INSTRUCTOR'S SOLUTIONS MANUAL

TO ACCOMPANY

MECHANICS *of* FLUIDS

FOURTH EDITION

MERLE C. POTTER
Michigan State University

DAVID C. WIGGERT
Michigan State University

BASSEM RAMADAN
Kettering University

Contents

CHAPTER 1

Basic Considerations

FE-type Exam Review Problems: Problems 1-1 to 1-14.

1.1 (**C**) $m = F/a$ or kg = N/m/s^2 = N·s^2/m.

1.2 (**B**) $[\mu] = [\tau/du/dy] = (F/L^2)/(L/T)/L = FT/L^2$.

1.3 (**A**) $2.36\times10^{-8} = 23.6\times10^{-9} = 23.6$ nPa.

1.4 (**C**) The mass is the same on earth and the moon: $\tau = \mu\left|\frac{du}{dr}\right| = \mu[4(8r)] = 32\mu r$.

1.5 (**C**) $F_{\text{shear}} = F\sin\theta = 4200\sin 30^\circ = 2100$ N.

$$\tau = \frac{F_{\text{shear}}}{A} = \frac{2100\text{ N}}{250\times10^{-4}\text{ m}^2} = 84\times10^3\text{ Pa} \quad\text{or}\quad 84\text{ kPa}$$

1.6 (**B**)

1.7 (**D**) $\rho_{\text{water}} = 1000 - \frac{(T-4)^2}{180} = 1000 - \frac{(80-4)^2}{180} = 968\text{ kg/m}^3$

1.8 (**A**) $\tau = \mu\left|\frac{du}{dr}\right| = \mu[10\times5000r] = 10^{-3}\times10\times5000\times0.02 = 1$ Pa.

1.9 (**D**) $h = \frac{4\sigma\cos\beta}{\rho g D} = \frac{4\times0.0736\text{ N/m}\times1}{1000\text{ kg/m}^3\times9.81\text{ m/s}^2\times10\times10^{-6}\text{ m}} = 3\text{ m}$ or 300 cm.

We used kg = N·s^2/m

1.10 (**C**)

1.11 (**C**) $m = \frac{pV\!\!\!/}{RT} = \frac{800\text{ kN/m}^2\times4\text{ m}^3}{0.1886\text{ kJ/(kg}\cdot\text{K)}\times(10+273)\text{ K}} = 59.95\text{ kg}$

1.12 (**B**) $\Delta E_{\text{ice}} = \Delta E_{\text{water}}$. $m_{\text{ice}} \times 320 = m_{\text{water}} \times c_{\text{water}} \Delta T$.

$5\times(40\times10^{-6})\times1000\times320=(2\times10^{-3})\times1000\times4.18\Delta T$. $\therefore \Delta T = \underline{7.66^\circ\text{C}}$.

We assumed the density of ice to be equal to that of water, namely 1000 kg/m^3. Ice is actually slightly lighter than water, but it is not necessary for such accuracy in this problem.

1.13 (**D**) For this high-frequency wave, $c=\sqrt{RT}=\sqrt{287\times323}=\underline{304\text{ m/s}}$.

Chapter 1 Problems: Dimensions, Units, and Physical Quantities

1.14 Conservation of mass — Mass — density
Newton's second law — Momentum — velocity
The first law of thermodynamics — internal energy — temperature

1.15 a) density = mass/volume = M/L^3
b) pressure = force/area = $F/L^2 = ML/T^2L^2 = M/LT^2$
c) power = force $\times$ velocity = $F\times L/T = ML/T^2 \times L/T = ML^2/T^3$
d) energy = force $\times$ distance = $ML/T^2 \times L = ML^2/T^2$
e) mass flux = ρ ρ$AV = M/L^3 \times L^2 \times L/T = M/T$
f) flow rate = $AV = L^2 \times L/T = L^3/T$

1.16 a) density = $\dfrac{M}{L^3}\dfrac{FT^2/L}{L^3} = FT^2/L^4$
b) pressure = F/L^2
c) power = $F\times$ velocity = $F\times L/T = FL/T$
d) energy = $F\times L = FL$
e) mass flux = $\dfrac{M}{T}=\dfrac{FT^2/L}{T}=FT/L$
f) flow rate = $AV = L^2 \times L/T = L^3/T$

1.17 a) $L = [C]\,T^2$. $\therefore [C] = L/T^2$
b) $F = [C]M$. $\therefore [C] = F/M = ML/T^2\,M = L/T^2$
c) $L^3/T = [C]\,L^2\,L^{2/3}$. $\therefore [C] = L^3/T\cdot L^2\cdot L^{2/3} = L^{1/3}T$
Note: the slope S_0 has no dimensions.

1.18 a) m = $[C]$ s^2. $\therefore [C]$ = m/s^2
b) N = $[C]$ kg. $\therefore [C]$ = N/kg = kg $\cdot$ m/s$^2\cdot$ kg = m/s^2
c) m^3/s = $[C]$ m^2 m$^{2/3}$. $\therefore [C]$ = m^3/s$\cdot$m$^2\cdot$ m$^{2/3}$ = m$^{1/3}$/s

1.19 a) pressure: $N/m^2 = kg \cdot m/s^2/m^2 = kg/m\cdot s^2$

b) energy: $N\cdot m = kg \cdot m/s^2 \times m = kg\cdot m^2/s^2$

c) power: $N\cdot m/s = kg \cdot m^2/s^3$

d) viscosity: $N\cdot s/m^2 = \frac{kg\cdot m}{s^2}\cdot s\frac{1}{m^2} = kg/m\cdot s$

e) heat flux: $J/s = \frac{N\cdot m}{s} = \frac{kg\cdot m}{s^2}\cdot\frac{m}{s} = kg\cdot m^2/s^3$

f) specific heat: $\frac{J}{kg\cdot K} = \frac{N\cdot m}{kg\cdot K} = \frac{kg\cdot m}{s^2}\cdot\frac{m}{kg\cdot K} = m^2/K\cdot s^2$

1.20 $kg\frac{m}{s^2} + c\frac{m}{s} + km = f$. Since all terms must have the same dimensions (units) we require:

$[c] = kg/s,\ [k] = kg/s^2 = N\cdot s^2/m\cdot s^2 = N/m,\ [f] = kg\cdot m/s^2 = N.$

Note: we could express the units on c as $[c] = kg/s = N\cdot s^2/m\cdot s = N\cdot s/m$

1.21 a) 250 kN b) 572 GPa c) 42 nPa d) 17.6 cm^3 e) 1.2 cm^2 f) 76 mm^3

1.22 a) 1.25×10^8 N b) 3.21×10^{-5} s c) 6.7×10^8 Pa d) 5.6×10^{-12} m^3 e) 5.2×10^{-2} m^2 f) 7.8×10^9 m^3

1.23 $$\lambda = 0.225\frac{0.06854m}{0.00194\rho\times3.281^2 d^2} = 0.738\frac{m}{\rho d^2}$$

where m is in slugs, ρ in slug/ft^3 and d in feet. We used the conversions in the front cover.

1.24 a) 20 cm/hr = $\frac{20/100}{3600} = 5.555\times10^{-5}$ m/s

b) 2000 rev/min = $2000\times2\pi/60$ = 209.4 rad/s

c) 50 Hp = 50×745.7 = 37 285 W

d) 100 ft^3/min = $100\times0.02832/60$ = 0.0472 m^3/s

e) 2000 kN/cm^2 = 2×10^6 N/cm$^2\times100^2$ cm^2/m^2 = 2×10^{10} N/m^2

f) 4 slug/min = $4\times14.59/60$ = 0.9727 kg/s

g) 500 g/L = 500×10^{-3} kg/10^{-3} m^3 = 500 kg/m^3

h) 500 kWh = $500\times1000\times3600 = 1.8\times10^9$ J

1.25 a) $F = ma = 10\times40 = \underline{400\text{ N}}$.

b) $F - W = ma.$ $\therefore\ F = 10\times40 + 10\times9.81 = \underline{498.1\text{ N}}$.

c) $F - W\sin30° = ma.$ $\therefore\ F = 10\times40 + 9.81\times0.5 = \underline{449\text{ N}}$.

1.26 The mass is the same on the earth and the moon:

$$m = \frac{60}{32.2} = 1.863.\quad \therefore\ W_{moon} = 1.863\times5.4 = \underline{10.06\text{ lb}}$$

1.27 a) $\lambda = 0.225\dfrac{m}{\rho d^2} = 0.225\dfrac{4.8\times10^{-26}}{0.184\times(3.7\times10^{-10})^2} = 0.43\times10^{-6}\,\text{m}$ or $\underline{0.00043\text{ mm}}$

b) $\lambda = 0.225\dfrac{m}{\rho d^2} = 0.225\dfrac{4.8\times10^{-26}}{0.00103\times(3.7\times10^{-10})^2} = 7.7\times10^{-5}\,\text{m}$ or $\underline{0.077\text{ mm}}$

c) $\lambda = 0.225\dfrac{m}{\rho d^2} = 0.225\dfrac{4.8\times10^{-26}}{0.00002\times(3.7\times10^{-10})^2} = 0.0039\text{ m}$ or $\underline{3.9\text{ mm}}$

Pressure and Temperature

1.28 Use the values from Table B.3 in the Appendix.

a) 52.3 + 101.3 = 153.6 kPa.
b) 52.3 + 89.85 = 142.2 kPa.
c) 52.3 + 54.4 = 106.7 kPa (use a straight-line interpolation).
d) 52.3 + 26.49 = 78.8 kPa.
e) 52.3 + 1.196 = 53.5 kPa.

1.29 a) 101 – 31 = 70 kPa abs.

b) $760 - \dfrac{31}{101}\times 760 = \underline{527\text{ mm of Hg abs}}$.

c) $14.7 - \dfrac{31}{101}\times 14.7 = \underline{10.2\text{ psia}}$.

d) $34 - \dfrac{31}{101}\times 34 = \underline{23.6\text{ ft of } H_2O\text{ abs}}$.

e) $30 - \dfrac{31}{101}\times 30 = \underline{20.8\text{ in. of Hg abs}}$.

1.30 $p = p_o\, e^{-gz/RT} = 101\, e^{-9.81\times4000/287\times(15+273)} = \underline{62.8\text{ kPa}}$

From Table B.3, at 4000 m: p = 61.6 kPa. The percent error is

$$\%\text{ error} = \frac{62.8 - 61.6}{61.6}\times 100 = \underline{1.95\ \%}.$$

1.31 a) $p = 973 + \dfrac{22{,}560 - 20{,}000}{25{,}000 - 20{,}000}(785 - 973) = \underline{877\text{ psf}}$

$T = -12.3 + \dfrac{22{,}560 - 20{,}000}{25{,}000 - 20{,}000}(-30.1 + 12.3) = \underline{-21.4°\text{F}}$

b) $p = 973 + 0.512\,(785 - 973) + \dfrac{0.512}{2}(-0.488)\,(628 - 2\times785 + 973) = \underline{873\text{ psf}}$

$T = -12.3 + 0.512\,(-30.1 + 12.3) + \dfrac{0.512}{2}(-0.488)\,(-48 + 2\times30.1 - 12.3) = \underline{-21.4°\text{F}}$

Note: The results in (b) are more accurate than the results in (a). When we use a linear interpolation, we lose significant digits in the result.

1.32 $T = -48 + \dfrac{33{,}000 - 30{,}000}{35{,}000 - 30{,}000}(-65.8 + 48) = \underline{-59°\text{F}}$ or $(-59 - 32)\dfrac{5}{9} = \underline{-50.6°\text{C}}$

1.33 $p = \frac{F_n}{A} = \frac{26.5\cos 42^\circ}{152\times 10^{-4}} = 1296\text{ MN/m}^2 = \underline{1296\text{ MPa}}.$

1.34 $\left.\begin{array}{l} F_n = (120\,000)\times 0.2\times 10^{-4} = 2.4\text{ N} \\ F_t = 20\times 0.2\times 10^{-4} = 0.0004\text{ N}\end{array}\right\} F = \sqrt{F_n^2 + F_t^2} = \underline{2.400\text{ N}}.$

$$\theta = \tan^{-1}\frac{0.0004}{2.4} = \underline{0.0095^\circ}$$

Density and Specific Weight

1.35 $\rho = \frac{m}{V} = \frac{0.2}{180/1728} = \underline{1.92\text{ slug/ft}^3}.$ $\gamma = \rho g = 1.92\times 32.2 = \underline{61.8\text{ lb/ft}^3}.$

1.36 $\rho = 1000 - (T-4)^2/180 = 1000 - (70-4)^2/180 = \underline{976\text{ kg/m}^3}$
$\gamma = 9800 - (T-4)^2/18 = 9800 - (70-4)^2/180 = \underline{9560\text{ N/m}^3}$

$$\%\text{ error for } \rho = \frac{976-978}{978}\times 100 = \underline{-0.20\%}$$

$$\%\text{ error for } \gamma = \frac{9560 - 978\times 9.81}{978\times 9.81}\times 100 = \underline{-0.36\%}$$

1.37 $S = 13.6 - 0.0024T = 13.6 - 0.0024\times 50 = 13.48.$

$$\%\text{ error} = \frac{13.48-13.6}{13.6}\times 100 = \underline{-0.88\%}$$

1.38 a) $m = \frac{W}{g} = \frac{\gamma V}{g} = \frac{12\,400\times 500\times 10^{-6}}{9.81} = \underline{0.632\text{ kg}}$

b) $m = \frac{12\,400\times 500\times 10^{-6}}{9.77} = \underline{0.635\text{ kg}}$

c) $m = \frac{12\,400\times 500\times 10^{-6}}{9.83} = \underline{0.631\text{ kg}}$

1.39 $S = \frac{\rho}{\rho_{water}} = \frac{m/V}{\rho_{water}}.$ $1.2 = \frac{10/V}{1.94}.$ $\therefore V = \underline{4.30\text{ ft}^3}$

Viscosity

1.40 Assume carbon dioxide is an ideal gas at the given conditions, then

$$\rho = \frac{p}{RT} = \frac{200 \text{ kN/m}^3}{(0.189 \text{ kJ/kg}\cdot\text{K})(90+273)\text{ K}} = 2.915 \text{ kg/m}^3$$

$$\gamma = \frac{W}{V\!\!\!/} = \frac{mg}{V\!\!\!/} = \rho g = 2.915 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 = 28.6 \text{ kg/m}^2\cdot\text{s}^2 = \underline{28.6 \text{ N/m}^3}$$

From Fig. B.1 at 90°C, $\mu \cong 2\times10^{-5}\ \text{N}\cdot\text{s/m}^2$, so that the kinematic viscosity is

$$\nu = \frac{\mu}{\rho} = \frac{2\times10^{-5}\ \text{N}\cdot\text{s/m}^2}{2.915 \text{ kg/m}^3} = \underline{6.861\times10^{-6}\ \text{m}^2\text{/s}}$$

The kinematic viscosity cannot be read from Fig. B.2; the pressure is not 100 kPa.

1.41 At equilibrium the weight of the piston is balanced by the resistive force in the oil due to wall shear stress. This is represented by

$$W_{piston} = \tau \times \pi DL$$

where D is the diameter of the piston and L is the piston length. Since the gap between the piston and cylinder is small, assume a linear velocity distribution in the oil due to the piston motion. That is, the shear stress is

$$\tau = \mu\frac{\Delta V}{\Delta r} = \mu\frac{V_{piston} - 0}{(D_{cylinder} - D_{piston})/2}$$

Using $W_{piston} = m_{piston}g$, we can write

$$m_{piston}g = \left[\mu\frac{V_{piston}}{(D_{cylinder} - D_{piston})/2}\right]\times \pi DL$$

Solve V_{piston}:

$$V_{piston} = \frac{m_{piston}g(D_{cylinder} - D_{piston})}{2\mu(\pi DL)}$$

$$= \frac{(0.350 \text{ kg})(9.81 \text{ m/s}^2)(0.1205 - 0.120)\text{ m}}{2\times(0.025\ \text{N}\cdot\text{s/m}^2)(\pi\times0.12\times0.10 \text{ m}^2)} = 0.91 \text{ kg}\cdot\text{m}^2\text{/N}\cdot\text{s}^3 = 0.91 \text{ m/s}$$

where we used N = kg·m/s^2.

1.42 The shear stress can be calculated using $\tau = \mu|du/dy|$. From the given velocity distribution,

$$u(y) = 120(0.05y - y^2) \;\Rightarrow\; \frac{du}{dy} = 120(0.05 - 2y)$$

From Table B.1 at 10°C, $\mu = 1.308\times10^{-3}\ \text{N}\cdot\text{s/m}^2$ so, at the lower plate where $y = 0$,

$$\left.\frac{du}{dy}\right|_{y=0} = 120(0.05-0) = 6\ \text{s}^{-1} \;\Rightarrow\; \tau = 1.308\times10^{-3}\times 6 = \underline{7.848\times10^{-3}\ \text{N/m}^2}$$

At the upper plate where $y = 0.05$ m,

$$\left|\frac{du}{dy}\right|_{y=0.05} = |120(0.05 - 2\times0.05)| = 6\ \text{s}^{-1} \;\Rightarrow\; \tau = \underline{7.848\times10^{-3}\ \text{N/m}^2}$$

1.43 $\tau = \mu\left|\dfrac{du}{dr}\right| = 1.92\times10^{-5}\left[\dfrac{30(2\times1/12)}{(1/12)^2}\right] = \underline{0.014\ \text{lb/ft}^2}$

1.44 $\left[\dfrac{30(2\times1/12)}{(1/12)^2}\right]\ \tau = \mu\left|\dfrac{du}{dr}\right| = \mu[32r/r_0^2] = 32\mu r/r_0^2.$ $\quad\therefore \tau_{r=0} = 0,$

$$\tau_{r=0.25} = 32\times1\times10^{-3}\times\frac{0.25/100}{(0.5/100)^2} = \underline{3.2\ \text{Pa}},$$

$$\tau_{r=0.5} = 32\times1\times10^{-3}\times\frac{0.5/100}{(0.5/100)^2} = \underline{6.4\ \text{Pa}}$$

1.45 $T = \text{force}\times\text{moment arm} = \tau\,2\pi RL\times R = \mu\left|\dfrac{du}{dr}\right|2\pi R^2L = \mu\left(\dfrac{0.4}{R^2}+1000\right)2\pi R^2L.$

$$\therefore \mu = \frac{T}{\left(\dfrac{0.4}{R^2}+1000\right)2\pi R^2L} = \frac{0.0026}{\left(\dfrac{0.4}{12}+1000\right)2\pi\times.01^2\times0.2} = \underline{0.414\ \text{N·s/m}^2.}$$

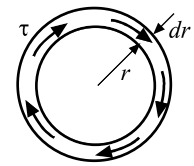
1.46 Use Eq.1.5.8: $T = \dfrac{2\pi R^3\omega L\mu}{h} = \dfrac{2\pi\times\ 0.5/12\ ^3\times\dfrac{2000\times2\pi}{60}\times4\times0.006}{0.01/12} = \underline{2.74\ \text{ft-lb}}.$

$$power = \frac{T\omega}{550} = \frac{2.74\times209.4}{550} = \underline{1.04\ \text{hp}}$$

1.47 $F_{belt} = \mu \dfrac{du}{dy} A = 1.31\times 10^{-3} \dfrac{10}{0.002}$ $(0.6 \times 4) = 15.7$ N.

$$power = \frac{F\times V}{746} = \frac{15.7\times 10}{746} = \underline{0.210} \text{ hp}$$

1.48 Assume a linear velocity so $\dfrac{du}{dy} = \dfrac{r\omega}{h}$. Due to the area element shown, $dT = dF \times r = \tau dA \times r = \mu \dfrac{du}{dy}\, 2\pi r\, dr \times r$.



$$T = \int_0^R \frac{\mu\omega 2\pi}{h} r^3 dr = \frac{2\pi\mu\omega}{h}\frac{R^4}{4} = \frac{\pi\times 2.36\times 10^{-5}\times \frac{400\times 2\pi}{60}\times (3/12)^4}{2\times 0.08/12} = \underline{91 \times 10^{-5} \text{ ft-lb}}.$$

1.49 The velocity at a radius r is $r\omega$. The shear stress is $\tau = \mu \dfrac{\Delta u}{\Delta y}$.

The torque is $dT = \tau r dA$ on a differential element. We have

$$T = \int \tau r dA = \int_0^{0.08} \mu \frac{r\omega}{0.0002} 2\pi r dx\,, \qquad \omega = \frac{2000\times 2\pi}{60} = 209.4 \text{ rad/s}$$

where x is measured along the rotating surface. From the geometry $x = \sqrt{2}\, r$, so that

$$T = \int_0^{0.08} 0.1 \frac{209.4\times x/\sqrt{2}}{0.0002} 2\pi \frac{x}{\sqrt{2}} dx = 329\,000 \int_0^{0.08} x^2 dx = \frac{329\,000}{3}(0.08^3) = \underline{56.1 \text{ N}\cdot\text{m}}$$

1.50 If $\tau = \mu \dfrac{du}{dy}$ = cons't and $\mu = Ae^{B/T} = Ae^{By/K} = Ae^{Cy}$, then

$$Ae^{Cy}\frac{du}{dy} = \text{cons't}. \qquad \therefore \frac{du}{dy} = De^{-Cy}.$$

Finally, or $u(y) = -\dfrac{D}{C} e^{-Cy}\Big|_0^y = \underline{E\,(e^{-Cy} - 1)}$ where $A, B, C, D, E,$ and K are constants.

1.51 $\mu = Ae^{B/T}$ $\quad \left.\begin{array}{r} 0.001 = Ae^{B/293} \\ 0.000357 = Ae^{B/353}\end{array}\right\}$ $\quad \therefore A = 2.334 \times 10^{-6}, B = 1776.$

$\mu_{40} = 2.334 \times 10^{-6}\, e^{1776/313} = \underline{6.80 \times 10^{-4} \text{ N}\cdot\text{s/m}^2}$

Compressibility

1.52 $m = \rho V$. Then $dm = \rho dV + V d\rho$. Assume mass to be constant in a volume subjected to a pressure increase; then $dm = 0$. $\therefore \rho dV = -V d\rho$, or $\frac{dV}{V} = -\frac{d\rho}{\rho}$.

1.53 $B = -\frac{V\Delta p}{\Delta V} = 2200$ MPa. $\therefore \Delta V = \frac{-V\Delta p}{B} = \frac{-2\times 10}{2200} = -\underline{0.00909 \text{ m}^3}$ or $-\underline{9090 \text{ cm}^3}$

1.54 Use $c = 1450$ m/s. $L = c\Delta t = 1450 \times 0.62 = \underline{899 \text{ m}}$

1.55 $\Delta p = -\frac{B\Delta V}{V} = -2100\,\frac{-1.3}{20} = \underline{136.5 \text{ MPa}}$

1.56 a) $c = \sqrt{327{,}000 \times 144/1.93} = \underline{4670 \text{ fps}}$ b) $c = \sqrt{327{,}000 \times 144/1.93} = \underline{4940 \text{ fps}}$
c) $c = \sqrt{308{,}000 \times 144/1.87} = \underline{4870 \text{ fps}}$

1.57 $\Delta V = 3.8 \times 10^{-4} \times -20 \times 1 = \underline{0.0076 \text{ m}^3}$. $\Delta p = -B\,\frac{\Delta V}{V} = -2270\frac{-0.0076}{1} = \underline{17.25 \text{ MPa}}$

Surface Tension

1.58 $p = \frac{2\sigma}{R} = \frac{2\times 0.0741}{5\times 10^{-6}} = 2.96 \times 10^4$ Pa or $\underline{29.6 \text{ kPa.}}$ Bubbles: $p = 4\sigma/R = \underline{59.3 \text{ kPa}}$

1.59 Use Table B.1: $\sigma = 0.00504$ lb/ft. $\therefore p = \frac{4\sigma}{R} = \frac{4\times 0.00504}{1/(32\times 12)} = 7.74$ psf or $\underline{0.0538 \text{ psi}}$

1.60 The droplet is assumed to be spherical. The pressure inside the droplet is greater than the outside pressure of 8000 kPa. The difference is given by Eq. 1.5.13:

$$\Delta p = \frac{2\sigma}{r} \quad \Rightarrow \quad p_{inside} - p_{outside} = \frac{2\times 0.025 \text{ N/m}}{5\times 10^{-6} \text{ m}} = 10 \text{ kPa}$$

Hence,

$$p_{inside} = p_{outside} + 10 \text{ kPa} = 8000 + 10 = \underline{8010 \text{ kPa}}$$

In order to achieve this high pressure in the droplet, diesel fuel is usually pumped to a pressure of about 20 000 kPa before it is injected into the engine.

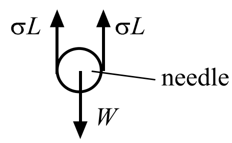
1.61 See Example 1.4: $h = \frac{4\sigma\cos\beta}{\rho g D} = \frac{4\times 0.0736\times 0.866}{1000\times 9.81\times 0.0002} = \underline{0.130 \text{ m.}}$

1.62 See Example 1.4: $h = \dfrac{4\sigma\cos\beta}{\rho g D} = \dfrac{4 \times 0.032 \cos 130^\circ}{1.94 \times 13.6 \times 32.2 \times 0.8/12}$

$= -0.00145$ ft or $\underline{-0.0174 \text{ in}}$

1.63 force up = $\sigma \times L \times 2\cos\beta$ = force down = $\rho g h t L$. $\therefore h = \dfrac{2\sigma\cos\beta}{\rho g t}$.

1.64 Draw a free-body diagram:
The force must balance:



$$W = 2\sigma L \text{ or } \left(\frac{\pi d^2}{4} L\right)\rho g = 2\sigma L.$$

$$\therefore d = \sqrt{\frac{8\sigma}{\pi \rho g}}$$

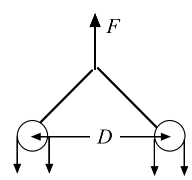
1.65 From the free-body diagram in No. 1.47, a force balance yields:

Is $\dfrac{\pi d^2}{4}\rho g < 2\sigma$? $\quad \dfrac{\pi(0.004)^2}{4} 7850 \times 9.81 < 2 \times 0.0741$

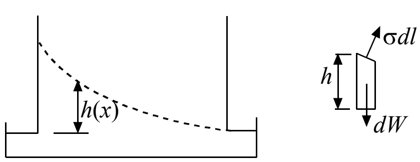
$0.968 < 0.1482 \quad \therefore$ No

1.66 Each surface tension force = $\sigma \times \pi D$. There is a force on the outside and one on the inside of the ring.

$\therefore F = \underline{2\sigma\pi D}$ neglecting the weight of the ring.



1.67



From the infinitesimal free-body shown:

$\sigma d\ell \cos\theta = \rho g h \alpha x\, dx. \qquad \cos\theta = \dfrac{dx}{d\ell}.$

$$\therefore h = \frac{\sigma d\ell\, dx/d\ell}{\rho g \alpha x dx} = \frac{\sigma}{\rho g \alpha x}$$

We assumed small α so that the element thickness is αx.

Vapor Pressure

1.68 The absolute pressure is $p = -80 + 92 = 12$ kPa. At 50°C water has a vapor pressure of 12.2 kPa; so $T = \underline{50°\text{C}}$ is a maximum temperature. The water would "boil" above this temperature.

1.69 The engineer knew that water boils near the vapor pressure. At 82°C the vapor pressure from Table B.1 is 50.8 (by interpolation). From Table B.3, the elevation that has a pressure of 50.8 kPa is interpolated to be 5500 m.

1.70 At 40°C the vapor pressure from Table B.1 is 7.4 kPa. This would be the minimum pressure that could be obtained since the water would vaporize below this pressure.

1.71 The absolute pressure is 14.5 – 11.5 = 3.0 psia. If bubbles were observed to form at 3.0 psia (this is boiling), the temperature from Table B.1 is interpolated, using vapor pressure, to be 141°F.

1.72 The inlet pressure to a pump cannot be less than 0 kPa absolute. Assuming atmospheric pressure to be 100 kPa, we have

$$10\,000 + 100 = 600\,x. \qquad \therefore x = \underline{16.83\text{ km}}.$$

Ideal Gas

1.73 $\rho = \dfrac{p}{RT} = \dfrac{101.3}{0.287 \times (273+15)} = \underline{1.226\text{ kg/m}^3}. \quad \gamma = 1.226 \times 9.81 = \underline{12.03\text{ N/m}^3}$

1.74 $\rho_{\text{in}} = \dfrac{p}{RT} = \dfrac{101.3}{0.287 \times (15+273)} = \underline{1.226\text{ kg/m}^3}. \quad \rho_{\text{out}} = \dfrac{85}{0.287 \times 248} = \underline{1.19\text{ kg/m}^3}.$

Yes. The heavier air outside enters at the bottom and the lighter air inside exits at the top. A circulation is set up and the air moves from the outside in and the inside out: infiltration. This is the "chimney" effect.

1.75 $\rho = \dfrac{p}{RT} = \dfrac{750 \times 44}{1716 \times 470} = \underline{0.1339\text{ slug/ft}^3}. \qquad m = \rho V\!\!\!\!- = 0.1339 \times 15 = \underline{2.01\text{ slug}}.$

1.76 $W = \dfrac{p}{RT} V\!\!\!\!- g = \dfrac{100}{0.287 \times 293} \times (10 \times 20 \times 4) \times 9.81 = \underline{9333\text{ N}}.$

1.77 Assume that the steel belts and tire rigidity result in a constant volume so that $m_1 = m_2$:

$$V\!\!\!\!-_1 = V\!\!\!\!-_2 \quad \text{or} \quad \frac{m_1 R T_1}{p_1} = \frac{m_2 R T_2}{p_2}.$$

$$\therefore p_2 = p_1 \frac{T_2}{T_1} = (35+14.7)\frac{150+460}{-10+460} = 67.4\text{ psia or } \underline{52.7\text{ psi gage}}.$$

1.78 The pressure holding up the mass is 100 kPa. Hence, using $pA = W$, we have

$$100\,000 \times 1 = m \times 9.81. \quad \therefore m = 10\,200 \text{ kg.}$$

Hence,

$$m = \frac{pV\!\!\!/}{RT} = \frac{100 \times 4\pi r^3/3}{0.287 \times 288} = 10\,200. \quad \therefore r = 12.6 \text{ m} \quad \text{or} \quad \underline{d = 25.2 \text{ m.}}$$

The First Law

1.79 $0 = \Delta KE + \Delta PE = \frac{1}{2}mV^2 + mg(-10). \quad \therefore V^2 = 20 \times 32.2. \quad \therefore V = \underline{25.4 \text{ fps.}}$

$$0 = \frac{1}{2}mV^2 + mg(-20). \quad \therefore V^2 = 40 \times 32.2. \quad \therefore V = \underline{35.9 \text{ fps.}}$$

1.80 $W_{1\text{-}2} = \Delta KE.$ a) $200 \times 0 = \frac{1}{2} \times 5(V_f^2 - 10^2). \quad \therefore V_f = \underline{19.15 \text{ m/s.}}$

b) $\int_0^{10} 20s\,ds = \frac{1}{2} \times 15(V_f^2 - 10^2).$

$$20 \times \frac{10^2}{2} = \frac{1}{2} \times 15(V_f^2 - 10^2). \quad \therefore V_f = \underline{15.27 \text{ m/s.}}$$

c) $\int_0^{10} 200\cos\frac{\pi s}{20}\,ds = \frac{1}{2} \times 15(V_f^2 - 10^2).$

$$\frac{20}{\pi} \times 200 \sin\frac{\pi}{2} = \frac{1}{2} \times 15(V_f^2 - 10^2). \quad \therefore V_f = \underline{16.42 \text{ m/s.}}$$

1.81 $E_1 = E_2. \quad \frac{1}{2} \times 10 \times 40^2 + 0.2\tilde{u}_1 = 0 + \tilde{u}_2. \quad \therefore \tilde{u}_2 - \tilde{u}_1 = 40\,000.$

$\Delta\tilde{u} = c_v \Delta T. \quad \therefore \Delta T = \frac{40\,000}{717} = \underline{55.8^\circ\text{C}}$ where c_v comes from Table B.4.

The following shows that the units check:

$$\left[\frac{m_{\text{car}} \times V^2}{m_{\text{air}} c}\right] = \frac{\text{kg} \cdot \text{m}^2/\text{s}^2}{\text{kg} \cdot \text{J/(kg} \cdot {}^\circ\text{C)}} = \frac{\text{m}^2 \cdot \text{kg} \cdot {}^\circ\text{C}}{\text{N} \cdot \text{m} \cdot \text{s}^2} = \frac{\text{m}^2 \cdot \text{kg} \cdot {}^\circ\text{C}}{(\text{kg} \cdot \text{m/s}^2) \cdot \text{m} \cdot \text{s}^2} = {}^\circ\text{C}$$

where we used N = kg·m/s^2 from Newton's 2$^{\text{nd}}$ law.

1.82 $E_2 = E_1. \quad \frac{1}{2}mV^2 = m_{\text{H}_2\text{O}} c \Delta T.$

$$\frac{1}{2} \times 1500 \times \left(\frac{100 \times 1000}{3600}\right)^2 = 1000 \times 2000 \times 10^{-6} \times 4180\,\Delta T. \quad \therefore \Delta T = \underline{69.2^\circ\text{C.}}$$

We used c = 4180 J/kg·°C from Table B.5. (See Problem 1.75 for a units check.)

1.83 $m_f h_f = m_{\text{water}} c\Delta T.\quad 0.2\times 40\,000 = 100\times 4.18\,\Delta T.\quad \therefore \Delta T = \underline{19.1^\circ\text{C}}.$
The specific heat c was found in Table B.5. Note: We used kJ on the left and kJ on the right.

1.84 $W = \int p d\mathcal{V} = \int \frac{mRT}{\mathcal{V}} d\mathcal{V} = mRT\int \frac{d\mathcal{V}}{\mathcal{V}} = mRT\ln\frac{\mathcal{V}_2}{\mathcal{V}_1} = mRT\ln\frac{p_2}{p_1}$
since, for the T = const process, $p_1\mathcal{V}_1 = p_2\mathcal{V}_2$. Finally,

$$W_{1\text{-}2} = \frac{4}{32.2}\times 1716\times 530\ln\frac{1}{2} = -78,310 \text{ ft-lb}.$$

The 1st law states: $Q - W = \Delta\tilde{u} = mc_v\Delta T = 0.\quad \therefore Q = W = -78,310$ ft-lb or $\underline{-101\text{ Btu}}$.

1.85 If the volume is fixed the reversible work is zero since the boundary does not move. Also, since $\mathcal{V} = \frac{mRT}{p},\ \frac{T_1}{p_1} = \frac{T_2}{p_2}$ the temperature doubles if the pressure doubles. Hence, using Table B.4 and Eq. 1.7.17,

a) $Q = mc_v\Delta T = \frac{200\times 2}{0.287\times 293}(1.004-0.287)(2\times 293-293) = \underline{999\text{ kJ}}$

b) $Q = mc_v\Delta T = \frac{200\times 2}{0.287\times 373}(1.004-0.287)(2\times 373-373) = \underline{999\text{ kJ}}$

c) $Q = mc_v\Delta T = \frac{200\times 2}{0.287\times 473}(1.004-0.287)(2\times 473-473) = \underline{999\text{ kJ}}$

1.86 $W = \int p d\mathcal{V} = p(\mathcal{V}_2 - \mathcal{V}_1)$. If p = const, $\frac{T_1}{\mathcal{V}_1} = \frac{T_2}{\mathcal{V}_2}$ so if $T_2 = 2T_1$,
then $\mathcal{V}_2 = 2\mathcal{V}_1$ and $W = p(2\mathcal{V}_1 - \mathcal{V}_1) = p\mathcal{V}_1 = mRT_1$.

a) $W = 2\times 0.287\times 333 = \underline{191\text{ kJ}}$

b) $W = 2\times 0.287\times 423 = \underline{243\text{ kJ}}$

c) $W = 2\times 0.287\times 473 = \underline{272\text{ kJ}}$

1.87 $c = \sqrt{kRT} = \sqrt{1.4\times 287\times 318} = 357$ m/s. $L = c\Delta t = 357\times 8.32 = \underline{2970\text{ m}}.$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{k-1/k} = (20+273)\left(\frac{500}{5000}\right)^{0.4/1.4} = 151.8\text{ K or } \underline{-121.2^\circ\text{C}}$$

1.88 We assume an isentropic process for the maximum pressure:

$$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{k/k-1} = (150+100)\left(\frac{423}{293}\right)^{1.4/0.4} = 904\text{ kPa abs or } \underline{804\text{ kPa gage}}.$$

Note: We assumed p_{atm} = 100 kPa since it was not given. Also, a measured pressure is a gage pressure.