Chapter 2
BASIC CONCEPTS OF THERMODYNAMICS

Systems and Properties

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

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

2-3C Intensive properties do not depend on the size (extent) of the system but extensive properties do.

State, Process, Forms of Energy

2-4C In electric heaters, electrical energy is converted to sensible internal energy.

2-5C The forms of energy involved are electrical energy and sensible internal energy. Electrical energy is converted to sensible internal energy, which is transferred to the water as heat.

2-6C The *macroscopic* forms of energy are those a system possesses as a whole with respect to some outside reference frame. The *microscopic* forms of energy, on the other hand, are those related to the molecular structure of a system and the degree of the molecular activity, and are independent of outside reference frames.

2-7C The sum of all forms of the energy a system possesses is called *total energy*. In the absence of magnetic, electrical and surface tension effects, the total energy of a system consists of the kinetic, potential, and internal energies.

2-8C The internal energy of a system is made up of sensible, latent, chemical and nuclear energies. The sensible internal energy is due to translational, rotational, and vibrational effects.

2-9C Thermal energy is the sensible and latent forms of internal energy, and it is referred to as heat in daily life.

2-10C For a system to be in thermodynamic equilibrium, the temperature has to be the same throughout but the pressure does not. However, there should be no unbalanced pressure forces present. The increasing pressure with depth in a fluid, for example, should be balanced by increasing weight.

2-11C 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.

2-12C 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.

2-13C The state of a simple compressible system is completely specified by two independent, intensive properties.

2-14C Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

2-15C A process is said to be steady-flow if it involves no changes with time anywhere within the system or at the system boundaries.

2-16 A 1000-MW power plant is powered by nuclear fuel. The amount of nuclear fuel consumed per year is to be determined

Assumptions **1** The power plant operates continuously. **2** The conversion efficiency of the power plant remains constant. **3** The nuclear fuel is uranium. **4** The uranium undergoes complete fission in the plant (this is not the case in practice).

Properties The complete fission of 1 kg of uranium-235 releases 6.73×10^{10} kJ/kg of heat (given in text).

Analysis Noting that the conversion efficiency is 30%, the amount of energy consumed by the power plant is

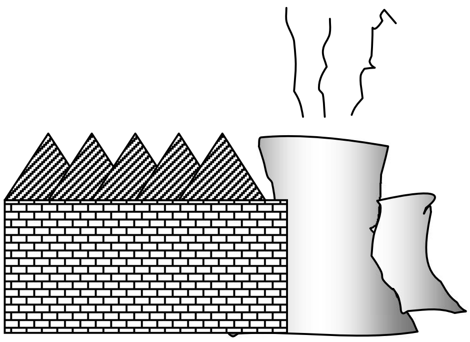
$$\begin{aligned}\text{Energy consumption rate} &= \text{Power production/Efficiency}\\ &= (1000\ \text{MW})/0.3 = 3333\ \text{MW} = 3.333\times10^{6}\ \text{kJ/s}\end{aligned}$$

$$\begin{aligned}\text{Annual energy consumption} &= (\text{Energy consumtion rate})(1\ \text{year})\\ &= (3.333\times10^{6}\ \text{kJ/s})(365\times24\times3600\ \text{s/year})\\ &= 1.051\times10^{14}\ \text{kJ/year}\end{aligned}$$

Noting that the complete fission of uranium-235 releases 6.73×10^{10} kJ/kg of heat, the amount of uranium that needs to be supplied to the power plant per year is

$$\begin{aligned}\text{Annual fuel consumption} &= \frac{\text{Annual energy consumption}}{\text{Heating value of fuel}} = \frac{1.051\times10^{14}\ \text{kJ/year}}{6.73\times10^{10}\ \text{kJ/kg}}\\ &= \mathbf{1562\ kg/year}\end{aligned}$$

Therefore, this power plant will consume about one and a half tons of nuclear fuel per year.



2-17 A 1000-MW power plant is powered by burning coal. The amount of coal consumed per year is to be determined

Assumptions **1** The power plant operates continuously. **2** The conversion efficiency of the power plant remains constant.

Properties The heating value of the coal is given to be 28,000 kJ/kg.

Analysis Noting that the conversion efficiency is 30%, the amount of chemical energy consumed by the power plant is

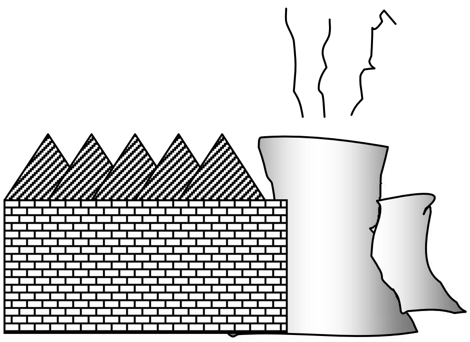
$$\begin{aligned}\text{Energy consumption rate} &= \text{Power production/Efficiency}\\ &= (1000\,\text{MW})/0.3 = 3333\,\text{MW} = 3.333\times10^{6}\ \text{kJ/s}\end{aligned}$$

$$\begin{aligned}\text{Annual energy consumption} &= (\text{ Energy consumtion rate})(1\,\text{year})\\ &= (3.333\times10^{6}\ \text{kJ/s})(365\times24\times3600\,\text{s/year})\\ &= 1.051\times10^{14}\ \text{kJ/year}\end{aligned}$$

Noting that the heating value of the coal is 28,000 kJ/kg, the amount of coal that needs to be supplied to the power plant per year is

$$\begin{aligned}\text{Annual fuel consumption} &= \frac{\text{Annual energy consumption}}{\text{Heating value of fuel}} = \frac{1.051\times10^{14}\ \text{kJ/year}}{28{,}000\,\text{kJ/kg}}\\ &= 3.754\times10^{9}\ \text{kg/year}\\ &= \mathbf{3{,}754{,}000\,tons/year}\end{aligned}$$

Therefore, this power plant will consume almost 4 millions tons of coal per year.



Energy and Environment

2-18C Energy conversion pollutes the soil, the water, and the air, and the environmental pollution is a serious threat to vegetation, wild life, and human health. The emissions emitted during the combustion of fossil fuels are responsible for smog, acid rain, and global warming and climate change. The primary chemicals that pollute the air are hydrocarbons (HC, also referred to as volatile organic compounds, VOC), nitrogen oxides (NOx), and carbon monoxide (CO). The primary source of these pollutants is the motor vehicles.

2-19C Smog is the brown haze that builds up in a large stagnant air mass, and hangs over populated areas on calm hot summer days. Smog is made up mostly of ground-level ozone (O_3), but it also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOC) such as benzene, butane, and other hydrocarbons. Ground-level ozone is formed when hydrocarbons and nitrogen oxides react in the presence of sunlight in hot calm days. Ozone irritates eyes and damage the air sacs in the lungs where oxygen and carbon dioxide are exchanged, causing eventual hardening of this soft and spongy tissue. It also causes shortness of breath, wheezing, fatigue, headaches, nausea, and aggravate respiratory problems such as asthma.

2-20C Fossil fuels include small amounts of sulfur. The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2), which is an air pollutant. The sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight to form sulfuric and nitric acids. The acids formed usually dissolve in the suspended water droplets in clouds or fog. These acid-laden droplets are washed from the air on to the soil by rain or snow. This is known as *acid rain*. It is called “rain” since it comes down with rain droplets.

As a result of acid rain, many lakes and rivers in industrial areas have become too acidic for fish to grow. Forests in those areas also experience a slow death due to absorbing the acids through their leaves, needles, and roots. Even marble structures deteriorate due to acid rain.

2-21C Carbon dioxide (CO_2), water vapor, and trace amounts of some other gases such as methane and nitrogen oxides act like a blanket and keep the earth warm at night by blocking the heat radiated from the earth. This is known as the *greenhouse effect*. The greenhouse effect makes life on earth possible by keeping the earth warm. But excessive amounts of these gases disturb the delicate balance by trapping too much energy, which causes the average temperature of the earth to rise and the climate at some localities to change. These undesirable consequences of the greenhouse effect are referred to as *global warming* or *global climate change*. The greenhouse effect can be reduced by reducing the net production of CO_2 by consuming less energy (for example, by buying energy efficient cars and appliances) and planting trees.

2-22C Carbon monoxide, which is a colorless, odorless, poisonous gas that deprives the body's organs from getting enough oxygen by binding with the red blood cells that would otherwise carry oxygen. At low levels, carbon monoxide decreases the amount of oxygen supplied to the brain and other organs and muscles, slows body reactions and reflexes, and impairs judgment. It poses a serious threat to people with heart disease because of the fragile condition of the circulatory system and to fetuses because of the oxygen needs of the developing brain. At high levels, it can be fatal, as evidenced by numerous deaths caused by cars that are warmed up in closed garages or by exhaust gases leaking into the cars.

2-23E A person trades in his Ford Taurus for a Ford Explorer. The extra amount of CO_2 emitted by the Explorer within 5 years is to be determined.

Assumptions The Explorer is assumed to use 940 gallons of gasoline a year compared to 715 gallons for Taurus.

Analysis The extra amount of gasoline the Explorer will use within 5 years is

Extra Gasoline = (Extra per year)(No. of years)
= (940 – 715 gal/yr)(5 yr)
= 1125 gal

Extra CO_2 produced = (Extra gallons of gasoline used)(CO_2 emission per gallon)
= (1125 gal)(19.7 lbm/gal)
= **22,163 lbm CO_2**

Discussion Note that the car we choose to drive has a significant effect on the amount of greenhouse gases produced.

2-24 A power plant that burns natural gas produces 0.59 kg of carbon dioxide (CO_2) per kWh. The amount of CO_2 production that is due to the refrigerators in a city is to be determined.

Assumptions The city uses electricity produced by a natural gas power plant.

Properties 0.59 kg of CO_2 is produced per kWh of electricity generated (given).

Analysis Noting that there are 200,000 households in the city and each household consumes 700 kWh of electricity for refrigeration, the total amount of CO_2 produced is

$$\begin{aligned}\text{Amount of CO}_2\text{ produced} &= (\text{Amount of electricity consumed})(\text{Amount of CO}_2\text{ per kWh})\\ &= (200{,}000\text{ household})(700\text{ kWh/household})(0.59\text{ kg/kWh})\\ &= 8.26\times10^7\ \text{CO}_2\text{ kg/year}\\ &= \mathbf{82{,}600\ CO_2\ ton/year}\end{aligned}$$

Therefore, the refrigerators in this city are responsible for the production of 82,600 tons of CO_2.

2-25 A power plant that burns coal, produces 1.1 kg of carbon dioxide (CO_2) per kWh. The amount of CO_2 production that is due to the refrigerators in a city is to be determined.

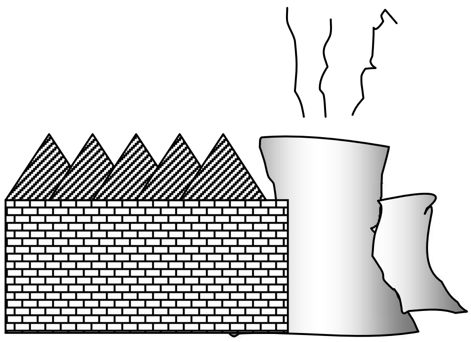
Assumptions The city uses electricity produced by a coal power plant.

Properties 1.1 kg of CO_2 is produced per kWh of electricity generated (given).

Analysis Noting that there are 200,000 households in the city and each household consumes 700 kWh of electricity for refrigeration, the total amount of CO_2 produced is

$$\begin{aligned}\text{Amount of CO}_2\text{ produced} &= (\text{Amount of electricity consumed})(\text{Amount of CO}_2\text{ per kWh})\\ &= (200{,}000\text{ household})(700\text{ kWh/household})(1.1\text{kg/kWh})\\ &= 15.4\times10^7\ \text{CO}_2\text{ kg/year}\\ &= \mathbf{154{,}000\ CO_2\ ton/year}\end{aligned}$$

Therefore, the refrigerators in this city are responsible for the production of 154,000 tons of CO_2.



2-26E A household uses fuel oil for heating, and electricity for other energy needs. Now the household reduces its energy use by 20%. The reduction in the CO_2 production this household is responsible for is to be determined.

Properties The amount of CO_2 produced is 1.54 lbm per kWh and 26.4 lbm per gallon of fuel oil (given).

Analysis Noting that this household consumes 8000 kWh of electricity and 1500 gallons of fuel oil per year, the amount of CO_2 production this household is responsible for is

$$
\begin{aligned}
\text{Amount of } CO_2 \text{ produced} &= (\text{Amount of electricity consumed})(\text{Amount of } CO_2 \text{ per kWh}) \\
&\quad + (\text{Amount of fuel oil consumed})(\text{Amount of } CO_2 \text{ per gallon}) \\
&= (8000\,\text{kWh/yr})(1.54\,\text{lbm/kWh}) + (1500\,\text{gal/yr})(26.4\ \text{lbm/gal}) \\
&= 51{,}920\ CO_2\ \text{lbm/year}
\end{aligned}
$$

Then reducing the electricity and fuel oil usage by 20% will reduce the annual amount of CO_2 production by this household by

$$
\begin{aligned}
\text{Reduction in } CO_2 \text{ produced} &= (0.20)(\text{Current amount of } CO_2 \text{ production}) \\
&= (0.20)(51{,}920\ CO_2\ \text{kg/year}) \\
&= \mathbf{10{,}384\ CO_2\ lbm/year}
\end{aligned}
$$

Therefore, any measure that saves energy also reduces the amount of pollution emitted to the environment.

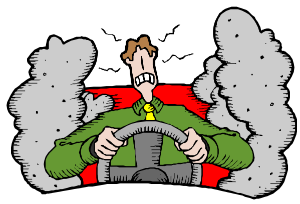
2-27 A household has 2 cars, a natural gas furnace for heating, and uses electricity for other energy needs. The annual amount of NO_x emission to the atmosphere this household is responsible for is to be determined.

Properties The amount of NO_x produced is 7.1 g per kWh, 4.3 g per therm of natural gas, and 11 kg per car (given).

Analysis Noting that this household has 2 cars, consumes 1200 therms of natural gas, and 9,000 kWh of electricity per year, the amount of NO_x production this household is responsible for is

$$
\begin{aligned}
\text{Amount of } NO_x \text{ produced} &= (\text{No. of cars})(\text{Amount of } NO_x \text{ produced per car}) \\
&\quad + (\text{Amount of electricity consumed})(\text{Amount of } NO_x \text{ per kWh}) \\
&\quad + (\text{Amount of gas consumed})(\text{Amount of } NO_x \text{ per gallon}) \\
&= (2\text{ cars})(11\,\text{kg/car}) + (9000\,\text{kWh/yr})(0.0071\,\text{kg/kWh}) \\
&\qquad + (1200\,\text{therms/yr})(0.0043\,\text{kg/therm}) \\
&= \mathbf{91.06\ NO_x\ kg/year}
\end{aligned}
$$

Discussion Any measure that saves energy will also reduce the amount of pollution emitted to the atmosphere.



Temperature

2-28C The zeroth law of thermodynamics states that two bodies are in thermal equilibrium if both have the same temperature reading, even if they are not in contact.

2-29C They are Celsius(°C) and Kelvin (K) in the SI, and Fahrenheit (°F) and Rankine (R) in the English system.

2-30C 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.

2-31 A temperature is given in °C. It is to be expressed in K.

Analysis The Kelvin scale is related to Celsius scale by

$$T(\mathrm{K}) = T(°\mathrm{C}) + 273$$

Thus,

$$T(\mathrm{K}) = 37°\mathrm{C} + 273 = \mathbf{310\ K}$$

2-32E 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,

$$T(\mathrm{K}) = T(°\mathrm{C}) + 273 = 18°\mathrm{C} + 273 = \mathbf{291\ K}$$
$$T(°\mathrm{F}) = 1.8T(°\mathrm{C}) + 32 = (1.8)(18) + 32 = \mathbf{64.4°F}$$
$$T(\mathrm{R}) = T(°\mathrm{F}) + 460 = 64.4 + 460 = \mathbf{524.4\ R}$$

2-33 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,

$$\Delta T(\mathrm{K}) = \Delta T(°\mathrm{C}) = \mathbf{15\ K}$$

2-34E A temperature change is given in °F. It is to be expressed in °C, K, and R.

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

$$\Delta T(\mathrm{R}) = \Delta T(°\mathrm{F}) = \mathbf{27\ R}$$

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

$$\Delta T(\mathrm{K}) = \Delta T(\mathrm{R})/1.8 = 27/1.8 = \mathbf{15\ K}$$

and

$$\Delta T(°\mathrm{C}) = \Delta T(\mathrm{K}) = \mathbf{15°C}$$

2-35 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.

Pressure, Manometer, and Barometer

2-36C The pressure relative to the atmospheric pressure is called the *gage pressure*, and the pressure relative to an absolute vacuum is called *absolute pressure*.

2-37C The atmospheric air 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.

2-38C 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.

2-39C If the lengths of the sides of the tiny cube suspended in water by a string are very small, the magnitudes of the pressures on all sides of the cube will be the same.

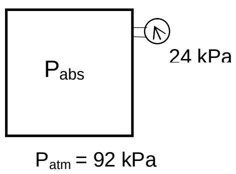
2-40C *Pascal's principle* states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction. An example of Pascal's principle is the operation of the hydraulic car jack.

2-41C 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.

2-42 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

$$P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}} = 92 - 24 = \mathbf{68\ kPa}$$



2-43E The pressure in a tank is measured with a manometer by measuring the differential height of the manometer fluid. The absolute pressure in the tank is to be determined for the cases of the manometer arm with the higher and lower fluid level being attached to the tank .

Assumptions The fluid in the manometer is incompressible.

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

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

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

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

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

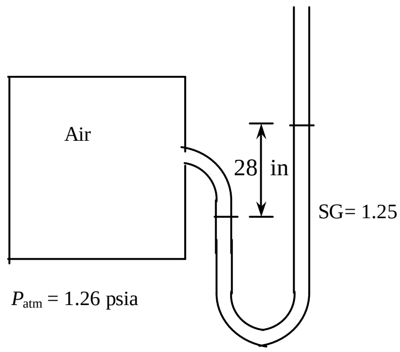
Then the absolute pressures in the tank for the two cases become:

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

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

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

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



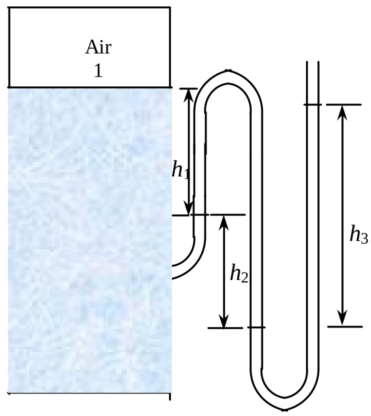
Discussion Note that we can determine whether the pressure in a tank is above or below atmospheric pressure by simply observing the side of the manometer arm with the higher fluid level.

2-44 The pressure in a pressurized water tank is measured by a multi-fluid manometer. The gage pressure of air in the tank is to be determined.

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

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

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



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

Solving for P_1,

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

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,

$$P_{1,gage} = (9.81\,\text{m/s}^2)[(13{,}600\,\text{kg/m}^3)(0.46\,\text{m}) - (1000\,\text{kg/m}^3)(0.2\,\text{m})$$

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

$$= \mathbf{56.9\,kPa}$$

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.

2-45 The barometric reading at a location is given in height of mercury column. The atmospheric pressure is to be determined.

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

Analysis The atmospheric pressure is determined directly from

$$P_{atm} = \rho gh$$

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

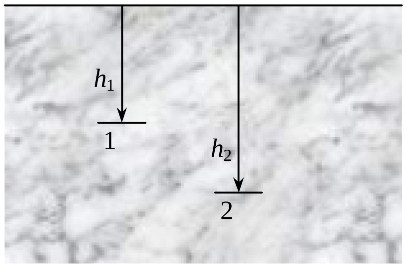
$$= 100.1\,\mathbf{kPa}$$

2-46 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

$$P_2 = \frac{h_2}{h_1} P_1 = \frac{12 \text{ m}}{3 \text{ m}} (28 \text{ kPa}) = \mathbf{112 \ kPa}$$

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

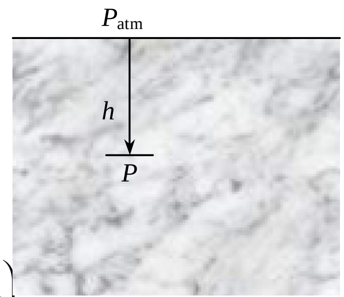
2-47 The absolute pressure in water at a specified depth is given. The local atmospheric pressure and the absolute pressure at the same depth in a different liquid are to be determined.

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



$$\begin{aligned} P_{atm} &= P - \rho g h \\ &= (145 \text{ kPa}) - (1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(5 \text{ m})\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) \\ &= \mathbf{96.0 \ kPa} \end{aligned}$$

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

$$\begin{aligned} P &= P_{atm} + \rho g h \\ &= (96.0 \text{ kPa}) + (850 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(5 \text{ m})\left(\frac{1 \text{kPa}}{1000 \text{N/m}^2}\right) \\ &= \mathbf{137.7 \ kPa} \end{aligned}$$

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

2-48E It is to be shown that 1 kgf/cm^2 = 14.223 psi .

Analysis Noting that 1 kgf = 9.80665 N, 1 N = 0.22481 lbf, and 1 in = 2.54 cm, we have

$$1\text{ kgf} = 9.80665\text{ N} = (9.80665\text{ N})\left(\frac{0.22481\text{ lbf}}{1\text{ N}}\right) = 2.20463\text{ lbf}$$

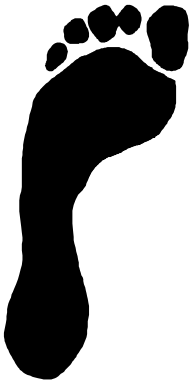
and

$$1\text{ kgf/cm}^2 = 2.20463\text{lbf/cm}^2 = (2.20463\text{lbf/cm}^2)\left(\frac{2.54\text{ cm}}{1\text{ in}}\right)^2 = 14.223\text{ lbf/in}^2 = \mathbf{14.223\,psi}$$

2-49E 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 one foot: $$P = \frac{W}{A} = \frac{200\text{ lbf}}{36\text{ in}^2} = 5.56\text{ lbf/in}^2 = \mathbf{5.56\,psi}$$

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

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

2-50 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.

2-51 The vacuum pressure reading of a tank is given. The absolute pressure in the tank is to be determined.

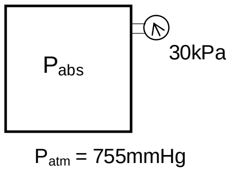
Properties The density of mercury is given to be ρ = 13,590 kg/m^3.

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

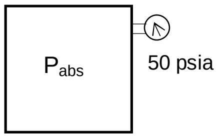
$$\begin{aligned} P_{atm} &= \rho g h \\ &= (13{,}590\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.755\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= 100.6\ \text{kPa} \end{aligned}$$

Then the absolute pressure in the tank becomes

$$P_{abs} = P_{atm} - P_{vac} = 100.6 - 30 = \mathbf{70.6\ \ kPa}$$



2-52E A pressure gage connected to a tank reads 50 psi. The absolute pressure in the tank is to be determined.



Properties The density of mercury is given to be ρ = 848.4 lbm/ft^3.

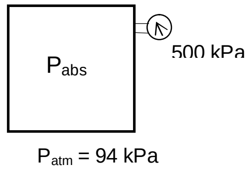
Analysis The atmospheric (or barometric) pressure can be expressed as

$$\begin{aligned} P_{atm} &= \rho g h \\ &= (848.4 \text{lbm/ft}^3)(32.174 \text{ft/s}^2)(29.1/12 \text{ft})\left(\frac{1 \text{lbf}}{32.174 \text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1 \text{ft}^2}{144 \text{in}^2}\right) \\ &= 14.29 \text{psia} \end{aligned}$$

Then the absolute pressure in the tank is

$$P_{abs} = P_{gage} + P_{atm} = 50 + 14.29 = \mathbf{64.29\ psia}$$

2-53 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

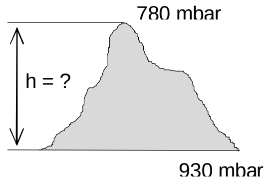
$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} = 500 + 94 = \mathbf{594\,kPa}$$

2-54 A mountain hiker records the barometric reading before and after a hiking trip. The vertical distance climbed is to be determined.

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

Properties The density of air is given to be ρ = 1.20 kg/m^3.

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



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

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

$$(1.20\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(h)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{bar}}{100{,}000\ \text{N/m}^2}\right) = (0.930 - 0.780)\ \text{bar}$$

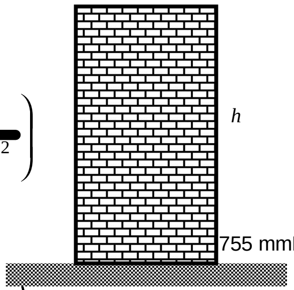
It yields h = **1274 m**

which is also the distance climbed.

2-55 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/m³. The density of mercury is 13,600 kg/m³.



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

$$\begin{aligned} P_{\text{top}} &= (\rho g h)_{\text{top}} \\ &= (13{,}600\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.730\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= 97.36\ \text{kPa} \end{aligned}$$

$$\begin{aligned} P_{\text{bottom}} &= (\rho g h)_{\text{bottom}} \\ &= (13{,}600\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.755\ \text{m})\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= 100.70\ \text{kPa} \end{aligned}$$

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

$$W_{\text{air}} / A = P_{\text{bottom}} - P_{\text{top}}$$
$$(\rho g h)_{\text{air}} = P_{\text{bottom}} - P_{\text{top}}$$
$$(1.18\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(h)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) = (100.70 - 97.36)\ \text{kPa}$$

It yields h = **288.6 m**

which is also the height of the building.

2-56 Problem 2-55 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.".

```
P_bottom=755"[mmHg]"
P_top=730"[mmHg]"
g=9.807    "[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/1000 "[kPa]"         "Equ. 1-16. Delta P due to the air fluid column height, h, between the top and bottom of the building."
"Instead of dividing by 1000 Pa/kPa we could have multiplied rho*g*h by the EES function, CONVERT('Pa','kPa')"
DELTAP_abs=DELTAP_h
```

SOLUTION

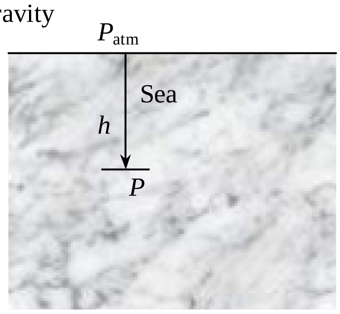
```
Variables in Main
DELTAP_abs=3.333 [kPa]
DELTAP_h=3.333 [kPa]
g=9.807 [m/s^2]
h=288 [m]
P_bottom=755 [mmHg]
P_top=730 [mmHg]
rho=1.18 [kg/m^3]
```

2-57 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 sea water is given to be SG = 1.03. We take the density of water to be 1000 kg/m^3.

Analysis The density of the sea water is obtained by multiplying its specific gravity by the density of water which is taken to be 1000 kg/m^3:



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

The pressure exerted on a diver at 30 m below the free surface of the sea is the absolute pressure at that location:

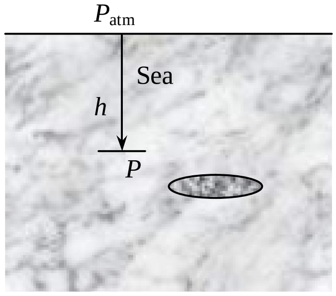
$$\begin{aligned} P &= P_{atm} + \rho g h \\ &= (101\text{kPa}) + (1030\text{kg/m}^3)(9.807\text{m/s}^2)(30\text{m})\left(\frac{1\text{kPa}}{1000\text{N/m}^2}\right) \\ &= \mathbf{404.0\ kPa} \end{aligned}$$

2-58E 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 sea water 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 sea water 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:

$$\begin{aligned} P &= P_{atm} + \rho g h \\ &= (14.7\,\text{psia}) + (64.27\,\text{lbm/ft}^3)(32.174\,\text{ft/s}^2)(300\,\text{ft})\left(\frac{1\,\text{lbf}}{32.174\,\text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\,\text{ft}^2}{144\,\text{in}^2}\right) \\ &= \mathbf{148.6\,psia} \end{aligned}$$

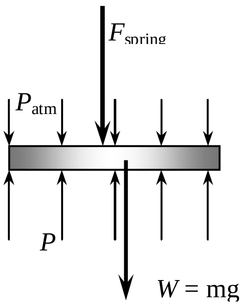
2-59 A gas contained in a vertical piston-cylinder device is pressurized by a spring and by the weight of the piston. The pressure of the gas is to be determined.

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

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

Thus,

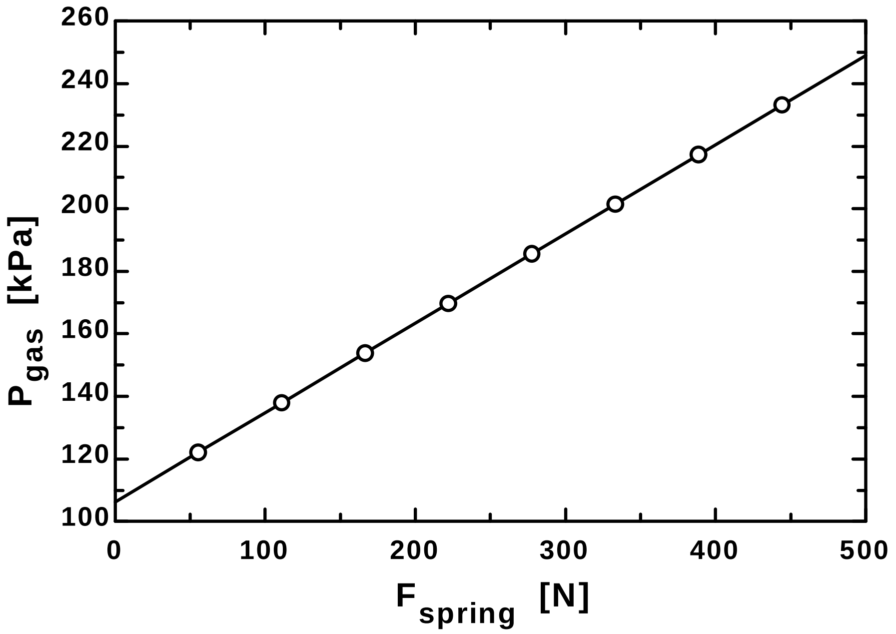
$$\begin{aligned} P &= P_{\text{atm}} + \frac{mg + F_{\text{spring}}}{A} \\ &= (95\ \text{kPa}) + \frac{(4\ \text{kg})(9.807\ \text{m/s}^2) + 60\ \text{N}}{35\times10^{-4}\,\text{m}^2}\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\ &= \mathbf{123.4\,kPa} \end{aligned}$$



2-60 Problem 2-59 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.

```
g=9.807"[m/s^2]"
P_atm= 95"[kPa]"
m_piston=4"[kg]"
{F_spring=60"[N]"}
A=35*CONVERT('cm^2','m^2')"[m^2]"
W_piston=m_piston*g"[N]"
F_atm=P_atm*A*CONVERT('kPa','N/m^2')"[N]"
"From the free body diagram of the piston, the balancing vertical forces yield:"
F_gas= F_atm+F_spring+W_piston"[N]"
P_gas=F_gas/A*CONVERT('N/m^2','kPa')"[kPa]"
```

F_{spring} [N]	P_{gas} [kPa]
0	106.2
55.56	122.1
111.1	138
166.7	153.8
222.2	169.7
277.8	185.6
333.3	201.4
388.9	217.3
444.4	233.2
500	249.1

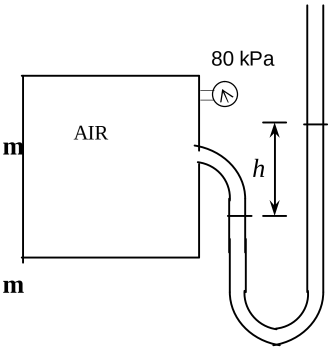


2-61 [*Also solved by EES on enclosed CD***]** Both a gage and a manometer are attached to a gas to measure its pressure. For a specified reading of gage pressure, the difference between the fluid levels of the two arms of the manometer is to be determined for mercury and water.

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

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



(*a*) For mercury,

$$h = \frac{P_{\text{gage}}}{\rho_{Hg}\, g} = \frac{80 \text{ kPa}}{(13600 \text{ kg/m}^3)(9.807 \text{ m/s}^2)}\left(\frac{1 \text{ kN/m}^2}{1 \text{ kPa}}\right)\left(\frac{1000 \text{ kg/m}\cdot\text{s}^2}{1 \text{ kN}}\right) = \mathbf{0.60\ m}$$

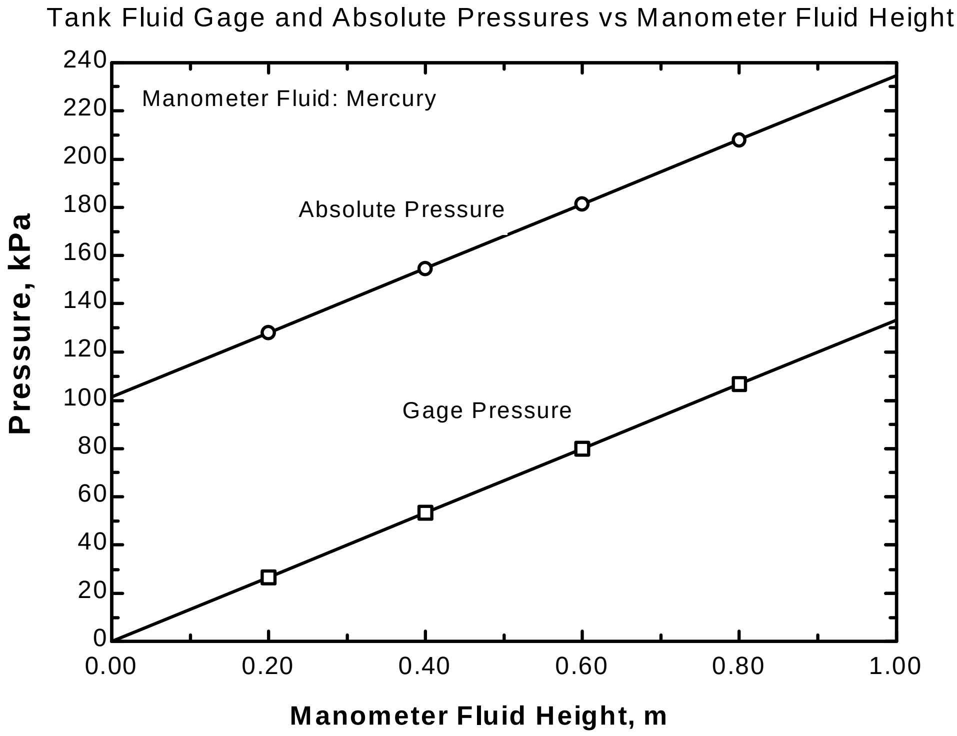
(*b*) For water,

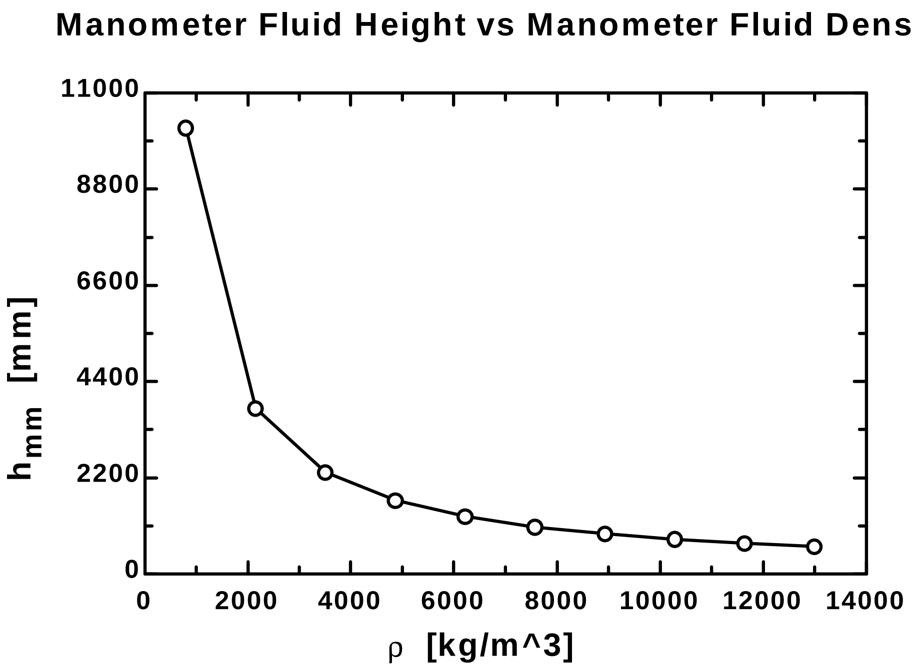
$$h = \frac{P_{\text{gage}}}{\rho_{H_2O}\, g} = \frac{80 \text{ kPa}}{(1000 \text{ kg/m}^3)(9.807 \text{m/s}^2)}\left(\frac{1 \text{ kN/m}^2}{1 \text{ kPa}}\right)\left(\frac{1000 \text{ kg/m}\cdot\text{s}^2}{1 \text{ kN}}\right) = \mathbf{8.16\ m}$$

2-62 Problem 2-61 is reconsidered. The effect of the manometer fluid density in the range of 800 to 13,000 kg/m3 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.

```
Function fluid_density(Fluid$)
    If fluid$='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/s2, 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 dividing 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."
```

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


Tank Fluid Gage and Absolute Pressures vs Manometer Fluid Height
Manometer Fluid: Mercury
Absolute Pressure
Gage Pressure
Pressure, kPa
240
220
200
180
160
140
120
100
80
60
40
20
0
0.00
0.20
0.40
0.60
0.80
1.00
Manometer Fluid Height, m

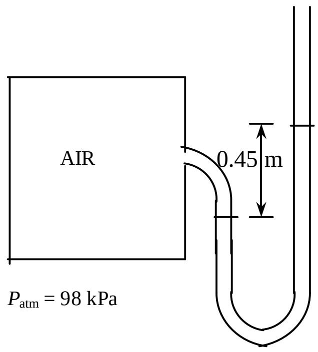

Manometer Fluid Height vs Manometer Fluid Density
h_{mm} [mm]
11000
8800
6600
4400
2200
0
0
2000
4000
6000
8000
10000
12000
14000
ρ [kg/m^3]

2-63 The air pressure in a tank is measured by an oil manometer. For a given oil-level difference between the two columns, the absolute pressure in the tank is to be determined.

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

Analysis The absolute pressure in the tank is determined from

$$P = P_{atm} + \rho g h$$
$$= (98\text{kPa}) + (850\text{kg/m}^3)(9.807\text{m/s}^2)(0.45\text{m})\left(\frac{1\text{kPa}}{1000\text{N/m}^2}\right)$$
$$= \mathbf{101.75kPa}$$



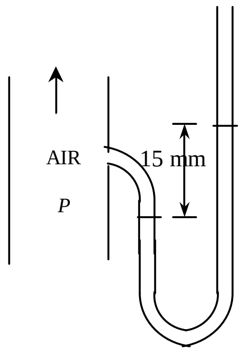
2-64 The air pressure in a duct is measured by a mercury manometer. For a given mercury-level difference between the two columns, the absolute pressure in the duct is to be determined.

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

$$P = P_{atm} + \rho g h$$
$$= (100 \text{ kPa}) + (13{,}600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.015 \text{ m})\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$
$$= \mathbf{102.0 \ \ kPa}$$



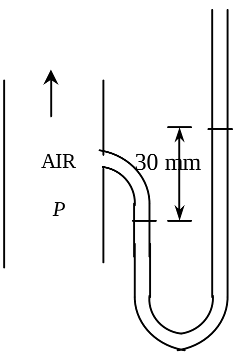
2-65 The air pressure in a duct is measured by a mercury manometer. For a given mercury-level difference between the two columns, the absolute pressure in the duct is to be determined.

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

$$P = P_{atm} + \rho g h$$
$$= (100 \text{ kPa}) + (13{,}600 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.030 \text{ m})\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$
$$= \mathbf{104.0 \ \ kPa}$$



2-66E 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,

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

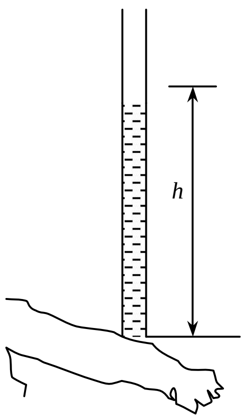
For a given pressure, the relation $P = \rho gh$ can be expressed for mercury and water as $P = \rho_{\text{water}}\, g h_{\text{water}}$ and $P = \rho_{\text{mercury}}\, g h_{\text{mercury}}$. Setting these two relations equal to each other and solving for water height gives

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

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.

2-67 A vertical tube open to the atmosphere is connected to the vein in the arm of a person. The height that the blood will rise in the tube is to be determined.

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

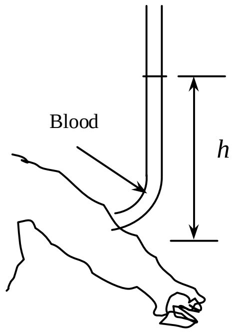
Properties The density of blood is given to be ρ = 1050 kg/m³.

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

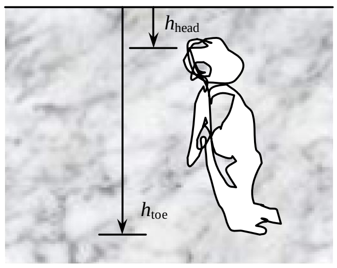
2-68 A man is standing in water vertically while being completely submerged. The difference between the pressures acting on the head and on the toes is to be determined.

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

Properties We take the density of water to be ρ =1000 kg/m³.

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

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



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

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

Substituting,

$$P_{\text{toe}} - P_{\text{head}} = (1000\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(1.80\ \text{m - 0})\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{kPa}}{1000\text{N/m}^2}\right) = \mathbf{17.7\ kPa}$$

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 1.8 m.

2-69 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, $h_a = 6h_{w2}$. Noting that both arms are open to the atmosphere, the pressure at the bottom of the U-tube can be expressed as

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

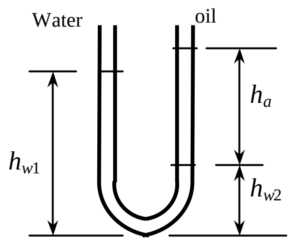
Setting them equal to each other and simplifying,

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

Noting that $h_a = 6h_{w2}$, the water and oil column heights in the second arm are determined to be

$$0.7\text{ m} = h_{w2} + (790/1000)6h_{w2} \quad \rightarrow \quad h_{w2} = \mathbf{0.122\,m}$$

$$0.7\text{ m} = 0.122\text{ m} + (790/1000)h_a \quad \rightarrow \quad h_a = \mathbf{0.732\,m}$$



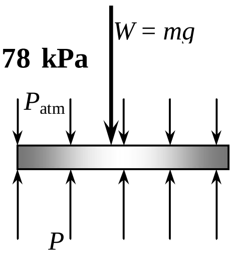
Discussion Note that the fluid height in the arm that contains oil is higher. This is expected since oil is lighter than water.

2-70 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,

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



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

2-71 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,

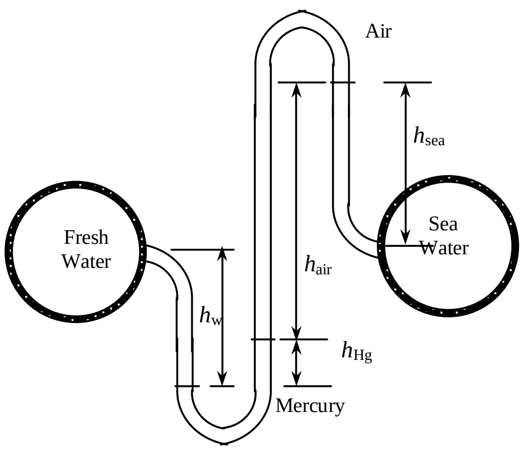
$$P_1 - P_2 = -\rho_w g h_w + \rho_{Hg} g h_{Hg} - \rho_{sea} g h_{sea} = g(\rho_{Hg} h_{Hg} - \rho_w h_w - \rho_{sea} h_{sea})$$

Substituting,

$$\begin{aligned} P_1 - P_2 &= (9.81\,\text{m/s}^2)[(13600\,\text{kg/m}^3)(0.1\,\text{m}) \\ &\quad - (1000\,\text{kg/m}^3)(0.6\,\text{m}) - (1035\,\text{kg/m}^3)(0.4\,\text{m})]\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) \\ &= 3.39\,\text{kN/m}^2 = \mathbf{3.39\,kPa} \end{aligned}$$

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.



2-72 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

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

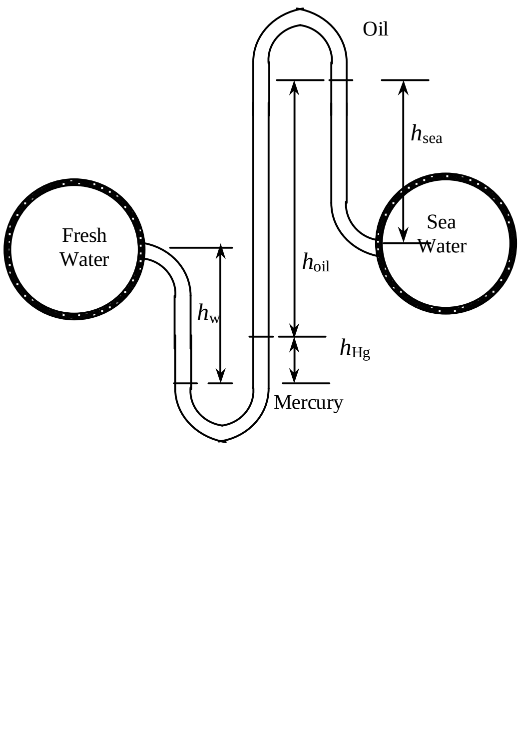
Rearranging,

$$\begin{aligned} P_1 - P_2 &= -\rho_w g h_w + \rho_{Hg} g h_{Hg} + \rho_{oil} g h_{oil} - \rho_{sea} g h_{sea} \\ &= g(\rho_{Hg} h_{Hg} + \rho_{oil} h_{oil} - \rho_w h_w - \rho_{sea} h_{sea}) \end{aligned}$$

Substituting,

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

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



2-73E The pressure in a natural gas pipeline is measured by a double U-tube manometer with one of the arms open to the atmosphere. The absolute pressure in the pipeline is to be determined.

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

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

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

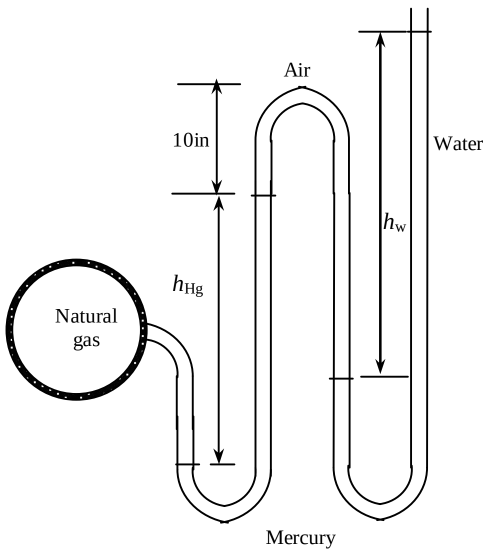
Solving for $P_{1,}$

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

Substituting,

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

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.



2-74E 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 $\rho_w = 62.4$ lbm/ft^3. The specific gravity of mercury is given to be 13.6, and thus its density is $\rho_{Hg} = 13.6\times62.4 = 848.6$ lbm/ft^3. The specific gravity of oil is given to be 0.69, and thus its density is $\rho_{oil} = 0.69\times62.4 = 43.1$ lbm/ft^3.

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

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

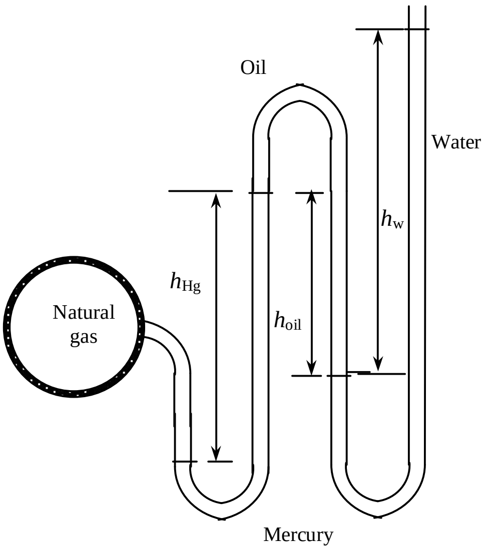
Solving for P_1,

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

Substituting,

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

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.

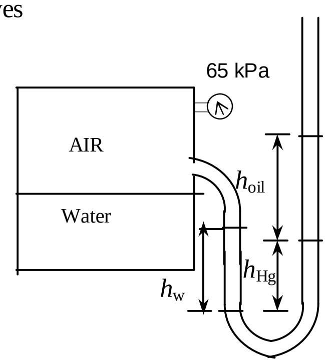


2-75 The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height *h* of the mercury column is to be determined.

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



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

Rearranging,

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

or,

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

Substituting,

$$\left(\frac{65\,\text{kPa}}{(1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)}\right)\left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\,\text{kPa.}\cdot\text{m}^2}\right) = 0.72\times(0.75\,\text{m}) + 13.6\times h_{Hg} - 0.3\,\text{m}$$

Solving for h_{Hg} gives h_{Hg} = **0.47 m**. Therefore, the differential height of the mercury column must be 47 cm.

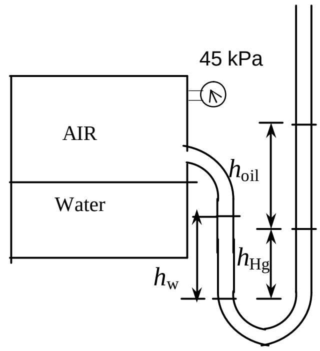
Discussion Double instrumentation like this allows one to verify the measurement of one of the instruments by the measurement of another instrument.

2-76 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



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

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,

$$\frac{45\,\text{kPa}}{(1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)}\left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\,\text{kPa.}\cdot\text{m}^2}\right) = 0.72\times(0.75\,\text{m}) + 13.6\times h_{Hg} - 0.3\,\text{m}$$

Solving for h_{Hg} gives h_{Hg} = **0.32 m**. Therefore, the differential height of the mercury column must be 32 cm.

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

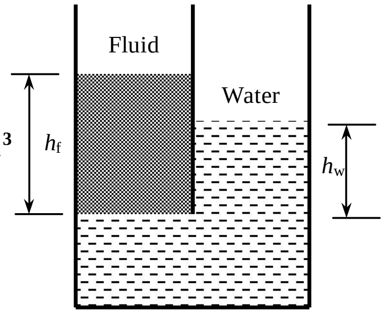
2-77 The top part of a water tank is divided into two compartments, and a fluid with an unknown density is poured into one side. The levels of the water and the liquid are measured. The density of the fluid is to be determined.

Assumptions **1** Both water and the added liquid are incompressible substances. **2** The added liquid does not mix with water.

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

Analysis Both fluids are open to the atmosphere. Noting that the pressure of both water and the added fluid is the same at the contact surface, the pressure at this surface can be expressed as

$$P_{\text{contact}} = P_{\text{atm}} + \rho_{\text{f}}\, g h_{\text{f}} = P_{\text{atm}} + \rho_{\text{w}}\, g h_{\text{w}}$$



Simplifying and solving for ρ_{f} gives

$$\rho_{\text{f}}\, g h_{\text{f}} = \rho_{\text{w}}\, g h_{\text{w}} \quad \rightarrow \quad \rho_f = \frac{h_w}{h_f}\rho_w = \frac{45\,\text{cm}}{80\,\text{cm}}(1000\,\text{kg/m}^3) = \mathbf{562.5\,kg/m^3}$$

Discussion Note that the added fluid is lighter than water as expected (a heavier fluid would sink in water).

2-78 A load on a hydraulic lift is to be raised by pouring oil from a thin tube. The height of oil in the tube required in order to raise that weight 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.

Properties The density of oil is given to be ρ =780 kg/m^3.

Analysis Noting that pressure is force per unit area, the gage pressure in the fluid under the load is simply the ratio of the weight to the area of the lift,

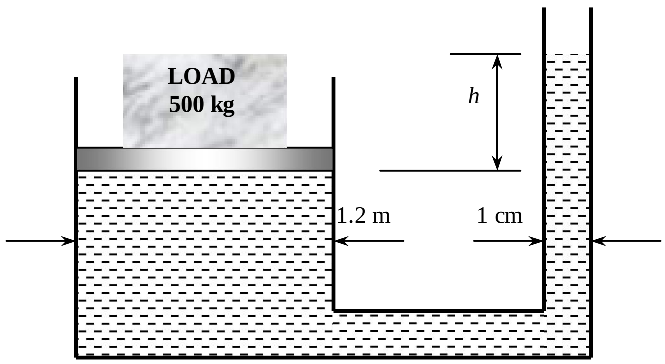
$$P_{\text{gage}} = \frac{W}{A} = \frac{mg}{\pi D^2/4} = \frac{(500\,\text{kg})(9.81\,\text{m/s}^2)}{\pi(1.20\,\text{m})^2/4}\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) = 4.34\,\text{kN/m}^2 = 4.34\,\text{kPa}$$

The required oil height that will cause 4.34 kPa of pressure rise is

$$P_{\text{gage}} = \rho g h \quad \rightarrow \quad h = \frac{P_{\text{gage}}}{\rho g} = \frac{4.34\,\text{kN/m}^2}{(780\,\text{kg/m}^3)(9.81\,\text{m/s}^2)}\left(\frac{1000\,\text{kg}\cdot\text{m/s}^2}{1\text{kN/m}^2}\right) = \mathbf{0.567\,m}$$

Therefore, a 500 kg load can be raised by this hydraulic lift by simply raising the oil level in the tube by 56.7 cm.

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



2-79E Two oil tanks are connected to each other through a mercury manometer. For a given differential height, the pressure difference between the two tanks is to be determined.

Assumptions **1** Both the oil and mercury are incompressible fluids. **2** The oils in both tanks have the same density.

Properties The densities of oil and mercury are given to be ρ_{oil} = 45 lbm/ft^3 and ρ_{Hg} = 848 lbm/ft^3.

Analysis Starting with the pressure at the bottom of tank 1 (where pressure is P_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 bottom of tank 2 (where pressure is P_2) gives

$$P_1 + \rho_{\text{oil}} g(h_1 + h_2) - \rho_{\text{Hg}} gh_2 - \rho_{\text{oil}} gh_1 = P_2$$

where h_1 = 10 in and h_2 = 32 in. Rearranging and simplifying,

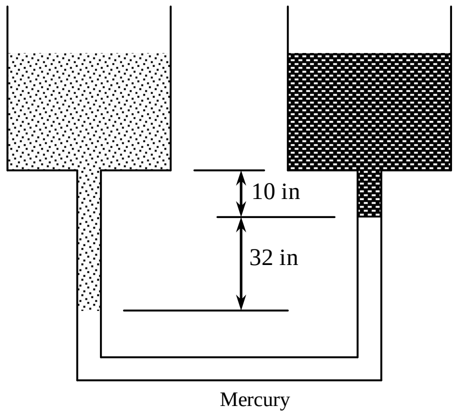
$$P_1 - P_2 = \rho_{\text{Hg}} gh_2 - \rho_{\text{oil}} gh_2 = (\rho_{\text{Hg}} - \rho_{\text{oil}}) gh_2$$

Substituting,

$$\Delta P = P_1 - P_2 = (848 - 45\ \text{lbm/ft}^3)(32.2\ \text{ft/s}^2)(32/12\ \text{ft})\left(\frac{1\,\text{lbf}}{32.2\,\text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\,\text{ft}^2}{144\,\text{in}^2}\right) = \mathbf{14.9\ \ psia}$$

Therefore, the pressure in the left oil tank is 14.9 psia higher than the pressure in the right oil tank.

Discussion Note that large pressure differences can be measured conveniently by mercury manometers. If a water manometer were used in this case, the differential height would be over 30 ft.



Review Problems

2-80E 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.

2-81E 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.

2-82E 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) 2×1.8 = **3.6°F**
(c) 2×1.8 = **3.6 R**

2-83E Hypothermia 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**

2-84E A house is losing heat at a rate of 3000 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) **3000 kJ/h** per K difference in temperature, and
(b), (c) 3000/1.8 = **1667 kJ/h** per R or °F rise in temperature.

2-85 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

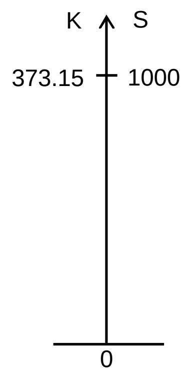
$$\begin{aligned} T_{atm} &= 288.15 - 6.5z \\ &= 288.15 - 6.5\times12 \\ &= \mathbf{210.15\ K = -63^\circ C} \end{aligned}$$

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

2-86 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



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

The ice point of water on the Smith scale is

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

2-87E 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(°F) = 1.8T(°C) + 32. The first thought that comes to mind is to replace T(°F) in the equation by its equivalent 1.8T(°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,

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

or

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

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:

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

which simplifies to

$$T_{\mathrm{equiv}}(^\circ\mathrm{C}) = 33.0 - (33.0 - T_{\mathrm{ambient}})(0.475 - 0.0126V + 0.240\sqrt{V})$$

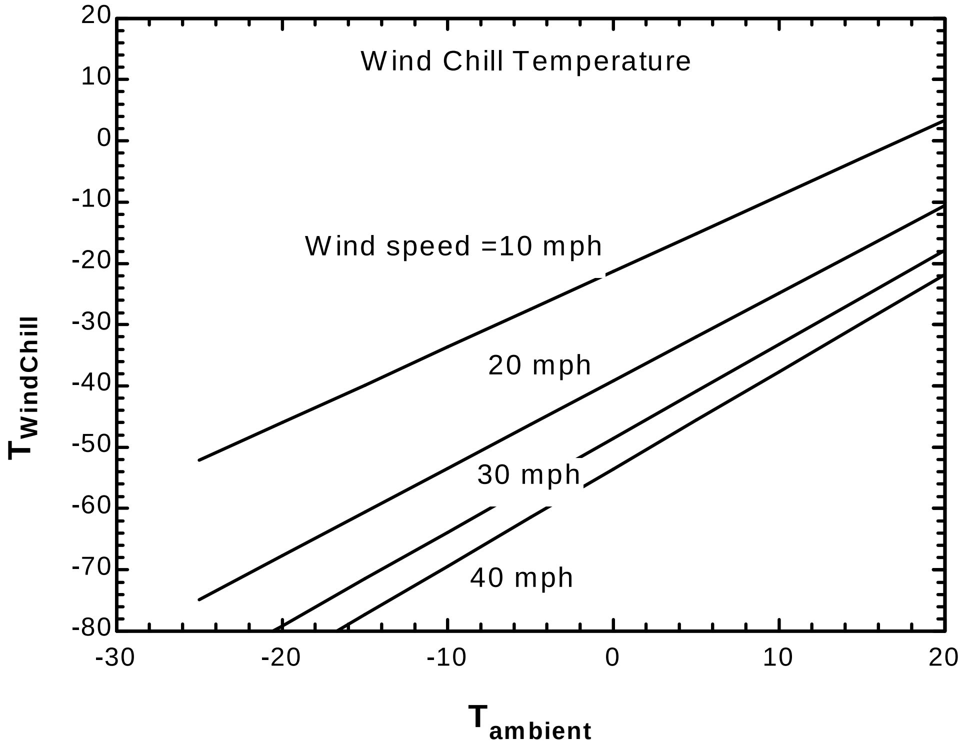
where the ambient air temperature is in °C.

2-88E Problem 2-87E is reconsidered. The equivalent wind-chill temperatures in °F as a function of wind velocity in the range of 4 mph to 100 mph for the ambient temperatures of 20, 40, and 40°F is to be plotted, and the results are to be discussed.

```
"Obtain V and T_ambient from the Diagram Window"
{T_ambient=10
V=20}
V_use=max(V,4)
T_equiv=91.4-(91.4-T_ambient)*(0.475 - 0.0203*V_use + 0.304*sqrt(V_use))
```

"The parametric table was used to generate the plot, Fill in values for T_ambient and V (use Alter Values under Tables menu) then use F3 to solve table. Plot the first 10 rows and then overlay the second ten, and so on. Place the text on the plot using Add Text under the Plot menu."

T_{equiv} [F]	$T_{ambient}$ [F]	V [mph]
-52	-25	10
-46	-20	10
-40	-15	10
-34	-10	10
-27	-5	10
-21	0	10
-15	5	10
-9	10	10
-3	15	10
3	20	10
-75	-25	20
-68	-20	20
-61	-15	20
-53	-10	20
-46	-5	20
-39	0	20
-32	5	20
-25	10	20
-18	15	20
-11	20	20
-87	-25	30
-79	-20	30
-72	-15	30
-64	-10	30
-56	-5	30
-49	0	30
-41	5	30
-33	10	30
-26	15	30
-18	20	30
-93	-25	40
-85	-20	40
-77	-15	40
-69	-10	40
-61	-5	40
-54	0	40
-46	5	40
-38	10	40
-30	15	40
-22	20	40



Wind Chill Temperature
Wind speed =10 mph
20 mph
30 mph
40 mph
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-30
-20
-10
0
10
20
T_WindChill
T_ambient

2-89 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.

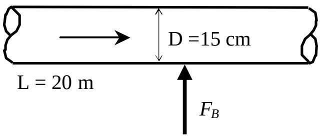
Properties The density of air is given to be ρ = 1.30 kg/m^3. We take the density of water to be 1000 kg/m^3.

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

$$V = AL = (\pi D^2/4)L = [\pi(0.15\text{ m})^2/4](20\text{ m}) = 0.353\text{ m}^3$$

Then the buoyancy force becomes

$$F_B = \rho g V = (1000\text{ kg/m}^3)(9.81\text{ m/s}^2)(0.353\text{m}^3)\left(\frac{1\text{ kN}}{1000\text{ kg}\cdot\text{m/s}^2}\right) = \mathbf{3.46\text{ kN}}$$



Discussion The upward force exerted by water on the duct is 3.46 kN, which is equivalent to the weight of a mass of 353 kg. Therefore, this force must be treated seriously.

2-90 A helium balloon tied to the ground carries 2 people. The acceleration of the balloon when it is first released is to be determined.

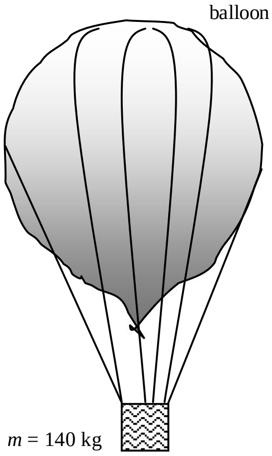
Assumptions The weight of the cage and the ropes of the balloon is negligible.

Properties The density of air is given to be ρ = 1.16 kg/m^3. The density of helium gas is 1/7th of this.

Analysis The buoyancy force acting on the balloon is

$$V_{balloon} = 4\pi r^3/3 = 4\pi(5m)^3/3 = 523.6m^3$$

$$F_B = \rho_{air} g V_{balloon}$$
$$= (1.16\text{kg/m}^3)(9.807\text{m/s}^2)(523.6\text{m}^3)\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right) = 5956.5\text{N}$$



The total mass is

$$m_{He} = \rho_{He} V = \left(\frac{1.16}{7}\text{kg/m}^3\right)(523.6\text{m}^3) = 86.8\text{kg}$$

$$m_{total} = m_{He} + m_{people} = 86.8 + 2\times 70 = 226.8\text{kg}$$

The total weight is

$$W = m_{total} g = (226.8\text{kg})(9.807\text{m/s}^2)\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right) = 2224.2\text{N}$$

Thus the net force acting on the balloon is

$$F_{net} = F_B - W = 5956.5 - 2224.2 = 3732.3\text{ N}$$

Then the acceleration becomes

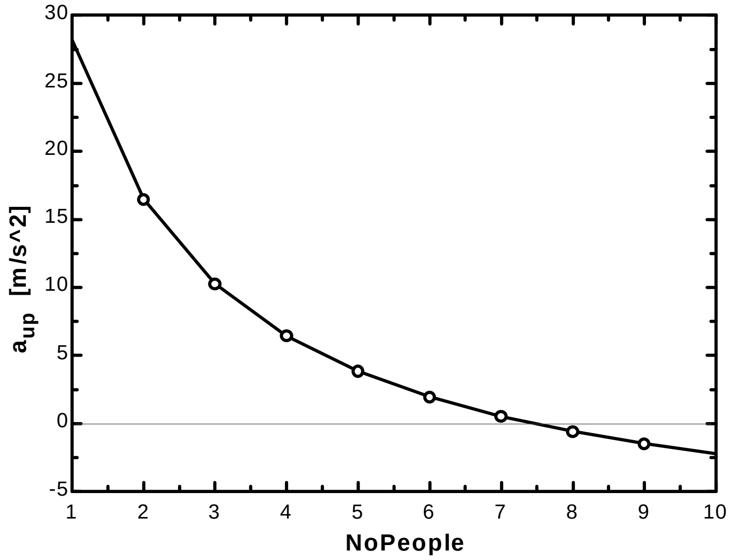
$$a = \frac{F_{net}}{m_{total}} = \frac{3732.2\text{N}}{226.8\text{kg}}\left(\frac{1\text{kg}\cdot\text{m/s}^2}{1\text{N}}\right) = \mathbf{16.5 m/s^2}$$

2-91 Problem 2-90 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.

"Given Data:"

```
rho_air=1.16"[kg/m^3]" "density of air"
g=9.807"[m/s^2]"
d_balloon=10"[m]"
m_1person=70"[kg]"
{NoPeople = 2}  "Data suppied in Parametric Table"

"Calculated values:"
rho_He=rho_air/7"[kg/m^3]" "density of helium"
r_balloon=d_balloon/2"[m]"
V_balloon=4*pi*r_balloon^3/3"[m^3]"
m_people=NoPeople*m_1person"[kg]"
m_He=rho_He*V_balloon"[kg]"
m_total=m_He+m_people"[kg]"
"The total weight of balloon and people is:"
W_total=m_total*g"[N]"
"The buoyancy force acting on the balloon, F_b, is equal to the weight of the air displaced by the balloon."
F_b=rho_air*V_balloon*g"[N]"
"From the free body diagram of the balloon, the balancing vertical forces must equal the product of the total mass and the vertical acceleration:"
F_b- W_total=m_total*a_up
```

A_{up} [m/s^2]	NoPeople
28.19	1
16.46	2
10.26	3
6.434	4
3.831	5
1.947	6
0.5204	7
-0.5973	8
-1.497	9
-2.236	10



2-92 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.

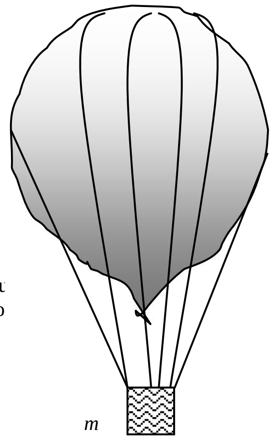
Analysis In the limiting case, the net force acting on the balloon will be zero. That is, the buoyancy force and the weight will balance each other:

$$W = mg = F_B$$

$$m_{total} = \frac{F_B}{g} = \frac{5956.5 \text{ N}}{9.807 \text{ m/s}^2} = 607.4 \text{ kg}$$

Thus,

$$m_{\text{people}} = m_{\text{total}} - m_{\text{He}} = 607.4 - 86.8 = \mathbf{520.6\ kg}$$



2-93 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: $$P = (75 \text{ kgf/cm}^2)\left(\frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2}\right) = 72.6 \text{ atm}$$

In psi: $$P = (75 \text{ kgf/cm}^2)\left(\frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2}\right)\left(\frac{14.696 \text{ psi}}{1 \text{ atm}}\right) = \mathbf{1067\ psi}$$

In kPa: $$P = (75 \text{ kgf/cm}^2)\left(\frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2}\right)\left(\frac{101.325 \text{ kPa}}{1 \text{ atm}}\right) = \mathbf{7355\ kPa}$$

In bars: $$P = (75 \text{ kgf/cm}^2)\left(\frac{1 \text{ atm}}{1.03323 \text{ kgf/cm}^2}\right)\left(\frac{1.01325 \text{ bar}}{1 \text{ atm}}\right) = \mathbf{73.55\ bar}$$

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

2-94 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/m³ and ρ = 13,600 kg/m³.

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

$$\begin{aligned} P_{\text{plane}} &= (\rho g h)_{\text{plane}} \\ &= (13{,}600\text{ kg/m}^3)(9.8\text{ m/s}^2)(0.690\text{ m})\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right) \\ &= 91.96\text{ kPa} \end{aligned}$$

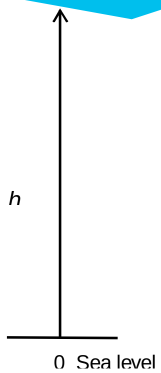
$$\begin{aligned} P_{\text{ground}} &= (\rho g h)_{\text{ground}} \\ &= (13{,}600\text{ kg/m}^3)(9.8\text{ m/s}^2)(0.753\text{ m})\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right) \\ &= 100.36\text{ kPa} \end{aligned}$$

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

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

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

$$(1.20\text{ kg/m}^3)(9.8\text{ m/s}^2)(h)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kPa}}{1000\text{ N/m}^2}\right) = (100.36 - 91.96)\text{ kPa}$$

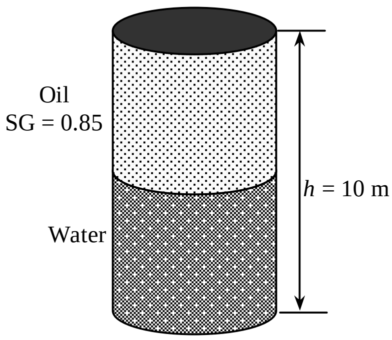


It yields h = **714 m**

which is also the altitude of the airplane.

2-95 A 10-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,

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

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

$$\begin{aligned}\Delta P_{total} &= \Delta P_{oil} + \Delta P_{water} = (\rho g h)_{oil} + (\rho g h)_{water} \\ &= \left[(850\,\text{kg/m}^3)(9.807\,\text{m/s}^2)(5\,\text{m}) + (1000\,\text{kg/m}^3)(9.807\,\text{m/s}^2)(5\,\text{m})\right]\left(\frac{1\,\text{kPa}}{1000\,\text{N/m}^2}\right) \\ &= \mathbf{90.7\,kPa}\end{aligned}$$

2-96 The pressure of a gas contained in a vertical piston-cylinder device is measured to be 500 kPa. The mass of the piston is to be determined.

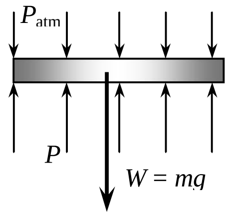
Assumptions There is no friction between the piston and the cylinder.

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

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

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

$$(m)(9.807\,\text{m/s}^2) = (500 - 100\,\text{kPa})(30 \times 10^{-4}\,\text{m}^2)\left(\frac{1000\,\text{kg/m}\cdot\text{s}^2}{1\,\text{kPa}}\right)$$



It yields m = **122.4 kg**

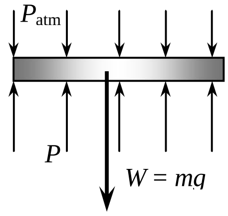
2-97 The gage pressure in a pressure cooker is maintained constant at 100 kPa by a petcock. The mass of the petcock is to be determined.

Assumptions There is no blockage of the pressure release valve.

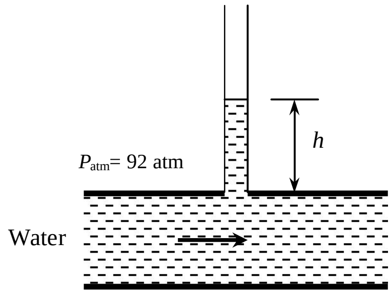
Analysis Atmospheric pressure is acting on all surfaces of the petcock, which balances itself out. Therefore, it can be disregarded in calculations if we use the gage pressure as the cooker pressure. A force balance on the petcock ($\Sigma F_y = 0$) yields

$$W = P_{gage}A$$

$$m = \frac{P_{gage}A}{g} = \frac{(100\,kPa)(4 \times 10^{-6}\,m^2)}{9.807\,m/s^2}\left(\frac{1000\,kg/m\cdot s^2}{1\,kPa}\right) = \mathbf{0.0408\,kg}$$



2-98 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,

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

$$= \frac{(115-92)\text{ kPa}}{(1000\text{ kg/m}^3)(9.8\text{ m/s}^2)}\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right)\left(\frac{1000\text{ N/m}^2}{1\text{ kPa}}\right)$$

$$= \mathbf{2.35\ m}$$

2-99 The average atmospheric pressure is given as $P_{atm} = 101.325(1-0.02256z)^{5.256}$ 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**

2-100 The air pressure in a duct is measured by an inclined manometer. For a given vertical level difference, the gage pressure in the duct and the length of the differential fluid column are to be determined.

Assumptions The manometer fluid is an incompressible substance.

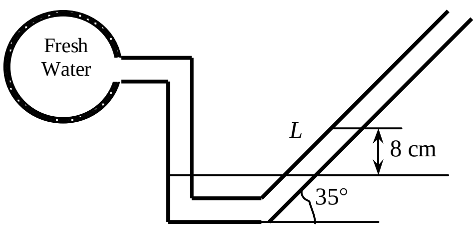
Properties The density of the liquid is given to be ρ = 0.81 kg/L = 810 kg/m^3.

Analysis The gage pressure in the duct is determined from

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}} = \rho g h$$

$$= (810\text{kg/m}^3)(9.81\text{m/s}^2)(0.08\text{m})\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{Pa}}{1\text{N/m}^2}\right)$$

$$= \mathbf{636\ \ Pa}$$



The length of the differential fluid column is

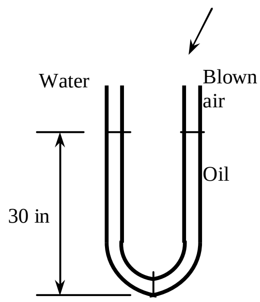
$$L = h/\sin\theta = (8\text{cm})/\sin 35° = \mathbf{13.9\ cm}$$

Discussion Note that the length of the differential fluid column is extended considerably by inclining the manometer arm for better readability.

2-101E 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

$$P_{\text{contact}} = P_{\text{blow}} + \rho_{\text{a}} g h_{\text{a}} = P_{\text{atm}} + \rho_{\text{w}} g h_{\text{w}}$$

Noting that $h_a = h_w$ and rearranging,

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

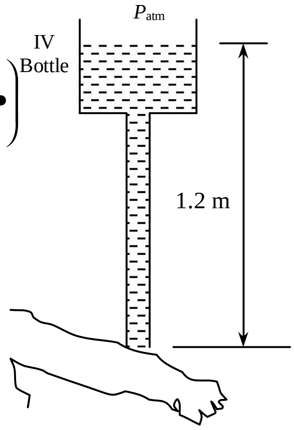
Discussion When the person stops blowing, the oil will rise and some water will flow into the right arm. It can be shown that when the curvature effects of the tube are disregarded, the differential height of water will be 23.7 in to balance 30-in of oil.

2-102 It is given that an IV fluid and the blood pressures balance each other when the bottle is at a certain height, and a certain gage pressure at the arm level is needed for sufficient flow rate. The gage pressure of the blood and elevation of the bottle required to maintain flow at the desired rate are to be determined.

Assumptions **1** The IV fluid is incompressible. **2** The IV bottle is open to the atmosphere.

Properties The density of the IV fluid is given to be $\rho = 1020\ \text{kg/m}^3$.

Analysis (*a*) Noting that the IV fluid and the blood pressures balance each other when the bottle is 1.2 m above the arm level, the gage pressure of the blood in the arm is simply equal to the gage pressure of the IV fluid at a depth of 1.2 m,



$$\begin{aligned} P_{\text{gage, arm}} &= P_{\text{abs}} - P_{\text{atm}} = \rho g h_{\text{arm-bottle}} \\ &= (1020\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(1.20\ \text{m})\left(\frac{1\text{kN}}{1000\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1\ \text{kN/m}^2}\right) \\ &= \mathbf{12.0\ kPa} \end{aligned}$$

(*b*) To provide a gage pressure of 20 kPa at the arm level, the height of the bottle from the arm level is again determined from $P_{\text{gage, arm}} = \rho g h_{\text{arm-bottle}}$ to be

$$\begin{aligned} h_{\text{arm-bottle}} &= \frac{P_{\text{gage, arm}}}{\rho g} \\ &= \frac{20\ \text{kPa}}{(1020\ \text{kg/m}^3)(9.81\ \text{m/s}^2)}\left(\frac{1000\ \text{kg}\cdot\text{m/s}^2}{1\ \text{kN}}\right)\left(\frac{1\ \text{kN/m}^2}{1\ \text{kPa}}\right) = \mathbf{2.0\ m} \end{aligned}$$

Discussion Note that the height of the reservoir can be used to control flow rates in gravity driven flows. When there is flow, the pressure drop in the tube due to friction should also be considered. This will result in raising the bottle a little higher to overcome pressure drop.

2-103 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

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

Rearranging,

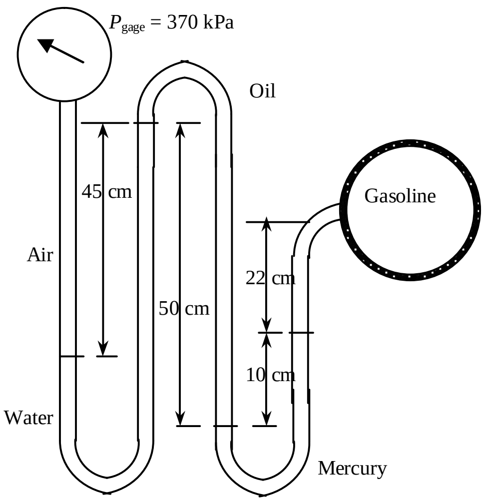
$$P_{\text{gasoline}} = P_{\text{gage}} - \rho_{\text{w}} g (h_w - SG_{\text{alcohol}} h_{\text{alcohol}} + SG_{\text{Hg}} h_{\text{Hg}} + SG_{\text{gasoline}} h_{\text{gasoline}})$$

Substituting,

$$\begin{aligned} P_{\text{gasoline}} &= 370\,\text{kPa - }(1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)[(0.45\,\text{m}) - 0.79(0.5\,\text{m}) + 13.6(0.1\,\text{m}) + 0.70(0.22\,\text{m})] \\ &\quad \times \left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\,\text{kPa}}{1\,\text{kN/m}^2}\right) \\ &= \mathbf{354.6\ kPa} \end{aligned}$$

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.



2-104 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

$$P_{gage} - \rho_{\text{w}} gh_w + \rho_{\text{alcohol}} gh_{\text{alcohol}} - \rho_{\text{Hg}} gh_{\text{Hg}} - \rho_{\text{gasoline}} gh_{\text{gasoline}} = P_{\text{gasoline}}$$

Rearranging,

$$P_{\text{gasoline}} = P_{\text{gage}} - \rho_{\text{w}} g(h_w - SG_{\text{alcohol}} h_{\text{s,alcohol}} + SG_{\text{Hg}} h_{\text{Hg}} + SG_{\text{gasoline}} h_{\text{s,gasoline}})$$

Substituting,

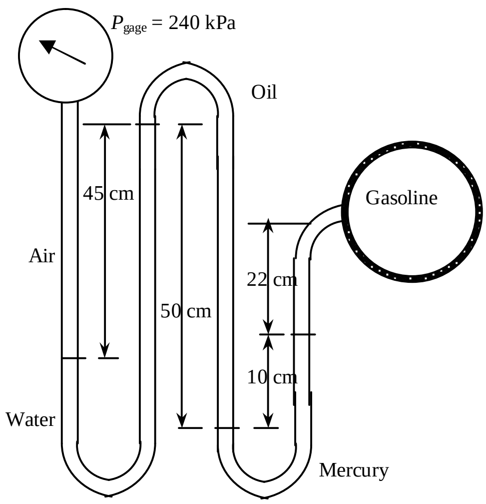
$$P_{\text{gasoline}} = 240\text{ kPa} - (1000\text{ kg/m}^3)(9.81\text{ m/s}^2)[(0.45\text{ m}) - 0.79(0.5\text{ m}) + 13.6(0.1\text{ m}) + 0.70(0.22\text{ m})]$$

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

$$= \mathbf{224.6\ kPa}$$

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.



2-105E 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

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

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

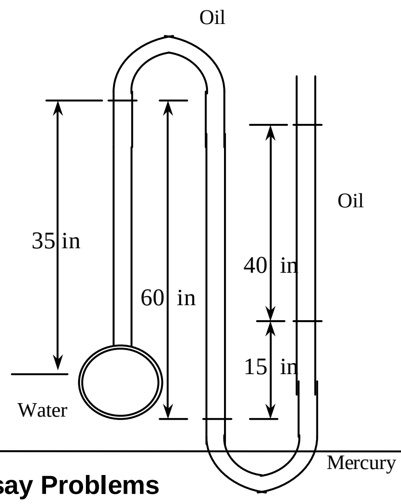
$$P_{\text{water pipe}} = P_{atm} + \rho_{\text{water}} g(h_{\text{water}} - SG_{\text{oil}} h_{\text{alcohol}} + SG_{\text{Hg}} h_{\text{Hg}} + SG_{\text{oil}} h_{\text{oil}})$$

Substituting,

$$\begin{aligned} P_{\text{water pipe}} &= 14.2\,\text{psia} + (62.4\,\text{lbm/ft}^3)(32.2\,\text{ft/s}^2)[(35/12\,\text{ft}) - 0.80(60/12\,\text{ft}) + 13.6(15/12\,\text{ft}) \\ &\quad + 0.8(40/12\,\text{ft})] \times \left(\frac{1\,\text{lbf}}{32.2\,\text{lbm}\cdot\text{ft/s}^2}\right)\left(\frac{1\,\text{ft}^2}{144\,\text{in}^2}\right) \\ &= 22.3\,\textbf{psia} \end{aligned}$$

Therefore, the absolute pressure in the water pipe is 22.3 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.



2-106 … 2-107 Design and Essay Problems

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