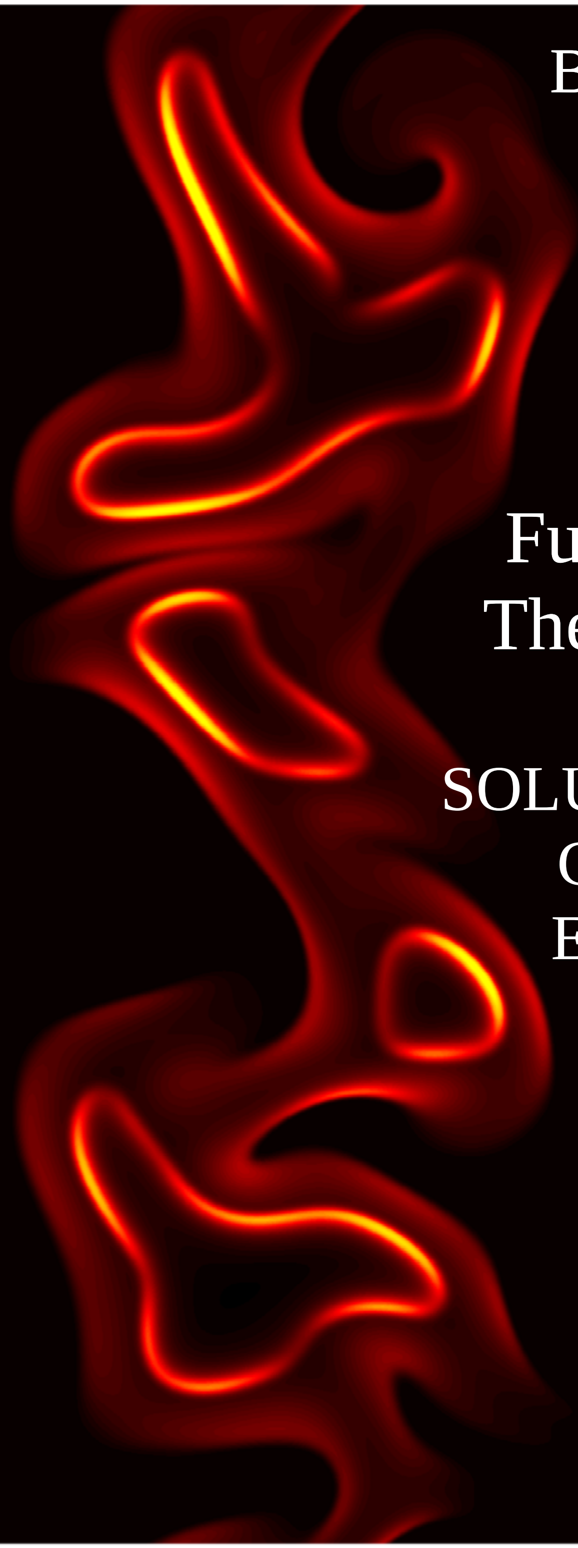

Borgnakke Sonntag

Fundamentals of Thermodynamics

SOLUTION MANUAL
CHAPTER 1
English Units

8e

UPDATED JULY 2013

CHAPTER 1

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Concept Problems

1.102E

A mass of 2 lbm has acceleration of 5 ft/s^2, what is the needed force in lbf?

Solution:

Newtons 2nd law: $F = ma$

$$F = ma = 2 \text{ lbm} \times 5 \text{ ft/s}^2 = 10 \text{ lbm ft/s}^2$$
$$= \frac{10}{32.174} \text{ lbf} = \mathbf{0.31\ lbf}$$

1.103E

How much mass is in 1 gallon of gasoline? If helium in a balloon at atmospheric *P* and *T*?

Solution:

A volume of 1 gal equals 231 in^3, see Table A.1. From Table F.3 the density is 46.8 lbm/ft^3, so we get

$$m = \rho V = 46.8 \text{ lbm/ft}^3 \times 1 \times (231/12^3\ ) \text{ ft}^3 = \mathbf{6.256\ lbm}$$

A more accurate value from Table F.3 is $\rho = 848 \text{ lbm/ft}^3$.

For the helium we see Table F.4 that density is 10.08×10^{-3} lbm/ft^3 so we get

$$m = \rho V = 10.08 \times 10^{-3} \text{ lbm/ft}^3 \times 1 \times (231/12^3\ ) \text{ ft}^3 = \mathbf{0.00135\ lbm}$$

1.104E

Can you easily carry a one gallon bar of solid gold?

Solution:

The density of solid gold is about 1205 lbm/ft^3 from Table F.2, we could also have read Figure 1.7 and converted the units.

$$V = 1 \text{ gal} = 231 \text{ in}^3 = 231 \times 12^{-3} \text{ ft}^3 = 0.13368 \text{ ft}^3$$

Therefore the mass in one gallon is

$$m = \rho V = 1205 \text{ lbm/ft}^3 \times 0.13368 \text{ ft}^3$$
$$= 161 \text{ lbm}$$

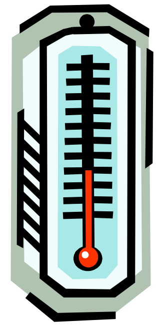
and some people can just about carry that in the standard gravitational field.

1.105E

What is the temperature of –5F in degrees Rankine?

Solution:

The offset from Fahrenheit to Rankine is 459.67 R, so we get



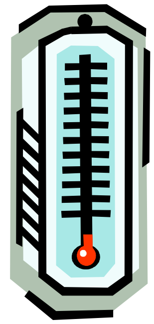
$$T_R = T_F + 459.67 = -5 + 459.67$$
$$= \mathbf{454.7\ R}$$

1.106E

What is the smallest temperature in degrees Fahrenheit you can have? Rankine?

Solution:

The lowest temperature is absolute zero which is at zero degrees Rankine at which point the temperature in Fahrenheit is negative



$$T_R = 0 \text{ R} = -459.67 \text{ F}$$

1.107E

What is the relative magnitude of degree Rankine to degree Kelvin

Look in Table A.1 p. 757:

$$1\text{ K} = 1\ ^{o}\text{C} = 1.8\text{ R} = 1.8\text{ F}$$

$$1\text{ R} = \frac{5}{9}\text{ K} = 0.5556\text{ K}$$

1.108E

Chemical reaction rates genrally double for a 10 K increase in temperature. How large an increase is that in Fahrenheit?

From the Conversion Table A.1: $1 \text{ K} = 1\ ^{o}\text{C} = 1.8 \text{ R} = 1.8 \text{ F}$

So the 10 K increase becomes

$$10 \text{ K} = 18 \text{ F}$$

Properties and Units

1.109E

An apple weighs 0.2 lbm and has a volume of 6 in^3 in a refrigerator at 38 F. What is the apple density? List three intensive and two extensive properties for the apple.

Solution:

$$\rho = \frac{m}{V} = \frac{0.2}{6}\ \frac{\text{lbm}}{\text{in}^3} = 0.0333\ \frac{\text{lbm}}{\text{in}^3} = 57.6\ \frac{\text{lbm}}{\text{ft}^3}$$

Intensive

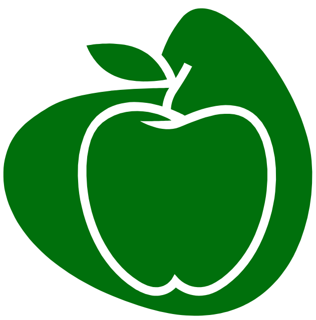
$$\rho = 57.6\ \frac{\text{lbm}}{\text{ft}^3}; \qquad v = \frac{1}{\rho} = 0.0174\ \frac{\text{ft}^3}{\text{lbm}}$$

$$T = 38\text{ F}; \qquad P = 14.696\ \text{lbf/in}^2$$

Extensive

$$m = 0.2\ \text{lbm}$$

$$V = 6\ \text{in}^3 = 0.026\ \text{gal} = 0.00347\ \text{ft}^3$$



1.110E

A steel piston of 10 lbm is in the standard gravitational field where a force of 10 lbf is applied vertically up. Find the acceleration of the piston.

Solution:

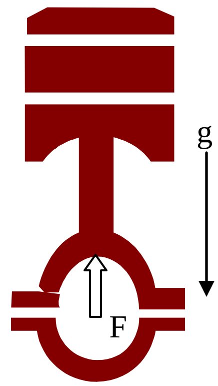
$$F_{up} = ma = F - mg$$

$$a = \frac{F - mg}{m} = \frac{F}{m} - g$$

$$= \frac{10 \text{ lbf}}{10 \text{ lbm}} - 32.174 \text{ ft/s}^2$$

$$= (1 \times 32.174 - 32.174) \text{ ft/s}^2$$

$$= \mathbf{0 \text{ fts}^{-2}}$$



The mass does not move, it is held stationary.

Force, Energy, Density

1.111E

A 2500-lbm car moving at 25 mi/h is accelerated at a constant rate of 15 ft/s^2 up to a speed of 50 mi/h. What are the force and total time required?

Solution:

$$a = \frac{d\mathbf{V}}{dt} = \frac{\Delta\mathbf{V}}{\Delta t} \quad \Rightarrow \quad \Delta t = \frac{\Delta\mathbf{V}}{a}$$

$$\Delta t = \frac{(50 - 25)\ \text{mi/h} \times 1609.34\ \text{m/mi} \times 3.28084\ \text{ft/m}}{3600\ \text{s/h} \times 15\ \text{ft/s}^2} = \mathbf{2.44\ sec}$$

$$F = ma = 2500\ \text{lbm} \times 15\ \text{ft/s}^2 \ /\ (32.174\ \text{lbm ft /lbf-s}^2\ )$$

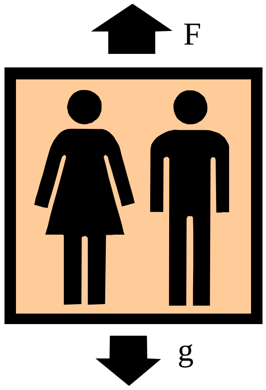
$$= \mathbf{1165\ lbf}$$

1.112E

An escalator brings four people of total 600 lbm and a 1000 lbm cage up with an acceleration of 3 ft/s^2 what is the needed force in the cable?

Solution:

The total mass moves upwards with an acceleration plus the gravitations acts with a force pointing down.



$ma = \sum F = F - mg$

$F = ma + mg = m(a + g)$
$= (1000 + 600) \text{ lbm} \times (3 + 32.174) \text{ ft/s}^2$
$=$ **56 278 lbm ft/s^2** $=$ **56 278 lbf**

1.113E

One pound-mass of diatomic oxygen (O_2 molecular weight 32) is contained in a 100-gal tank. Find the specific volume on both a mass and mole basis (*v* and $\bar{v}$).

Solution:

$$V = 100 \times 231 \text{ in}^3 = (23\ 100/12^3)\ \text{ft}^3 = 13.37 \text{ ft}^3$$

conversion seen in Table A.1

This is based on the definition of the specific volume

$$v = V/m = 13.37 \text{ ft}^3/1 \text{ lbm} = \mathbf{13.37\ ft^3/lbm}$$

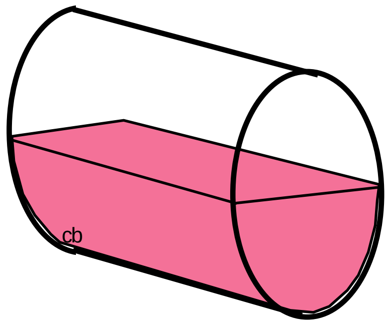
$$\bar{v} = V/n = \frac{V}{m/M} = Mv = 32 \times 13.37 = \mathbf{427.8\ ft^3/lbmol}$$

1.114E

A 30-lbm steel gas tank holds 10 ft^3 of liquid gasoline, having a density of 50 lbm/ft^3. What force is needed to accelerate this combined system at a rate of 15 ft/s^2?

Solution:

$$m = m_{tank} + m_{gasoline}$$
$$= 30 \text{ lbm} + 10 \text{ ft}^3 \times 50 \text{ lbm/ft}^3$$
$$= 530 \text{ lbm}$$



$$F = ma = (530 \text{ lbm} \times 15 \text{ ft/s}^2) / (32.174 \text{ lbm ft/s}^2\text{- lbf}) = \mathbf{247.1\ lbf}$$

1.115E

A powerplant that separates carbon-dioxide from the exhaust gases compresses it to a density of 8 lbm/ft^3 and stores it in an un-minable coal seam with a porous volume of 3 500 000 ft^3. Find the mass they can store.

Solution:

$$m = \rho V = 8 \text{ lbm/ft}^3 \times 3\,500\,000 \text{ ft}^3 = 2.8 \times 10^7 \text{ lbm}$$

Just to put this in perspective a power plant that generates 2000 MW by burning coal would make about 20 million tons of carbon-dioxide a year. That is 2000 times the above mass so it is nearly impossible to store all the carbon-dioxide being produced.

1.116E

A laboratory room keeps a vacuum of 4 in. of water due to the exhaust fan. What is the net force on a door of size 6 ft by 3 ft?

Solution:

The net force on the door is the difference between the forces on the two sides as the pressure times the area

$$
\begin{aligned}
F &= P_{outside} A - P_{inside} A = \Delta P \times A \\
&= 4 \text{ in } H_2O \times 6 \text{ ft} \times 3 \text{ ft} \\
&= 4 \times 0.036126 \text{ lbf/in}^2 \times 18 \text{ ft}^2 \times 144 \text{ in}^2/\text{ft}^2 \\
&= \mathbf{374.6\ lbf}
\end{aligned}
$$

Table A.1: 1 in. H_2O is 0.036 126 lbf/in^2, a unit also often listed as psi.

1.117E

A 150-lbm human total footprint is 0.5 ft when the person is wearing boots. If snow can support an extra 1 psi, what should the total snow shoe area be?

Force balance: $ma = 0 = PA - mg$

$$A = \frac{mg}{P} = \frac{150 \text{ lbm} \times 32.174 \text{ ft/s}^2}{1 \text{ lbf/in}^2} = \frac{150 \text{ lbm} \times 32.174 \text{ ft/s}^2}{32.174 \text{ lbm-ft/(s}^2\text{in}^2)}$$

$$= \mathbf{150\ in^2} = 1.04 \text{ ft}^2$$

1.118E

A tornado rips off a 1000 ft^2 roof with a mass of 2000 lbm. What is the minimum vacuum pressure needed to do that if we neglect the anchoring forces?

Solution:

The net force on the roof is the difference between the forces on the two sides as the pressure times the area

$$F = P_{inside}\,A - P_{outside}A = \Delta P\ A$$

That force must overcome the gravitation mg, so the balance is

$$\Delta P\ A = mg$$

$$\Delta P = mg/A = (2000\text{ lbm} \times 32.174\text{ ft/s}^2\,)/1000\text{ ft}^2$$
$$= 2000\,/(1000 \times 144)\text{ psi} = \mathbf{0.0139\ psi}$$

Remember that psi = lbf/in^2.

1.119E

A manometer shows a pressure difference of 3.5 in of liquid mercury. Find ΔP in psi.

Solution:

Hg : $L = 3.5$ in; $\rho = 848 \text{ lbm/ft}^3$ from Table F.3

Pressure: 1 psi = 1 lbf/ in^2

The pressure difference ΔP balances the column of height L so from Eq.2.2

$$\Delta P = \rho g L = 848 \text{ lbm/ft}^3 \times 32.174 \text{ ft/s}^2 \times (3.5/12) \text{ ft}$$

$$= 247.3 \text{ lbf/ft}^2 = (247.3 / 144) \text{ lbf/in}^2$$

$$= \mathbf{1.72\ psi}$$

1.120E

A 7 ft m tall steel cylinder has a cross sectional area of 15 ft^2. At the bottom with a height of 2 ft m is liquid water on top of which is a 4 ft high layer of gasoline. The gasoline surface is exposed to atmospheric air at 14.7 psia. What is the highest pressure in the water?

Solution:

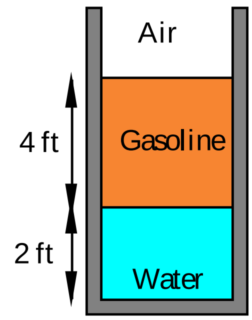
The pressure in the fluid goes up with the depth as

$$P = P_{top} + \Delta P = P_{top} + \rho g h$$

and since we have two fluid layers we get

$$P = P_{top} + [(\rho h)_{gasoline} + (\rho h)_{water}]g$$

The densities from Table F.3 are:



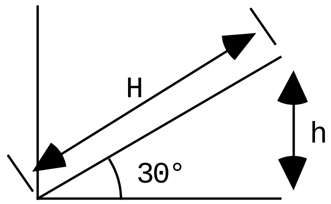
$$\rho_{gasoline} = 46.8 \text{ lbm/ft}^3; \quad \rho_{water} = 62.2 \text{ lbm/ft}^3$$

$$P = 14.7 + [46.8 \times 4 + 62.2 \times 2] \frac{32.174}{144 \times 32.174} = \mathbf{16.86\ lbf/in^2}$$

1.121E

A U-tube manometer filled with water, density 62.3 lbm/ft^3, shows a height difference of 10 in. What is the gauge pressure? If the right branch is tilted to make an angle of 30° with the horizontal, as shown in Fig. P1.77, what should the length of the column in the tilted tube be relative to the U-tube?

Solution:



$$\Delta P = F/A = mg/A = h\rho g$$

$$= \frac{(10/12) \times 62.3 \times 32.174}{32.174 \times 144}$$

$$= P_{gauge} = \mathbf{0.36\ lbf/in^2}$$

$$h = H \times \sin 30°$$

$$\Rightarrow \ H = h/\sin 30° = 2h = 20 \text{ in} = \mathbf{0.833\ ft}$$

1.122E

A piston/cylinder with cross-sectional area of 0.1 ft^2 has a piston mass of 200 lbm resting on the stops, as shown in Fig. P1.50. With an outside atmospheric pressure of 1 atm, what should the water pressure be to lift the piston?

Solution:

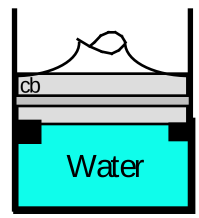
The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

Force balance: $F\uparrow = F\downarrow = PA = m_p g + P_0 A$

Now solve for P (multiply by 144 to convert from ft^2 to in^2)

$$P = P_0 + \frac{m_p g}{A} = 14.696 + \frac{200 \times 32.174}{0.1 \times 144 \times 32.174}$$

$$= 14.696 \text{ psia} + 13.88 \text{ psia} = \mathbf{28.58\ lbf/in^2}$$



1.123E

The main waterline into a tall building has a pressure of 90 psia at 16 ft elevation below ground level. How much extra pressure does a pump need to add to ensure a waterline pressure of 30 psia at the top floor 450 ft above ground?

Solution:

The pump exit pressure must balance the top pressure plus the column ΔP. The pump inlet pressure provides part of the absolute pressure.

$P_{after\ pump} = P_{top} + \Delta P$

$$\Delta P = \rho g h = 62.2\ \text{lbm/ft}^3 \times 32.174\ \text{ft/s}^2 \times (450 + 16)\ \text{ft} \times \frac{1\ \text{lbf s}^2}{32.174\ \text{lbm ft}}$$

$$= 28\ 985\ \text{lbf/ft}^2 = 201.3\ \text{lbf/in}^2$$

$P_{after\ pump} = 30 + 201.3 = 231.3$ psia

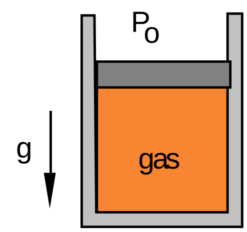
$\Delta P_{pump} = 231.3 - 90 =$ **141.3 psi**

1.124E

A piston, m_p = 10 lbm, is fitted in a cylinder, A = 2.5 in.^{2}, that contains a gas. The setup is in a centrifuge that creates an acceleration of 75 ft/s^2. Assuming standard atmospheric pressure outside the cylinder, find the gas pressure.

Solution:

Force balance: $F\uparrow = F\downarrow = P_0A + m_pg = PA$



$$P = P_0 + \frac{m_p g}{A}$$

$$= 14.696 + \frac{10 \times 75}{2.5 \times 32.174} \frac{\text{lbm ft/s}^2}{\text{in}^2} \frac{\text{lbf-s}^2}{\text{lbm-ft}}$$

$$= 14.696 + 9.324 = \mathbf{24.02\ lbf/in^2}$$

Temperature

1.125E

The human comfort zone is between 18 and 24°C. What is that range in Fahrenheit?

$$T = 18°C = 32 + 1.8 \times 18 = 64.4 \text{ F}$$
$$T = 24°C = 32 + 1.8 \times 24 = 75.2 \text{ F}$$

So the range is like **64 to 75 F**.

1.126E

The atmosphere becomes colder at higher elevation. As an average the standard atmospheric absolute temperature can be expressed as $T_{atm} = 518 - 3.84 \times 10^{-3}\, z$, where z is the elevation in feet. How cold is it outside an airplane cruising at 32 000 ft expressed in Rankine and in Fahrenheit?

Solution:

For an elevation of $z = 32\,000$ ft we get

$$T_{atm} = 518 - 3.84 \times 10^{-3}\, z = \mathbf{395.1\ R}$$

To express that in degrees Fahrenheit we get

$$T_F = T - 459.67 = \mathbf{-64.55\ F}$$

1.127E

The density of mercury changes approximately linearly with temperature as

$$\rho_{Hg} = 851.5 - 0.086\,T \text{ lbm/ft}^3 \qquad T \text{ in degrees Fahrenheit}$$

so the same pressure difference will result in a manometer reading that is influenced by temperature. If a pressure difference of 14.7 lbf/in.^{2} is measured in the summer at 95 F and in the winter at 5 F, what is the difference in column height between the two measurements?

Solution:

$$\Delta P = \rho g h \quad \Rightarrow \quad h = \Delta P/\rho g$$

$$\rho_{su} = 843.33 \text{ lbm/ft}^3; \qquad \rho_W = 851.07 \text{ lbm/ft}^3$$

$$h_{su} = \frac{14.7 \times 144 \times 32.174}{843.33 \times 32.174} = 2.51 \text{ ft} = 30.12 \text{ in}$$

$$h_W = \frac{14.7 \times 144 \times 32.174}{851.07 \times 32.174} = 2.487 \text{ ft} = 29.84 \text{ in}$$

$$\Delta h = h_{su} - h_W = 0.023 \text{ ft} = \mathbf{0.28\ in}$$