Solutions Manual

for

Fundamentals of Thermal Fluid Sciences

5th Edition

Yunus A. Çengel, John M. Cimbala, Robert H. Turner

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Chapter 2

BASIC CONCEPTS OF THERMODYNAMICS

Systems, Properties, State, and Processes

2-1C The radiator should be analyzed as an open system since mass is crossing the boundaries of the system.

2-2C 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.

2-3C A can of soft drink should be analyzed as a closed system since no mass is crossing the boundaries of the system.

2-4C Intensive properties do not depend on the size (extent) of the system but extensive properties do.

2-5C 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*.

2-6C Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

2-7C 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*.

2-8C 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.

2-9C 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.

2-10C 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.

2-11C 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.

2-12C 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, $SG = \rho / \rho_{H2O}$. When specific gravity is known, density is determined from $\rho = SG \times \rho_{H2O}$.

2-13 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

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

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

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 = $\mathbf{5.092 \times 10^{18}}$ **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

2-14C They are Celsius (°C) and kelvin (K) in the SI, and fahrenheit (°F) and rankine (R) in the English system.

2-15C 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.

2-16C 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.

2-17 A temperature is given in °C. It is to be expressed in K.

Analysis The Kelvin scale is related to Celsius scale by

$$T(\text{K}] = T(°\text{C}) + 273$$

Thus,

$$T(\text{K}] = 37°\text{C} + 273 = \mathbf{310\ K}$$

2-18E 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,

$$T(°\text{F}) = 1.8T(°\text{C}) + 32 = (1.8)(150) + 32 = \mathbf{302°F}$$

$$T(\text{R}) = T(°\text{F}) + 460 = 302 + 460 = \mathbf{762\ R}$$

2-19 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,

$$\Delta T(\text{K}] = \Delta T(°\text{C}) = \mathbf{70\ K}$$

2-20E 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,

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

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

2-21E 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,

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

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

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

2-22E 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,

$\Delta T(\text{R}) = \Delta T(°\text{F}) = 45$ **R**

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

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

and $\Delta T(°\text{C}) = \Delta T(\text{K}) =$ **25°C**

Pressure, Manometer, and Barometer

2-23C 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.

2-24C 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.

2-25C 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.

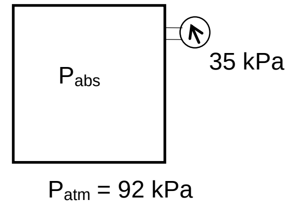
2-26C *Pascal's principle* states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction. An example of Pascal's principle is the operation of the hydraulic car jack.

2-27C 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.

2-28 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

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



2-29 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*) $$P = (1200\,\text{kPa})\left(\frac{1\,\text{kN/m}^2}{1\,\text{kPa}}\right)\left(\frac{1000\,\text{kg}\cdot\text{m/s}^2}{1\,\text{kN}}\right)\left(\frac{1000\,\text{m}}{1\,\text{km}}\right) = \mathbf{1{,}200{,}000{,}000\ kg/km\cdot s^2}$$

2-30E 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*) $$P = (1500\,\text{kPa})\left(\frac{20.886\,\text{lbf/ft}^2}{1\,\text{kPa}}\right)\left(\frac{1\,\text{ft}^2}{144\,\text{in}^2}\right)\left(\frac{1\,\text{psia}}{1\,\text{lbf/in}^2}\right) = \mathbf{217.6\ psia}$$

2-31E The pressure given in mm Hg unit is to be converted to psia.

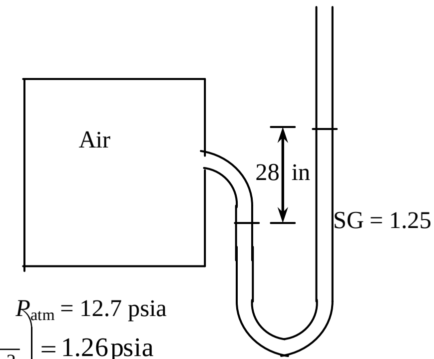
Analysis Using the mm Hg to kPa and kPa to psia units conversion factors,

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

2-32E 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,

$$\rho = \text{SG} \times \rho_{\text{H}_2\text{O}} = (1.25)(62.4\,\text{lbm/ft}^3) = 78.0\,\text{lbm/ft}^3$$

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):

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

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

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

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.

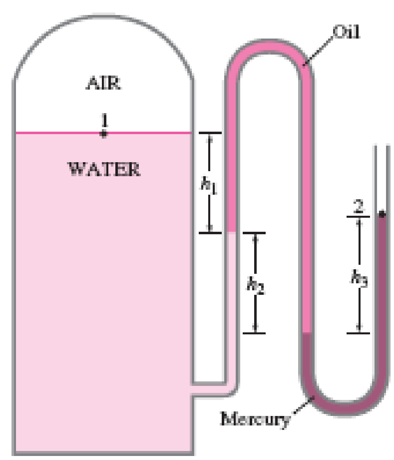
2-33 The pressure in a pressurized water tank is measured by a multi-fluid manometer. The gage pressure of air in the tank is to be determined.

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 $\rho g h$ terms until we reach point 2, and setting the result equal to P_{atm} since the tube is open to the atmosphere gives

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



Solving for P_1,

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

or,

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

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

$$P_{1,\text{gage}} = (9.81\,\text{m/s}^2)[(13{,}600\,\text{kg/m}^3)(0.4\,\text{m}) - (1000\,\text{kg/m}^3)(0.2\,\text{m})$$

$$- (850\,\text{kg/m}^3)(0.3\,\text{m})]\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kPa}}{1000\,\text{N/m}^2}\right)$$

$$= \mathbf{48.9\ kPa}$$

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.

2-34 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/m³.

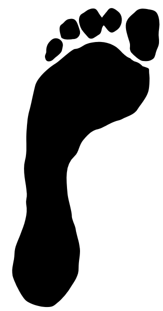
Analysis The atmospheric pressure is determined directly from

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

2-35E 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: $$P = \frac{W}{A} = \frac{200\,\text{lbf}}{36\,\text{in}^2} = 5.56\,\text{lbf/in}^2 = \mathbf{5.56\,psi}$$

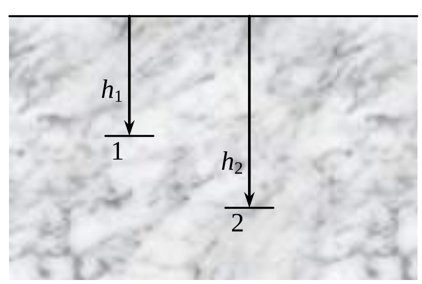
Discussion Note that the pressure exerted on the ground (and on the feet) is reduced by half when the person stands on both feet.

2-36 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.

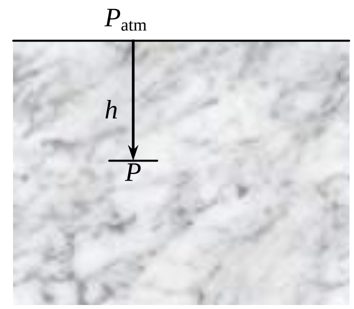
2-37 The absolute pressure in water at a specified depth is given. The local atmospheric pressure and the absolute pressure at the same depth in a different liquid are to be determined.

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



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

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

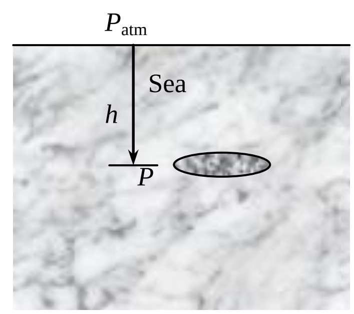
$$P = P_{atm} + \rho g h$$
$$= (96.7\ \text{kPa}) + (850\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(9\ \text{m})\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right)$$
$$= \mathbf{171.8\ kPa}$$

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

2-38E 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,

$$\rho = \text{SG} \times \rho_{H_2O} = (1.03)(62.4\ \text{lbm/ft}^3) = 64.27\ \text{lbm/ft}^3$$

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:

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

2-39 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.

2-40E 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,

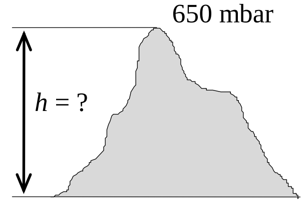
$$P_{\text{abs}} = (18\,\text{kPa})\left(\frac{1\,\text{kN/m}^2}{1\,\text{kPa}}\right) = \mathbf{18\ kN/m^2}$$

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

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

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

2-41 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

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

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

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

It yields

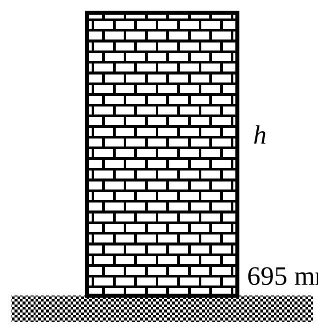
h = **850 m**

which is also the distance climbed.

2-42 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

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

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

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

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

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

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

It yields

h = **231 m**

which is also the height of the building.

2-43 Problem 2-42 is reconsidered. The entire software 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
```

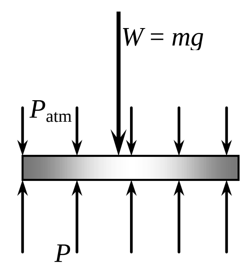
SOLUTION

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]

2-44 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.

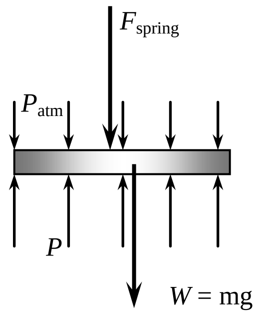
2-45 A gas contained in a vertical piston-cylinder device is pressurized by a spring and by the weight of the piston. The pressure of the gas is to be determined.

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

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

Thus,

$$\begin{aligned} P &= P_{atm} + \frac{mg + F_{spring}}{A} \\ &= (95\text{ kPa}) + \frac{(3.2\text{ kg})(9.81\text{ m/s}^2) + 150\text{ N}}{35\times10^{-4}\text{ m}^2}\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right) \\ &= \mathbf{147\ kPa} \end{aligned}$$

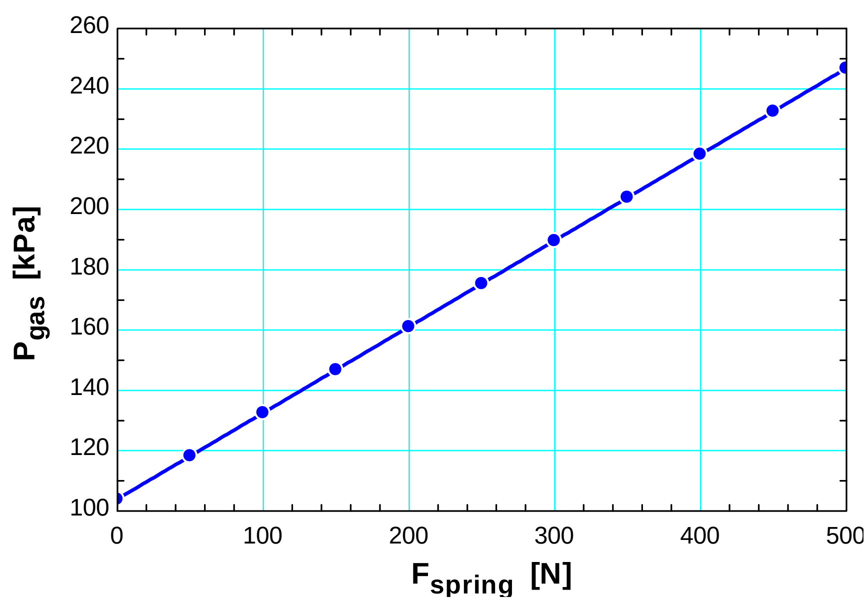


2-46  Problem 2-45 is reconsidered. The effect of the spring force in the range of 0 to 500 N on the pressure inside the cylinder is to be investigated. The pressure against the spring force is to be plotted, and results are to be discussed.

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)
```

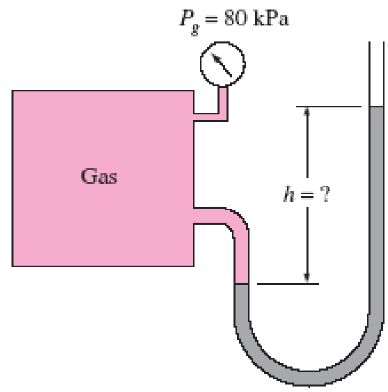
F_{spring} [N]	P_{gas} [kPa]
0	104
50	118.3
100	132.5
150	146.8
200	161.1
250	175.4
300	189.7
350	204
400	218.3
450	232.5
500	246.8



2-47 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,

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

(*b*) For water,

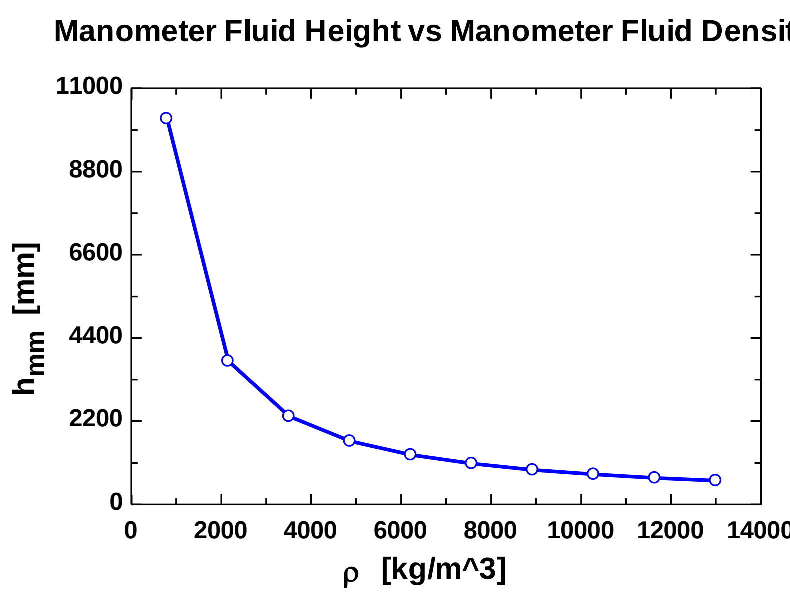
$$h = \frac{P_{gage}}{\rho_{H_2O} g} = \frac{80 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)}\left(\frac{1 \text{ kN/m}^2}{1 \text{ kPa}}\right)\left(\frac{1000 \text{ kg/m}\cdot\text{s}^2}{1 \text{ kN}}\right) = \mathbf{8.16\ m}$$

2-48 Problem 2-47 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

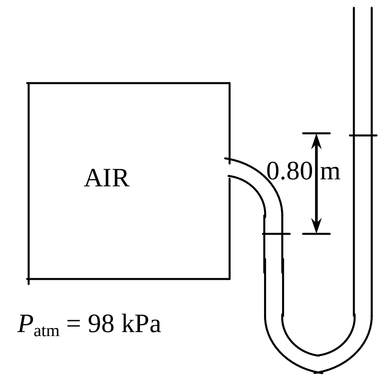


2-49 The air pressure in a tank is measured by an oil manometer. For a given oil-level difference between the two columns, the absolute pressure in the tank is to be determined.

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

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



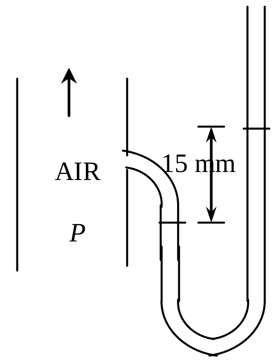
2-50 The air pressure in a duct is measured by a mercury manometer. For a given mercury-level difference between the two columns, the absolute pressure in the duct is to be determined.

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

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



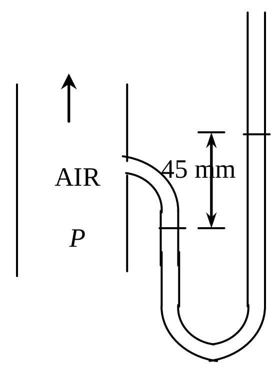
2-51 The air pressure in a duct is measured by a mercury manometer. For a given mercury-level difference between the two columns, the absolute pressure in the duct is to be determined.

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

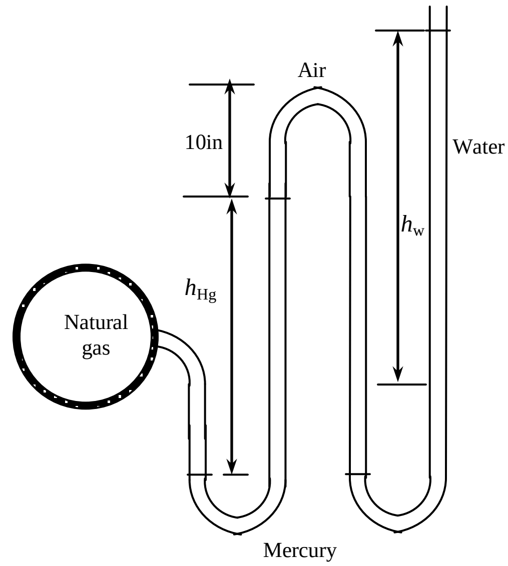
Analysis (*a*) The pressure in the duct is above atmospheric pressure since the fluid column on the duct side is at a lower level.

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

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



2-52E 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 $P_{1,}$

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

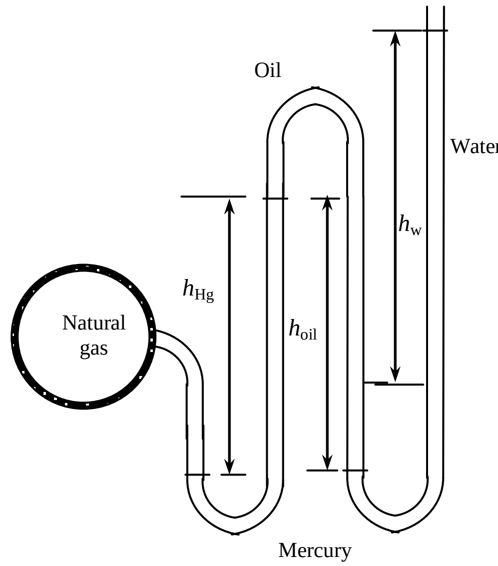
Substituting,

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

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.

2-53E 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 $\rho g h$ 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_{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.

2-54E 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.

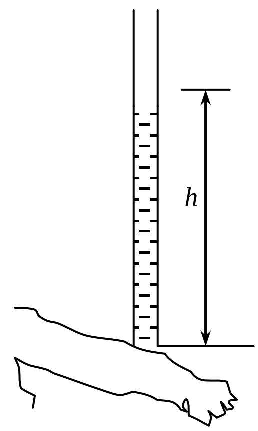
Analysis Using the relation $P = \rho gh$ for gage pressure, the high and low pressures are expressed as

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

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

Noting that 1 psi = 6.895 kPa,

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



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

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

Therefore,

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

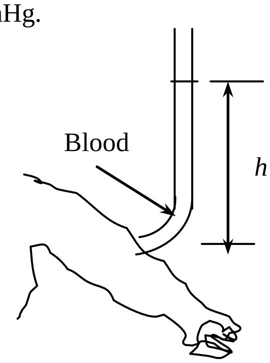
$$h_{\text{water, low}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury, low}} = \frac{13{,}600\ \text{kg/m}^3}{1000\ \text{kg/m}^3}(0.08\ \text{m}) = \mathbf{1.09\ m}$$

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.

2-55 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/m^3.



Analysis For a given gage pressure, the relation $P = \rho g h$ 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

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

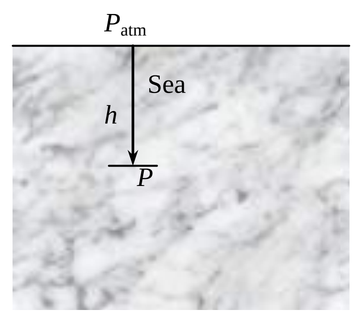
Discussion Note that the blood can rise about one and a half meters in a tube connected to the vein. This explains why IV tubes must be placed high to force a fluid into the vein of a patient.

2-56 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/m^3.

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/m^3:



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

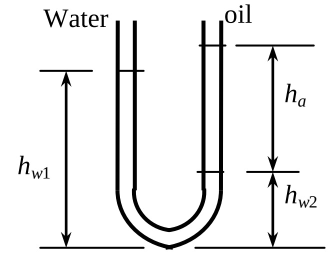
The pressure exerted on a diver at 45 m below the free surface of the sea is the absolute pressure at that location:

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

2-57 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

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

Setting them equal to each other and simplifying,

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

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

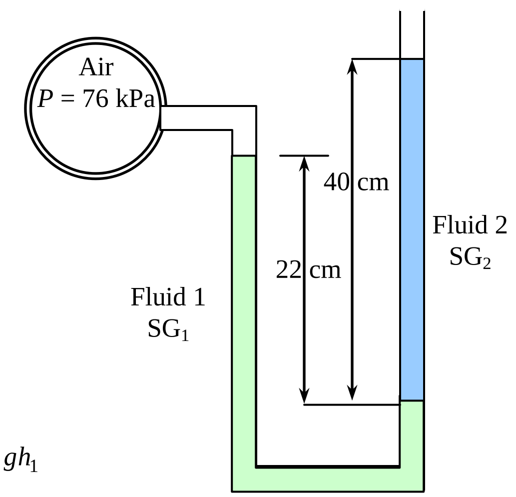
$$0.7\text{ m} = h_{w2} + (790/1000)4h_{w2} \quad \rightarrow \quad h_{w2} = \mathbf{0.168\ m}$$

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

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

2-58 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 $\rho g h$ terms until we reach the free surface where the oil tube is exposed to the atmosphere, and setting the result equal to P_{atm} give

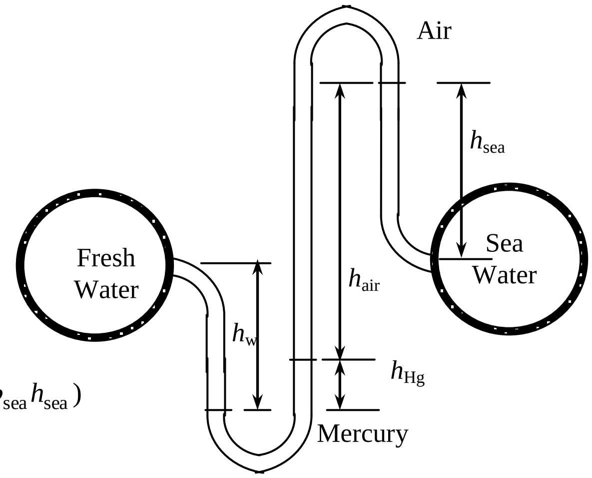
$$P_{\text{air}} + \rho_1 g h_1 - \rho_2 g h_2 = P_{\text{atm}} \quad \rightarrow \quad P_{\text{air}} - P_{\text{atm}} = SG_2 \rho_w g h_2 - SG_1 \rho_w g h_1$$

Rearranging and solving for SG_2,

$$SG_2 = SG_1 \frac{h_1}{h_2} + \frac{P_{\text{air}} - P_{\text{atm}}}{\rho_w g h_2} = 13.55 \frac{0.22\text{ m}}{0.40\text{ m}} + \left(\frac{76 - 100\text{ kPa}}{(1000\text{ kg/m}^3)(9.81\text{ m/s}^2)(0.40\text{ m})} \right) \left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kPa.}\cdot\text{m}^2} \right) = \mathbf{1.34}$$

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.

2-59 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,

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

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

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

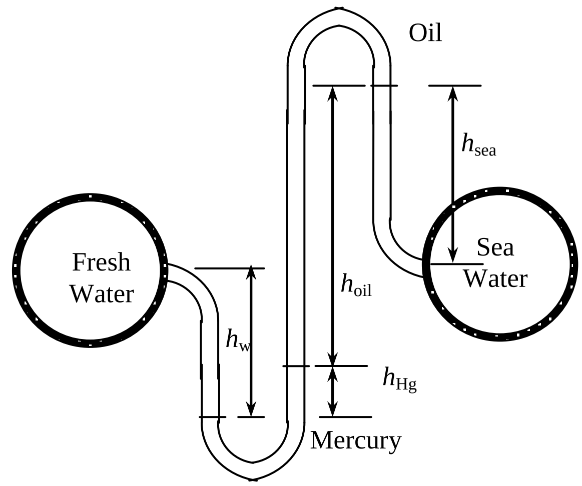
Therefore, the pressure in the fresh water pipe is 3.39 kPa higher than the pressure in the sea water pipe.

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.

2-60 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 All the liquids are incompressible.

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. The specific gravity of oil is given to be 0.72, and thus its density is 720 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

$$P_1 + \rho_w gh_w - \rho_{Hg} gh_{Hg} - \rho_{oil} gh_{oil} + \rho_{sea} gh_{sea} = P_2$$

Rearranging,

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

Substituting,

$$P_1 - P_2 = (9.81 \text{m/s}^2)[(13600 \text{kg/m}^3)(0.1 \text{m}) + (720 \text{kg/m}^3)(0.7 \text{m}) - (1000 \text{kg/m}^3)(0.6 \text{m})$$
$$- (1035 \text{kg/m}^3)(0.4 \text{m})]\left(\frac{1 \text{kN}}{1000 \text{kg} \cdot \text{m/s}^2}\right)$$
$$= 8.34 \text{kN/m}^2 = \mathbf{8.34 \text{kPa}}$$

Therefore, the pressure in the fresh water pipe is 8.34 kPa higher than the pressure in the sea water pipe.

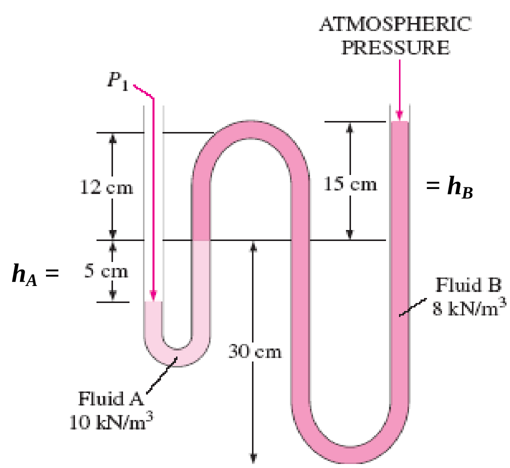
2-61 The pressure indicated by a manometer is to be determined.

Properties The specific weights of fluid A and fluid B are given to be 10 kN/m^3 and 8 kN/m^3, respectively.

Analysis The absolute pressure P_1 is determined from

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

Note that 1 kPa = 1 kN/m^2.



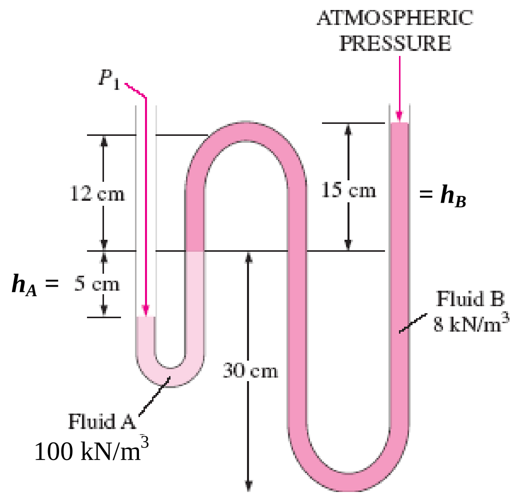
2-62 The pressure indicated by a manometer is to be determined.

Properties The specific weights of fluid A and fluid B are given to be 100 kN/m^3 and 8 kN/m^3, respectively.

Analysis The absolute pressure P_1 is determined from

$$P_1 = P_{\text{atm}} + (\rho g h)_A + (\rho g h)_B$$
$$= P_{\text{atm}} + \gamma_A h_A + \gamma_B h_B$$
$$= 90\,\text{kPa} + (100\,\text{kN/m}^3)(0.05\,\text{m}) + (8\,\text{kN/m}^3)(0.15\,\text{m})$$
$$= \mathbf{96.2\ kPa}$$

Note that 1 kPa = 1 kN/m^2.



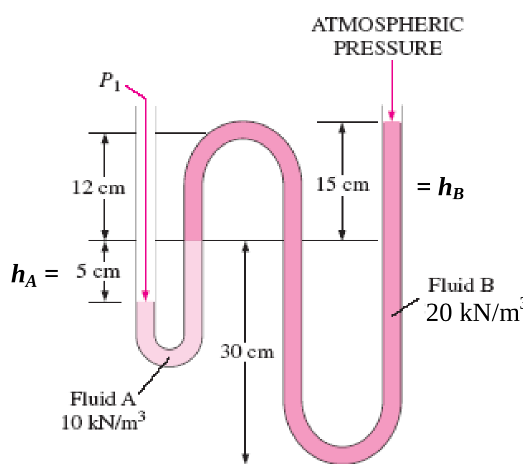
2-63 The pressure indicated by a manometer is to be determined.

Properties The specific weights of fluid A and fluid B are given to be 10 kN/m^3 and 20 kN/m^3, respectively.

Analysis The absolute pressure P_1 is determined from

$$P_1 = P_{\text{atm}} + (\rho g h)_A + (\rho g h)_B$$
$$= P_{\text{atm}} + \gamma_A h_A + \gamma_B h_B$$
$$= (720\,\text{mm Hg})\left(\frac{0.1333\,\text{kPa}}{1\,\text{mm Hg}}\right)$$
$$+ (10\,\text{kN/m}^3)(0.05\,\text{m}) + (20\,\text{kN/m}^3)(0.15\,\text{m})$$
$$= \mathbf{99.5\ kPa}$$

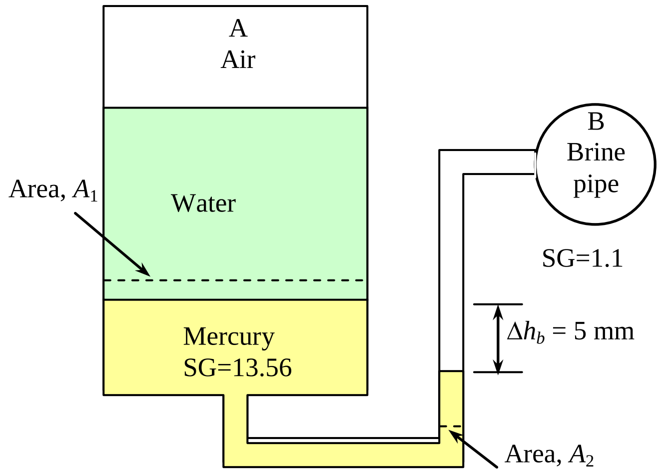
Note that 1 kPa = 1 kN/m^2.



2-64 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 ρ_w =1000 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 ρgh 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

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

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

Subtracting,

$$P_{A2} - P_{A1} + \rho_{Hg} g \Delta h_{Hg} - \rho_{br} g \Delta h_{br} = 0 \quad \rightarrow \quad \frac{P_{A1} - P_{A2}}{\rho_w g} = SG_{Hg} \Delta h_{Hg} - SG_{br} \Delta h_{br} = 0 \qquad (1)$$

where Δh_{Hg} and Δh_{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 $A_1 \Delta h_{Hg,left} = A_2 \Delta h_{Hg,right}$ and

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

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

$$\Delta h_{Hg} = \Delta h_{Hg,right} + \Delta h_{Hg,left} = \Delta h_{br} + \Delta h_{br} A_2/\text{A}_1 = \Delta h_{br}(1 + A_2/\text{A}_1)$$

Substituting,

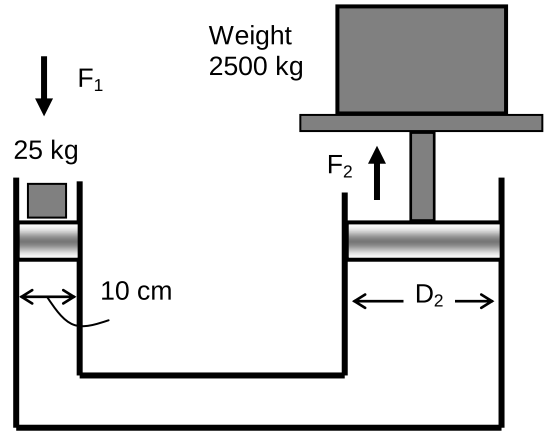
$$\frac{700\text{ kg/m}\cdot\text{s}^2}{(1000\text{ kg/m}^3)(9.81\text{ m/s}^2)} = [13.56\times 0.005(1 + A_2/A_1) - (1.1\times 0.005)]\text{m}$$

It gives

A_2/A_1 = **0.134**

Review Problems

2-65 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

$$P_1 = P_2 = \frac{F_2}{A_2} = \frac{m_2 g}{\pi D_2^2/4} \longrightarrow 31.23\,\text{kN/m}^2 = \frac{(2500\,\text{kg})(9.81\,\text{m/s}^2)}{\pi D_2^2/4}\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) \longrightarrow D_2 = \mathbf{1.0\,m}$$

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

2-66E The efficiency of a refrigerator increases by 3% per °C rise in the minimum temperature. This increase is to be expressed per °F, K, and R rise in the minimum temperature.

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 increase in efficiency is

(a) **3%** for each K rise in temperature, and

(b), (c) 3/1.8 = **1.67%** for each R or °F rise in temperature.

2-67E 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) 5×1.8 = **9°F**

(c) 5×1.8 = **9 R**

2-68E A house is losing heat at a rate of 1800 kJ/h per °C temperature difference between the indoor and the outdoor temperatures. The rate of heat loss is to be expressed per °F, K, and R of temperature difference between the indoor and the outdoor temperatures.

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 rate of heat loss from the house is

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

(b), (c) 1800/1.8 = **1000 kJ/h** per R or °F rise in temperature.

2-69 The average temperature of the atmosphere is expressed as $T_{atm} = 288.15 - 6.5z$ where z is altitude in km. The temperature outside an airplane cruising at 12,000 m is to be determined.

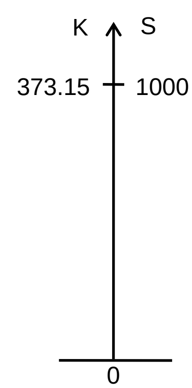
Analysis Using the relation given, the average temperature of the atmosphere at an altitude of 12,000 m is determined to be

$$T_{atm} = 288.15 - 6.5z$$
$$= 288.15 - 6.5\times12$$
$$= \mathbf{210.15\ K = -\ 63°C}$$

Discussion This is the "average" temperature. The actual temperature at different times can be different.

2-70 A new "Smith" absolute temperature scale is proposed, and a value of 1000 S is assigned to the boiling point of water. The ice point on this scale, and its relation to the Kelvin scale are to be determined.

Analysis All linear absolute temperature scales read zero at absolute zero pressure, and are constant multiples of each other. For example, T(R) = 1.8 T(K). That is, multiplying a temperature value in K by 1.8 will give the same temperature in R.



The proposed temperature scale is an acceptable absolute temperature scale since it differs from the other absolute temperature scales by a constant only. The boiling temperature of water in the Kelvin and the Smith scales are 315.15 K and 1000 K, respectively. Therefore, these two temperature scales are related to each other by

$$T(S) = \frac{1000}{373.15}T(\mathrm{K}) = \mathbf{2.6799T(K)}$$

The ice point of water on the Smith scale is

$$T(\mathrm{S})_{ice} = 2.6799\ T(\mathrm{K})_{ice} = 2.6799\times273.15 = \mathbf{732.0\ S}$$

2-71E An expression for the equivalent wind chill temperature is given in English units. It is to be converted to SI units.

Analysis The required conversion relations are 1 mph = 1.609 km/h and $T(°\text{F}) = 1.8T(°\text{C}) + 32$. The first thought that comes to mind is to replace $T(°\text{F})$ in the equation by its equivalent $1.8T(°\text{C}) + 32$, and V in mph by 1.609 km/h, which is the "regular" way of converting units. However, the equation we have is not a regular dimensionally homogeneous equation, and thus the regular rules do not apply. The V in the equation is a constant whose value is equal to the numerical value of the velocity in mph. Therefore, if V is given in km/h, we should divide it by 1.609 to convert it to the desired unit of mph. That is,

$$T_{\text{equiv}}(°\text{F}) = 91.4 - [91.4 - T_{\text{ambient}}(°\text{F})][0.475 - 0.0203(V/1.609) + 0.304\sqrt{V/1.609}]$$

or

$$T_{\text{equiv}}(°\text{F}) = 91.4 - [91.4 - T_{\text{ambient}}(°\text{F})][0.475 - 0.0126V + 0.240\sqrt{V}]$$

where V is in km/h. Now the problem reduces to converting a temperature in °F to a temperature in °C, using the proper convection relation:

$$1.8T_{\text{equiv}}(°\text{C}) + 32 = 91.4 - [91.4 - (1.8T_{\text{ambient}}(°\text{C}) + 32)][0.475 - 0.0126V + 0.240\sqrt{V}]$$

which simplifies to

$$T_{\text{equiv}}(°\text{C}) = 33.0 - (33.0 - T_{\text{ambient}})(0.475 - 0.0126V + 0.240\sqrt{V})$$

where the ambient air temperature is in °C.

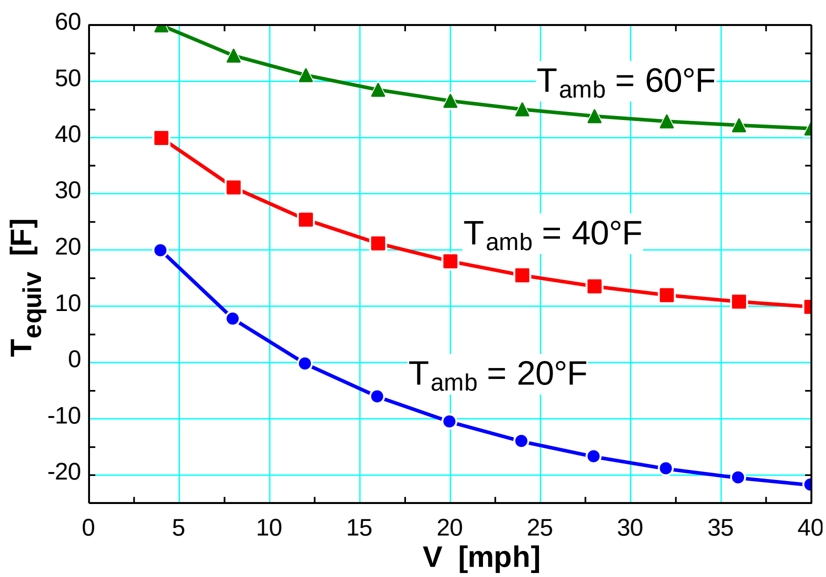
2-72E Problem 2-71E is reconsidered. The equivalent wind-chill temperatures in °F as a function of wind velocity in the range of 4 mph to 40 mph for the ambient temperatures of 20, 40, and 60°F are to be plotted, and the results are to be discussed.

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

```
T_ambient=20
"V=20"
T_equiv=91.4-(91.4-T_ambient)*(0.475 - 0.0203*V + 0.304*sqrt(V))
```

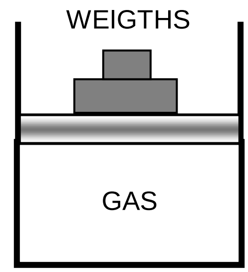
V [mph]	T_{equiv} [F]
4	59.94
8	54.59
12	51.07
16	48.5
20	46.54
24	45.02
28	43.82
32	42.88
36	42.16
40	41.61

The table is for T_{ambient}=60°F



2-73 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

$$P_{\text{atm}} = P - \frac{m_{\text{piston}}g}{A} = 100\,\text{kPa} - \frac{(5\,\text{kg})(9.81\,\text{m/s}^2)}{\pi(0.12\,\text{m}^2)/4}\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) = 95.66\,\text{kN/m}^2 = \mathbf{95.7\,kPa}$$

The force balance when the weights are placed is used to determine the mass of the weights

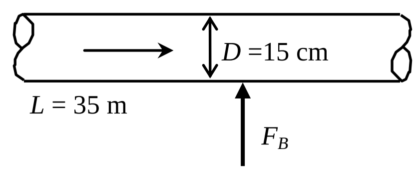
$$P = P_{\text{atm}} + \frac{(m_{\text{piston}} + m_{\text{weights}})g}{A}$$

$$200\,\text{kPa} = 95.66\,\text{kPa} + \frac{(5\,\text{kg} + m_{\text{weights}})(9.81\,\text{m/s}^2)}{\pi(0.12\,\text{m}^2)/4}\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) \longrightarrow m_{\text{weights}} = \mathbf{115\,kg}$$

A large mass is needed to double the pressure.

2-74 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^3. We take the density of water to be 1000 kg/m^3.

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

$$F_B = \rho g V = (1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)(0.6185\,\text{m}^3)\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) = \mathbf{6.07\,kN}$$

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.

2-75E The average body temperature of a person rises by about 2°C during strenuous exercise. This increase in 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 rise in the body temperature during strenuous exercise is

(a) **2 K**

(b) $2\times1.8 =$ **3.6°F**

(c) $2\times1.8 =$ **3.6 R**

2-76 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

m = 170 kg

$$V_{balloon} = 4\pi r^3/3 = 4\pi(6\ \text{m})^3/3 = 904.8\ \text{m}^3$$

$$F_B = \rho_{\text{air}}\, g V_{\text{balloon}}$$

$$= (1.16\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(904.8\ \text{m}^3)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = 10{,}296\ \text{N}$$

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

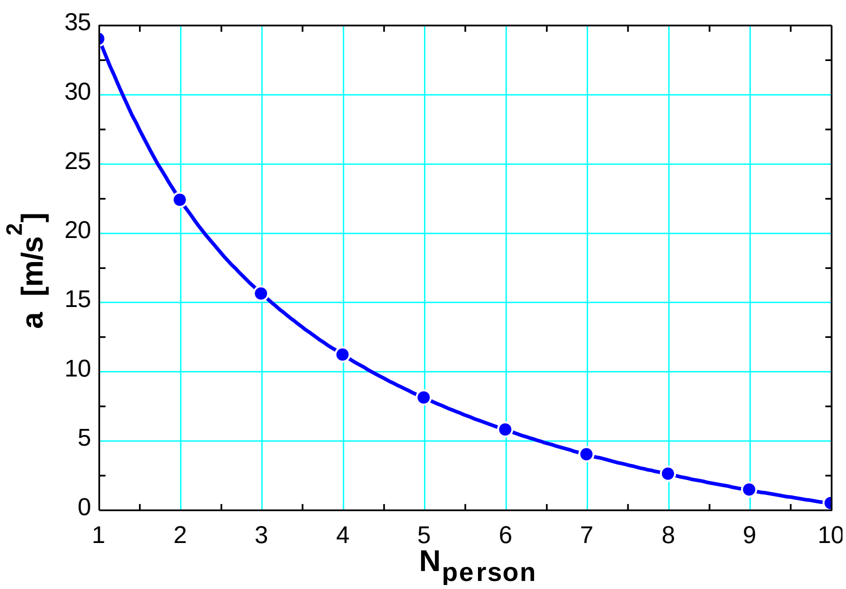
$$a = \frac{F_{\text{net}}}{m_{\text{total}}} = \frac{7157\ \text{N}}{319.9\ \text{kg}}\left(\frac{1\text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right) = \mathbf{22.4\ m/s^2}$$

2-77 Problem 2-76 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 EES, and the solution is given below.

```
"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
m_He=rho_He*V_ballon
m_people=N_person*m_person
m_total=m_He+m_people
W=m_total*g
F_net=F_B-W
a=F_net/m_total
```

N_{person}	a [m/s^2]
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



2-78 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 ρ = 1.16 kg/m^3. The density of helium gas is 1/7th of this.

Analysis The buoyancy force acting on the balloon is

$$V_{balloon} = 4\pi r^3/3 = 4\pi(6\text{ m})^3/3 = 904.8\text{ m}^3$$

$$F_B = \rho_{\text{air}}\, g\, V_{\text{balloon}}$$
$$= (1.16\text{ kg/m}^3)(9.81\text{m/s}^2)(904.8\text{ m}^3)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 10{,}296\text{ N}$$

The 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:

$$W = mg = F_B$$

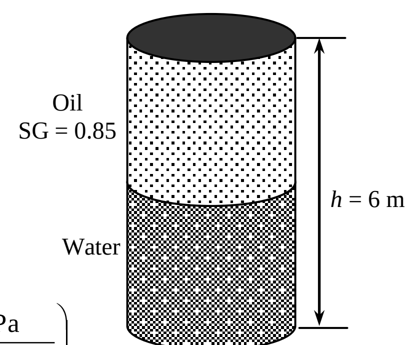
$$m_{\text{total}} = \frac{F_B}{g} = \frac{10{,}296\text{ N}}{9.81\text{ m/s}^2} = 1050\text{ kg}$$

Thus,

$$m_{\text{people}} = m_{\text{total}} - m_{\text{He}} = 1050 - 149.9 = \mathbf{900\ kg}$$

2-79 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 ρ = 1000 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,

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

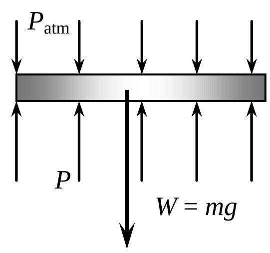
The pressure difference between the top and the bottom of the cylinder is the sum of the pressure differences across the two fluids,

$$\Delta P_{\text{total}} = \Delta P_{\text{oil}} + \Delta P_{\text{water}} = (\rho g h)_{\text{oil}} + (\rho g h)_{\text{water}}$$
$$= \left[(850\text{ kg/m}^3)(9.81\text{ m/s}^2)(3\text{ m}) + (1000\text{ kg/m}^3)(9.81\text{ m/s}^2)(3\text{ m})\right]\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right)$$
$$= \mathbf{54.4\ kPa}$$

2-80 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



$$W = PA - P_{atm}A$$

$$mg = (P - P_{atm})A$$

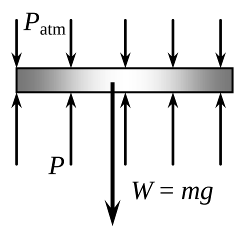
$$(m)(9.81\,\text{m/s}^2) = (180 - 100\,\text{kPa})(25\times10^{-4}\,\text{m}^2)\left(\frac{1000\,\text{kg/m}\cdot\text{s}^2}{1\text{kPa}}\right)$$

It yields m = **20.4 kg**

2-81 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



$$W = P_{gage}A$$

$$m = \frac{P_{gage}A}{g} = \frac{(100\,\text{kPa})(4\times10^{-6}\,\text{m}^2)}{9.81\,\text{m/s}^2}\left(\frac{1000\,\text{kg/m}\cdot\text{s}^2}{1\,\text{kPa}}\right)$$

$$= \mathbf{0.0408\ kg}$$

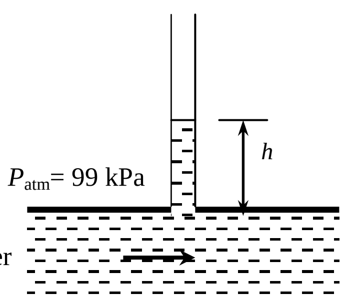
2-82 A glass tube open to the atmosphere is attached to a water pipe, and the pressure at the bottom of the tube is measured. It is to be determined how high the water will rise in the tube.

Properties The density of water is given to be ρ = 1000 kg/m^3.

Analysis The pressure at the bottom of the tube can be expressed as

$$P = P_{atm} + (\rho g h)_{tube}$$

Solving for h,



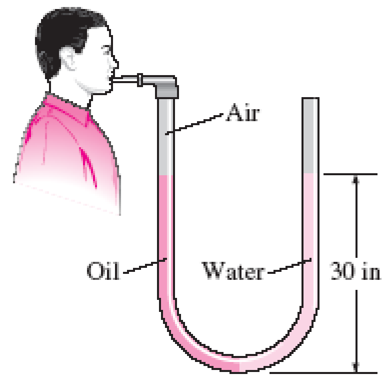
$$h = \frac{P - P_{atm}}{\rho g}$$

$$= \frac{(110 - 99)\,\text{kPa}}{(1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)}\left(\frac{1\,\text{kg}\cdot\text{m/s}^2}{1\,\text{N}}\right)\left(\frac{1000\,\text{N/m}^2}{1\,\text{kPa}}\right)$$

$$= \mathbf{1.12\ m}$$

2-83E Equal volumes of water and oil are poured into a U-tube from different arms, and the oil side is pressurized until the contact surface of the two fluids moves to the bottom and the liquid levels in both arms become the same. The excess pressure applied on the oil side is to be determined.

Assumptions **1** Both water and oil are incompressible substances. **2** Oil does not mix with water. **3** The cross-sectional area of the U-tube is constant.



Properties The density of oil is given to be ρ_{oil} = 49.3 lbm/ft^3. We take the density of water to be ρ_w = 62.4 lbm/ft^3.

Analysis Noting that the pressure of both the water and the oil is the same at the contact surface, the pressure at this surface can be expressed as

$$P_{\text{contact}} = P_{\text{blow}} + \rho_a g h_a = P_{\text{atm}} + \rho_w g h_w$$

Noting that $h_a = h_w$ and rearranging,

$$\begin{aligned} P_{\text{gage, blow}} &= P_{\text{blow}} - P_{\text{atm}} = (\rho_w - \rho_{oil}) g h \\ &= (62.4 - 49.3\ \text{lbm/ft}^3)(32.2\ \text{ft/s}^2)(30/12\ \text{ft})\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\ \text{ft}^2}{144\ \text{in}^2}\right) \\ &= \mathbf{0.227\ psi} \end{aligned}$$

Discussion When the person stops blowing, the oil will rise and some water will flow into the right arm. It can be shown that when the curvature effects of the tube are disregarded, the differential height of water will be 23.7 in to balance 30-in of oil.

2-84 A barometer is used to measure the altitude of a plane relative to the ground. The barometric readings at the ground and in the plane are given. The altitude of the plane is to be determined.

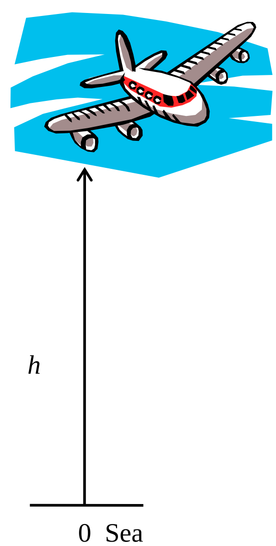
Assumptions The variation of air density with altitude is negligible.

Properties The densities of air and mercury are given to be ρ = 1.20 kg/m^3 and ρ = 13,600 kg/m^3.

Analysis Atmospheric pressures at the location of the plane and the ground level are

$$\begin{aligned} P_{\text{plane}} &= (\rho g h)_{\text{plane}} \\ &= (13{,}600\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.690\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= 92.06\ \text{kPa} \end{aligned}$$

$$\begin{aligned} P_{\text{ground}} &= (\rho g h)_{\text{ground}} \\ &= (13{,}600\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.753\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= 100.46\ \text{kPa} \end{aligned}$$



Taking an air column between the airplane and the ground and writing a force balance per unit base area, we obtain

$$W_{\text{air}} / A = P_{\text{ground}} - P_{\text{plane}}$$

$$(\rho g h)_{\text{air}} = P_{\text{ground}} - P_{\text{plane}}$$

$$(1.20\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(h)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) = (100.46 - 92.06)\ \text{kPa}$$

It yields

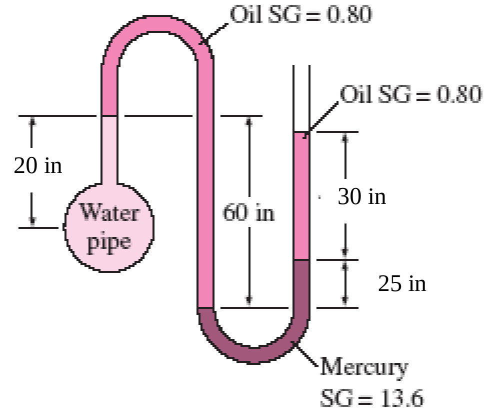
h = **714 m**

which is also the altitude of the airplane.

2-85E A water pipe is connected to a double-U manometer whose free arm is open to the atmosphere. The absolute pressure at the center of the pipe is to be determined.

Assumptions **1** All the liquids are incompressible. **2** The solubility of the liquids in each other is negligible.

Properties The specific gravities of mercury and oil are given to be 13.6 and 0.80, respectively. We take the density of water to be ρ_w = 62.4 lbm/ft^3.



Analysis Starting with the pressure at the center of the water pipe, 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

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

Solving for $P_{\text{water pipe}}$,

$$P_{\text{water pipe}} = P_{atm} + \rho_{\text{water}} g(h_{\text{water}} - SG_{\text{oil}} h_{\text{oil}} + SG_{\text{Hg}} h_{\text{Hg}} + SG_{\text{oil}} h_{\text{oil}})$$

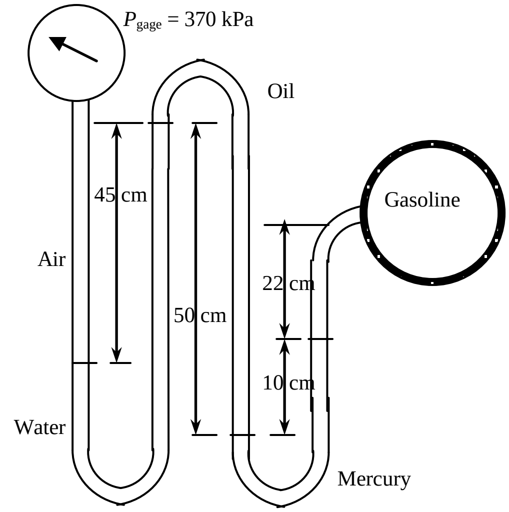
Substituting,

$$P_{\text{water pipe}} = 14.2\text{psia} + (62.4\text{lbm/ft}^3)(32.2\text{ ft/s}^2)[(20/12\text{ft}) - 0.8(60/12\text{ft}) + 13.6(25/12\text{ft})$$
$$+ 0.8(30/12\text{ft})] \times \left(\frac{1\text{ lbf}}{32.2\text{ lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\text{ ft}^2}{144\text{ in}^2}\right)$$
$$= \mathbf{26.4\ psia}$$

Therefore, the absolute pressure in the water pipe is 26.4 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.

2-86 A gasoline line is connected to a pressure gage through a double-U manometer. For a given reading of the pressure gage, the gage pressure of the gasoline line is to be determined.



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

Properties The specific gravities of oil, mercury, and gasoline are given to be 0.79, 13.6, and 0.70, respectively. We take the density of water to be ρ_w = 1000 kg/m^3.

Analysis Starting with the pressure indicated by the pressure gage and moving along the tube by adding (as we go down) or subtracting (as we go up) the ρgh terms until we reach the gasoline pipe, and setting the result equal to P_{gasoline} gives

$$P_{\text{gage}} - \rho_{\text{w}} g h_w + \rho_{\text{oil}} g h_{\text{oil}} - \rho_{\text{Hg}} g h_{\text{Hg}} - \rho_{\text{gasoline}} g h_{\text{gasoline}} = P_{\text{gasoline}}$$

Rearranging,

$$P_{\text{gasoline}} = P_{\text{gage}} - \rho_{\text{w}} g (h_w - \text{SG}_{\text{oil}} h_{\text{oil}} + \text{SG}_{\text{Hg}} h_{\text{Hg}} + \text{SG}_{\text{gasoline}} h_{\text{gasoline}})$$

Substituting,

$$P_{\text{gasoline}} = 370\,\text{kPa - }(1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)[(0.45\,\text{m}) - 0.79(0.5\,\text{m}) + 13.6(0.1\,\text{m}) + 0.70(0.22\,\text{m})]$$

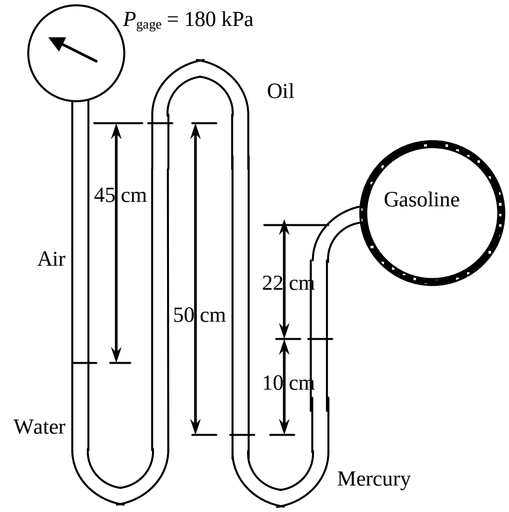
$$\times \left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kPa}}{1\,\text{kN/m}^2}\right)$$

$$= \mathbf{354.6\ kPa}$$

Therefore, the pressure in the gasoline pipe is 15.4 kPa lower than the pressure reading of the pressure gage.

Discussion Note that sometimes the use of specific gravity offers great convenience in the solution of problems that involve several fluids.

2-87 A gasoline line is connected to a pressure gage through a double-U manometer. For a given reading of the pressure gage, the gage pressure of the gasoline line is to be determined.



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

Properties The specific gravities of oil, mercury, and gasoline are given to be 0.79, 13.6, and 0.70, respectively. We take the density of water to be $\rho_w = 1000 \text{ kg/m}^3$.

Analysis Starting with the pressure indicated by the pressure gage and moving along the tube by adding (as we go down) or subtracting (as we go up) the ρgh terms until we reach the gasoline pipe, and setting the result equal to P_{gasoline} gives

$$P_{gage} - \rho_{\text{w}} g h_w + \rho_{\text{oil}} g h_{\text{oil}} - \rho_{\text{Hg}} g h_{\text{Hg}} - \rho_{\text{gasoline}} g h_{\text{gasoline}} = P_{\text{gasoline}}$$

Rearranging,

$$P_{\text{gasoline}} = P_{\text{gage}} - \rho_{\text{w}} g (h_w - \text{SG}_{\text{oil}} h_{\text{oil}} + \text{SG}_{\text{Hg}} h_{\text{Hg}} + \text{SG}_{\text{gasoline}} h_{\text{gasoline}})$$

Substituting,

$$P_{\text{gasoline}} = 180 \text{ kPa} - (1000 \text{ kg/m}^3)(9.807 \text{ m/s}^2)[(0.45 \text{ m}) - 0.79(0.5 \text{ m}) + 13.6(0.1 \text{ m}) + 0.70(0.22 \text{ m})]$$
$$\times \left(\frac{1 \text{ kN}}{1000 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1 \text{ kN/m}^2}\right)$$
$$= \mathbf{164.6 \text{ kPa}}$$

Therefore, the pressure in the gasoline pipe is 15.4 kPa lower than the pressure reading of the pressure gage.

Discussion Note that sometimes the use of specific gravity offers great convenience in the solution of problems that involve several fluids.

2-88 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

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

Atlanta: (z = 0.306 km): $P_{atm} = 101.325(1 - 0.02256 \times 0.306)^{5.256}$ = **97.7 kPa**

Denver: (z = 1.610 km): $P_{atm} = 101.325(1 - 0.02256 \times 1.610)^{5.256}$ = **83.4 kPa**

M. City: (z = 2.309 km): $P_{atm} = 101.325(1 - 0.02256 \times 2.309)^{5.256}$ = **76.5 kPa**

Mt. Ev.: (z = 8.848 km): $P_{atm} = 101.325(1 - 0.02256 \times 8.848)^{5.256}$ = **31.4 kPa**

2-89 Design and Essay Problems