CHAPTER 1

Basic Considerations

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

1.2 a) density = mass/volume = M / L^3
b) pressure = force/area = $F / L^2 = ML / T^2 L^2 = M / LT^2$
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 = $\rho AV = M/L^3 \times L^2 \times L/T = M/T$
f) flow rate = $AV = L^2 \times L/T = L^3/T$

1.3 a) density = $\frac{M}{L^3}\frac{FT^2 / L}{L^3} = FT^2 / L^4$
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 = $\frac{M}{T} = \frac{FT^2 / L}{T} = FT / L$
f) flow rate = $AV = L^2 \times L/T = L^3/T$

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

1.5 (**B**) $[\mu] = [\tau/du/dy] = (F/L^2)/(L/T)/L = F{\cdot}T/L^2$.

1.6 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.

1.7 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·m$^2 \cdot$ m$^{2/3}$ = m$^{1/3}$/s

1.8 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 = $\frac{\text{kg} \cdot \text{m}}{\text{s}^2} \cdot \text{s} \frac{1}{\text{m}^2} = \text{kg} / \text{m} \cdot \text{s}$

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

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

1.9 $\text{kg}\frac{\text{m}}{\text{s}^2} + c\frac{\text{m}}{\text{s}} + k\text{m} = f$. Since all terms must have the same dimensions (units) we require:

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

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

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

1.11 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

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

1.13 $\boldsymbol{l} = 0.225\frac{0.06854m}{0.00194\boldsymbol{r}\times3.281^2 d^2} = 0.738\frac{m}{\boldsymbol{r}d^2}$

where m is in slugs, $\boldsymbol{r}$ in slug/ft^3 and d in feet. We used the conversions in the front cover.

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

b) 2000 rev/min = $2000\times 2\pi/60$ = 209.4 rad/s

c) 50 Hp = 50×745.7 = 37 285 W

d) 100 ft^3/min = $100\times 0.02832/60$ = 0.0472 m^3/s

e) 2000 kN/cm^2 = 2×10^6 N/cm$^2\times 100^2$ cm^2/m^2 = 2×10^{10} N/m^2

f) 4 slug/min = $4\times 14.59/60$ = 0.9727 kg/s

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

h) 500 kWh = $500\times 1000\times 3600$ = 1.8×10^9 J

1.15 a) $F = ma = 10\times 40$ = <u>400 N</u>.
b) $F - W = ma$. $\therefore$ $F = 10\times 40 + 10\times 9.81$ = <u>498.1 N</u>.
c) $F - W\sin 30° = ma$. $\therefore$ $F = 10\times 40 + 9.81\times 0.5$ = <u>449 N</u>.

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

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

$m = \dfrac{60}{32.2} = 1.863.\quad \therefore\ W_{\text{moon}} = 1.863 \times 5.4 = \underline{10.06\text{ lb}}$

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

$$\tau = \frac{F_{\text{shear}}}{A} = \frac{2100}{250\times 10^{-4}} = 84\text{ kPa}$$

1.19 a) $\lambda = .225\dfrac{m}{\rho d^2} = .225\dfrac{4.8\times 10^{-26}}{.184\times(3.7\times 10^{-10})^2} = .43\times 10^{-6}\text{ m}$ or $\underline{0.00043\text{ mm}}$

b) $\lambda = .225\dfrac{m}{\rho d^2} = .225\dfrac{4.8\times 10^{-26}}{.00103\times(3.7\times 10^{-10})^2} = 7.7\times 10^{-5}\text{ m}$ or $\underline{0.077\text{ mm}}$

c) $\lambda = .225\dfrac{m}{\rho d^2} = .225\dfrac{4.8\times 10^{-26}}{.00002\times(3.7\times 10^{-10})^2} = .0039\text{ m}$ or $\underline{3.9\text{ mm}}$

1.20 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.

1.21 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) $30 - \dfrac{31}{101}\times 30 = \underline{20.8\text{ in. of Hg abs}}$.

1.22 $p = p_o\, e^{-gz/RT} = 101\, e^{-9.81\times 4000/287\times(15+273)} = \underline{62.8\text{ kPa}}$

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

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

1.23 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) $p = 973 + .512\,(785 - 973) + \dfrac{.512}{2}(-.488)\,(628 - 2\times 785 + 973) = \underline{873\text{ psf}}$

$T = -12.3 + .512\,(-30.1 + 12.3) + \dfrac{.512}{2}(-.488)\,(-48 + 2\times 30.1 - 12.3) = \underline{-21.4°\text{F}}$

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.

1.24 $T = -48 + \dfrac{33{,}000 - 30{,}000}{35{,}000 - 30{,}000}(-65.8 + 48) = \underline{-59°\text{F}}$ or $(-59 - 32)\dfrac{5}{9} = \underline{-50.6°\text{C}}$

1.25 (**B**)

1.26 $p = \dfrac{F_n}{A} = \dfrac{26.5 \cos 42°}{152\times10^{-4}} = 1296 \text{ MN/m}^2 = \underline{1296 \text{ MPa}}.$

1.27 $\left.\begin{aligned} F_\text{n} &= (120000)\times.2\times10^{-4} = 2.4\text{N} \\ F_\text{t} &= 20\times.2\times10^{-4} = .0004\text{N} \end{aligned}\right\} F = \sqrt{F_n^2 + F_t^2} = \underline{2.400 \text{ N}}.$

$\boldsymbol{q} = \tan^{-1}\dfrac{.0004}{2.4} = \underline{.0095°}$

1.28 $\boldsymbol{r} = \dfrac{m}{V} = \dfrac{0.2}{180/1728} = \underline{1.92 \text{ slug/ft}^3}.$ $\boldsymbol{t} = \boldsymbol{r}\text{g} = 1.92 \times 32.2 = \underline{61.8 \text{ lb/ft}^3}.$

1.29 $\boldsymbol{r} = 1000 - (T-4)^2/180 = 1000 - (70-4)^2/180 = \underline{976 \text{ kg/m}^3}$

$\boldsymbol{g} = 9800 - (T-4)^2/18 = 9800 - (70-4)^2/180 = \underline{9560 \text{ N/m}^3}$

% error for $\boldsymbol{r} = \dfrac{976-978}{978} \times 100 = \underline{-.20\%}$

% error for $\boldsymbol{g} = \dfrac{9560 - 978\times9.81}{978\times9.81} \times 100 = \underline{-.36\%}$

1.30 $S = 13.6 - .0024T = 13.6 - .0024 \times 50 = 13.48.$

% error $= \dfrac{13.48-13.6}{13.6} \times 100 = \underline{-.88\%}$

1.31 a) $m = \dfrac{W}{g} = \dfrac{\boldsymbol{g}V}{g} = \dfrac{12\,400\times500\times10^{-6}}{9.81} = \underline{0.632 \text{ kg}}$

b) $m = \dfrac{12\,400\times500\times10^{-6}}{9.77} = \underline{0.635 \text{ kg}}$

c) $m = \dfrac{12\,400\times500\times10^{-6}}{9.83} = \underline{0.631 \text{ kg}}$

1.32 $S = \dfrac{\boldsymbol{r}}{\boldsymbol{r}_{water}} = \dfrac{m/V}{\boldsymbol{r}_{water}}.$ $1.2 = \dfrac{10/V}{1.94}.$ $\therefore V = \underline{4.30 \text{ ft}^3}$

1.33 (**D**) $\boldsymbol{r}_\text{water} = 1000 - \dfrac{(T-4)^2}{180} = 1000 - \dfrac{(80-4)^2}{180} = 968 \text{ kg/m}^3$

1.34 $\boldsymbol{t} = m\left|\frac{du}{dr}\right| = 1.92 \times 10^{-5}\left[\frac{30(2\times 1/12)}{(1/12)^2}\right] = \underline{0.014\ \text{lb/ft}^2}$

1.35 T = force × moment arm = $\boldsymbol{t}\,2\boldsymbol{p}RL \times R = m\left|\frac{du}{dr}\right| 2\boldsymbol{p}R^2L = m\left(\frac{0.4}{R^2}+1000\right)2\pi R^2L.$

$$\therefore m = \frac{T}{\left(\frac{0.4}{R^2}+1000\right)2\boldsymbol{p}R^2L} = \frac{0.0026}{\left(\frac{0.4}{12}+1000\right)2\boldsymbol{p}\times .01^2\times 0.2} = \underline{0.414\ \text{N·s/m}^2.}$$

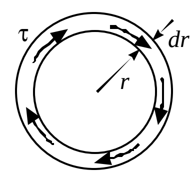
1.36 Use Eq.1.5.8: $T = \frac{2\boldsymbol{p}R^3\boldsymbol{w}L\boldsymbol{m}}{h} = \frac{2\boldsymbol{p}\times(.5/12)^3\times\frac{2000\times 2\boldsymbol{p}}{60}\times 4\times .006}{.01/12} = \underline{2.74\ \text{ft-lb}}.$

$$Hp = \frac{T\boldsymbol{w}}{550} = \frac{2.74\times 209.4}{550} = \underline{1.04\ \text{Hp}}$$

1.37 $F_{belt} = m\frac{du}{dy}A = 1.31\times 10^{-3}\,\frac{10}{.002}\,(.6\times 4) = 15.7\ \text{N}.$

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

1.38 Assume a linear velocity so $\frac{du}{dy} = \frac{r\boldsymbol{w}}{h}$. Due to the area element shown, $dT = dF \times r = \boldsymbol{t}dA \times r = m\,\frac{du}{dy}\,2\boldsymbol{p}r\,dr \times r.$



$$T = \int_0^R \frac{m\boldsymbol{w}2\boldsymbol{p}}{h}r^3dr = \frac{2\boldsymbol{p}m\boldsymbol{w}}{h}\frac{R^4}{4} = \frac{\boldsymbol{p}\times 2.36\times 10^{-5}\times\frac{400\times 2\boldsymbol{p}}{60}\times(3/12)^4}{2\times .08/12} = \underline{91\times 10^{-5}\ \text{ft-lb}}.$$

1.39 $\left[\frac{30(2\times 1/12)}{(1/12)^2}\right]\boldsymbol{t} = m\left|\frac{du}{dr}\right| = m[32r/r_0^2] = 32mr/r_0^2.$ $\therefore \boldsymbol{t}_{r=0} = 0,$

$$\boldsymbol{t}_{r=0.25} = 32\times 1\times 10^{-3}\times\frac{.25/100}{(.5/100)^2} = \underline{3.2\ \text{Pa}},\quad \boldsymbol{t}_{r=0.5} = 32\times 1\times 10^{-3}\times\frac{.5/100}{(.5/100)^2} = \underline{6.4\ \text{Pa}}$$

1.40 (**A**) $\boldsymbol{t} = m\left|\frac{du}{dr}\right| = m[10\times 5000r] = 10^{-3}\times 10\times 5000\times 0.02 = 1\ \text{Pa}.$

1.41 The velocity at a radius r is $r\boldsymbol{w}$. The shear stress is $\boldsymbol{t} = m\frac{\Delta u}{\Delta y}$.

The torque is $dT = \boldsymbol{t}rdA$ on a differential element. We have

$$T = \int t r dA = \int_0^{0.08} m \frac{r w}{0.0002} 2 p r dx\,, \qquad w = \frac{2000\times 2 p}{60} = 209.4 \text{ rad/s}$$

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

$$T = \int_0^{0.08} 0.1 \frac{209.4\times x/\sqrt{2}}{0.0002} 2 p \frac{x}{\sqrt{2}} dx = 329000 \int_0^{0.08} x^2 dx = \frac{329000}{3}(0.08^3) = \underline{56.1 \text{ N}\cdot\text{m}}$$

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

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

Finally, $\int_0^u du = \int_0^y De^{-Cy} dy$ 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.

1.43 $\left.\begin{aligned} m = Ae^{B/T} \quad .001 &= Ae^{B/293} \\ .000357 &= Ae^{B/353} \end{aligned}\right\} \quad \therefore A = 2.334\times 10^{-6},\ B = 1776.$

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

1.44 $m = r V$. Then $dm = r dV + V dr$. Assume mass to be constant in a volume subjected to a pressure increase; then $dm = 0$. $\therefore r dV = -V dr$, or $\dfrac{dV}{V} = -\dfrac{dr}{r}$.

1.45 $B = -\dfrac{V\Delta p}{\Delta V} = 2200$ MPa. $\therefore \Delta V = \dfrac{-V\Delta p}{B} = \dfrac{-2\times 10}{2200} = -\underline{0.00909 \text{ m}^3}$ or $-\underline{9090 \text{ cm}^3}$

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

1.47 $\Delta p = -\dfrac{B\Delta V}{V} = -2100\ \dfrac{-1.3}{20} = \underline{136.5 \text{ MPa}}$

1.48 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) $c = \sqrt{308{,}000\times 144/1.87} = \underline{4870 \text{ fps}}$

1.49 $\Delta V = 3.8\times 10^{-4}\times -20\times 1 = \underline{.0076 \text{ m}^3}$.

$$\Delta p = -B\frac{\Delta V}{V} = -2270\frac{-.0076}{1} = \underline{17.25 \text{ MPa}}$$

1.50 $p = \dfrac{2s}{R} = \dfrac{2\times .0741}{5\times 10^{-6}} = 2.96\times 10^4$ Pa or $\underline{29.6 \text{ kPa.}}$ Bubbles: $p = 4s/R = \underline{59.3 \text{ kPa}}$

1.51 Use Table B.1: $\sigma = 0.00504$ lb/ft. $\therefore p = \frac{4\sigma}{R} = \frac{4\times.00504}{1/32\times 12}$ = 7.74 psf or <u>0.0538 psi</u>

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

1.53 (**D**) $h = \frac{4\sigma\cos\beta}{\rho g D} = \frac{4\times 0.0736\times 1}{1000\times 9.81\times 10\times 10^{-6}} = 3$ m or 300 cm.

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

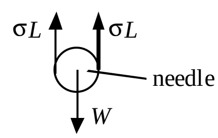
$= -0.00145$ ft or <u>-0.0174 in</u>

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

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

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

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



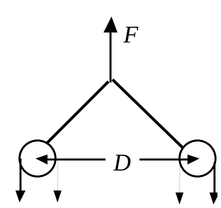
1.57 From the free-body diagram in No. 1.47, a force balance yields:

Is $\frac{\pi d^2}{4}\rho g < 2\sigma$? $\qquad \frac{\pi(.004)^2}{4}7850\times 9.81 < 2\times.0741$

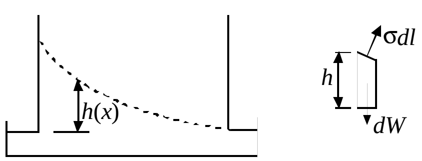
$0.968 < 0.1482 \qquad \therefore$ No

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

$\therefore F =$ <u>$2\sigma\pi D$</u> neglecting the weight of the ring.



1.59



From the infinitesimal free-body shown:

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

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

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

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

1.61 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 <u>5500 m</u>.

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

1.63 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 <u>141°F</u>.

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

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

1.65 (**C**)

1.66 $\rho = \dfrac{p}{RT} = \dfrac{101.3}{0.287 \times (273 + 15)} = \underline{1.226\text{ kg/m}^3}. \quad \gamma = 1.226 \times 9.81 = \underline{12.03\text{ N/m}^3}$

1.67 $\rho_{\text{in}} = \dfrac{p}{RT} = \dfrac{101.3}{0.287 \times (15 + 273)} = \underline{1.226\text{ kg/m}^3}. \quad \rho_{\text{out}} = \dfrac{85}{0.287 \times 248} = \underline{1.19\text{ kg/m}^3}.$

<u>Yes.</u> 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.

1.68 $\rho = \dfrac{p}{RT} = \dfrac{750 \times 44}{1716 \times 470} = \underline{0.1339\text{ slug/ft}^3}. \qquad m = \rho V = 0.1339 \times 15 = \underline{2.01\text{ slug.}}$

1.69 (**C**) $m = \dfrac{pV}{RT} = \dfrac{800 \times 4}{0.1886 \times (10 + 273)} = \underline{59.95\text{ kg}}$

1.70 $W = \dfrac{p}{RT} V g = \dfrac{100}{0.287 \times 293} \times (10 \times 20 \times 4) \times 9.81 = \underline{9333\text{ N.}}$

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

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

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

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

$$100000 \times 1 = m \times 9.81. \quad \therefore m = 10200 \text{ kg.}$$

Hence,

$$m = \frac{p\mathcal{V}}{RT} = \frac{100 \times 4\pi r^3/3}{0.287 \times 288} = 10200. \quad \therefore r = 12.6 \text{ m} \quad \text{or} \quad \underline{d = 25.2 \text{ m}}.$$

1.73 $$0 = \Delta KE + \Delta PE = \frac{1}{2} m V^2 + mg(-10). \quad \therefore V^2 = 20 \times 32.2. \quad \therefore V = \underline{25.4 \text{ fps.}}$$

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

1.74 $$W_{1\text{-}2} = \Delta KE. \quad \text{a) } 200 \times 0 = \frac{1}{2} \times 5(V_f^2 - 10^2). \quad \therefore V_f = \underline{19.15 \text{ m/s.}}$$

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

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

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

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

1.75 $$E_1 = E_2. \quad \frac{1}{2} \times 10 \times 40^2 + 0.2\tilde{u}_1 = 0 + \tilde{u}_2. \quad \therefore \tilde{u}_2 - \tilde{u}_1 = 40000.$$

$$\Delta\tilde{u} = c_v \Delta T. \quad \therefore \Delta T = \frac{40000}{717} = \underline{55.8^\circ \text{C}} \text{ where } c_v \text{ comes from Table B.4.}$$

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 2nd law.

1.76 $E_2 = E_1$. $\dfrac{1}{2}mV^2 = m_{H_2O}c\Delta T$.

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

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

1.77 $m_f h_f = m_{\text{water}} c\Delta T$. $0.2\times 40000 = 100\times 4.18\Delta T$. $\therefore \Delta T = \underline{19.1^\circ\text{C.}}$

The specific heat c was found in Table B.5. Note: We used kJ on the left and kJ on the right.

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

$$5\times(40\times 10^{-6})\times 1000\times 320 = (2\times 10^{-3})\times 1000\times 4.18\Delta T. \quad \therefore \Delta T = \underline{7.66^\circ\text{C.}}$$

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.

1.79. $$W = \int p\,d\mathcal{V} = \int \frac{mRT}{\mathcal{V}}d\mathcal{V} = mRT\int\frac{d\mathcal{V}}{\mathcal{V}} = mRT\ln\frac{\mathcal{V}_2}{\mathcal{V}_1} = mRT\ln\frac{p_2}{p_1}$$

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 that

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

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

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

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

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

1.81 $W = \int p\,d\mathcal{V} = p(\mathcal{V}_2 - \mathcal{V}_1)$. If p = const, $\dfrac{T_1}{\mathcal{V}_1} = \dfrac{T_2}{\mathcal{V}_2}$ 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) $W = 2\times 0.287\times 473 = \underline{272 \text{ kJ}}$

1.82 $c=\sqrt{kRT} = \sqrt{1.4\times 287\times 318} = 357$ m/s. $L = c\Delta t = 357\times 8.32 = \underline{2970 \text{ m}}$.

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

1.83 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.

1.84 $$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{k/k-1} = 100\left(\frac{473}{293}\right)^{1.4/0.4} = \underline{534 \text{ kPa}} \text{ abs.}$$

$w = -\Delta u = -c_v(T_2 - T_1) = -(1.004 - 0.287)(473 - 293) = \underline{-129 \text{ kJ/kg}}.$

We used Eq. 1.7.17 for c_v.

1.85 a) $c = \sqrt{kRT} = \sqrt{1.4\times 287\times 293} = \underline{343.1 \text{ m/s}}$

b) $c = \sqrt{kRT} = \sqrt{1.4\times 188.9\times 293} = \underline{266.9 \text{ m/s}}$

c) $c = \sqrt{kRT} = \sqrt{1.4\times 296.8\times 293} = \underline{348.9 \text{ m/s}}$

d) $c = \sqrt{kRT} = \sqrt{1.4\times 4124\times 293} = \underline{1301 \text{ m/s}}$

e) $c = \sqrt{kRT} = \sqrt{1.4\times 461.5\times 293} = \underline{424.1 \text{ m/s}}$

Note: We must use the units on R to be J/kgK in the above equations.

1.86 (**D**) For this high-frequency wave, $c = \sqrt{RT} = \sqrt{287\times 323} = 304$ m/s.

1.87 At 10 000 m the speed of sound $c = \sqrt{kRT} = \sqrt{1.4\times 287\times 223} = 299$ m/s.

At sea level, $c = \sqrt{kRT} = \sqrt{1.4\times 287\times 288} = 340$ m/s.

$$\text{\% decrease} = \frac{340-299}{340}\times 100 = \underline{12.06\ \%}.$$

1.88 a) $c=\sqrt{kRT} = \sqrt{1.4\times 287\times 253} = 319$ m/s. $L = c\Delta t = 319\times 8.32 = \underline{2654 \text{ m.}}$

b) $c=\sqrt{kRT} = \sqrt{1.4\times 287\times 293} = 343$ m/s. $L = c\Delta t = 343\times 8.32 = \underline{2854 \text{ m.}}$

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