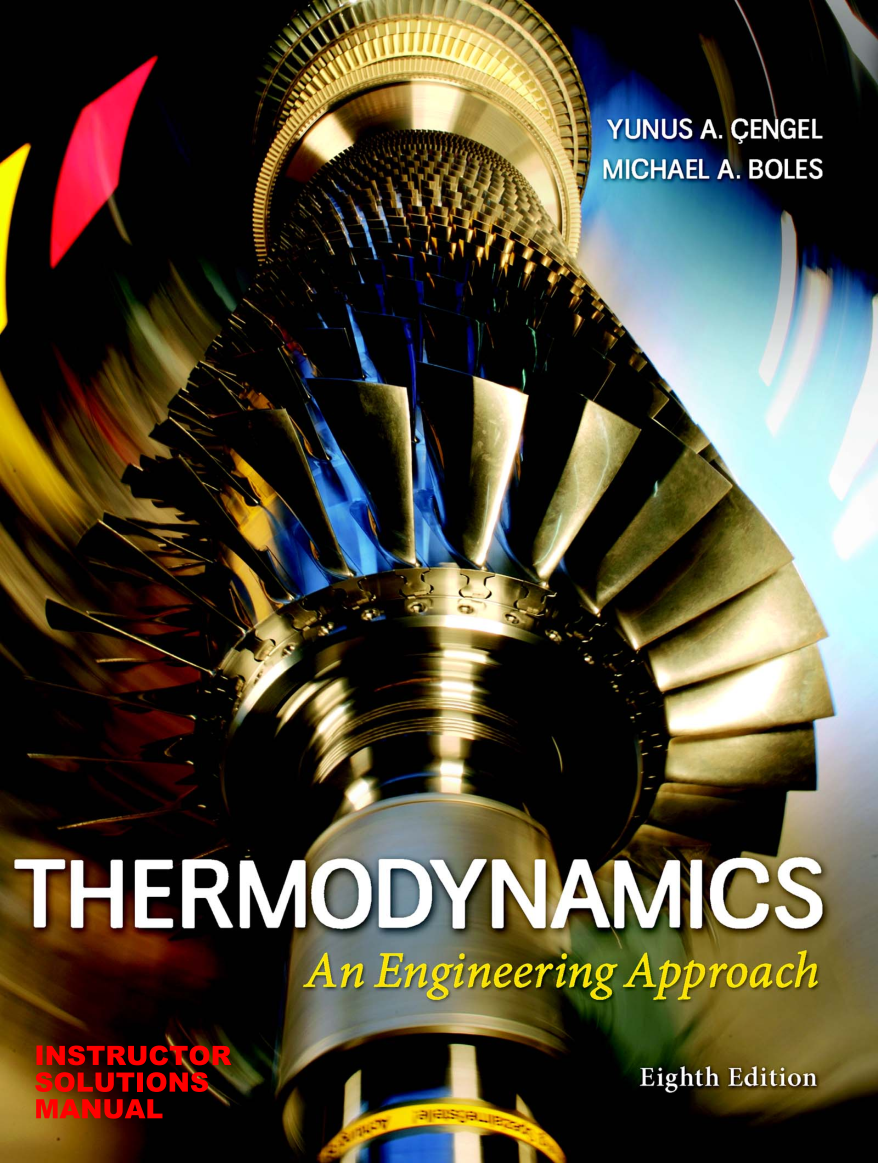


YUNUS A. ÇENGEL
MICHAEL A. BOLES

THERMODYNAMICS

An Engineering Approach

Eighth Edition

INSTRUCTOR SOLUTIONS MANUAL

Solutions Manual for

Thermodynamics: An Engineering Approach

8th Edition

Yunus A. Cengel, Michael A. Boles

McGraw-Hill, 2015

Chapter 1

INTRODUCTION AND BASIC CONCEPTS

Thermodynamics

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

1-2C 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.

1-3C 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 shown that the road that looks uphill to the eye is actually downhill.

1-4C There is no truth to his claim. It violates the second law of thermodynamics.

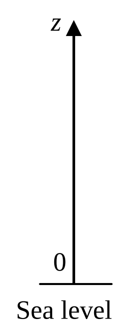
Mass, Force, and Units

1-5C Kg-mass is the mass unit in the SI system whereas kg-force is a force unit. 1-kg-force is the force required to accelerate a 1-kg mass by 9.807 m/s^2. In other words, the weight of 1-kg mass at sea level is 1 kg-force.

1-6C 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.

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

1-8 The variation of gravitational acceleration above the sea level is given as a function of altitude. The height at which the weight of a body will decrease by 0.3% is to be determined.



Analysis The weight of a body at the elevation z can be expressed as

$$W = mg = m(9.807 - 3.32 \times 10^{-6} z)$$

In our case,

$$W = (1 - 0.3/100)W_s = 0.997W_s = 0.997mg_s = 0.997(m)(9.807)$$

Substituting,

$$0.997(9.807) = (9.807 - 3.32 \times 10^{-6} z) \longrightarrow z = \mathbf{8862\ m}$$

1-9 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

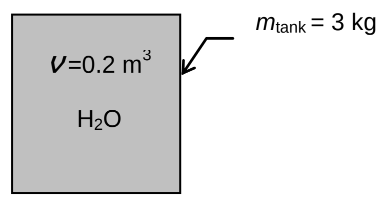
$$W = mg = (200\,\text{kg})(9.6\,\text{m/s}^2) = \mathbf{1920\,N}$$

1-10 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 ρ = 1000 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,

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

1-11E The constant-pressure specific heat of air given in a specified unit is to be expressed in various units.

Analysis Using proper unit conversions, the constant-pressure specific heat is determined in various units to be

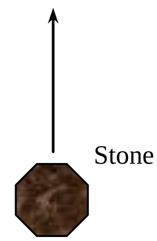
$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{kJ/kg}\cdot\text{K}}{1\,\text{kJ/kg}\cdot°\text{C}}\right) = \mathbf{1.005\,kJ/kg\cdot K}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1000\,\text{J}}{1\,\text{kJ}}\right)\left(\frac{1\,\text{kg}}{1000\,\text{g}}\right) = \mathbf{1.005\,J/g\cdot °C}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{kcal}}{4.1868\,\text{kJ}}\right) = \mathbf{0.240\,kcal/kg\cdot °C}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{Btu/lbm}\cdot°\text{F}}{4.1868\,\text{kJ/kg}\cdot°\text{C}}\right) = \mathbf{0.240\,Btu/lbm\cdot °F}$$

1-12 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

$$W = mg = (3\text{ kg})(9.79\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 29.37\text{ N}$$

Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 200 - 29.37 = 170.6\text{ N}$$

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

$$a = \frac{F}{m} = \frac{170.6\text{ N}}{3\text{ kg}}\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right) = \mathbf{56.9\text{ m/s}^2}$$

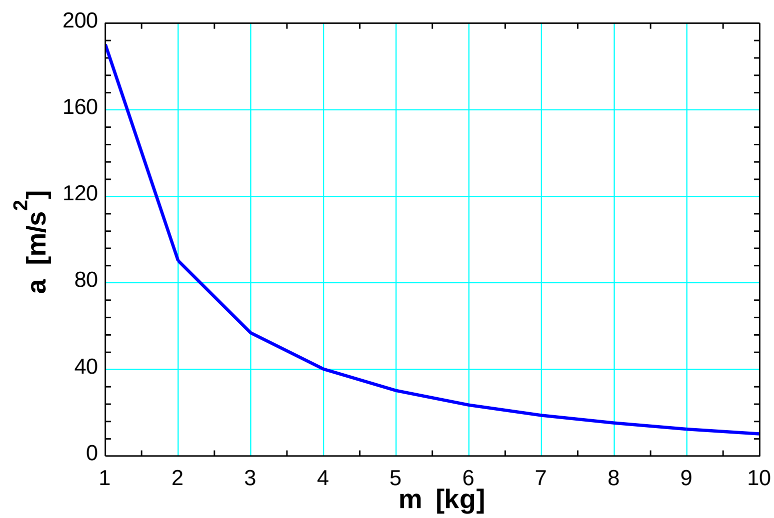
1-13 Problem 1-12 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

Analysis The problem is solved using EES, and the solution is given below.

```
"The weight of the rock is"
W=m*g
m=3 [kg]
g=9.79 [m/s2]
"The force balance on the rock yields the net force acting on the rock as"
F_up=200 [N]
F_net = F_up - F_down
F_down=W
"The acceleration of the rock is determined from Newton's second law."
F_net=m*a

"To Run the program, press F2 or select Solve from the Calculate menu."
```

SOLUTION
a=56.88 [m/s^2]
F_down=29.37 [N]
F_net=170.6 [N]
F_up=200 [N]
g=9.79 [m/s2]
m=3 [kg]
W=29.37 [N]

m [kg]	a [m/s^2]
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



1-14 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

Total energy = (Energy per unit time)(Time interval)

= (4 kW)(3 h)

= **12 kWh**

Noting that 1 kWh = (1 kJ/s)(3600 s) = 3600 kJ,

Total energy = (12 kWh)(3600 kJ/kWh)

= **43,200 kJ**

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

1-15E 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:

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

(*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,

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

1-16 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

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

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

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

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

1-17 A pool is to be filled with water using a hose. Based on unit considerations, a relation is to be obtained for the volume of the pool.

Assumptions Water is an incompressible substance and the average flow velocity is constant.

Analysis The pool volume depends on the filling time, the cross-sectional area which depends on hose diameter, and flow velocity. Also, we know that the unit of volume is m^3. 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

$\mathcal{V}$ [m^3] is a function of t [s], D [m], and V [m/s}

It is obvious that the only way to end up with the unit "m^3" for volume is to multiply the quantities t and V with the square of D. Therefore, the desired relation is

$$\mathcal{V} = CD^2Vt$$

where the constant of proportionality is obtained for a round hose, namely, $C = \pi/4$ so that $\mathcal{V} = (\pi D^2/4)Vt$.

Discussion Note that the values of dimensionless constants of proportionality cannot be determined with this approach.

Systems, Properties, State, and Processes

1-18C The radiator should be analyzed as an open system since mass is crossing the boundaries of the system.

1-19C The system is taken as the air contained in the piston-cylinder device. This system is a closed or fixed mass system since no mass enters or leaves it.

1-20C A can of soft drink should be analyzed as a closed system since no mass is crossing the boundaries of the system.

1-21C Intensive properties do not depend on the size (extent) of the system but extensive properties do.

1-22C If we were to divide the system into smaller portions, the weight of each portion would also be smaller. Hence, the weight is an *extensive property*.

1-23C Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

1-24C If we were to divide this system in half, both the volume and the number of moles contained in each half would be one-half that of the original system. The molar specific volume of the original system is

$$\bar{v} = \frac{V}{N}$$

and the molar specific volume of one of the smaller systems is

$$\bar{v} = \frac{V/2}{N/2} = \frac{V}{N}$$

which is the same as that of the original system. The molar specific volume is then an *intensive property*.

1-25C 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.

1-26C 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.

1-27C The pressure and temperature of the water are normally used to describe the state. Chemical composition, surface tension coefficient, and other properties may be required in some cases.

As the water cools, its pressure remains fixed. This cooling process is then an isobaric process.

1-28C When analyzing the acceleration of gases as they flow through a nozzle, the proper choice for the system is the volume within the nozzle, bounded by the entire inner surface of the nozzle and the inlet and outlet cross-sections. This is a control volume since mass crosses the boundary.

1-29C 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°C, for which ρ_{H2O} = 1000 kg/m^3). That is, $\mathrm{SG} = \rho / \rho_{\mathrm{H2O}}$. When specific gravity is known, density is determined from $\rho = \mathrm{SG} \times \rho_{\mathrm{H2O}}$.

1-30 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	ρ, 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 EES, (1) Define a trivial function rho= a+z 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 2nd order polynomial and enter/edit equation. The results are:

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

(or, $\rho(z) = (1.20252 - 0.101674z + 0.0022375z^2)\times 10^9$ for the unit of kg/km^3)

where z is the vertical distance from the earth surface at sea level. At z = 7 km, the equation would give ρ = 0.60 kg/m^3.

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

$$m = \int_V \rho dV = \int_{z=0}^{h} (a+bz+cz^2)4\pi(r_0+z)^2 dz = 4\pi\int_{z=0}^{h} (a+bz+cz^2)(r_0^2+2r_0 z+z^2)dz$$

$$= 4\pi\left[ar_0^2 h + r_0(2a+br_0)h^2/2 + (a+2br_0+cr_0^2)h^3/3 + (b+2cr_0)h^4/4 + ch^5/5\right]$$

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 kg/km^3, the mass of the atmosphere is determined to be

m = $\mathbf{5.092\times10^{18}}$ **kg**

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

EES Solution for final result:

```
a=1.2025166;        b=-0.10167
c=0.0022375;        r=6377;        h=25
m=4*pi*(a*r^2*h+r*(2*a+b*r)*h^2/2+(a+2*b*r+c*r^2)*h^3/3+(b+2*c*r)*h^4/4+c*h^5/5)*1E+9
```

Temperature

1-31C They are Celsius (°C) and kelvin (K) in the SI, and fahrenheit (°F) and rankine (R) in the English system.

1-32C 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.

1-33C 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.

1-34 A temperature is given in °C. It is to be expressed in K.

Analysis The Kelvin scale is related to Celsius scale by

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

Thus,

$$T(\text{K}) = 37^\circ\text{C} + 273 = \mathbf{310\ K}$$

1-35E The temperature of air given in °C unit is to be converted to °F and R unit.

Analysis Using the conversion relations between the various temperature scales,

$$T(^\circ\text{F}) = 1.8T(^\circ\text{C}) + 32 = (1.8)(150) + 32 = \mathbf{302^\circ F}$$
$$T(\text{R}) = T(^\circ\text{F}) + 460 = 302 + 460 = \mathbf{762\ R}$$

1-36 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,

$$\Delta T(\text{K}) = \Delta T(^\circ\text{C}) = \mathbf{70\ K}$$

1-37E The flash point temperature of engine oil given in °F unit is to be converted to K and R units.

Analysis Using the conversion relations between the various temperature scales,

$$T(\mathrm{R}) = T(°\mathrm{F}) + 460 = 363 + 460 = \mathbf{823R}$$

$$T(\mathrm{K}) = \frac{T(\mathrm{R})}{1.8} = \frac{823}{1.8} = \mathbf{457K}$$

1-38E The temperature of ambient air given in °C unit is to be converted to °F, K and R units.

Analysis Using the conversion relations between the various temperature scales,

$$T = -40°\mathrm{C} = (-40)(1.8) + 32 = \mathbf{-40°F}$$

$$T = -40 + 273.15 = \mathbf{233.15K}$$

$$T = -40 + 459.67 = \mathbf{419.67R}$$

1-39E 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,

$$\Delta T(\mathrm{R}) = \Delta T(°\mathrm{F}) = 45\ \mathbf{R}$$

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

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

and $$\Delta T(°\mathrm{C}) = \Delta T(\mathrm{K}) = \mathbf{25°C}$$

Pressure, Manometer, and Barometer

1-40C 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.

1-41C 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.

1-42C 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.

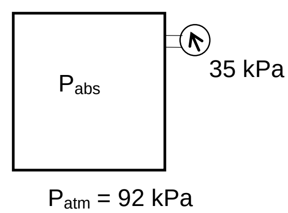
1-43C *Pascal's principle* states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction. An example of Pascal's principle is the operation of the hydraulic car jack.

1-44C 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.

1-45 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

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



1-46 The pressure in a tank is given. The tank's pressure in various units are to be determined.

Analysis Using appropriate conversion factors, we obtain

(*a*) $$P = (1200\ \text{kPa})\left(\frac{1\ \text{kN/m}^2}{1\ \text{kPa}}\right) = \mathbf{1200\ kN/m^2}$$

(*b*) $$P = (1200\ \text{kPa})\left(\frac{1\ \text{kN/m}^2}{1\ \text{kPa}}\right)\left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\ \text{kN}}\right) = \mathbf{1{,}200{,}000\ kg/m\cdot s^2}$$

(*c*) $$P = (1200\ \text{kPa})\left(\frac{1\ \text{kN/m}^2}{1\ \text{kPa}}\right)\left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\ \text{kN}}\right)\left(\frac{1000\ \text{m}}{1\ \text{km}}\right) = \mathbf{1{,}200{,}000{,}000\ kg/km\cdot s^2}$$

1-47E The pressure in a tank in SI unit is given. The tank's pressure in various English units are to be determined.

Analysis Using appropriate conversion factors, we obtain

(*a*) $$P = (1500\ \text{kPa})\left(\frac{20.886\ \text{lbf/ft}^2}{1\ \text{kPa}}\right) = \mathbf{31{,}330\ lbf/ft^2}$$

(*b*) $$P = (1500\ \text{kPa})\left(\frac{20.886\ \text{lbf/ft}^2}{1\ \text{kPa}}\right)\left(\frac{1\ \text{ft}^2}{144\ \text{in}^2}\right)\left(\frac{1\ \text{psia}}{1\ \text{lbf/in}^2}\right) = \mathbf{217.6\ psia}$$

1-48E The pressure given in mm Hg unit is to be converted to psia.

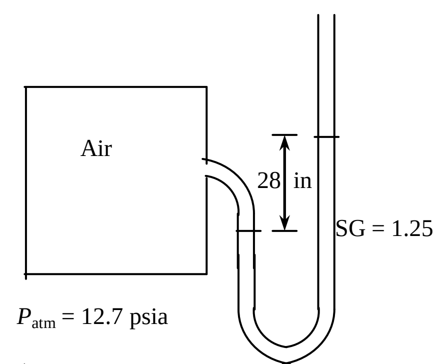
Analysis Using the mm Hg to kPa and kPa to psia units conversion factors,

$$P = (1500\ \text{mm Hg})\left(\frac{0.1333\ \text{kPa}}{1\ \text{mm Hg}}\right)\left(\frac{1\ \text{psia}}{6.895\ \text{kPa}}\right) = \mathbf{29.0\ psia}$$

1-49E 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°F is 62.4 lbm/ft^3 (Table A-3E)



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

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

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):

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

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

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

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.

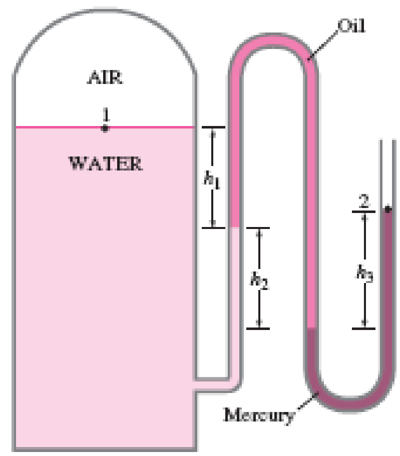
1-50 The pressure in a pressurized water tank is measured by a multi-fluid manometer. The gage pressure of air in the tank is to be determined.

Assumptions The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus we can determine the pressure at the air-water interface.

Properties The densities of mercury, water, and oil are given to be 13,600, 1000, and 850 kg/m^3, respectively.

Analysis Starting with the pressure at point 1 at the air-water interface, and moving along the tube by adding (as we go down) or subtracting (as we go up) the ρgh terms until we reach point 2, and setting the result equal to P_{atm} since the tube is open to the atmosphere gives

$$P_1 + \rho_{water} gh_1 + \rho_{oil} gh_2 - \rho_{mercury} gh_3 = P_{atm}$$



Solving for P_1,

$$P_1 = P_{atm} - \rho_{water} gh_1 - \rho_{oil} gh_2 + \rho_{mercury} gh_3$$

or,

$$P_1 - P_{atm} = g(\rho_{mercury} h_3 - \rho_{water} h_1 - \rho_{oil} h_2)$$

Noting that $P_{1,gage} = P_1 - P_{atm}$ and substituting,

$$P_{1,gage} = (9.81\,\text{m/s}^2)[(13{,}600\,\text{kg/m}^3)(0.4\,\text{m}) - (1000\,\text{kg/m}^3)(0.2\,\text{m})$$
$$-(850\,\text{kg/m}^3)(0.3\,\text{m})]\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kPa}}{1000\,\text{N/m}^2}\right)$$
$$= \mathbf{48.9\,kPa}$$

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.

1-51 The barometric reading at a location is given in height of mercury column. The atmospheric pressure is to be determined.

Properties The density of mercury is given to be 13,600 kg/m^3.

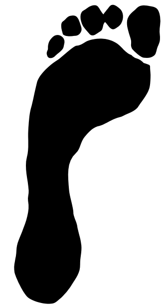
Analysis The atmospheric pressure is determined directly from

$$P_{atm} = \rho gh$$
$$= (13{,}600\,\text{kg/m}^3)(9.81\,\text{m/s}^2)(0.750\,\text{m})\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kPa}}{1000\,\text{N/m}^2}\right)$$
$$= \mathbf{100.1\,kPa}$$

1-52E 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: $$P = \frac{W}{2A} = \frac{200\,\text{lbf}}{2 \times 36\,\text{in}^2} = 2.78\,\text{lbf/in}^2 = \mathbf{2.78\,psi}$$

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

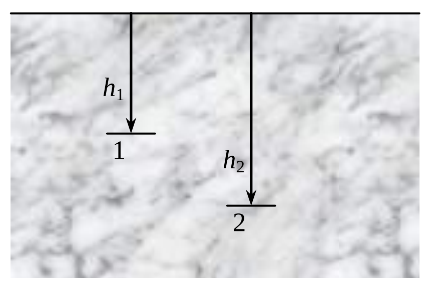
Discussion Note that the pressure exerted on the ground (and on the feet) is reduced by half when the person stands on both feet.

1-53 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

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

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

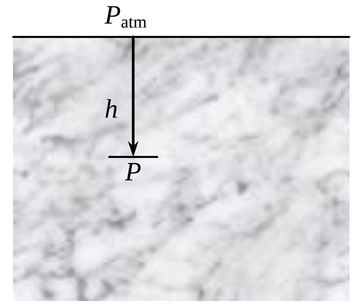
1-54 The absolute pressure in water at a specified depth is given. The local atmospheric pressure and the absolute pressure at the same depth in a different liquid are to be determined.

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 kg/m^3. Then density of the liquid is obtained by multiplying its specific gravity by the density of water,

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

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



$$\begin{aligned} P_{\text{atm}} &= P - \rho g h \\ &= (185\ \text{kPa}) - (1000\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(9\ \text{m})\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= \mathbf{96.7\ kPa} \end{aligned}$$

(*b*) The absolute pressure at a depth of 5 m in the other liquid is

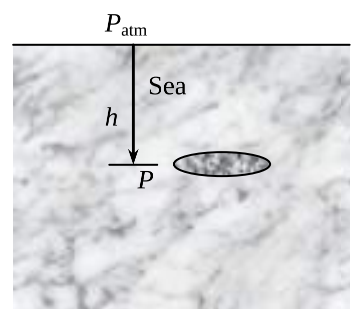
$$\begin{aligned} P &= P_{\text{atm}} + \rho g h \\ &= (96.7\ \text{kPa}) + (850\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(9\ \text{m})\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= \mathbf{171.8\ kPa} \end{aligned}$$

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

1-55E A submarine is cruising at a specified depth from the water surface. The pressure exerted on the surface of the submarine by water is to be determined.

Assumptions The variation of the density of water with depth is negligible.

Properties The specific gravity of seawater is given to be SG = 1.03. The density of water at 32°F is 62.4 lbm/ft^3 (Table A-3E).



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

$$\rho = \text{SG} \times \rho_{\text{H}_2\text{O}} = (1.03)(62.4\ \text{lbm/ft}^3) = 64.27\ \text{lbm/ft}^3$$

The pressure exerted on the surface of the submarine cruising 300 ft below the free surface of the sea is the absolute pressure at that location:

$$\begin{aligned} P &= P_{\text{atm}} + \rho g h \\ &= (14.7\ \text{psia}) + (64.27\ \text{lbm/ft}^3)(32.2\ \text{ft/s}^2)(175\ \text{ft})\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\ \text{ft}^2}{144\ \text{in}^2}\right) \\ &= \mathbf{92.8\ psia} \end{aligned}$$

1-56 The mass of a woman is given. The minimum imprint area per shoe needed to enable her to walk on the snow without sinking is to be determined.

Assumptions **1** The weight of the person is distributed uniformly on the imprint area of the shoes. **2** One foot carries the entire weight of a person during walking, and the shoe is sized for walking conditions (rather than standing). **3** The weight of the shoes is negligible.

Analysis The mass of the woman is given to be 70 kg. For a pressure of 0.5 kPa on the snow, the imprint area of one shoe must be

$$A = \frac{W}{P} = \frac{mg}{P}$$

$$= \frac{(70\text{ kg})(9.81\text{ m/s}^2)}{0.5\text{ kPa}}\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right) = \mathbf{1.37\ m^2}$$

Discussion This is a very large area for a shoe, and such shoes would be impractical to use. Therefore, some sinking of the snow should be allowed to have shoes of reasonable size.

1-57E The vacuum pressure given in kPa unit is to be converted to various units.

Analysis Using the definition of vacuum pressure,

$$P_{\text{gage}} = \text{not applicable for pressures below atmospheric pressure}$$

$$P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}} = 98 - 80 = \mathbf{18\ kPa}$$

Then using the conversion factors,

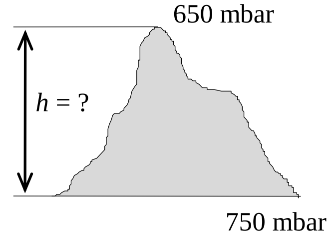
$$P_{\text{abs}} = (18\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right) = \mathbf{18\ kN/m^2}$$

$$P_{\text{abs}} = (18\text{ kPa})\left(\frac{1\text{ lbf/in}^2}{6.895\text{ kPa}}\right) = \mathbf{2.61\ lbf/in^2}$$

$$P_{\text{abs}} = (18\text{ kPa})\left(\frac{1\text{ psi}}{6.895\text{ kPa}}\right) = \mathbf{2.61\ psi}$$

$$P_{\text{abs}} = (18\text{ kPa})\left(\frac{1\text{ mm Hg}}{0.1333\text{ kPa}}\right) = \mathbf{135\ mm\ Hg}$$

1-58 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 ρ = 1.20 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

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

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

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

It yields

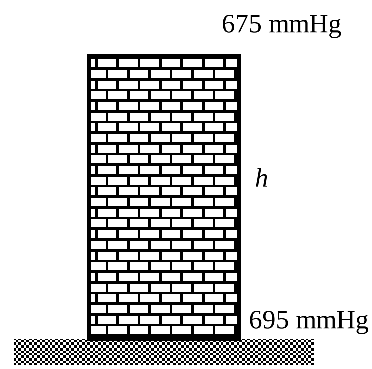
h = **850 m**

which is also the distance climbed.

1-59 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 ρ = 1.18 kg/m^3. The density of mercury is 13,600 kg/m^3.



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

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

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

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

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

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

$$(1.18 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(h)\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) = (92.72 - 90.06) \text{ kPa}$$

It yields

h = **231 m**

which is also the height of the building.

1-60 Problem 1-59 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

Analysis The problem is solved using EES, and the solution is given below.

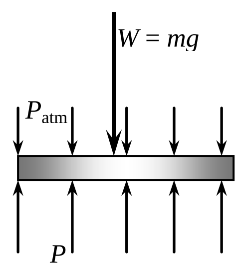
```
P_bottom=695 [mmHg]
P_top=675 [mmHg]
g=9.81 [m/s^2]   "local acceleration of gravity at sea level"
rho=1.18  [kg/m^3]
DELTAP_abs=(P_bottom-P_top)*CONVERT(mmHg, kPa) "[kPa]"     "Delta P reading from the barometers, converted from mmHg to kPa."
DELTAP_h =rho*g*h*Convert(Pa, kPa) "Delta P due to the air fluid column height, h, between the top and bottom of the building."
DELTAP_abs=DELTAP_h
```

SOLUTION
DELTAP_abs=2.666 [kPa]
DELTAP_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]

1-61 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,



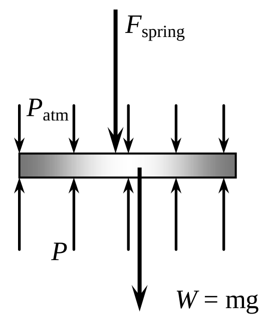
$$P_{\text{gage}} = \frac{W}{A} = \frac{mg}{\pi D^2/4}$$

$$= \frac{(2000\text{ kg})(9.81\text{ m/s}^2)}{\pi(0.30\text{ m})^2/4}\left(\frac{1\text{ kN}}{1000\text{ kg}\cdot\text{m/s}^2}\right) = 278\text{ kN/m}^2 = \mathbf{278\ \ kPa}$$

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

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



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

Thus,

$$P = P_{atm} + \frac{mg + F_{spring}}{A}$$

$$= (95 \text{ kPa}) + \frac{(3.2 \text{ kg})(9.81 \text{ m/s}^2) + 150 \text{ N}}{35 \times 10^{-4} \text{ m}^2}\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$

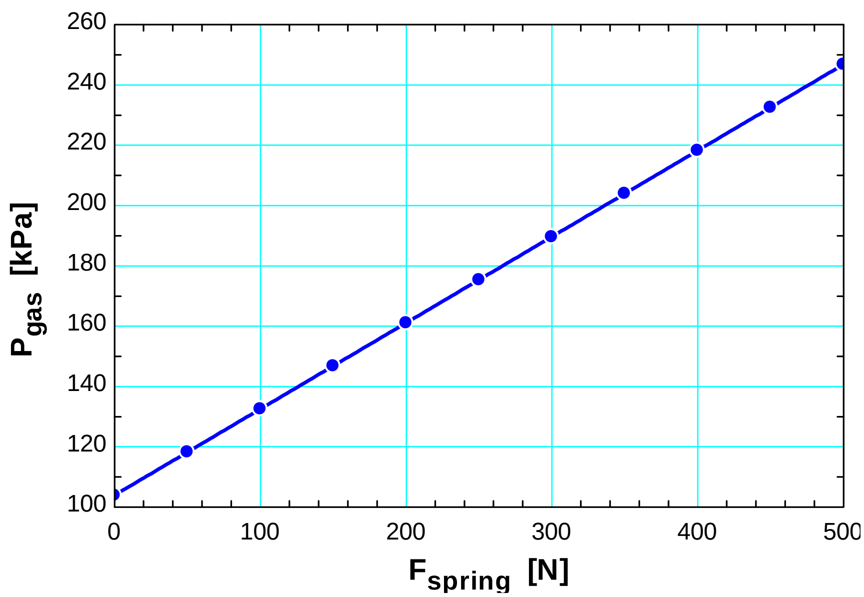
$$= \mathbf{147 \text{ kPa}}$$

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 EES, and the solution is given below.

```
g=9.81 [m/s^2]
P_atm= 95 [kPa]
m_piston=3.2 [kg]
{F_spring=150 [N]}
A=35*CONVERT(cm^2, m^2)
W_piston=m_piston*g
F_atm=P_atm*A*CONVERT(kPa, N/m^2)
"From the free body diagram of the piston, the balancing vertical forces yield:"
F_gas= F_atm+F_spring+W_piston
P_gas=F_gas/A*CONVERT(N/m^2, kPa)
```

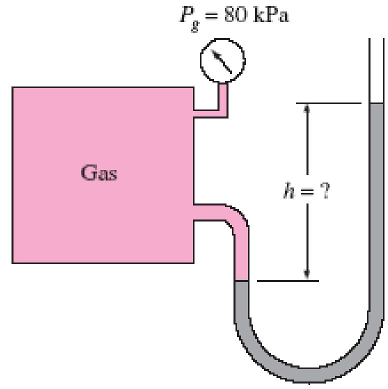
F_{spring} [N]	P_{gas} [kPa]
0	104
50	118.3
100	132.5
150	146.8
200	161.1
250	175.4
300	189.7
350	204
400	218.3
450	232.5
500	246.8



1-64 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 ρ_{water} = 1000 kg/m^3 and be ρ_{Hg} = 13,600 kg/m^3.

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



$$P_{gage} = \rho g h \longrightarrow h = \frac{P_{gage}}{\rho g}$$

(*a*) For mercury,

$$h = \frac{P_{gage}}{\rho_{Hg} g}$$

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

(*b*) For water,

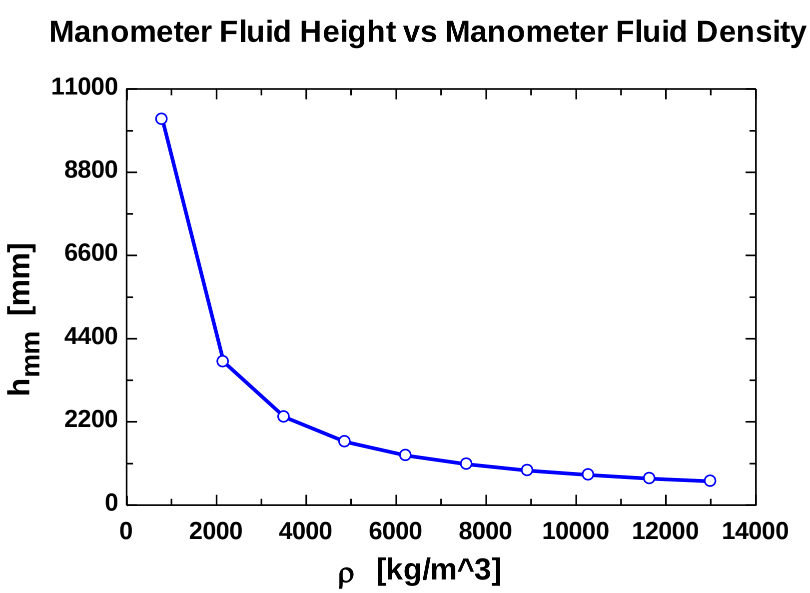
$$h = \frac{P_{gage}}{\rho_{H_2O} g} = \frac{80 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)}\left(\frac{1 \text{ kN/m}^2}{1 \text{ kPa}}\right)\left(\frac{1000 \text{ kg/m}\cdot\text{s}^2}{1 \text{ kN}}\right) = \mathbf{8.16 \text{ m}}$$

1-65 Problem 1-64 is reconsidered. The effect of the manometer fluid density in the range of 800 to 13,000 kg/m^3 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 EES, 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.
Use the relationship between the pressure gage reading and the manometer fluid column height. "

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

{Input from the diagram window.  If the diagram window is hidden, then all of the input must come from the equations window.  Also note that brackets can also denote comments - but these comments do not appear in the formatted equations window.}
{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"
"To plot fluid height against density place {} around the above equation.  Then set up the parametric table and solve."
DELTAP = RHO*g*h/1000
"Instead of dividiing by 1000 Pa/kPa we could have multiplied by the EES 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

"To make the graph, hide the diagram window and remove the {}brackets from Fluid$ and from P_atm.  Select New Parametric Table from the Tables menu.  Choose P_abs, DELTAP and h to be in the table.  Choose Alter Values from the Tables menu.  Set values of h to range from 0 to 1 in steps of 0.2.  Choose Solve Table (or press F3) from the Calculate menu.  Choose New Plot Window from the Plot menu.  Choose to plot P_abs vs h and then choose Overlay Plot from the Plot menu and plot DELTAP on the same scale."
```

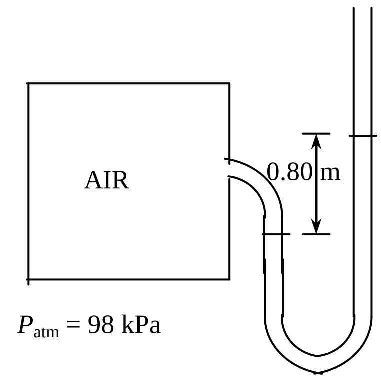
ρ [kg/m^3]	h_{mm} [mm]
800	10197
2156	3784
3511	2323
4867	1676
6222	1311
7578	1076
8933	913.1
10289	792.8
11644	700.5
13000	627.5



1-66 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 ρ = 850 kg/m^3.

Analysis The absolute pressure in the tank is determined from

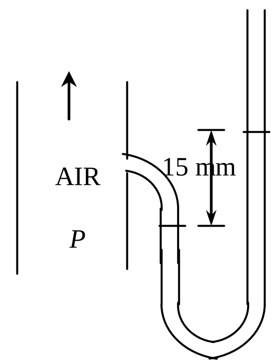


$$\begin{aligned} P &= P_{atm} + \rho gh \\ &= (98 \text{ kPa}) + (850 \text{ kg/m}^3)(9.81 \text{m/s}^2)(0.80 \text{ m})\left(\frac{1 \text{kPa}}{1000 \text{N/m}^2}\right) \\ &= \mathbf{104.7 \, kPa} \end{aligned}$$

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

Properties The density of mercury is given to be ρ = 13,600 kg/m^3.

Analysis (*a*) The pressure in the duct is above atmospheric pressure since the fluid column on the duct side is at a lower level.



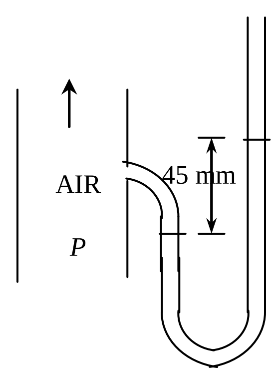
(*b*) The absolute pressure in the duct is determined from

$$\begin{aligned} P &= P_{atm} + \rho gh \\ &= (100 \text{ kPa}) + (13{,}600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.015 \text{ m})\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) \\ &= \mathbf{102 \ kPa} \end{aligned}$$

1-68 The air pressure in a duct is measured by a mercury manometer. For a given mercury-level difference between the two columns, the absolute pressure in the duct is to be determined.

Properties The density of mercury is given to be ρ = 13,600 kg/m^3.

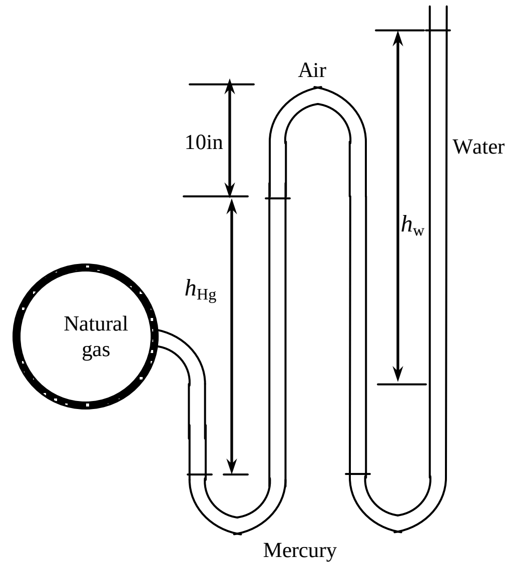
Analysis (*a*) The pressure in the duct is above atmospheric pressure since the fluid column on the duct side is at a lower level.



(*b*) The absolute pressure in the duct is determined from

$$\begin{aligned} P &= P_{atm} + \rho gh \\ &= (100 \text{ kPa}) + (13{,}600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.045 \text{ m})\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) \\ &= \mathbf{106 \ kPa} \end{aligned}$$

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 ρ_w = 62.4 lbm/ft^3. The specific gravity of mercury is given to be 13.6, and thus its density is ρ_{Hg} = 13.6×62.4 = 848.6 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 ρgh 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

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

Solving for $P_{1,}$

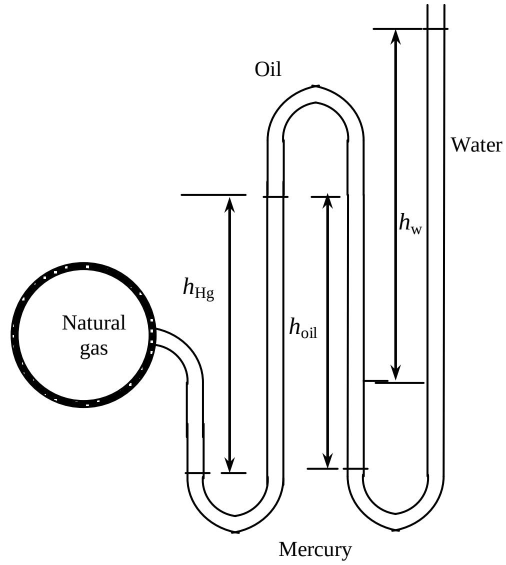
$$P_1 = P_{atm} + \rho_{Hg} g h_{Hg} + \rho_{water} g h_1$$

Substituting,

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

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 lbm/ft^3 corresponds to a pressure difference of 0.00065 psi. Therefore, its effect on the pressure difference between the two pipes is negligible.

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 ρ_w = 62.4 lbm/ft^3. The specific gravity of mercury is given to be 13.6, and thus its density is ρ_{Hg} = 13.6×62.4 = 848.6 lbm/ft^3. The specific gravity of oil is given to be 0.69, and thus its density is ρ_{oil} = 0.69×62.4 = 43.1 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 ρgh 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

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

Solving for $P_{1,}$

$$P_1 = P_{atm} + \rho_{Hg} g h_{Hg} + \rho_{water} g h_1 - \rho_{oil} g h_{oil}$$

Substituting,

$$P_1 = 14.2 \text{ psia} + (32.2 \text{ ft/s}^2)[(848.6 \text{ lbm/ft}^3)(6/12 \text{ ft}) + (62.4 \text{ lbm/ft}^3)(27/12 \text{ ft})$$
$$-(43.1 \text{ lbm/ft}^3)(15/12 \text{ ft})]\left(\frac{1 \text{ lbf}}{32.2 \text{ lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right)$$
$$= \mathbf{17.7 psia}$$

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.

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 kg/m^3 and 13,600 kg/m^3, respectively.

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

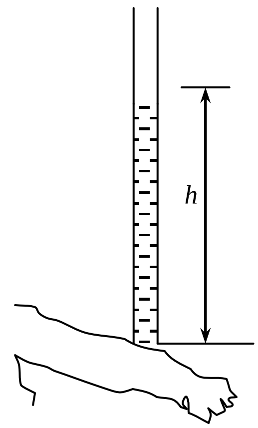
$$P_{\text{high}} = \rho g h_{\text{high}} = (13{,}600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.12 \text{ m})\left(\frac{1 \text{N}}{1 \text{kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{kPa}}{1000 \text{ N/m}^2}\right) = \mathbf{16.0 \text{ kPa}}$$

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

Noting that 1 psi = 6.895 kPa,

$$P_{\text{high}} = (16.0 \text{ Pa})\left(\frac{1 \text{ psi}}{6.895 \text{kPa}}\right) = \mathbf{2.32 \text{ psi}} \quad \text{and} \quad P_{\text{low}} = (10.7 \text{ Pa})\left(\frac{1 \text{ psi}}{6.895 \text{kPa}}\right) = \mathbf{1.55 \text{ psi}}$$

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



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

Therefore,

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

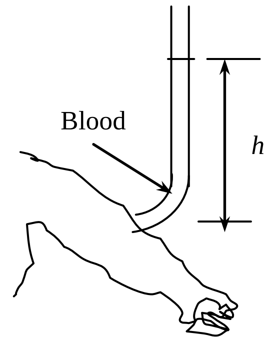
$$h_{\text{water, low}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury, low}} = \frac{13{,}600 \text{ kg/m}^3}{1000 \text{ kg/m}^3}(0.08 \text{ m}) = \mathbf{1.09 \text{ m}}$$

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.

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 ρ = 1050 kg/m³.



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

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

Solving for blood height and substituting gives

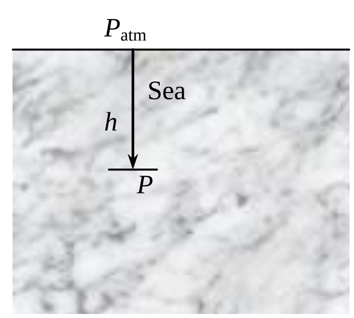
$$h_{\text{blood}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{blood}}} h_{\text{mercury}} = \frac{13{,}600\ \text{kg/m}^3}{1050\ \text{kg/m}^3}(0.12\ \text{m}) = \mathbf{1.55\ m}$$

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.

1-73 A diver is moving at a specified depth from the water surface. The pressure exerted on the surface of the diver by water is to be determined.

Assumptions The variation of the density of water with depth is negligible.

Properties The specific gravity of seawater is given to be SG = 1.03. We take the density of water to be 1000 kg/m³.



Analysis The density of the seawater is obtained by multiplying its specific gravity by the density of water which is taken to be 1000 kg/m³:

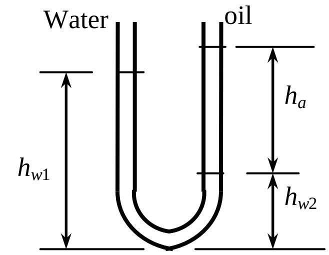
$$\rho = \text{SG} \times \rho_{H_2O} = (1.03)(1000\ \text{kg/m}^3) = 1030\ \text{kg/m}^3$$

The pressure exerted on a diver at 45 m below the free surface of the sea is the absolute pressure at that location:

$$\begin{aligned} P &= P_{\text{atm}} + \rho gh \\ &= (101\ \text{kPa}) + (1030\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(45\ \text{m})\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= \mathbf{556\ kPa} \end{aligned}$$

1-74 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 ρ = 790 kg/m^3. We take the density of water to be ρ =1000 kg/m^3.

Analysis The height of water column in the left arm of the monometer is given to be h_{w1} = 0.70 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

$$P_{\text{bottom}} = P_{\text{atm}} + \rho_{\text{w}} g h_{\text{w1}} \quad \text{and} \quad P_{\text{bottom}} = P_{\text{atm}} + \rho_{\text{w}} g h_{\text{w2}} + \rho_{\text{a}} g h_{\text{a}}$$

Setting them equal to each other and simplifying,

$$\rho_{\text{w}} g h_{\text{w1}} = \rho_{\text{w}} g h_{\text{w2}} + \rho_{\text{a}} g h_{\text{a}} \quad \rightarrow \quad \rho_{\text{w}} h_{\text{w1}} = \rho_{\text{w}} h_{\text{w2}} + \rho_{\text{a}} h_{\text{a}} \quad \rightarrow \quad h_{\text{w1}} = h_{\text{w2}} + (\rho_{\text{a}} / \rho_w) h_{\text{a}}$$

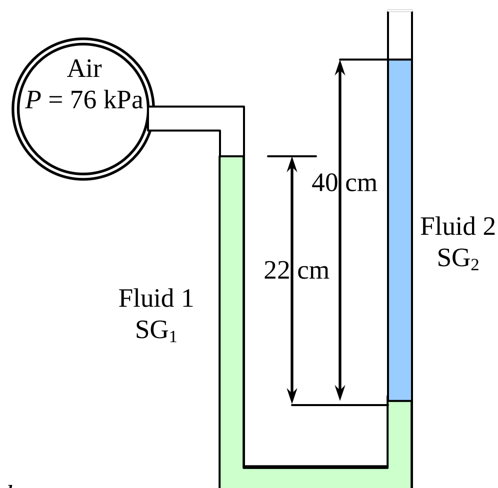
Noting that $h_a = 4h_{w2}$, the water and oil column heights in the second arm are determined to be

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

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

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

1-75 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 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 ρgh terms until we reach the free surface where the oil tube is exposed to the atmosphere, and setting the result equal to P_{atm} give

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

Rearranging and solving for SG$_2$,

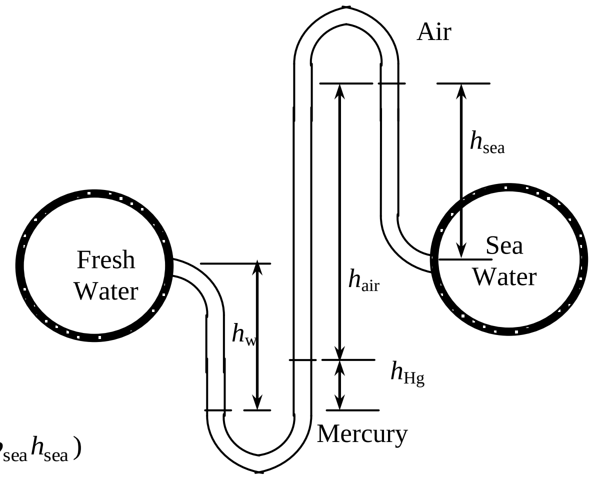
$$\text{SG}_2 = \text{SG}_1 \frac{h_1}{h_2} + \frac{P_{\text{air}} - P_{\text{atm}}}{\rho_{\text{w}} g h_2} = 13.55 \frac{0.22\text{ m}}{0.40\text{ m}} + \left(\frac{76 - 100\text{ kPa}}{(1000\text{ kg/m}^3)(9.81\text{ m/s}^2)(0.40\text{ m})} \right) \left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\text{kPa.}\cdot\text{m}^2} \right) = \mathbf{1.34}$$

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.

1-76 Fresh and seawater flowing in parallel horizontal pipelines are connected to each other by a double U-tube manometer. The pressure difference between the two pipelines is to be determined.

Assumptions **1** All the liquids are incompressible. **2** The effect of air column on pressure is negligible.

Properties The densities of seawater and mercury are given to be ρ_{sea} = 1035 kg/m^3 and ρ_{Hg} = 13,600 kg/m^3. We take the density of water to be ρ_w =1000 kg/m^3.



Analysis Starting with the pressure in the fresh water pipe (point 1) and moving along the tube by adding (as we go down) or subtracting (as we go up) the ρgh terms until we reach the sea water pipe (point 2), and setting the result equal to P_2 gives

$$P_1 + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{air} g h_{air} + \rho_{sea} g h_{sea} = P_2$$

Rearranging and neglecting the effect of air column on pressure,

$$P_1 - P_2 = -\rho_w g h_w + \rho_{Hg} g h_{Hg} - \rho_{sea} g h_{sea} = g(\rho_{Hg} h_{Hg} - \rho_w h_w - \rho_{sea} h_{sea})$$

Substituting,

$$P_1 - P_2 = (9.81\,\text{m/s}^2)[(13600\ \text{kg/m}^3)(0.1\,\text{m})$$

$$-(1000\ \text{kg/m}^3)(0.6\,\text{m}) - (1035\ \text{kg/m}^3)(0.4\,\text{m})]\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right)$$

$$= 3.39\,\text{kN/m}^2 = \mathbf{3.39\,kPa}$$

Therefore, the pressure in the fresh water pipe is 3.39 kPa higher than the pressure in the sea water pipe.

Discussion A 0.70-m high air column with a density of 1.2 kg/m^3 corresponds to a pressure difference of 0.008 kPa. Therefore, its effect on the pressure difference between the two pipes is negligible.