. The actual temperature at different times can be different.

*Solution with appropriate Software*

"Given"

z=12000\*Convert(m, km)

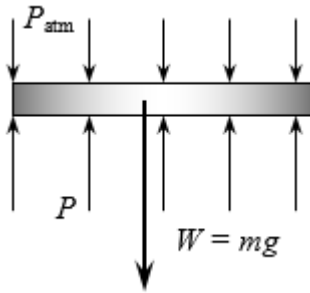
"Analysis"

T\_atm\_K=288.15-6.5\*z

T\_atm\_C=T\_atm\_K-273.15

**1-99** The pressure of a gas contained in a vertical piston-cylinder device is measured to be 180 kPa. The mass of the piston is to be determined.

**Assumptions** There is no friction between the piston and the cylinder.



**Analysis** Drawing the free body diagram of the piston and balancing the vertical forces yield

$$W = PA - P_{atm}A$$

$$mg = (P - P_{atm})A$$

$$(m)(9.81 \text{ m/s}^2) = (180 - 100 \text{ kPa})(25 \times 10^{-4} \text{ m}^2) \left( \frac{1000 \text{ kg/m} \cdot \text{s}^2}{1 \text{ kPa}} \right)$$

It yields

$$m = 20.4 \text{ kg}$$

*Solution with appropriate Software*

"Given"

$$P=180 \text{ [kPa]}$$

$$P_{atm}=100 \text{ [kPa]}$$

$$A=25E-4 \text{ [m}^2\text{]}$$

"Analysis"

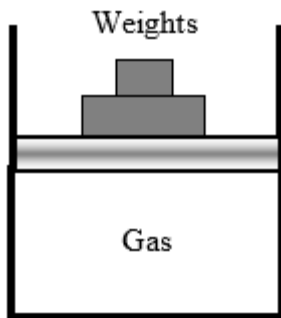
$$g=9.81 \text{ [m/s}^2\text{]}$$

$$W=m \cdot g$$

$$W=(P \cdot A - P_{atm} \cdot A) \cdot \text{Convert}(\text{kPa}, \text{kg/m} \cdot \text{s}^2)$$

**1-100** A vertical piston-cylinder device contains a gas. Some weights are to be placed on the piston to increase the gas pressure. The local atmospheric pressure and the mass of the weights that will double the pressure of the gas are to be determined.

**Assumptions** Friction between the piston and the cylinder is negligible.



**Analysis** The gas pressure in the piston-cylinder device initially depends on the local atmospheric pressure and the weight of the piston. Balancing the vertical forces yield

$$P_{atm} = P - \frac{m_{piston}g}{A} = 100 \text{ kPa} - \frac{(10 \text{ kg})(9.81 \text{ m/s}^2)}{\pi(0.12 \text{ m}^2)/4} \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right)$$

$$= 93.63 \text{ kN/m}^2 \cong 93.6 \text{ kPa}$$

The force balance when the weights are placed is used to determine the mass of the weights

$$P = P_{\text{atm}} + \frac{(m_{\text{piston}} + m_{\text{weights}})g}{A}$$

$$200 \text{ kPa} = 93.63 \text{ kPa} + \frac{(10 \text{ kg} + m_{\text{weights}})(9.81 \text{ m/s}^2)}{\pi(0.12 \text{ m})^2/4} \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) \rightarrow m_{\text{weights}} = 157 \text{ kg}$$

A large mass is needed to double the pressure.

*Solution with appropriate Software*

"GIVEN"

$$P_1 = 100 \text{ [kPa]}$$

$$m_p = 10 \text{ [kg]}$$

$$D = 0.14 \text{ [m]}$$

$$P_2 = 2 \cdot P_1$$

"ANALYSIS"

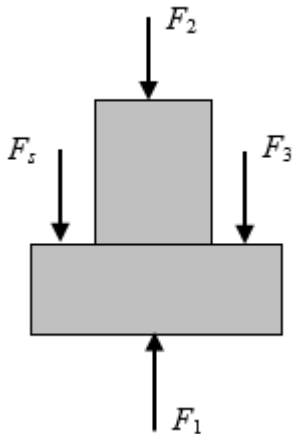
$$A_p = \pi \cdot D^2 / 4$$

$$P_1 = P_{\text{atm}} + (m_p \cdot g) / A_p \cdot \text{Convert}(\text{Pa}, \text{kPa}) \text{ "vertical force balance without weights"}$$

$$P_2 = P_{\text{atm}} + ((m_p + m_{\text{weights}}) \cdot g) / A_p \cdot \text{Convert}(\text{Pa}, \text{kPa}) \text{ "vertical force balance with weights"}$$

$$g = 9.81 \text{ [m/s}^2\text{]}$$

**1-101** The deflection of the spring of the two-piston cylinder with a spring shown in the figure is to be determined.



**Analysis** Summing the forces acting on the piston in the vertical direction gives

$$F_5 + F_2 + F_3 = F_1$$

$$kx + P_2 A_2 + P_3 (A_1 - A_2) = P_1 A_1$$

which when solved for the deflection of the spring and substituting  $A = \pi D^2 / 4$  gives

$$sx = \frac{\pi}{4k} [P_1 D_1^2 - P_2 D_2^2 - P_3 (D_1^2 - D_2^2)]$$

$$= \frac{\pi}{4 \times 800} [5000 \times 0.08^2 - 10,000 \times 0.03^2 - 1000(0.08^2 - 0.03^2)]$$

$$= 0.0172 \text{ m}$$

$$= 1.72 \text{ cm}$$

We expressed the spring constant  $k$  in kN/m, the pressures in kPa (i.e., kN/m<sup>2</sup>) and the diameters in m units.

*Solution with appropriate Software*

"Given"

$$k = 8 \text{ [kN/cm]}$$

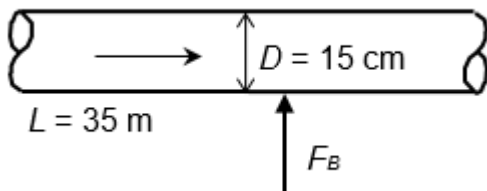
$P_1=5000$  [kPa]  
 $P_2=10000$  [kPa]  
 $P_3=1000$  [kPa]  
 $D_1=0.08$  [m]  
 $D_2=0.03$  [m]  
 "Analysis"  
 $A_1=\pi \cdot D_1^2/4$   
 $A_2=\pi \cdot D_2^2/4$   
 $A_3=A_1-A_2$   
 $F_1=P_1 \cdot A_1$   
 $F_2=P_2 \cdot A_2$   
 $F_3=P_3 \cdot A_3$   
 $F_s+F_2+F_3=F_1$   
 $F_s=k \cdot x$

**1-102** One section of the duct of an air-conditioning system is laid underwater. The upward force the water will exert on the duct is to be determined.

**Assumptions 1** The diameter given is the outer diameter of the duct (or, the thickness of the duct material is negligible).

**2** The weight of the duct and the air in is negligible.

**Properties** The density of air is given to be  $\rho = 1.30$  kg/m<sup>3</sup>. We take the density of water to be 1000 kg/m<sup>3</sup>.



**Analysis** Noting that the weight of the duct and the air in it is negligible, the net upward force acting on the duct is the buoyancy force exerted by water. The volume of the underground section of the duct is

$$V = AL = (\pi D^2/4)L = [\pi(0.15 \text{ m})^2/4](35 \text{ m}) = 0.6185 \text{ m}^3$$

Then the buoyancy force becomes

$$F_B = \rho g V = (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.6185 \text{ m}^3) \left( \frac{1 \text{ kN}}{1000 \text{ kg} \cdot \text{m/s}^2} \right) = 6.07 \text{ kN}$$

**Discussion** The upward force exerted by water on the duct is 6.07 kN, which is equivalent to the weight of a mass of 619 kg. Therefore, this force must be treated seriously.

*Solution with appropriate Software*

"Given"

$L=35$  [m]  
 $D=0.15$  [m]  
 $\rho_{\text{air}}=1.3$  [kg/m<sup>3</sup>]  
 $\rho_{\text{water}}=1000$  [kg/m<sup>3</sup>]

"Analysis"

$g=9.81$  [m/s<sup>2</sup>]  
 $V=\pi \cdot D^2/4 \cdot L$   
 $F_B=\rho_{\text{water}} \cdot g \cdot V \cdot \text{Convert}(\text{kg/m} \cdot \text{s}^2, \text{kPa})$

**1-103** A helium balloon tied to the ground carries 2 people. The acceleration of the balloon when it is first released is to be determined.

**Assumptions** The weight of the cage and the ropes of the balloon is negligible.

**Properties** The density of air is given to be  $\rho = 1.16 \text{ kg/m}^3$ . The density of helium gas is  $1/7^{\text{th}}$  of this.



**Analysis** The buoyancy force acting on the balloon is

$$V_{\text{balloon}} = \frac{4\pi r^3}{3} = \frac{4\pi (6 \text{ m})^3}{3} = 904.8 \text{ m}^3$$

$$F_B = \rho_{\text{air}} g V_{\text{balloon}}$$

$$= (1.16 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(904.8 \text{ m}^3) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 10,296 \text{ N}$$

The total mass is

$$m_{\text{He}} = \rho_{\text{He}} V = \left( \frac{1.16}{7} \text{ kg/m}^3 \right) (904.8 \text{ m}^3) = 149.9 \text{ kg}$$

$$m_{\text{total}} = m_{\text{He}} + m_{\text{people}} = 149.9 + 2 \times 85 = 319.9 \text{ kg}$$

The total weight is

$$W = m_{\text{total}} g = (319.9 \text{ kg})(9.81 \text{ m/s}^2) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 3138 \text{ N}$$

Thus the net force acting on the balloon is

$$F_{\text{net}} = F_B - W = 10,296 - 3138 = 7157 \text{ N}$$

Then the acceleration becomes

$$a = \frac{F_{\text{net}}}{m_{\text{total}}} = \frac{7157 \text{ N}}{319.9 \text{ kg}} \left( \frac{1 \text{ kg} \cdot \text{m/s}^2}{1 \text{ N}} \right) = 22.4 \text{ m/s}^2$$

*Solution with appropriate Software*

"Given"

D=12 [m]

N\_person=2

m\_person=85 [kg]

rho\_air=1.16 [kg/m^3]

rho\_He=rho\_air/7

"Analysis"

g=9.81 [m/s^2]

V\_ballon=pi\*D^3/6

F\_B=rho\_air\*g\*V\_ballon

$$\begin{aligned}
 m_{\text{He}} &= \rho_{\text{He}} V_{\text{ballon}} \\
 m_{\text{people}} &= N_{\text{person}} m_{\text{person}} \\
 m_{\text{total}} &= m_{\text{He}} + m_{\text{people}} \\
 W &= m_{\text{total}} g \\
 F_{\text{net}} &= F_{\text{B}} - W \\
 a &= F_{\text{net}} / m_{\text{total}}
 \end{aligned}$$



**1-104** Problem 1-103 is reconsidered. The effect of the number of people carried in the balloon on acceleration is to be investigated. Acceleration is to be plotted against the number of people, and the results are to be discussed.

**Analysis** The problem is solved using appropriate software, and the solution is given below.

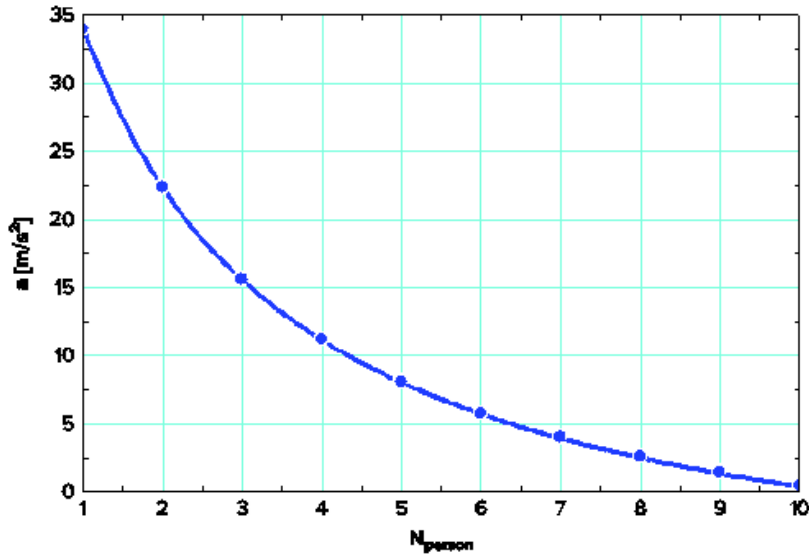
"Given"

$$\begin{aligned}
 D &= 12 \text{ [m]} \\
 N_{\text{person}} &= 2 \\
 m_{\text{person}} &= 85 \text{ [kg]} \\
 \rho_{\text{air}} &= 1.16 \text{ [kg/m}^3\text{]} \\
 \rho_{\text{He}} &= \rho_{\text{air}} / 7
 \end{aligned}$$

"Analysis"

$$\begin{aligned}
 g &= 9.81 \text{ [m/s}^2\text{]} \\
 V_{\text{ballon}} &= \pi D^3 / 6 \\
 F_{\text{B}} &= \rho_{\text{air}} g V_{\text{ballon}} \\
 m_{\text{He}} &= \rho_{\text{He}} V_{\text{ballon}} \\
 m_{\text{people}} &= N_{\text{person}} m_{\text{person}} \\
 m_{\text{total}} &= m_{\text{He}} + m_{\text{people}} \\
 W &= m_{\text{total}} g \\
 F_{\text{net}} &= F_{\text{B}} - W \\
 a &= F_{\text{net}} / m_{\text{total}}
 \end{aligned}$$

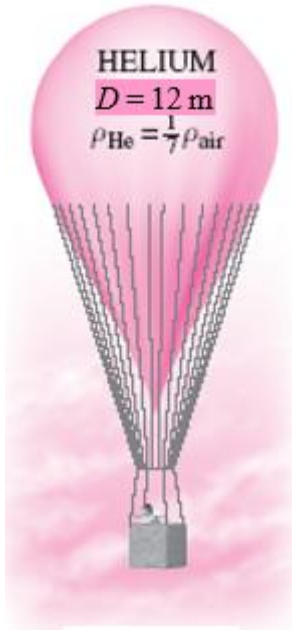
$N_{\text{person}}$	$a \text{ [m/s}^2\text{]}$
1	34
2	22.36
3	15.61
4	11.2
5	8.096
6	5.79
7	4.01
8	2.595
9	1.443
10	0.4865



**1-105** A balloon is filled with helium gas. The maximum amount of load the balloon can carry is to be determined.

*Assumptions* The weight of the cage and the ropes of the balloon is negligible.

*Properties* The density of air is given to be  $\rho = 1.16 \text{ kg/m}^3$ . The density of helium gas is 1/7th of this.



*Analysis* The buoyancy force acting on the balloon is

$$V_{\text{balloon}} = 4\pi r^3/3 = 4\pi(6 \text{ m})^3/3 = 904.8 \text{ m}^3$$

$$F_B = \rho_{\text{air}}gV_{\text{balloon}}$$

$$= (1.16 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(904.8 \text{ m}^3) \left( \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 10,296 \text{ N}$$

The mass of helium is

$$m_{\text{He}} = \rho_{\text{He}}V = \left( \frac{1.16}{7} \text{ kg/m}^3 \right) (904.8 \text{ m}^3) = 149.9 \text{ kg}$$

In the limiting case, the net force acting on the balloon will be zero. That is, the buoyancy force and the weight will balance each other:

$$W = mg = F_B$$

$$m_{\text{total}} = \frac{F_B}{g} = \frac{10,296 \text{ N}}{9.81 \text{ m/s}^2} = 1050 \text{ kg}$$

Thus,

$$m_{\text{people}} = m_{\text{total}} - m_{\text{He}} = 1050 - 149.9 = 900 \text{ kg}$$

### *Solution with appropriate Software*

#### "Given"

$$D=12 \text{ [m]}$$

$$N_{\text{person}}=2$$

$$m_{\text{person}}=85 \text{ [kg]}$$

$$\rho_{\text{air}}=1.16 \text{ [kg/m}^3\text{]}$$

$$\rho_{\text{He}}=\rho_{\text{air}}/7$$

#### "Analysis"

$$g=9.81 \text{ [m/s}^2\text{]}$$

$$m_{\text{total}_a}=F_B/g$$

$$m_{\text{people}_a}=m_{\text{total}_a}-m_{\text{He}}$$

$$V_{\text{ballon}}=\pi D^3/6$$

$$F_B=\rho_{\text{air}}*g*V_{\text{ballon}}$$

$$m_{\text{He}}=\rho_{\text{He}}*V_{\text{ballon}}$$

$$m_{\text{people}}=N_{\text{person}}*m_{\text{person}}$$

$$m_{\text{total}}=m_{\text{He}}+m_{\text{people}}$$

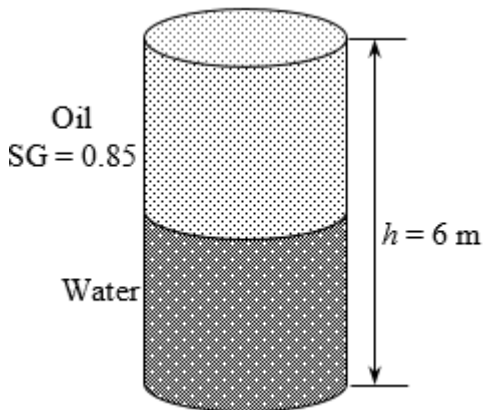
$$W=m_{\text{total}}*g$$

$$F_{\text{net}}=F_B-W$$

$$a=F_{\text{net}}/m_{\text{total}}$$

**1-106** A 6-m high cylindrical container is filled with equal volumes of water and oil. The pressure difference between the top and the bottom of the container is to be determined.

**Properties** The density of water is given to be  $\rho = 1000 \text{ kg/m}^3$ . The specific gravity of oil is given to be 0.85.



**Analysis** The density of the oil is obtained by multiplying its specific gravity by the density of water,

$$\rho = \text{SG} \times \rho_{\text{H}_2\text{O}} = (0.85)(1000 \text{ kg/m}^3) = 850 \text{ kg/m}^3$$

The pressure difference between the top and the bottom of the cylinder is the sum of the pressure differences across the two fluids,

$$\Delta P_{\text{total}} = \Delta P_{\text{oil}} + \Delta P_{\text{water}} = (\rho gh)_{\text{oil}} + (\rho gh)_{\text{water}}$$

$$= [(850 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(3 \text{ m}) + (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(3 \text{ m})] \left( \frac{1 \text{ kPa}}{1000 \text{ N/m}^2} \right)$$

$$= 54.4 \text{ kPa}$$

*Solution with appropriate Software*

"Given"

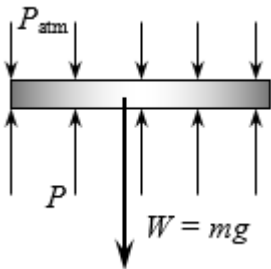
h<sub>water</sub>=3 [m]  
h<sub>oil</sub>=3 [m]  
rho<sub>water</sub>=1000 [kg/m<sup>3</sup>]  
rho<sub>s\_oil</sub>=0.85

"Analysis"

g=9.807 [m/s<sup>2</sup>]  
rho<sub>oil</sub>=rho<sub>s\_oil</sub>\*rho<sub>water</sub>  
DELTA<sub>oil</sub>=rho<sub>oil</sub>\*g\*h<sub>oil</sub>\*Convert(kg/m-s<sup>2</sup>, kPa)  
DELTA<sub>water</sub>=rho<sub>water</sub>\*g\*h<sub>water</sub>\*Convert(kg/m-s<sup>2</sup>, kPa)  
DELTA<sub>total</sub>=DELTA<sub>oil</sub>+DELTA<sub>water</sub>

**1-107** The gage pressure in a pressure cooker is maintained constant at 100 kPa by a petcock. The mass of the petcock is to be determined.

*Assumptions* There is no blockage of the pressure release valve.



*Analysis* Atmospheric pressure is acting on all surfaces of the petcock, which balances itself out. Therefore, it can be disregarded in calculations if we use the gage pressure as the cooker pressure. A force balance on the petcock ( $\Sigma F_y = 0$ ) yields

$$W = P_{\text{gage}}A$$

$$m = \frac{P_{\text{gage}}A}{g} = \frac{(100 \text{ kPa})(4 \times 10^{-6} \text{ m}^2)}{9.81 \text{ m/s}^2} \left( \frac{1000 \text{ kg/m} \cdot \text{s}^2}{1 \text{ kPa}} \right)$$

$$= 0.0408 \text{ kg}$$

*Solution with appropriate Software*

"Given"

P<sub>gage</sub>=100 [kPa]  
A=4E-6 [m<sup>2</sup>]  
P<sub>atm</sub>=101 [kPa]

"Analysis"

g=9.807 [m/s<sup>2</sup>]  
W=m\*g  
W=P<sub>gage</sub>\*A\*Convert(kPa, kg/m-s<sup>2</sup>)