Thermodynamics

1-1C 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.

1-2C There is no truth to his claim. It violates the second law of thermodynamics.

1-3C Classical thermodynamics is based on experimental observations whereas statistical thermodynamics is based on the average behavior of large groups of particles.

Mass, Force, and Units

1-4C 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.

1-5C Pound-mass lbm is the mass unit in English system whereas pound-force lbf is the force unit. One pound-force is the force required to accelerate a mass of 32.174 lbm by 1 ft/s^2. In other words, the weight of a 1-lbm mass at sea level is 1 lbf.

1-6C There is no acceleration, thus the net force is zero in both cases.

1-7 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

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

1-8 The acceleration of an aircraft is given in *g*'s. The net upward force acting on a man in the aircraft is to be determined.

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

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

1-9 Gravitational acceleration g and thus the weight of bodies decreases with increasing elevation. The percent reduction in the weight of an airplane cruising at 13,000 m is to be determined.

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

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

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

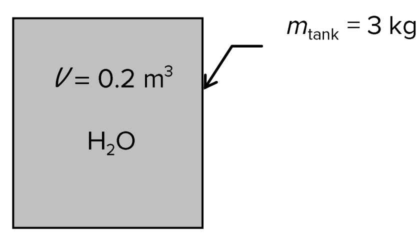
Therefore, the airplane and the people in it will weight 0.41% less at 13,000 m altitude.

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

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 $\rho = 1000$ kg/m^3.



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

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

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

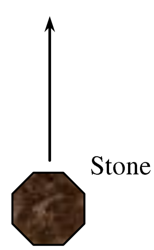
Thus,

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

1-11 A rock is thrown upward with a specified force. The acceleration of the rock is to be determined.

Analysis The weight of the rock is

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



Then the net force that acts on the rock is

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

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

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

1-12 Problem 1-11 is reconsidered. The entire solution by appropriate software is to be printed out, including the numerical results with proper units.

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

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

SOLUTION

a=90.21 [m/s^2]

F_down=19.58 [N]

F_net=180.4 [N]

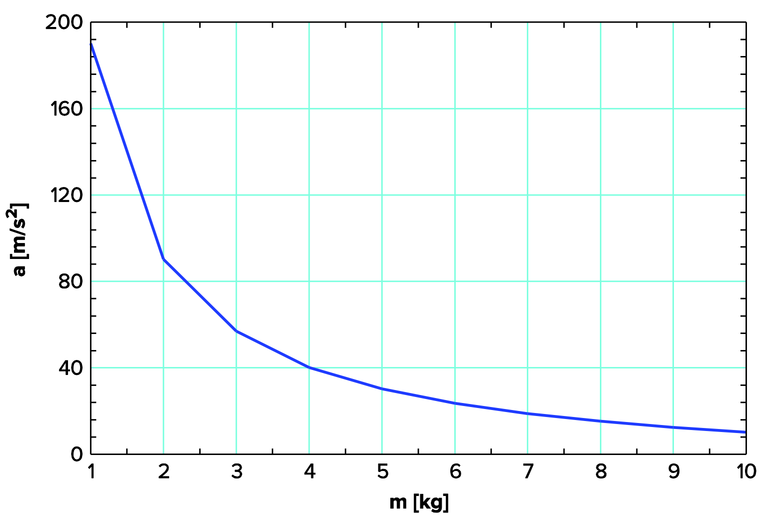
F_up=200 [N]

g=9.79 [m/s^2]

m=2 [kg]

W=19.58 [N]

m [kg]	a [m/s^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



1-13 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.

1-14 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:

$$W = mg = (70\,\text{kg})(1.67\,\text{m/s}^2)\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kgf}}{9.81\,\text{N}}\right) = \mathbf{11.9\ kgf}$$

(*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,

$$W = mg = (70\,\text{kg})(9.81\,\text{m/s}^2)\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kgf}}{9.81\,\text{N}}\right) = \mathbf{70\ kgf}$$

1-15 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

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

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

Systems, Properties, State, and Processes

1-16C Carbon dioxide is generated by the combustion of fuel in the engine. Any system selected for this analysis must include the fuel and air while it is undergoing combustion. The volume that contains this air-fuel mixture within piston-cylinder device can be used for this purpose. One can also place the entire engine in a control boundary and trace the system-surroundings interactions to determine the rate at which the engine generates carbon dioxide.

1-17C The radiator should be analyzed as an open system since mass is crossing the boundaries of the system.

1-18C A can of soft drink should be analyzed as a closed system since no mass is crossing the boundaries of the system.

1-19C When analyzing the control volume selected, we must account for all forms of water entering and leaving the control volume. This includes all streams entering or leaving the lake, any rain falling on the lake, any water evaporated to the air above the lake, any seepage to the underground earth, and any springs that may be feeding water to the lake.

1-20C In order to describe the state of the air, we need to know the value of all its properties. Pressure, temperature, and water content (i.e., relative humidity or dew point temperature) are commonly cited by weather forecasters. But, other properties like wind speed and chemical composition (i.e., pollen count and smog index, for example} are also important under certain circumstances.

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

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

1-22C The original specific weight is

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

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

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

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

1-23C The number of moles of a substance in a system is directly proportional to the number of atomic particles contained in the system. If we divide a system into smaller portions, each portion will contain fewer atomic particles than the original system. The number of moles is therefore an *extensive property*.

1-24C Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

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.

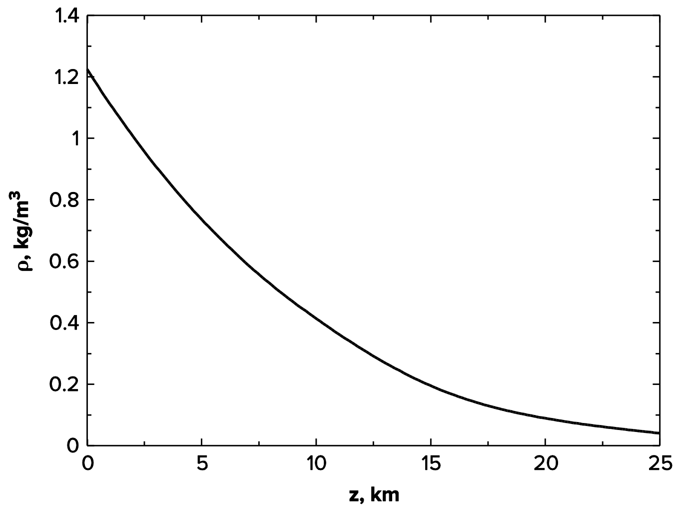
1-27C The **specific gravity,** or **relative density,** and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which ρ_{H2O} = 1000 kg/m^3). That is, $SG = \rho / \rho_{H2O}$. When specific gravity is known, density is determined from $\rho = SG \times \rho_{H2O}$.

1-28 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**

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

EES Solution:

```
"Using linear regression feature of EES based on the data on parametric table, we obtain"
rho=1.20251659E+00-1.01669722E-01*z+2.23747073E-03*z^2
z=7 [km]
"The mass of the atmosphere is obtained by integration to be"
m=4*pi*(a*r0^2*h+r0*(2*a+b*r0)*h^2/2+(a+2*b*r0+c*r0^2)*h^3/3+(b+2*c*r0)*h^4/4+c*h^5/5)*1E9
a=1.20252
b=-0.101670
c=0.0022375
r0=6377 [km]
h=25 [km]
```

Temperature

1-29C They are Celsius (°C) and kelvin (K) in the SI, and fahrenheit (°F) and rankine (R) in the English system.

1-30C 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.

1-31C 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.

1-32 A temperature is given in °C. It is to be expressed in °F, K, and R.

Analysis Using the conversion relations between the various temperature scales,

$$T[\text{K}] = T(°\text{C}) + 273 = 18°\text{C} + 273 = \mathbf{291\ K}$$

$$T[°\text{F}] = 1.8T(°\text{C}) + 32 = (1.8)(18) + 32 = \mathbf{64.4°F}$$

$$T[\text{R}] = T(°\text{F}) + 460 = 64.4 + 460 = \mathbf{524.4\ R}$$

1-33 The temperature of steam given in K unit is to be converted to °F unit.

Analysis Using the conversion relations between the various temperature scales,

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

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

1-34 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,

$$\Delta T[\text{K}] = \Delta T(°\text{C}) = \mathbf{130\ K}$$

1-35 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,

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

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

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

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

1-36 The temperature of oil given in °F unit is to be converted to °C unit.

Analysis Using the conversion relation between the temperature scales,

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

Pressure, Manometer, and Barometer

1-37C The pressure relative to the atmospheric pressure is called the *gage pressure*, and the pressure relative to an absolute vacuum is called *absolute pressure*.

1-38C 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.

1-39C 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.

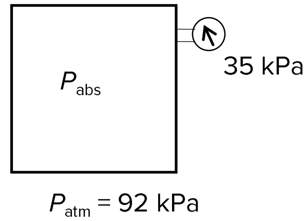
1-40C No, the absolute pressure in a liquid of constant density does not double when the depth is doubled. It is the *gage pressure* that doubles when the depth is doubled.

1-41C 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.

1-42 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

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



1-43 The maximum pressure of a tire is given in English units. It is to be converted to SI units.

Assumptions The listed pressure is gage pressure.

Analysis Noting that 1 atm = 101.3 kPa = 14.7 psi, the listed maximum pressure can be expressed in SI units as

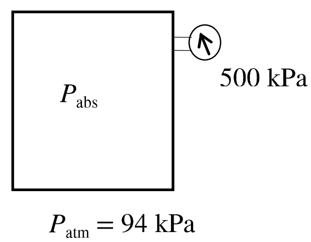
$$P_{max} = 35 \text{ psi} = (35 \text{ psi})\left(\frac{101.3 \text{ kPa}}{14.7 \text{ psi}}\right) = \mathbf{241\ \ kPa}$$

Discussion We could also solve this problem by using the conversion factor 1 psi = 6.895 kPa.

1-44 A pressure gage connected to a tank reads 500 kPa. The absolute pressure in the tank is to be determined.

Analysis The absolute pressure in the tank is determined from

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



1-45 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

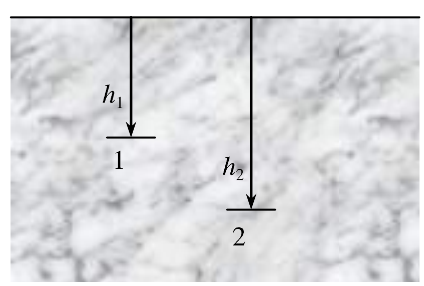
$$P_1 = \rho g h_1 \qquad \text{and} \qquad P_2 = \rho g h_2$$

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.

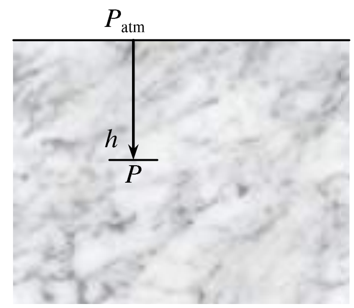
1-46 The absolute pressure in water at a specified depth is given. The local atmospheric pressure and the absolute pressure at the same depth in a different liquid are to be determined.

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



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

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

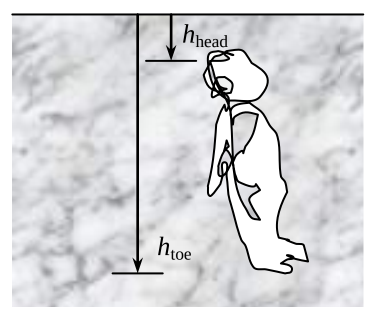
$$\begin{aligned} P &= P_{atm} + \rho g h \\ &= (96.7 \text{ kPa}) + (850 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(9 \text{ m})\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) \\ &= \mathbf{171.8 \text{ kPa}} \end{aligned}$$

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

1-47 A man is standing in water vertically while being completely submerged. The difference between the pressures acting on the head and on the toes is to be determined.

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

Properties We take the density of water to be ρ =1000 kg/m^3.



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

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

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

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

Substituting,

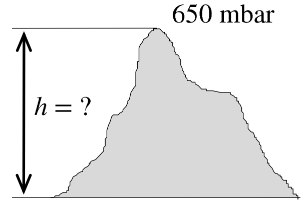
$$P_{toe} - P_{head} = (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(1.75 \text{ m - 0})\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) = \mathbf{17.2 \text{ kPa}}$$

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

1-48 A mountain hiker records the barometric reading before and after a hiking trip. The vertical distance climbed is to be determined.

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

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



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

$$W_{\text{air}} / A = P_{\text{bottom}} - P_{\text{top}}$$
$$(\rho g h)_{\text{air}} = P_{\text{bottom}} - P_{\text{top}}$$
$$(1.20\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(h)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{bar}}{100{,}000\ \text{N/m}^2}\right) = (0.750 - 0.650)\ \text{bar}$$

It yields

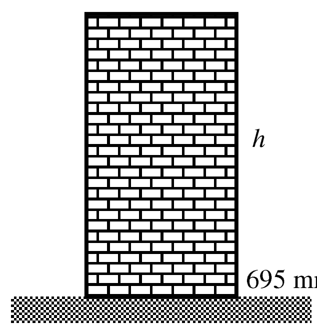
$h = \mathbf{850\ m}$

which is also the distance climbed.

1-49 A barometer is used to measure the height of a building by recording reading at the bottom and at the top of the building. The height of the building is to be determined.

Assumptions The variation of air density with altitude is negligible.

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

$h = \mathbf{231\ m}$

which is also the height of the building.

1-50 Problem 1-49 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]
rho=1.18  [kg/m^3]
DELTAP_abs=(P_bottom-P_top)*CONVERT(mmHg, 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]

1-51 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

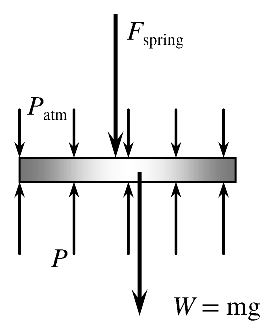
$$PA = P_{atm}A + W + F_{spring}$$

Thus,

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

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

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

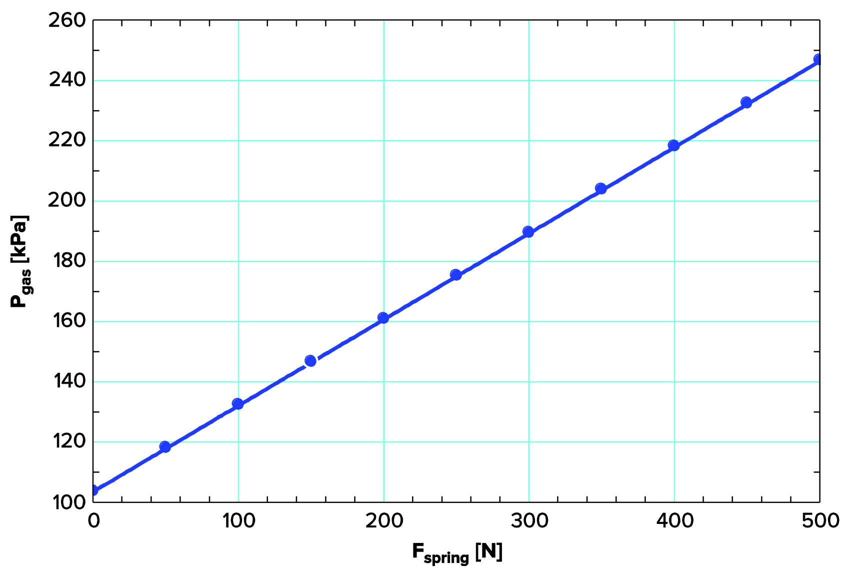


1-52 Problem 1-51 is reconsidered. The effect of the spring force in the range of 0 to 500 N on the pressure inside the cylinder is to be investigated. The pressure against the spring force is to be plotted, and results are to be discussed.

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

```
P_atm= 95 [kPa]
m_piston=3.2 [kg]
F_spring=150 [N]
A=35*CONVERT(cm^2, m^2)
g=9.81 [m/s^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



1-53 A gas is contained in a vertical cylinder with a heavy piston. The pressure inside the cylinder and the effect of volume change on pressure are to be determined.

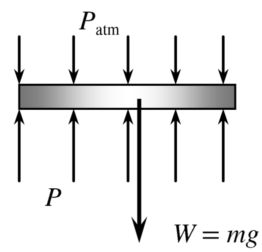
Assumptions Friction between the piston and the cylinder is negligible.

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

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

Thus,

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



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

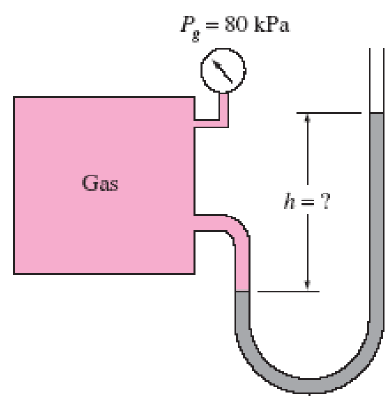
Discussion If the gas behaves as an ideal gas, the absolute temperature doubles when the volume is doubled at constant pressure.

1-54 Both a gage and a manometer are attached to a gas to measure its pressure. For a specified reading of gage pressure, the difference between the fluid levels of the two arms of the manometer is to be determined for mercury and water.

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

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

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



(*a*) For mercury,

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

(*b*) For water,

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

1-55  Problem 1-54 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.

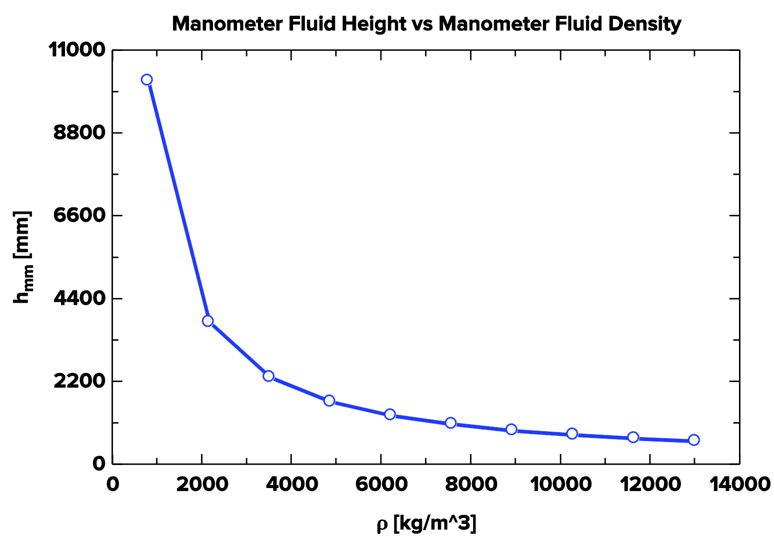
Analysis The problem is solved using EES, and the solution is given below.

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

Function fluid_density(Fluid$)
"This function is needed since if-then-else logic can only be used in functions or procedures.
The underscore displays whatever follows as subscripts in the Formatted Equations Window."
    If fluid$='Mercury' then  fluid_density=13600 else fluid_density=1000
end

Fluid$='Mercury'
P_atm = 101.325 [kPa]
DELTAP=80 [kPa] "Note how DELTAP is displayed on the Formatted Equations Window."
g=9.807 [m/s^2] "local acceleration of gravity at sea level"
rho=Fluid_density(Fluid$)   "Get the fluid density, either Hg or H2O, from the function"
DELTAP = RHO*g*h/1000 "Instead of 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
```

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

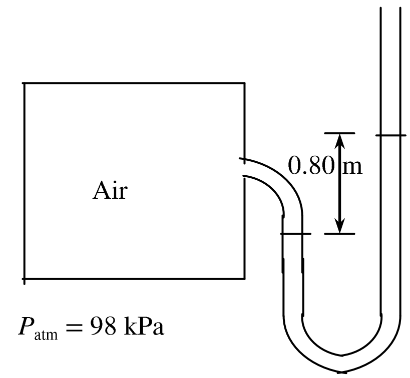


1-56 The air pressure in a tank is measured by an oil manometer. For a given oil-level difference between the two columns, the absolute pressure in the tank is to be determined.

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

Analysis The absolute pressure in the tank is determined from

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



1-57 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 0°C is 1000 kg/m^3 (Table A-3)

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

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

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

$$\Delta P = \rho g h = (1250 \text{kg/m}^3)(9.81 \text{m/s}^2)(0.72 \text{m})\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{kPa}}{1000 \text{N/m}^2}\right) = 8.83 \text{kPa}$$

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):

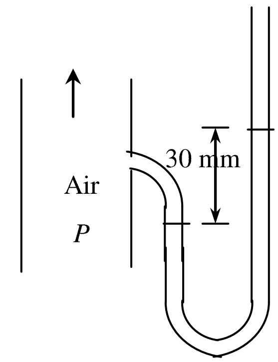
$$P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}} = 87.6 - 8.83 = \mathbf{78.8 \text{ kPa}}$$

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

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} = 8.83 + 87.6 = \mathbf{96.4 \text{ kPa}}$$

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.

1-58 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.



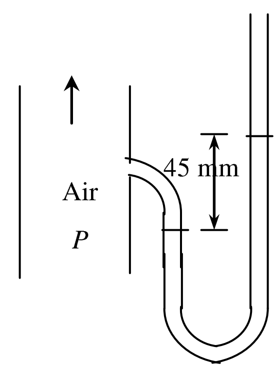
Properties The density of mercury is given to be $\rho = 13{,}600\ \text{kg/m}^3$.

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

$$\begin{aligned} P &= P_{\text{atm}} + \rho g h \\ &= (100\ \text{kPa}) + (13{,}600\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.030\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= \mathbf{104\ kPa} \end{aligned}$$

1-59 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 $\rho = 13{,}600\ \text{kg/m}^3$.

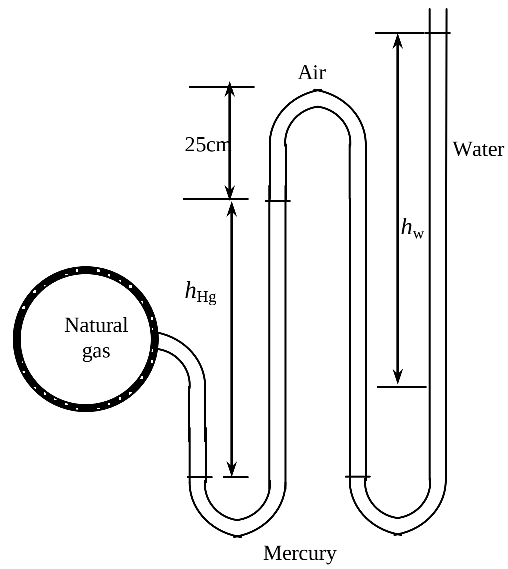
Analysis (*a*) The pressure in the duct is above atmospheric pressure since the fluid column on the duct side is at a lower level.

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

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

1-60 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 = 1000 kg/m^3. The specific gravity of mercury is given to be 13.6, and thus its density is ρ_{Hg} = 13.6×1000 =13,600 kg/m^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,

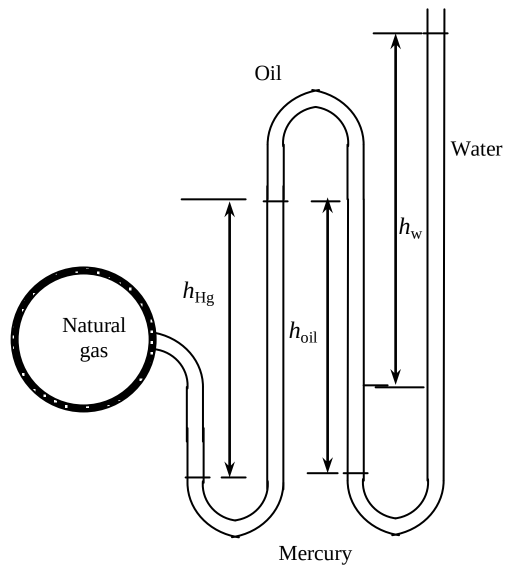
$$P = 98 \text{ kPa} + (9.81 \text{ m/s}^2)[(13{,}600 \text{ kg/m}^3)(0.15 \text{ m}) + (1000 \text{ kg/m}^3)(0.70 \text{ m})]\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$
$$= \mathbf{125\ kPa}$$

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. Also, it can be shown that the 40-cm high air column with a density of 1.2 kg/m^3 corresponds to a pressure difference of 0.0047 kPa. Therefore, its effect on the pressure difference between the two pipes is negligible.

1-61 The pressure in a natural gas pipeline is measured by a double U-tube manometer with one of the arms open to the atmosphere. The absolute pressure in the pipeline is to be determined.

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

Properties We take the density of water to be $\rho_w = 1000$ kg/m^3. The specific gravity of mercury is given to be 13.6, and thus its density is $\rho_{Hg} = 13.6 \times 1000 = 13{,}600$ kg/m^3. The specific gravity of oil is given to be 0.69, and thus its density is $\rho_{oil} = 0.69 \times 1000 = 690$ kg/m^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,

$$P = 98 \text{ kPa} +$$

$$(9.81 \text{ m/s}^2)[(13{,}600 \text{ kg/m}^3)(0.15 \text{ m}) + (1000 \text{ kg/m}^3)(0.70 \text{ m}) - (690 \text{ kg/m}^3)(0.40 \text{ m})]\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$

$$= \mathbf{122 \text{ kPa}}$$

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.

1-62 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.

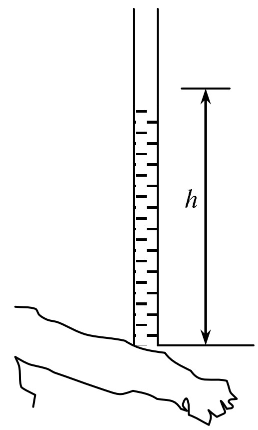
Assumptions Both mercury and water are incompressible substances.

Properties We take the densities of water and mercury to be 1000 kg/m³ and 13,600 kg/m³, respectively.

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

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

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



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

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

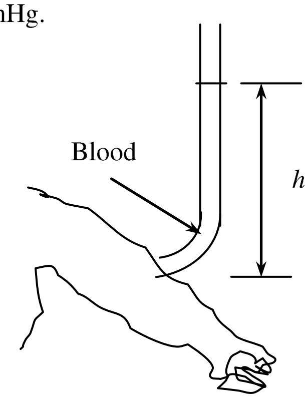
$$h_{\text{water, low}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{water}}} h_{\text{mercury, low}} = \frac{13{,}600\ \text{kg/m}^3}{1000\ \text{kg/m}^3}(0.08\ \text{m}) = \mathbf{1.09\ m}$$

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.

1-63 A vertical tube open to the atmosphere is connected to the vein in the arm of a person. The height that the blood will rise in the tube is to be determined.

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

Properties The density of blood is given to be $\rho = 1050$ 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

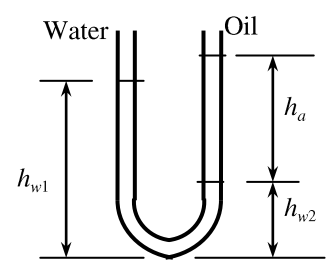
$$h_{\text{blood}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{blood}}} h_{\text{mercury}} = \frac{13{,}600 \text{ kg/m}^3}{1050 \text{ kg/m}^3}(0.12 \text{ m}) = \mathbf{1.55\ m}$$

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.

1-64 Water is poured into the U-tube from one arm and oil from the other arm. The water column height in one arm and the ratio of the heights of the two fluids in the other arm are given. The height of each fluid in that arm is to be determined.

Assumptions Both water and oil are incompressible substances.

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

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

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

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

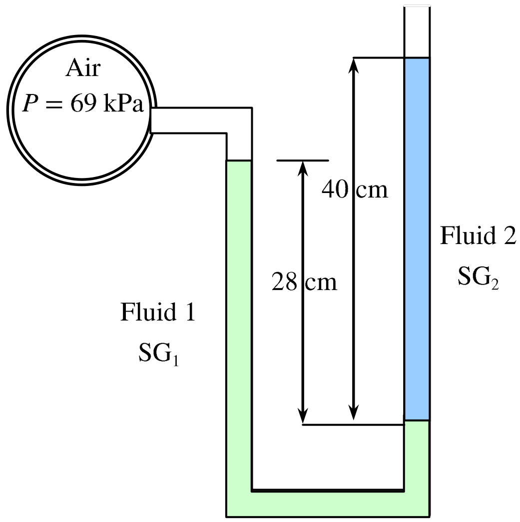
$$0.7 \text{ m} = 0.168 \text{ m} + (790/1000) h_a \;\rightarrow\; h_a = \mathbf{0.673\ m}$$

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

1-65 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

$$P_{air} + \rho_1 gh_1 - \rho_2 gh_2 = P_{atm} \quad \rightarrow \quad P_{air} - P_{atm} = SG_2 \rho_w gh_2 - SG_1 \rho_w gh_1$$

Rearranging and solving for SG$_2$,

$$SG_2 = SG_1 \frac{h_1}{h_2} + \frac{P_{air} - P_{atm}}{\rho_w gh_2} = 13.55 \frac{0.28 \text{ m}}{0.40 \text{ m}} + \left(\frac{69 - 100 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.40 \text{ m})} \right) \left(\frac{1000 \text{ kg} \cdot \text{m/s}^2}{1 \text{ kPa} \cdot \text{m}^2} \right) = \mathbf{1.59}$$

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

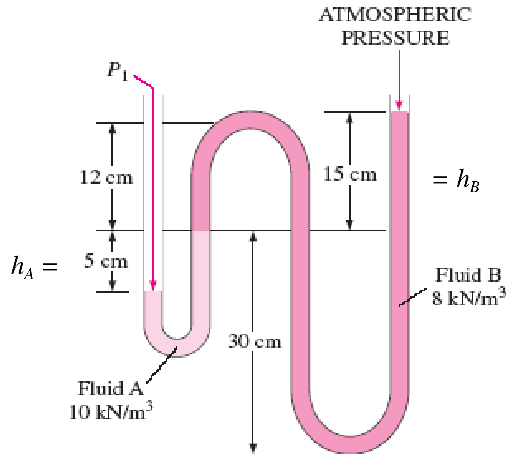
1-66 The pressure indicated by a manometer is to be determined.

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

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

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



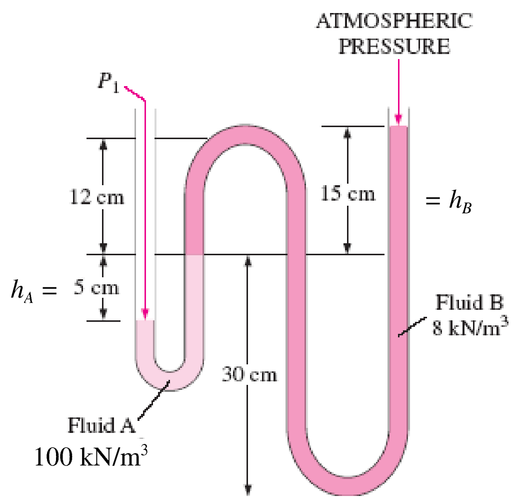
1-67 The pressure indicated by a manometer is to be determined.

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

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

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



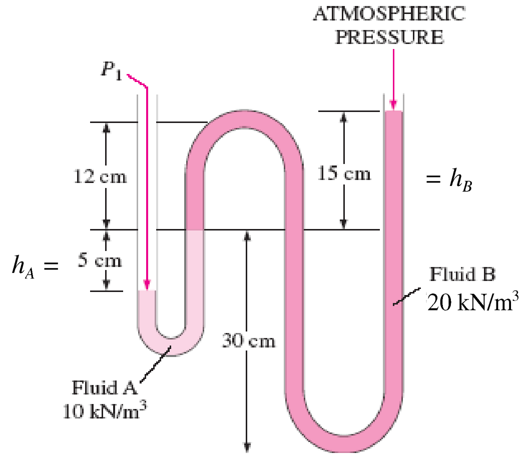
1-68 The pressure indicated by a manometer is to be determined.

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

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

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



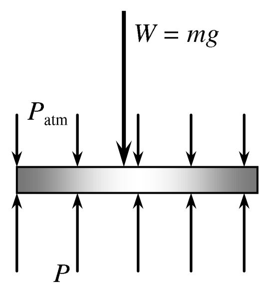
1-69 The hydraulic lift in a car repair shop is to lift cars. The fluid gage pressure that must be maintained in the reservoir is to be determined.

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,

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

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

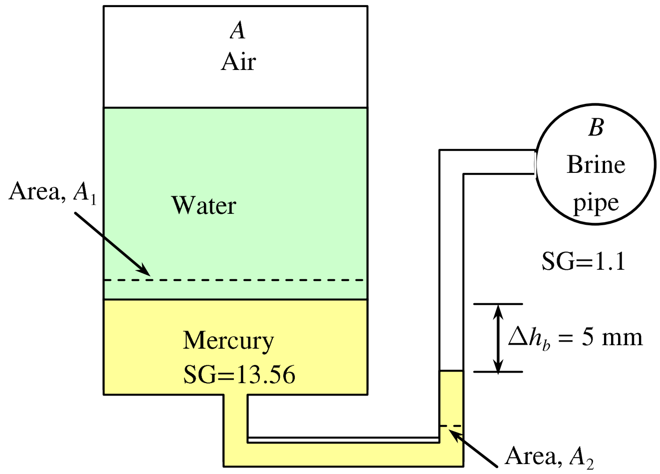


Discussion Note that the pressure level in the reservoir can be reduced by using a piston with a larger area.

1-70 The fluid levels in a multi-fluid U-tube manometer change as a result of a pressure drop in the trapped air space. For a given pressure drop and brine level change, the area ratio is to be determined.

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

Properties The specific gravities are given to be 13.56 for mercury and 1.1 for brine. We take the standard density of water to be $\rho_w = 1000$ 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

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

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

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

Substituting,

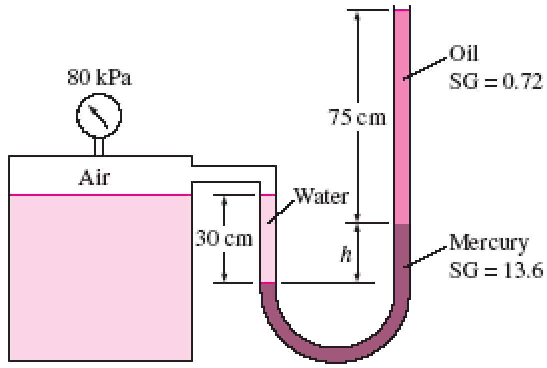
$$\frac{700 \text{ kg/m} \cdot \text{s}^2}{(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)} = [13.56 \times 0.005(1 + A_2/A_1) - (1.1 \times 0.005)] \text{ m}$$

It gives $A_2/A_1 =$ **0.134**

1-71 The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height *h* of the mercury column is to be determined.

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

Properties We take the density of water to be ρ_w =1000 kg/m^3. The specific gravities of oil and mercury are given to be 0.72 and 13.6, respectively.



Analysis Starting with the pressure of air in the tank (point 1), and moving along the tube by adding (as we go down) or subtracting (as we go up) the 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

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

Rearranging,

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

or,

$$\frac{P_{1,\text{gage}}}{\rho_{\text{w}} g} = \text{SG}_{\text{oil}} h_{\text{oil}} + \text{SG}_{\text{Hg}} h_{\text{Hg}} - h_w$$

Substituting,

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

Solving for h_{Hg} gives

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

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

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

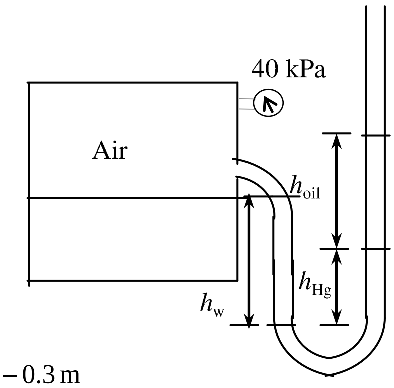
1-72 The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height *h* of the mercury column is to be determined.

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

Properties We take the density of water to be ρ_w =1000 kg/m^3. The specific gravities of oil and mercury are given to be 0.72 and 13.6, respectively.

Analysis Starting with the pressure of air in the tank (point 1), and moving along the tube by adding (as we go down) or subtracting (as we go up) the $\rho g h$ 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

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



Rearranging,

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

or,

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

Substituting,

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

Solving for h_{Hg} gives

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

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

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

Solving Engineering Problems and Equation Solvers

1-73C Despite the convenience and capability the engineering software packages offer, they are still just tools, and they will not replace the traditional engineering courses. They will simply cause a shift in emphasis in the course material from mathematics to physics. They are of great value in engineering practice, however, as engineers today rely on software packages for solving large and complex problems in a short time, and perform optimization studies efficiently.

1-74 Determine a positive real root of the following equation using appropriate software:

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

Solution by EES Software (Copy the following line and paste on a blank EES screen to verify solution):

```
2*x^3-10*x^0.5-3*x = -3
```

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

1-75 Solve the following system of 2 equations with 2 unknowns using appropriate software:

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

$$3xy + y = 3.5$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^3–y^2=5.9
3*x*y+y=3.5
```

Answer x=1.836 y=0.5378

1-76 Solve the following system of 3 equations with 3 unknowns using appropriate software:

$$2x - y + z = 7$$
$$3x^2 + 2y = z + 3$$
$$xy + 2z = 4$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
2*x-y+z=7
3*x^2+2*y=z+3
x*y+2*z=4
```

Answer x=1.609, y= – 0.9872, z=2.794

1-77 Solve the following system of 3 equations with 3 unknowns using appropriate software:

$$x^2y - z = 1$$
$$x - 3y^{0.5} + xz = -2$$
$$x + y - z = 2$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^2*y-z=1
x-3*y^0.5+x*z= – 2
x+y-z=2
```

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

Review Problems

1-78 The gravitational acceleration changes with altitude. Accounting for this variation, the weights of a body at different locations are to be determined.

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

$$W = mg = (80\text{ kg})(9.807 - 3.32\times10^{-6} z\text{m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)$$

Sea level: (z = 0 m): W = 80×(9.807-3.32x10^{-6}×0) = 80×9.807 = **784.6 N**

Denver: (z = 1610 m): W = 80×(9.807-3.32x10^{-6}×1610) = 80×9.802 = **784.2 N**

Mt. Ev.: (z = 8848 m): W = 80×(9.807-3.32x10^{-6}×8848) = 80×9.778 = **782.2 N**

1-79 The mass of a substance is given. Its weight is to be determined in various units.

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

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

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

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

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

1-80 The pressure in a steam boiler is given in kgf/cm^2. It is to be expressed in psi, kPa, atm, and bars.

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

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

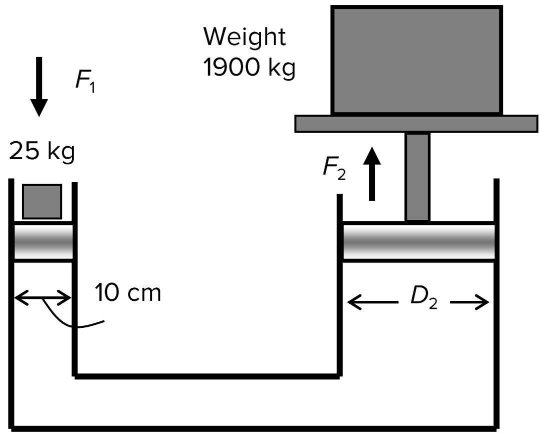
In kPa: $$P = (92\text{ kgf/cm}^2)\left(\frac{1\text{ atm}}{1.03323\text{ kgf/cm}^2}\right)\left(\frac{101.325\text{ kPa}}{1\text{ atm}}\right) = \mathbf{9022\,kPa}$$

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

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

1-81 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

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

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

1-82 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 - 0.02256×0.306)$^{5.256}$ = **97.7 kPa**

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

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

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

1-83 The boiling temperature of water decreases by 3°C for each 1000 m rise in altitude. This decrease 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 decrease in the boiling temperature is

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

(*b*), (*c*) 3×1.8 = **5.4°F = 5.4 R** for each 1000 m rise in altitude.

1-84 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.

1-85 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**

1-86 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.

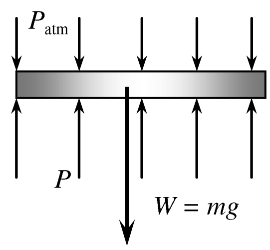
Analysis Using the relation given, the average temperature of the atmosphere at an altitude of 12,000 m is determined to be

$$T_{atm} = 288.15 - 6.5z$$
$$= 288.15 - 6.5 \times 12$$
$$= \mathbf{210.15\ K = -\ 63°C}$$

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

1-87 The pressure of a gas contained in a vertical piston-cylinder device is measured to be 180 kPa. The mass of the piston is to be determined.

Assumptions There is no friction between the piston and the cylinder.



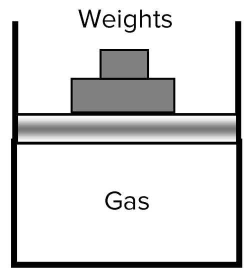
Analysis Drawing the free body diagram of the piston and balancing the vertical forces yield

$$W = PA - P_{atm}A$$
$$mg = (P - P_{atm})A$$
$$(m)(9.81\ \text{m/s}^2) = (180 - 100\ \text{kPa})(25 \times 10^{-4}\text{m}^2)\left(\frac{1000\ \text{kg/m}\cdot\text{s}^2}{1\ \text{kPa}}\right)$$

It yields

$$m = \mathbf{20.4\ kg}$$

1-88 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

$$P_{\text{atm}} = P - \frac{m_{\text{piston}}g}{A} = 100 \text{ kPa} - \frac{(10 \text{ kg})(9.81 \text{ m/s}^2)}{\pi(0.12 \text{ m}^2)/4}\left(\frac{1 \text{ kN}}{1000 \text{ kg}\cdot\text{m/s}^2}\right)$$
$$= 93.63 \text{ kN/m}^2 \cong \mathbf{93.6\,kPa}$$

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

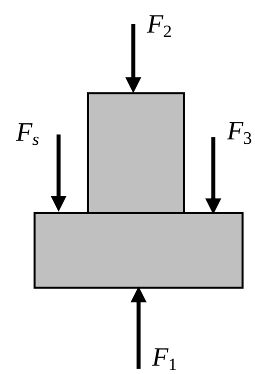
$$P = P_{\text{atm}} + \frac{(m_{\text{piston}} + m_{\text{weights}})g}{A}$$

$$200 \text{ kPa} = 93.63 \text{ kPa} + \frac{(10 \text{ kg} + m_{\text{weights}})(9.81 \text{ m/s}^2)}{\pi(0.12 \text{ m}^2)/4}\left(\frac{1 \text{ kN}}{1000 \text{ kg}\cdot\text{m/s}^2}\right) \longrightarrow m_{\text{weights}} = \mathbf{157\,kg}$$

A large mass is needed to double the pressure.

1-89 The deflection of the spring of the two-piston cylinder with a spring shown in the figure is to be determined.

Analysis Summing the forces acting on the piston in the vertical direction gives



$$F_s + F_2 + F_3 = F_1$$
$$kx + P_2A_2 + P_3(A_1 - A_2) = P_1A_1$$

which when solved for the deflection of the spring and substituting $A = \pi D^2/4$ gives

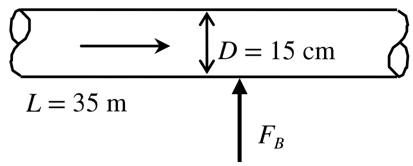
$$x = \frac{\pi}{4k}\left[P_1D_1^2 - P_2D_2^2 - P_3(D_1^2 - D_2^2)\right]$$
$$= \frac{\pi}{4\times 800}\left[5000\times 0.08^2 - 10{,}000\times 0.03^2 - 1000(0.08^2 - 0.03^2)\right]$$
$$= 0.0172 \text{ m}$$
$$= \mathbf{1.72\,cm}$$

We expressed the spring constant k in kN/m, the pressures in kPa (i.e., kN/m^2) and the diameters in m units.

1-90 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 ρ = 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

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

Discussion The upward force exerted by water on the duct is 6.07 kN, which is equivalent to the weight of a mass of 619 kg. Therefore, this force must be treated seriously.

1-91 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 ρ = 1.16 kg/m³. The density of helium gas is 1/7th of this.

Analysis The buoyancy force acting on the balloon is

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

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

m = 170 kg

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

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

1-92 Problem 1-91 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