Chapter 1

Properties of Fluids

1.1. (a) Find the dimensions of C_L as follows,

$$C_\mathrm{L} = \frac{F_\mathrm{L}}{\frac{1}{2}\rho V^2 A} \quad \rightarrow \quad C_\mathrm{L} = \frac{\mathrm{MLT^{-2}}}{(\mathrm{ML^{-3}})(\mathrm{LT^{-1}})^2(\mathrm{L^2})} = \frac{\mathrm{MLT^{-2}}}{\mathrm{MLT^{-2}}} = 1$$

Therefore C_L is $\boxed{\text{dimensionless}}$ and does not depend on the system of units used.

(b) $\boxed{\text{No adjustment factor}}$ is necessary when USCS units are used instead of SI units.

1.2. (a) Inserting the dimensions of the variables in the given equation yields

$$\rho\frac{\mathrm{d}^2 z}{\mathrm{d}t^2} + a\frac{\mathrm{d}z}{\mathrm{d}t} + bz = c$$

$$\left[\frac{\mathrm{M}}{\mathrm{L}^3}\right]\left[\frac{\mathrm{L}}{\mathrm{T}^2}\right] + a\left[\frac{\mathrm{L}}{\mathrm{T}}\right] + b[\mathrm{L}] = c$$

$$\left[\frac{\mathrm{M}}{\mathrm{L}^2\mathrm{T}^2}\right] + a\left[\frac{\mathrm{L}}{\mathrm{T}}\right] + b[\mathrm{L}] = c$$

Therefore, the required dimensions of the parameters a, b, and c are,

$$\boxed{a = \left[\frac{\mathrm{M}}{\mathrm{L}^3\mathrm{T}}\right], \qquad b = \left[\frac{\mathrm{M}}{\mathrm{L}^3\mathrm{T}^2}\right], \qquad c = \left[\frac{\mathrm{M}}{\mathrm{L}^2\mathrm{T}^2}\right]}$$

(b) If ρ^*, z^*, and t^* are the given variables in nonstandard units, then the conversion factors are:

$$\boxed{\frac{\rho}{\rho^*} = 10^3, \qquad \frac{z}{z^*} = 10^{-3}, \qquad \frac{t}{t^*} = 3600}$$

1.3. (a) Inserting the dimensions of the variables in the given equation yields

$$Q = \frac{1}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}S_0^{\frac{1}{2}} \quad \rightarrow \quad \mathrm{L^3T^{-1}} = \frac{1}{(-)}\frac{(\mathrm{L}^2)^{\frac{5}{3}}}{\mathrm{L}^{\frac{2}{3}}}(-)^{\frac{1}{2}} \quad \rightarrow \quad \mathrm{L^3T^{-1}} = \mathrm{L}^{\frac{8}{3}}$$

Since the dimension of the left-hand side of the equation is not equal to the dimension on the right-hand side of the equation, the given equation is $\boxed{\text{not dimensionally homogeneous}}$.

(b) If the length units are changed from m to ft and 1 m = 3.281 ft, then inserting this conversion factor into the given equations requires that

$$(3.281)^{-3}Q' = \frac{1}{n}\frac{\left[(3.281)^{-2}A'\right]^{\frac{5}{3}}}{\left[(3.281)^{-1}P'\right]^{\frac{2}{3}}}S_0^{\frac{1}{2}}$$

where the primed quantities have length units of ft. Simplifying the above equation and removing the primes gives

$$Q = \frac{3.281^{\frac{1}{3}}}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}S_0^{\frac{1}{2}} \quad \rightarrow \quad Q = \frac{1.486}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}S_0^{\frac{1}{2}}$$

Therefore, the conversion factor to be added is $\boxed{1.486}$.

1.4.

Quantity	Dimension	Typical SI Unit
energy	$\mathrm{FL} = \mathrm{ML^2T^{-2}}$	J
force	$\mathrm{F} = \mathrm{MLT^{-2}}$	N
heat	$\mathrm{FL} = \mathrm{ML^2T^{-2}}$	J
moment	$\mathrm{FL} = \mathrm{ML^2T^{-2}}$	N·m
momentum	$\mathrm{MV} = \mathrm{MLT^{-1}}$	kg·m/s
power	$\mathrm{FLT^{-1}} = \mathrm{ML^2T^{-3}}$	W
pressure	$\mathrm{FL^{-2}} = \mathrm{ML^{-1}T^{-2}}$	Pa
strain	$\mathrm{LL^{-1}} = -$	–
stress	$\mathrm{FL^{-2}} = \mathrm{ML^{-1}T^{-2}}$	Pa
work	$\mathrm{FL} = \mathrm{ML^2T^{-2}}$	J

1.5.

Given	With Prefix
6.27×10^7 N	62.7 MN
7.28×10^5 Pa	728 kPa
4.76×10^{-4} m^2	0.0476 km^2
8.56×10^5 m	856 km

1.6.

Quantity	USCS Abbreviation	In SI Units
15 gallons per minute	15 gpm	56.7 L/min
99 miles per hour	99 mph	159.3 km/h
20 feet per second	20 ft/s	6.096 m/s
150 cubic feet per minute	150 cfm	4.24 m^3/min
1540 gallons	1540 gal	5828.9 L
28 acres	28 ac	11.3 ha
600 horsepower	600 hp	447.6 kW

1.7. (a)

$$1\,\text{hp} = 550\frac{\text{ft}\cdot\text{lb}}{\text{s}} \times 0.3048\frac{\text{m}}{\text{ft}} \times 4.448\frac{\text{N}}{\text{lb}} = \boxed{745.7\,\text{W}}$$

(b)

$$1\ \text{lb/in}^2 = 1\frac{\text{lb}}{\text{in}^2} \times 4.448\frac{\text{N}}{\text{lb}} \times \frac{1}{0.0254^2}\frac{\text{in}^2}{\text{m}^2} = 6.894 \times 10^3\,\text{Pa} = \boxed{6.894\,\text{kPa}}$$

1.8. From the given data: $\rho_0 = 990$ kg/m^3, and the density deviates most from 990 kg/m^3 at $T = 100$°C, where $\rho = 958.4$ kg/m^3. Hence, the maximum error in assuming a density of 990 kg/m^3 is

$$\text{error} = \frac{990 - 958.4}{958.4} \times 100 = \boxed{3.29\%}$$

1.9. From the given data: $V_1 = 4\,\text{L}$, $\rho_1 = 1020\,\text{kg/m}^3$, $V_2 = 6\,\text{L}$, and $\rho = 940\,\text{kg/m}^3$. The density of the mixture, ρ_m, is given by

$$\rho_\text{m} = \frac{\rho_1 V_1 + \rho_2 V_2}{V_1 + V_2} = \frac{(1020)(4) + (940)(6)}{4+6} = \boxed{972\,\text{kg/m}^3}$$

Note: The volumes do not need to be converted from L to m^3 since the conversion factor would cancel out.

1.10. (a) The specific weight, γ, is derived from the density, ρ, using the relation: $\gamma = \rho g = 9.807\rho$. Obtaining ρ from Appendix B.1 gives:

Temperature (°C)	ρ (kg/m^3)	γ (N/m^3)
0	999.8	9805
20	998.2	9789
100	958.4	9399

(b) The specific gravity, SG, is derived from the density, ρ, using the relation: SG $= \rho/\rho_{4^\circ\text{C}}$. Obtaining ρ from Appendix B.1 gives:

Temperature (°C)	ρ (kg/m^3)	SG (–)
0	999.8	1.000
20	998.2	0.998
100	958.4	0.958

1.11. From the given data: $V_1 = 450\,\text{L}$, $T_1 = 25$°C, and $T_2 = 80$°C. The densities of water corresponding to T_1 and T_2 (from Appendix B.1) are: $\rho_1 = 997.0\,\text{kg/m}^3$ and $\rho_2 = 971.8\,\text{kg/m}^3$.

(a) The initial mass, m_1, in the tank is given by

$$m_1 = \rho_1 V_1 = (997.0)(0.45) = 448.65\,\text{kg}$$

The volume of water after heating to 80°C is given by

$$V_2 = \frac{m_1}{\rho_2} = \frac{448.65}{971.8} = 0.4617\,\text{m}^3 = 461.7\,\text{L}$$

Therefore, the spilled volume, ΔV, is given by

$$\Delta V = V_2 - V_1 = 461.7 - 450 = \boxed{11.7\,\text{L}}$$

(b) The spilled mass, Δm is given by

$$\Delta m = \rho_2 \Delta V = (971.8)(11.7 \times 10^{-3}) = 11.37\,\text{kg}$$

The percent change in the mass (= percent change in weight) is $11.37/448.65 \times 100 = \boxed{2.53\%}$

1.12. From the given data: $\gamma = 15$ kN/m^3 = 15 000 N/m^3. For water at 4°C: $\rho_\text{w} = 1000$ kg/m^3. According to the definitions of density and specific gravity,

$$\rho = \frac{\gamma}{g} = (15000)(9.807) = \boxed{1530\,\text{kg/m}^3}$$

$$\text{SG} = \frac{\rho}{\rho_\text{w}} = \frac{1530}{1000} = \boxed{1.53}$$

1.13. From the given data: SG = 2.5. For water at 4°C: $\rho_\text{w} = 1000$ kg/m^3. According to the definitions of density and specific weight,

$$\rho = \text{SG} \cdot \rho_\text{w} = (2.5)(1000) = \boxed{2500\,\text{kg/m}^3}$$

$$\gamma = \rho g = (2500)(9.807) = 24517.5\,\text{N/m}^3 \simeq \boxed{24.5\,\text{kN}\cdot\text{m}^3}$$

1.14. For any given volume, V, containing a mixture, let C_m = mass ratio, ρ_f = density of the pure fluid, ρ_m = density of the mixture, m_f = mass of pure fluid, m_m = mass of mixture, m_s = mass of solids in the mixture, SG$_\text{f}$ = specific gravity of pure fluid, and SG$_\text{m}$ = specific gravity of mixture. Therefore,

$$m_\text{f} = \rho_\text{f} V, \qquad m_\text{m} = \rho_\text{m} V, \qquad m_\text{s} = m_\text{m} - m_\text{f} = (\rho_\text{m} - \rho_\text{f})V$$

Using these relationships yields,

$$C_\text{m} = \frac{m_\text{s}}{m_\text{m}} = \frac{(\rho_\text{m} - \rho_\text{f})\cancel{V}}{\rho_\text{m}\cancel{V}} = 1 - \frac{\rho_\text{f}}{\rho_\text{m}} \quad \rightarrow \quad \boxed{C_\text{m} = 1 - \frac{\text{SG}_\text{f}}{\text{SG}_\text{m}}}$$

1.15. From the given data: $\rho = 810$ kg/m^3. For water at 4°C: $\rho_\text{w} = 1000$ kg/m^3. According to the definitions given in Equations 1.9 and 1.10,

$$\gamma = \rho g = (810)(9.807) = 7943.67\,\text{N/m}^3 \simeq \boxed{7.94\,\text{kN/m}^3}$$

$$\text{SG} = \frac{\rho}{\rho_\text{w}} = \frac{810}{1000} = \boxed{0.81}$$

1.16. From the given data: $M = 250$ kg, and SG $= 2$. At 4°C the density of water is $\rho_\mathrm{w} = 1000$ kg/m^3. The volume, V, of the reservoir is given by

$$V = \frac{M}{\rho_\mathrm{w} \cdot \mathrm{SG}} = \frac{250}{(1000)(2)} = \boxed{0.125\,m^3}$$

1.17. From the given data: $W_\mathrm{c} = 10\,\mathrm{N}$, and $W_\mathrm{t} = 50\,\mathrm{N}$. For kerosene at 20°C, $\rho = 808\,\mathrm{kg/m^3}$ and $\gamma = 7924\,\mathrm{N/m^3}$ (Appendix B.4). Using these data gives the following,

$$\text{weight of kerosene, } W_\mathrm{k} = W_\mathrm{t} - W_\mathrm{c} = 50 - 10 = 40\,\mathrm{N}$$

$$\text{volume of kerosene, } V_\mathrm{k} = \frac{W_\mathrm{k}}{\gamma} = \frac{40}{7924} = 5.048 \times 10^{-3}\,\mathrm{m^3} = \boxed{5.05\,\mathrm{L}}$$

$$\text{mass of kerosene} = \frac{W_\mathrm{k}}{g} = \frac{40}{9.807} = \boxed{4.08\,\mathrm{kg}}$$

1.18. The bulk modulus, E_v, is defined by Equation 1.12 as

$$E_\mathrm{v} = -\frac{\mathrm{d}p}{\mathrm{d}V/V} \tag{1}$$

where the density of the fluid, ρ, is defined by

$$\rho = \frac{M}{V} \tag{2}$$

where M is the (constant) mass of fluid and V is the volume of fluid that is compressed by the fluid pressure. Differentiating Equation 2 with respect to V gives

$$\frac{\mathrm{d}\rho}{\mathrm{d}V} = -\frac{M}{V^2} \tag{3}$$

Combining Equations 2 and 3 to eliminate M yields

$$\frac{\mathrm{d}\rho}{\mathrm{d}V} = -\frac{\rho}{V}$$

or

$$\frac{\mathrm{d}V}{V} = -\frac{\mathrm{d}\rho}{\rho} \tag{4}$$

Finally, combining Equations 1 and 4 gives

$$\boxed{E_\mathrm{v} = \frac{\mathrm{d}p}{\mathrm{d}\rho/\rho}}$$

1.19. Equation 1.13 can be approximated by

$$\frac{\Delta\rho}{\rho} = \frac{\Delta p}{E_\mathrm{v}} \tag{1}$$

and at 20°C, $E_\mathrm{v} = 2.18 \times 10^6$ kPa (Table B.1). For $\Delta\rho/\rho = 0.01$, Equation 1 becomes

$$0.01 = \frac{\Delta p}{2.18 \times 10^6} \quad \rightarrow \quad \Delta p = 2.18 \times 10^4\,\mathrm{kPa} = \boxed{21.8\,\mathrm{MPa}}$$

1.20. From the given data: $T = 20°\text{C}$, $D = 3\,\text{m}$, $R = D/2 = 1.5\,\text{m}$, and $\Delta p = 9\,\text{MPa}$. For water at 20°C, $\rho_0 = 998.2\,\text{kg/m}^3$ and $E_\text{v} = 2.18 \times 10^6\,\text{kPa}$ (from Appendix B.1). Using these data, the volume, V, of the tank, and the initial mass, m_0 is the tank are calculated as

$$V = \tfrac{4}{3}\pi R^3 = \tfrac{4}{3}\pi(1.5)^3 = 14.14\,\text{m}^3, \qquad m_0 = \rho_0 V = (998.2)(14.14) = 1.411 \times 10^4\,\text{kg}$$

From the definition of the bulk modulus, E_v,

$$E_\text{v} \approx \frac{\Delta p}{\Delta\rho/\rho_0} \quad \rightarrow \quad \frac{\Delta m}{m_0} = \frac{\Delta p}{E_\text{v}} \quad \rightarrow \quad \Delta m = m_0 \frac{\Delta p}{E_\text{v}}$$

Substituting the given and derived data into this relationship yields,

$$\Delta m = (1.411 \times 10^4)\frac{9 \times 10^3}{2.18 \times 10^6} = \boxed{58.3\,\text{kg}}$$

1.21. From the given data: $p_1 = 150$ kPa, $p_2 = 28\,000$ kPa, $V_1 = 1.500$ m^3, and $V_2 = 1.450$ m^3. Using the definition of the bulk modulus given by Equation 1.12,

$$E_\text{v} \approx -\frac{\Delta p}{\Delta V/V} = -\frac{28000 - 150}{\dfrac{1.450 - 1.500}{1.500}} = 8.355 \times 10^5\,\text{kPa} = \boxed{835.5\,\text{MPa}}$$

1.22. From the given data: $V_1 = 10$ m^3, and $\Delta p = 10$ MPa. For benzene, $E_\text{v} = 1030$ MPa (Appendix B.4). Using the definition of the bulk modulus given by Equation 1.12,

$$E_\text{v} \approx -\frac{\Delta p}{\Delta V/V_1} \quad \rightarrow \quad 1030 \approx -\frac{10}{\dfrac{\Delta V}{10}} \quad \rightarrow \quad \Delta V \approx \boxed{0.0971\,\text{m}^3}$$

1.23. From the given data: $T_1 = 20°\text{C}$, and $T_2 = 100°\text{C}$. The average coefficient of volume expansion, $\bar{\beta}$, between T_1 and T_2 is derived from Appendix B.1 as $\bar{\beta} = 0.523 \times 10^{-3}\,\text{K}^{-1}$.

(a) Applying Equation 1.19 (with $\Delta p = 0$) gives

$$\frac{\Delta\rho}{\rho} \approx -\bar{\beta}\Delta T = -0.523 \times 10^{-3}(100 - 20) = -0.0418 = \boxed{-4.18\%}$$

(b) Let A be the surface area of the water in the pot (assumed to be constant), h_1 is the depth of water at T_1, and $h_1 + \Delta h$ be the depth of water at T_2. Therefore, since the mass of water is constant,

$$\rho_1 \cancel{A} h_1 = \rho_2 \cancel{A}(h_1 + \Delta h) \quad \rightarrow \quad \rho_1 h_1 = \rho_2 h_1 + \rho_2 \Delta h \quad \rightarrow \quad \frac{\Delta h}{h_1} = \frac{\rho_1 - \rho_2}{\rho_2} \qquad (1)$$

The density of water at $T_1 = 20°\text{C}$ and $T_2 = 100°\text{C}$ are obtained from Appendix B.1 as $\rho_1 = 998.2\,\text{kg/m}^3$ and $\rho_2 = 958.4\,\text{kg/m}^3$, respectively. Using Equation 1 gives

$$\frac{\Delta h}{h_1} = \frac{998.2 - 958.4}{958.4} = 0.0415 = \boxed{4.15\%}$$

1.24. From the given data: $\beta = 5.7 \times 10^{-4}\,\text{K}^{-1}$, $T_1 = 10°\text{C}$, and $T_2 = 90°\text{C}$. Applying Equation 1.19 (with $\Delta p = 0$) gives

$$\frac{\Delta\rho}{\rho} \approx -\beta\Delta T = -5.7 \times 10^{-4}(90 - 10) = -0.0432 = \boxed{-4.32\%}$$

1.25. From the given data: $T_1 = 15°\text{C}$, $\Delta V/V_1 = 0.01$, and $\beta = 9.5 \times 10^{-4}\,\text{K}^{-1}$. Using the given data,

$$\frac{V_2 - V_1}{V_1} = 0.01 \quad \rightarrow \quad \frac{V_2}{V_1} - 1 = 0.01 \quad \rightarrow \quad \frac{V_2}{V_1} = 1.01 \tag{1}$$

$$\frac{\Delta\rho}{\rho_1} = \frac{\cancel{m}/V_2 - \cancel{m}/V_1}{\cancel{m}/V_1} \quad \rightarrow \quad \frac{\Delta\rho}{\rho_1} = \frac{V_1}{V_2} - 1 \tag{2}$$

$$\frac{\Delta\rho}{\rho_1} = -5.7 \times 10^{-4}\Delta T \tag{3}$$

where ΔT is the maximum allowable temperature rise. Combining Equations 1 to 3 yields $\boxed{\Delta T = 10.4°\text{C}}$.

1.26. From the given data: $T = 20°\text{C} = 293$ K. Noting that the speed of sound, c, is given by $c = \sqrt{E_\text{v}/\rho}$, the calculation of the speed of sound in water and mercury are summarized in the following table:

Medium	E_v ($\times 10^6$ Pa)	ρ (kg/m^3)	c (m/s)
Water	2171	998	1475
Mercury	26200	13550	1390

Therefore, the speed of sound in water at 20°C is $\boxed{1475 \text{ m/s}}$, and the speed of sound in mercury at 20°C is $\boxed{1390 \text{ m/s}}$.

1.27. From the given data: $c = 1800$ m/s, and SG = 1.9. For water at 4°C, $\rho_\text{w} = 1000$ kg/m^3. Using Equation 1.15, the bulk modulus, E_v, is calculated as follows:

$$c = \sqrt{\frac{E_\text{v}}{\text{SG} \cdot \rho_\text{w}}} \quad \rightarrow \quad 1800 = \sqrt{\frac{E_\text{v}}{(1.9)(1000)}} \quad \rightarrow \quad E_\text{v} = 6156 \times 10^6 \text{ Pa} = \boxed{6156\,\text{MPa}}$$

1.28. From the given data: $n_1 = 10^{10}$ molecules per mm^3, and $T = 15°\text{C} = 288\,\text{K}$. For an ideal gas, $R_\text{u} = 8.314\,\text{J/(kg·K)}$.

(a) Using the given data with the ideal-gas law,

$$n = \frac{10^{10}}{6.023 \times 10^{23}} = 1.660 \times 10^{-14} \text{ moles}$$

$$V = 1\,\text{mm}^3 = 10^{-9}\,\text{m}^3$$

$$p = \frac{n}{V}R_\text{u}T = \frac{1.660 \times 10^{-14}}{10^{-9}}(8.314)(288) = \boxed{0.0397\,\text{Pa}}$$

(b) The term used to describe a gas in which the continuum approximation is not valid is a $\boxed{\text{rarefied gas}}$.

1.29. From the given data: $p = 101\,\text{kPa}$, and $T = 25°\text{C} = 298\,\text{K}$. For He, $R_\text{He} = 8314/4.003 = 2077\,\text{J/(kg·K)}$, and for air, $R_\text{air} = 8314/28.96 = 287.1\,\text{J/(kg·K)}$ (from Appendix B.5). Using the ideal gas law,

$$\rho_\text{He} = \frac{p}{R_\text{He}T} = \frac{101 \times 10^3}{(2077)(298)} = \boxed{0.1632\,\text{kg/m}^3}$$

$$\rho_\text{air} = \frac{p}{R_\text{air}T} = \frac{101 \times 10^3}{(287.1)(298)} = \boxed{1.181\,\text{kg/m}^3}$$

The specific volume is defined by Equation 1.11 as the volume per unit mass, hence

$$v_\text{He} = \frac{1}{\rho_\text{He}} = \frac{1}{0.1632} = \boxed{6.13\ \text{m}^3/\text{kg}}$$

$$v_\text{air} = \frac{1}{\rho_\text{air}} = \frac{1}{1.181} = \boxed{0.847\ \text{m}^3/\text{kg}}$$

1.30. For air at standard atmospheric pressure, $p = 101\,\text{kPa}$ and $R = 287.1\,\text{J/(kg·K)}$. Taking $\rho_1 =$ density from Appendix B.2, and $\rho_2 =$ density from ideal gas law, gives:

T (°C)	ρ_1 (kg/m^3)	T (K)	ρ_2 (kg/m^3)	Δ (%)
−40	1.514	233	1.5098	−0.27
−20	1.394	253	1.3905	−0.25
0	1.292	273	1.2886	−0.26
5	1.269	278	1.2654	−0.28
10	1.246	283	1.2431	−0.23
15	1.225	288	1.2215	−0.29
20	1.204	293	1.2007	−0.28
25	1.184	298	1.1805	−0.29
30	1.164	303	1.1610	−0.25
40	1.127	313	1.1239	−0.27
50	1.092	323	1.0891	−0.26
60	1.059	333	1.0564	−0.24
70	1.028	343	1.0256	−0.23
80	0.9994	353	0.9966	−0.28
90	0.9718	363	0.9691	−0.27
100	0.9458	373	0.9431	−0.28
200	0.7459	473	0.7438	−0.29
300	0.6158	573	0.6140	−0.30
400	0.5243	673	0.5227	−0.30
500	0.4565	773	0.4551	−0.31
1000	0.2772	1273	0.2764	−0.31

Based on these results, the ideal gas law gives quite accurate estimates with $\boxed{\text{errors less than 0.31\%}}$.

1.31. From the given data: $\rho = 5$ kg/m^3, and $p = 450$ kPa. Properties of O$_2$ from Appendix B.5: $c_p = 909$ J/kg·K, $c_v = 649$ J/kg·K, and $R = c_p - c_v = 909 - 649 = 260$ J/kg·K. The ideal gas law, Equation 1.24, gives

$$\rho = \frac{p}{RT} \quad\rightarrow\quad 5 = \frac{450\times10^3}{(260)T} \quad\rightarrow\quad T = 346\,\text{K} = \boxed{73^\circ\text{C}}$$

1.32. From the given data: $V = 3$ m^3, $T = 17^\circ$C $= 290$ K, and $p = 550$ kPa. The molar mass of helium is 4.003 g/mol, and hence the gas constant for helium can be taken as $R = 8314/4.003 = 2077$ J/kg·K. The density, mass, and weight of helium in the tank are given by

$$\rho = \frac{p}{RT} = \frac{550\times10^3}{(2077)(290)} = \boxed{0.91312\,\text{kg/m}^3}$$

$$M = \rho V = (0.91312)(3) = \boxed{2.7393\,\text{kg}}$$

$$W = Mg = (2.7393)(9.807) = \boxed{26.86\,\text{N}}$$

1.33. From the given data: $m = 12\,\text{kg}$, $T = 27^\circ\text{C} = 300\,\text{K}$, $p = 15\,\text{MPa}$, and $L = 3D$. For pure oxygen, $R = R_\text{u}/M = 8314/32 = 259.8\,\text{J/(kg·K)}$. Using the given data and the ideal gas law,

$$V = \frac{\pi}{4}D^2L = \frac{\pi}{4}D^2(3D) = \frac{3\pi}{4}D^3, \qquad m = \frac{pV}{RT} \quad\rightarrow\quad V = \frac{mRT}{p}$$

Combining these equations gives

$$\tfrac{3}{4}\pi D^3 = \frac{mRT}{p} \quad\rightarrow\quad D = \left[\frac{4mRT}{3\pi p}\right]^{\frac{1}{3}} = \left[\frac{4(12)(259.8)(300)}{3\pi(15\times10^6)}\right]^{\frac{1}{3}} = 0.298\,\text{m}$$

Since the length must be three times the diameter, $L = 3(0.298) = 0.894\,\text{m}$. The required dimensions of the tank are a diameter of $\boxed{0.298\,\text{mm}}$ and a length of $\boxed{0.894\,\text{m}}$.

1.34. From the given data: $M = 12$ kg, $T = 67^\circ$C $= 340$ K, and $p = 210$ kPa. For air, $R = 287.1$ J/kg·K. The volume, V, can be derived from the ideal gas law, Equation 1.24, as follows

$$\frac{M}{V} = \frac{p}{RT} \quad\rightarrow\quad \frac{12}{V} = \frac{210\times10^3}{(287.1)(340)} \quad\rightarrow\quad V = \boxed{5.578\,\text{m}^3}$$

1.35. From the given data: $V = 210\,\text{L}$, $m = 3.2\,\text{kg}$, and $T = 25^\circ\text{C} = 298\,\text{K}$. This assumes that the temperature of the air in the tank is the same as in the room. For standard air, $R = 287.1\,\text{J/(kg·K)}$. Using the ideal-gas law gives

$$\rho = \frac{p}{RT} \quad\rightarrow\quad p = \frac{m}{V}RT = \frac{3.2}{0.21}(287.1)(298) = 1.304\times10^6\,\text{Pa} = \boxed{1.304\,\text{MPa}}$$

1.36. From the given data: $V = 0.1$ m^3, $T = 20°\text{C} = 293$ K, and $p = 400$ kPa. The gas constant for air can be taken as $R = 287.1$ J/kg·K. The density of air in the tank can be calculated using Equation 1.24, which gives

$$\rho = \frac{p}{RT} = \frac{400 \times 10^3}{(287.1)(293)} = 0.4898\,\text{kg/m}^3$$

Hence the weight of air in the tank , W, is given by

$$W = \rho V g = (0.4898)(0.1)(9.807) = 0.4803\,\text{N} \simeq 0.48\,\text{N}$$

The weight (0.48 N) has been rounded to two significant digits to be consistent with the accuracy of the given data.

1.37. From the given data: $V = 10\,\text{m} \times 12\,\text{m} \times 4\,\text{m} = 480\,\text{m}^3$, $p = 101.3\,\text{kPa}$, $T_1 = 20°\text{C} = 293.15\,\text{K}$, and $T_2 = 10°\text{C} = 283.15\,\text{K}$. For air, $R = 287.1\,\text{J/(kg·K)}$.

(a) Using the given data at a temperature of 20°C gives

$$\rho_1 = \frac{p}{RT_1} = \frac{101.3 \times 10^3}{(287.1)(293.15)} = 1.204\,\text{kg/m}^3, \quad m_1 = \rho_1 V = (1.204)(480) = \boxed{577.7\,\text{kg}}$$

$$W_1 = m_1 g = (577.7)(9.807) = 5.666 \times 10^3\,\text{N}$$

(b) When the temperature in the room is reduced to 10°C, then

$$\rho_2 = \frac{p}{RT_2} = \frac{101.3 \times 10^3}{(287.1)(283.15)} = 1.246\,\text{kg/m}^3, \quad m_2 = \rho_2 V = (1.246)(480) = 598.1\,\text{kg}$$

$$\text{change} = \frac{m_2 - m_1}{m_1} \times 100 = \frac{598.1 - 577.7}{577.7} \times 100 = \boxed{3.53\%}$$

1.38. From the given data: $p_1 = 600\,\text{kPa}$, $T_1 = 20°\text{C} = 293\,\text{K}$, and $T_2 = 30°\text{C} = 303\,\text{K}$. Taking ρ and R as constants, the ideal gas law gives

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \quad \rightarrow \quad \frac{600}{293} = \frac{p_2}{303} \quad \rightarrow \quad p_2 = 620\,\text{kPa}$$

Therefore the change in pressure is 620 kPa – 600 kPa = $\boxed{20\,\text{kPa}}$. This result would be the $\boxed{\text{same}}$ for any gas that obeys the ideal gas law.

1.39. From the given data: $p_1 = 130\,\text{kPa}$, $p_2 = 210\,\text{kPa}$, $V = 15\,\text{L} = 0.015\,\text{m}^3$, and $T = 30°\text{C}$. Required constants: $R = 8.314\,\text{kJ/kmol·K}$, molar mass of air, $\text{M} = 28.97\,\text{kg/kmol}$, $p_\text{atm} = 101\,\text{kPa}$. Using these data with the ideal gas law,

$$n_1 = \frac{p_1 V_1}{RT_1} = \frac{(101 + 130)(0.015)}{(8.314)(273.15 + 30)} = 0.00137\,\text{kmol}$$

$$n_2 = \frac{p_2 V_2}{RT_2} = \frac{(101 + 210)(0.015)}{(8.314)(273.15 + 30)} = 0.00185\,\text{kmol}$$

$$\text{mass added} = (n_2 - n_1)M = (0.00185 - 0.00137)28.97 = 0.0139\,\text{kg} = \boxed{13.9\,\text{g}}$$

1.40. Consider three states of the tire: State 1 is the initial state, State 2 is the heated-up state, and State 3 is the cooled-down state. From the given data: $p_{\text{atm}} = 101.3\,\text{kPa}$, $V = 20\,\text{L}$, p_1 (gauge) = 210 kPa, p_1 (absolute) = 210 kPa + 101.3 kPa = 311.3 kPa, $T_1 = 25°\text{C} = 298\,\text{K}$, $T_2 = 65°\text{C} = 338\,\text{K}$, and $T_3 = T_1 = 298\,\text{K}$.

(a) Between the initial state and the heated-up state, the air density in the tire remains constant, so the ideal-gas law gives

$$\rho R = \frac{p}{T} = \text{constant} \rightarrow \frac{p_1}{T_1} = \frac{p_2}{T_2} \quad \rightarrow \quad p_2 = \frac{T_2}{T_1}p_1 = \frac{338}{298}(311.3) = 353.1\,\text{kPa}$$

Hence, the resulting gauge pressure is 353.1 kPa − 101.3 kPa = $\boxed{251.78\text{ kPa}}$

(b) Between the heated-up state and the cooled-down state, the air density in the tire remains constant and the air pressure at the heated-up state is equal to 311.3 kPa. The ideal-gas law gives

$$\rho R = \frac{p}{T} = \text{constant} \rightarrow \frac{p_3}{T_3} = \frac{p_2}{T_2} \quad \rightarrow \quad p_3 = \frac{T_3}{T_2}p_2 = \frac{298}{338}(311.3) = 274.46\,\text{kPa}$$

Hence, the resulting gauge pressure is 274.46 kPa − 101.3 kPa = $\boxed{173.16\text{ kPa}}$

1.41. From the given data: $T_1 = 20°\text{C} = 293\,\text{K}$, $T_2 = 10°\text{C} = 283\,\text{K}$, $p_{1\text{g}} = 86.2$ kPa, and $p_1 = p_{1\text{g}} + p_{\text{atm}} = 86.2 + 101.3 = 187.5$ kPa.

(a) In this case the expected pressure, p_2 in a football is given by

$$p_2 = \frac{T_2}{T_1}p_1 = \frac{283}{293}(187.5) = 181.1\,\text{kPa} \quad \rightarrow \quad p_{2\text{g}} = p_2 - p_{\text{atm}} = 181.1 - 101.3 = \boxed{79.8\,\text{kPa}}$$

(b) In this case the required temperature, T_2 on the field is given by

$$p_2 = \frac{T_2}{T_1}p_1 \quad \rightarrow \quad (72.4 + 101.3) = \frac{T_2}{293}(187.5) = 271\,\text{K} = \boxed{-2°\text{C}}$$

(c) Theory: The New England Patriots did not inflate the footballs to the required pressure.

1.42. From the given data: $p_1 = 207\,\text{kPa}$ and $p_2 = 241\,\text{kPa}$.

(a) From the ideal-gas law,

$$\rho = \frac{p}{RT} \quad \rightarrow \quad \frac{p_1}{T_1} = \frac{p_2}{T_2} \quad \rightarrow \quad \frac{T_2}{T_1} = \frac{p_2}{p_1} = \frac{241}{207} = 1.164$$

Using this relationship, the percentage change in temperature is calculated as follows,

$$\%\text{ change in } T = \frac{T_2 - T_1}{T_1} \times 100 = \left[\frac{T_2}{T_1} - 1\right] \times 100 = [1.164 - 1] \times 100 = \boxed{16.4\%}$$

Note that this percentage change applies to a temperature given in degrees kelvin.

(b) From the given data: $T_1 = 25°\text{C} = 298\,\text{K}$. Hence, from the result in Part (a), $T_2 = 1.164(298) = 347\,\text{K} = \boxed{74°\text{C}}$. Note that thhe percentage change in °C is much higher than the percentage change in K.

1.43. (a) From the given data: $D = 8\,\text{m}$, $T = 22°\text{C} = 295\,\text{K}$ and $p = 210\,\text{kPa}$. For an ideal gas:

$$pV = nRT \tag{1}$$

where

$$V = \frac{\pi}{6}D^3 = \frac{\pi}{6}(8)^3 = 268.08\,\text{m}^3, \qquad R = 8312\text{N} \cdot \text{N} = \text{kmol} \cdot \text{K}$$

Substituting given and derived values into Equation 1 gives

$$(210 \times 10^3)(268.08) = n(8312)(295) \rightarrow n = \boxed{22.96\,\text{kmol}}$$

Since the relative molecular mass of He is 4.003, the mass of 22.96 kmol of He is $(22.96)(4.003)\text{kg} = \boxed{92\text{ kg}}$.

(b) From the given data: $T_1 = 27°\text{C} = 300\,\text{K}$, $p_1 = 215\,\text{kPa} + 101\,\text{kPa} = 316\,\text{kPa}$ (assuming atmospheric pressure is 101 kPa), $V = 0.03\,\text{m}^3$, and $T_2 = 53°\text{C} = 326\,\text{K}$. From the ideal gas law,

$$V = \frac{nRT_1}{p_1} = \frac{nRT_2}{p_2}$$

which yields

$$p_2 = p_1\left(\frac{T_2}{T_1}\right) = 316\left(\frac{326}{300}\right) = 343.387\,\text{kPa}$$

This corresponds to a pressure increase of $343.387\,\text{kPa} - 316\,\text{kPa} = \boxed{27.387\,\text{kPa}}$.

1.44. From given data: $W_\text{rat} = 1.5$ N, $W_\text{bal} = 0.5$ N, $\rho_\text{air} = 1.17$ kg/m^3, $p = 100$ kPa, $T = 25°\text{C} = 298$ K. Take $R_\text{u} = 8.314$ J/mol·K and molar mass of He, m_He, is 4.003 g/mol. To lift the rat:

$$\underbrace{W_\text{rat} + W_\text{bal} + \rho_\text{He} g V_\text{bal}}_{\text{Weight lifted}} = \underbrace{\rho_\text{air} g V_\text{bal}}_{\text{buoyant force}} \quad \rightarrow \quad W_\text{rat} + W_\text{bal} = (\rho_\text{air} - \rho_\text{He}) g V_\text{bal} \tag{1}$$

For helium in the balloon,

$$R_\text{He} = \frac{R_\text{u}}{m_\text{He}} = \frac{8.314}{4.003} = 2.077 \text{ J/g·K} = 2077 \text{ J/kg·K}$$

$$\rho_\text{He} = \frac{p}{R_\text{He}T} = \frac{100 \times 10^3}{(2077)(298)} = 0.162\,\text{kg/m}^3$$

$$V_\text{bal} = \frac{nR_\text{u}T}{p}$$

Substituting into Equation (1) gives

$$1.5 + 0.5 = (1.17 - 0.162)(9.81)\left[n\frac{(8.314)(298)}{100 \times 10^3}\right] \quad \rightarrow \quad n = 8.16 \text{ mol}$$

Hence, the mass of helium required is 8.16 × 4.003 = $\boxed{32.7 \text{ g}}$

1.45. Form the given data: $z = 12$ m, $D_1 = 6$ mm, $T_1 = 20°\text{C}$, and $p_\text{atm} = 101.3$ kPa. At the bubble release location,

$$p_1 = p_\text{atm} + \gamma z = 101.3 + 9.79(12) = 218.78\,\text{kPa}, \qquad T_1 = 20°\text{C}$$

At the surface of the lake, $p_2 = 101.3$ kPa and for an isothermal process,

$$p_1V_1 = p_2V_2 \quad \rightarrow \quad V_2 = \left(\frac{p_1}{p_2}\right)V_1 \quad \rightarrow \quad \frac{4}{3}\pi r_2^3 = \left(\frac{p_1}{p_2}\right)\frac{4}{3}\pi r_1^3 \quad \rightarrow \quad \frac{r_2}{r_1} = \frac{D_2}{D_1} = \left(\frac{p_1}{p_2}\right)^{\frac{1}{3}}$$

$$\rightarrow D_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1}{3}} D_1 = \left(\frac{218.78}{101.3}\right)^{\frac{1}{3}}(6) = 4.32\,\text{mm}$$

Therefore, the diameter of the bubble when it reaches the surface of the lake is $\boxed{4.32\text{ mm}}$.

1.46. From the given data: $V_1 = 1.1$ m^3, $V_2 = 0.45$ m^3, and $p_1 = 101$ kPa. For air, the ratio of specific heats is given by $k = 1.40$.

(a) Under isentropic conditions, the pressure of the compressed volume, p_2, is given by Equations 1.33 and 1.34 as

$$p_1v_1^k = p_2v_2^k \quad \rightarrow \quad (101)(1.1)^{1.40} = p_2(0.45)^{1.40} \quad \rightarrow \quad p_2 = \boxed{353\,\text{kPa}}$$

(b) Under isothermal conditions, the pressure of the compressed volume, p_2, is given by Equations 1.33 and 1.34 as

$$p_1v_1 = p_2v_2 \quad \rightarrow \quad (101)(1.1) = p_2(0.45) \quad \rightarrow \quad p_2 = \boxed{246.89\,\text{kPa}}$$

1.47. From the given data: $T = 20°\text{C} = 293\,\text{K}$, $p = 101.3\,\text{Pa}$, $f_1 = 0.20$, and $f_2 = 0.8$. For O_2, $R_1 = 259.8\,\text{J/(kg·K)}$, and for N_2, $R_2 = 296.7\,\text{J/(kg·K)}$. Under the given conditions, the densities of O_2 and N_2, represented by ρ_1 and ρ_2, are given by

$$\rho_1 = \frac{p}{R_1T} = \frac{101.3\times10^3}{(259.8)(293)} = 1.331\,\text{kg/m}^3, \qquad \rho_2 = \frac{p}{R_2T} = \frac{101.3\times10^3}{(296.7)(293)} = 1.166\,\text{kg/m}^3$$

(a) For each 1 m^3 of air there is f_1 m^3 of O_2 and f_2 m^3 of N_2. Therefore, the partial pressures of O_2 and N_2, denoted by p_1 and p_2, are given by

$$p_1 = f_1p = (0.2)(293) = \boxed{20.3\,\text{kPa}}, \qquad p_2 = f_2p = (0.8)(293) = \boxed{81.0\,\text{kPa}}$$

(b) The density, ρ_m of the mixture is given by

$$\rho_\text{m} = f_1\rho_1 + f_2\rho_2 = (0.2)(1.331) + (0.8)(1.166) = \boxed{1.199\,\text{kg/m}^3}$$

1.48. From the given data: $V_1 = 2.0$ m^3, $V_2 = 4.0$ m^3, $T_1 = 20°\text{C} = 293$ K, and $p_1 = 100$ kPa. For oxygen, $c_p = 909$ J/kg·K, $c_v = 649$ J/kg·K, and $k = c_p/c_v = 909/649 = 1.40$. The gas constant for oxygen, R, is given by

$$R = c_p - c_v = 909 - 649 = 260\text{ J/kg·K}$$

(a) Under isentropic conditions, the pressure of the expanded volume, p_2, is given by Equations 1.33 and 1.34 as

$$p_1 v_1^k = p_2 v_2^k \quad \rightarrow \quad (100)(2.0)^{1.40} = p_2(4.0)^{1.40} \quad \rightarrow \quad p_2 = \boxed{37.9\,\text{kPa}}$$

The initial density, ρ_1 is given by the ideal gas law as follows,

$$\rho_1 = \frac{p_1}{RT_1} = \frac{100 \times 10^3}{(260)(293)} = \boxed{1.131\,\text{kg/m}^3}$$

The ratio of the final density to the initial density is given by Equation 1.37 as follows:

$$\frac{\rho_2}{\rho_1} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}} \rightarrow \frac{\rho_2}{1.131} = \left(\frac{37.9}{100}\right)^{\frac{1}{1.40}} \rightarrow \rho_2 = \boxed{0.566\,\text{kg/m}^3}$$

(b) Under isothermal conditions, the pressure of the expanded volume, p_2, is given by Equations 1.33 and 1.34 as

$$p_1 v_1 = p_2 v_2 \quad \rightarrow \quad (100)(2.0) = p_2(4.0) \quad \rightarrow \quad p_2 = \boxed{50\,\text{kPa}}$$

In this case the temperature remains constant at $T = 293$ K. The initial density is $\boxed{1.131\ \text{kg/m}^3}$ as calculated in Part (a). The final density is given by the ideal gas law as follows:

$$\rho_2 = \frac{p_2}{RT} = \frac{50 \times 10^3}{(260)(293)} = \boxed{0.656\,\text{kg/m}^3}$$

(c) Applying the ideal-gas law (Equation 1.20) gives

$$p_1 V_1 = nR_\text{u}T_1 \quad \rightarrow \quad nR_\text{u}T_1 = (100 \times 10^3)(293) = 2.93 \times 10^7\ \text{J}$$

Since the process is isothermal and reversible, $nR_\text{u}T$ remains constant and Equation 1.32 gives

$$Q_{12} = nR_\text{u}T \ln\frac{V_2}{V_1} = (2.93 \times 10^7)\ln\frac{4}{4} = 2.03 \times 10^7\ \text{J} = \boxed{20.3\,\text{MJ}}$$

1.49. From the given data: $T_1 = 27°\text{C} = 300\,\text{K}$, $p_2 = 101\,\text{kPa}$, and $T_2 = -73°\text{C} = 200\,\text{K}$. For air, $k = 1.40$ and $R = 287.1\,\text{J/(kg·K)}$. Applying the ideal-gas law and assuming an isentropic process gives

$$\rho_1 = \frac{p_1}{RT_1} = \frac{101 \times 10^3}{(287.1)(300)} = 1.173\,\text{kg/m}^3$$

$$\frac{T_1}{T_2} = \left(\frac{\rho_2}{\rho_1}\right)^{k-1} \quad \rightarrow \quad \rho_2 = \left(\frac{T_1}{T_2}\right)^{\frac{1}{k-1}} \rho_1 = \left(\frac{300}{200}\right)^{\frac{1}{1.4-1}} (1.173) = \boxed{3.231\,\text{kg/m}^3}$$

$$\frac{T_1}{T_2} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} \quad \rightarrow \quad p_2 = \left(\frac{T_1}{T_2}\right)^{\frac{k}{k-1}} p_1 = \left(\frac{300}{200}\right)^{\frac{1.4}{1.4-1}} (101) = \boxed{417\,\text{kPa}}$$

1.50. From the given data: $V_1 = 0.3\,\mathrm{m}^3$, $T_1 = 20°\mathrm{C} = 293\,\mathrm{K}$, $p_1 = 120\,\mathrm{kPa}$, and $p_2 = 700\,\mathrm{kPa}$. The thermodynamic properties of air are: $k = 1.40$, and $R = 287.1\,\mathrm{J/(kg{\cdot}K)}$. The initial density of air, ρ_1, is given by the ideal gas law as

$$\rho_1 = \frac{p_1}{RT_1} = \frac{120 \times 10^3}{(287.1)(293)} = 1.427\,\mathrm{kg/m^3}$$

The relationship between variables before and after isentropic compression is given by Equation 1.37 with $n = k = 1.40$, which yields

$$\frac{T_1}{T_2} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \quad \rightarrow \quad \frac{293}{T_2} = \left(\frac{700}{120}\right)^{\frac{1.40-1}{1.40}} \quad \rightarrow \quad T_2 = 177\,\mathrm{K} = \mathbf{-96°C}$$

1.51. From the given data: $T = 22°\mathrm{C} = 295$ K and $x = 1.1$ km $= 1100$ m. For air, $R = 287.1$ J/kg·K and $k = 1.40$. The speed of sound, c, is given by Equation 1.40 as

$$c = \sqrt{RTk} = \sqrt{(287.1)(295)(1.40)} = 344\,\mathrm{m/s}$$

The time, t, for the sound to travel 1.1 km is given by

$$t = \frac{x}{c} = \frac{1100}{344} = \boxed{3.2 \text{ seconds}}$$

1.52. From the given data: $T = 20°\mathrm{C} = 293$ K. Noting that the speed of sound, c, is given by $c = \sqrt{RTk}$, where $R = c_p - c_v$ and $k = c_p/c_v$, the calculation of the speed of sound in air and hydrogen are summarized in the following table:

Medium	c_p (J/kg·K)	c_v (J/kg·K)	R (J/kg·K)	k (–)	c (m/s)
Air	1003	716	287	1.40	343
Hydrogen	14450	10330	4120	1.40	1300

Therefore, the speed of sound in air at 20°C is $\boxed{343 \text{ m/s}}$, and the speed of sound in pure hydrogen at 20°C is $\boxed{1300 \text{ m/s}}$. Air travels much faster in pure hydrogen since it is much denser than air.

1.53. From the given data: $M = 35$, $c_p = 1025\,\mathrm{J/(kg{\cdot}K)}$, and $T = 22°\mathrm{C} = 295\,\mathrm{K}$. The universal gas constant is $R_\mathrm{u} = 8314\,\mathrm{J/(kg{\cdot}K)}$. Assuming that the behavior of the mystery gas can be approximated by the behavior of an ideal gas,

$$R = \frac{R_\mathrm{u}}{M} = \frac{8314}{35} = 237.543\,\mathrm{J/(kg{\cdot}K)}$$

$$R = c_p - c_v \quad \rightarrow \quad c_v = c_p - R = 1025 - 237.543 = 780.5\,\mathrm{J/(kg{\cdot}K)}$$

$$k = \frac{c_p}{c_v} = \frac{1025}{780.5} = 1.313$$

$$c = \sqrt{RTk} = \sqrt{(237.543)(295)(1.313)} = 307.676\,\mathrm{m/s}$$

Therefore, the speed of sound in the gas at 20°C is estimated as $\boxed{307.676 \text{ m/s}}$.

1.54. There are two methods that can be used to do this problem.

Method 1:
Using the given data in Table B.5 directly gives $\boxed{T = -42.6°\text{C}}$ and $\boxed{p = 31.5 \text{ kPa}}$.

Method 2:
From the given data: $z = 8840$ m $= 8.840$ km. For the standard atmosphere: $p_0 = 101.3$ kPa, $T_0 = 15°\text{C} = 288.15$ K, and $b = 6.5°\text{C/km} = 0.0065$ k/m; for air, $M = 28.96$ g/mol; and the universal gas constant is R =8.314 J/mol·K. Hence, at the top of Mount Everest,

$$T = T_0 - bz = 15 - 6.5(8.840) = \boxed{-42.6°\text{C}}$$

$$p = p_0 \left[1 - \frac{bz}{T_0}\right]^{gM/Rb} = (101.3)\left[1 - \frac{(6.5)(8.840)}{288.15}\right]^{(9.81)(28.96\times 10^{-3})/(8.314)(0.0065)} = \boxed{31.5\,\text{kPa}}$$

Measured values put the average temperature between −20°C and −35°C, which is $\boxed{\text{“warmer”}}$ than the temperature given by the standard atmosphere. A reported typical pressure is 34.6 kPa, which is a $\boxed{\text{higher pressure}}$ than the standard value.

1.55. (a) The weight of the atmosphere above sea level is calculated by summing the weight of air in each increment of elevation given in Appendix B.3. These calculations are summarized in the following table:

z (m)	ρ (kg/m^3)	Δz (m)	Δm (kg)	g (m/s^2)	ΔW (kN)
0	1.225			9.8067	
1	1.1117	1000	1168.35	9.8036	11.455
2	1.0066	1000	1059.15	9.8005	10.382
3	0.90925	1000	957.93	9.7974	9.387
4	0.81935	1000	864.3	9.7943	8.467
5	0.73643	1000	777.89	9.7912	7.618
6	0.66011	1000	698.27	9.7882	6.834
7	0.59	1000	625.055	9.785	6.117
8	0.52579	1000	557.895	9.782	5.458
9	0.4671	1000	496.445	9.779	4.855
10	0.41351	1000	440.305	9.776	4.305
11	0.3639	1000	388.705	9.773	3.799
12	0.3108	1000	337.35	9.77	3.296
13	0.2655	1000	288.15	9.767	2.815
14	0.2268	1000	246.15	9.774	2.405
15	0.1948	1000	210.8	9.761	2.059
20	0.08891	5000	709.275	9.745	6.918
25	0.04008	5000	322.475	9.73	3.140
30	0.01841	5000	146.225	9.715	1.422
40	0.003996	10000	112.03	9.684	1.087
50	0.001027	10000	25.115	9.654	0.243
60	0.0003097	10000	6.6835	9.624	0.064
70	0.00008283	10000	1.96265	9.594	0.019
80	0.00001846	10000	0.50645	9.564	0.005
Total:			10441		102.152

Based on these calculations, the weight of air above 1 m^2 is approximately $\boxed{102.2\ \text{kN}}$

(b) The pressure on the surface of the earth at sea level is 102.2 kN/1 m^2 = $\boxed{102.2\ \text{kPa}}$. The close agreement between the pressure caused by the calculated weight of the atmosphere and the conventional sea-level pressure is due to the fact that the conventional sea-level pressure is in fact due to the weight of the atmosphere above sea level.

(c) Under standard conditions at sea level, $\rho = 1.225\,\text{kg/m}^3$. Taking $g = 9.807\,\text{m}^2/\text{s}$ leads to the following calculations:

$$\text{mass of air} = \frac{102.2 \times 1000}{9.807} = 1.042 \times 10^4\,\text{kg}$$

$$\text{volume of air} = \frac{1.042 \times 10^4}{1.225} = 8.507 \times 10^3\,\text{m}^3$$

$$\text{height of air} = \frac{8.507 \times 10^3\,\text{m}^3}{1\,\text{m}^2} = 8507\,\text{m} = \boxed{8.507\,\text{km}}$$

1.56. From the given data: $p = 87.06$ kPa. Interpolating from the standard-atmosphere table in Appendix B.3 gives the elevation corresponding to $p = 87.06\,\text{kPa}$ as 1.28 km = $\boxed{1280\ \text{m}}$.

1.57. Interpolating from the standard atmosphere in Appendix B.3, the expected temperature at an elevation of 4342 m is $\boxed{-13.2^\circ\text{C}}$. This is within the range of the given average high and low temperatures. Interpolating in the standard atmosphere gives an expected atmospheric pressure of $\boxed{59.06\ \text{kPa}}$.

1.58. For a standard atmosphere at sea level: $p_1 = 101.325$ kPa, and $T_1 = 15^\circ\text{C} = 288.15$ K. For a standard atmosphere at 3000 m: $p_2 = 70.121$ kPa, and $T_2 = -4.49^\circ\text{C} = 268.7$ K. For oxygen, $R = 8314/32 = 259.8$ J/kg·K. The corresponding densities are:

$$\rho_1 = \frac{p_1}{RT_1} = \frac{101.325 \times 10^3}{(259.8)(268.7)} = \boxed{1.354\,\text{kg/m}^3}$$

$$\rho_2 = \frac{p_2}{RT_2} = \frac{70.121 \times 10^3}{(259.8)(268.7)} = \boxed{1.004\,\text{kg/m}^3}$$

The percentage reduction in oxygen intake is given by

$$\text{percent reduction} = \frac{1.354 - 1.004}{1.354} \times 100 = \boxed{25.8\%}$$

1.59. From the given data: $w = 0.270\,\text{m}$, $h = 0.380\,\text{m}$, $A = wh = 0.1026\,\text{m}^2$, $p_1 = 100\,\text{kPa}$, and $z = 11\,\text{km}$. In a standard atmosphere (Appendix B.3) the pressure at an altitude of 11 km is $p_2 = 22.632\,\text{kPa}$. Therefore, the force, F, on the airplane window is calculated as follows:

$$F = (p_1 - p_2)A = (100 - 22.632)(0.1026) = \boxed{7.94\,\text{kN}}$$

1.60. From the given data: $V = 913$ km/h $= 253.6\,\text{m/s}$, and $z = 10.7\,\text{km}$. For a standard atmosphere at elevation z, the speed of sound is given by $c = 296.4\,\text{m/s}$ from Appendix B.3 (by interpolation). Therefore, the Mach number, Ma, is given by

$$\text{Ma} = \frac{V}{c} = \frac{253.6}{296.4} = \boxed{0.86}$$

Since Ma > 0.3, $\boxed{\text{compressibility must be taken into account}}$.

1.61. From the given data: $V = 885\,\text{km/h} = 246\,\text{m/s}$ and $\text{Ma} = 0.85$. Calculate the speed of sound, c, as follows:

$$\text{Ma} = \frac{V}{c} = 0.85 \quad \rightarrow \quad c = \frac{V}{0.85} = \frac{246}{0.85} = 289\,\text{m/s}$$

Interpolating from the standard atmosphere given in Appendix B.3, an elevation of $\boxed{74.6\ \text{km}}$ corresponds to a sonic speed of 289 m/s.

1.62. The dynamic viscosity, ν, is defined as $\nu = \mu/\rho$. Using this relation and the properties of water given in Appendix B.1 gives,

Temperature (°C)	μ (N· s/m^2)	ρ (kg/m^3)	ν (10^{-6} m^2/s)
0	0.001781	999.8	1.781
20	0.001002	998.2	1.004
100	0.000282	958.4	0.294

1.63. From the given data: SG = 0.92, and $\nu = 5\times10^{-4}$ m^2/s. For water at 4°C, $\rho_\mathrm{w} = 1000$ kg/m^3. Using the definitions of specific gravity,

$$\rho = \mathrm{SG}\cdot\rho_\mathrm{w} = (0.92)(1000) = 920\,\mathrm{kg/m^3}$$

$$\nu = \frac{\mu}{\rho} \quad\to\quad 5\times10^{-4} = \frac{\mu}{920} \quad\to\quad \mu = \boxed{0.46\ \mathrm{Pa{\cdot}s}}$$

1.64. From the given data: $T = 25°\mathrm{C} = 298$ K, $p = 110$ kPa, and $\mu = 12\ \mu\mathrm{Pa{\cdot}s} = 1.2\times10^{-5}$ Pa·s. The molar mass of methane is 16.04 g/mol, and hence the gas constant for methane can be taken as $R = 8314/16.04 = 518$ J/kg·K. The density, ρ, and kinematic viscosity, ν, of methane are calculated as follows:

$$\rho = \frac{p}{RT} = \frac{110\times10^3}{(518)(298)} = 0.7126\,\mathrm{kg/m^3}$$

$$\nu = \frac{1.2\times10^{-5}}{0.7126} = \boxed{1.684\times10^{-5}\,\mathrm{m^2/s}}$$

1.65. From the given data: $\tau_0 = 0.5$ Pa, and $y = 2$ mm $= 0.002$ m. For benzene at 20°C, Appendix B.4 gives $\mu = 0.65$ mPa·s $= 6.5\times10^{-4}$ Pa·s. The velocity gradient can be derived from Newton's law of viscosity, Equation 1.44, as follows

$$\tau_0 = \mu\left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0} \quad\to\quad 0.5 = (6.5\times10^{-4})\left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0} \quad\to\quad \left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0} = \boxed{769\,\mathrm{s^{-1}}}$$

The velocity at 2 mm (= 0.002 m) from the surface, V_2, can be estimated by

$$V_2 = \left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0}(0.002) = (769)(0.002) = \boxed{1.54\,\mathrm{m/s}}$$

1.66. From the given data: $\mu = 0.300$ Pa·s, $A = 1.5$ m^2, and $h = 200$ mm $= 0.2$ m.

(a) The shear stress on the top and bottom plates are the same due to symmetry (i.e., same velocity gradient adjacent to top and bottom plane). The shear stress on the top plate, τ_top is given by

$$\tau_\mathrm{top} = \mu\left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0.1} = \mu\left.\frac{\mathrm{d}}{\mathrm{d}y}\left[0.8(1-100y^2)\right]\right|_{y=0.1} = \mu\left[160y\right]_{y=0.1} = (0.3)[160(0.1)] = 4.8\,\mathrm{Pa}$$

Therefore the shear stress on both the top and bottom plate is equal to $\boxed{4.8\ \mathrm{Pa}}$.

(b) The shear force on the top plate, F_{top}, is given by

$$F_{\text{top}} = \tau_{\text{top}} \cdot A = (4.8)(1.5) = 7.2\,\text{N}$$

Due to symmetry, the shear force on both the top and bottom plate is equal to $\boxed{7.2\text{ N}}$.

1.67. From the given data: L = 1.3 m, D = 60 mm = 0.060 m, Δy = 0.6 mm = 0.0006 m, μ = 0.82 Pa·s, and ΔV = 1.7 m/s. Assuming that the velocity distribution is linear between cylinders, the shear stress, τ_0, on the inner cylinder can be estimates using the relation

$$\tau_0 = \mu\frac{\Delta V}{\Delta y} = (0.82)\frac{1.7}{0.0006} = 2323.34\,\text{Pa}$$

The force, F, required to move the inner cylinder is given by

$$F = \tau_0 \pi D L = (2323.34)\pi(0.060)(1.3) = \boxed{569.321\,\text{N}}$$

1.68. From given data: $L = 75\,\text{cm} = 0.75\,\text{m}$, $D_\text{i} = 15\,\text{cm} = 0.15\,\text{m}$, $D_\text{o} = 15.24\,\text{cm} = 0.1524\,\text{m}$, $\dot{n} = 200\,\text{rpm}$, and $\mu = 0.023\,\text{Pa·s}$. From these given data: $\omega = 2\pi\dot{n}/60 = 20.94\,\text{rad/s}$, $\Delta R = (D_\text{o} - D_\text{i})/2 = 0.12\,\text{cm}$, $R_\text{o} = D_\text{o}/2 = 7.62\,\text{cm}$, and $R_\text{i} = D_\text{i}/2 = 7.50\,\text{cm}$.

(a) The following relationship applies to calculating the force, F_o, on the outer cylinder:

$$F_\text{o} = \mu\frac{\Delta u}{\Delta x}A = \mu\frac{R_\text{i}\omega}{\Delta R}2\pi R_\text{o} L = (0.023)\frac{(0.075)(20.94)}{(0.0012)}2\pi(0.0762)(0.75) = \boxed{10.81\,\text{N}}$$

(b) The force, F_i, on the inner cylinder is given by,

$$F_\text{i} = \mu\frac{\Delta u}{\Delta x}A = \mu\frac{R_\text{i}\omega}{\Delta R}2\pi R_\text{i} L = (0.023)\frac{(0.075)(20.94)}{(0.0012)}2\pi(0.0750)(0.75) = 10.64\,\text{N}$$

Therefore the torque, T, and power, P, required to rotate the inner cylinder are given by

$$T = F_\text{i}R_\text{i} = (10.64)(0.075) = \boxed{0.798\,\text{N·m}}, \qquad P = T\omega = (0.798)(20.94) = \boxed{16.7\,\text{W}}$$

1.69. The required equation is:

$$T = \mu\frac{4\pi^2 R^3 \dot{n} L}{D} \tag{1}$$

From the given data: $R = 0.5(0.20) = 0.10$ m, $L = 0.30$ m, $D = 0.5(0.202 - 0.200) = 0.001$ m, $T = 0.13$ Nm, and $\dot{n} = 400$ rpm $= 6.667$ s^{-1}. Substituting into Equation 1 gives

$$0.13 = \mu\frac{4\pi^2(0.10)^3(6.667)(0.30)}{0.001}$$

which gives $\boxed{\mu = 0.001646\ \text{N·s/m}^2}$.

1.70. From the given data: $\Delta z = 2$ mm $= 0.002$ m, $D = 0.5$ m, $R = D/2 = 0.25$ m, and $\omega =$ 3 rpm $= 0.3142$ rad/s. For SAE 30 oil at 20°C, $\mu = 0.44$ Pa·s (Appendix B.4). Since the velocity varies with distance from the center of rotation, an expression for the torque, T, can be derived as follows,

$$\mathrm{d}F = \tau\,\mathrm{d}A = \tau\,2\pi r\,\mathrm{d}r = \left[\mu\frac{r\omega}{\Delta z}\right]2\pi r\,\mathrm{d}r$$

$$\mathrm{d}T = r\,\mathrm{d}F = \frac{2\pi\mu\omega}{\Delta z}r^3\,\mathrm{d}r$$

$$T = \int_{r=0}^{r=R}\mathrm{d}T = \frac{2\pi\mu\omega}{\Delta z}\int_0^R r^3\,\mathrm{d}r = \frac{\pi\mu\omega R^4}{2\Delta z}$$

Hence, in this case, the torque, T, is given by

$$T = \frac{\pi\mu\omega R^4}{2\Delta z} = \frac{\pi(0.44)(0.3142)(0.25)^4}{2(0.002)} = \boxed{0.135\,\mathrm{N{\cdot}m}}$$

1.71. From the given data: $m = 0.8\,\mathrm{kg}$, $D_1 = 50\,\mathrm{mm} = 0.05\,\mathrm{m}$, $D_2 = 53\,\mathrm{mm}$, $\Delta y = (D_2 - D_1)/2 = 1.5\,\mathrm{mm} = 0.0015\,\mathrm{m}$, $L = 10\,\mathrm{cm} = 0.10\,\mathrm{m}$, and $\mu = 0.29\,\mathrm{Pa{\cdot}s}$.

(a) Let V be the velocity of the inner cylinder, Newton's law of viscosity gives

$$\tau = \mu\frac{\mathrm{d}u}{\mathrm{d}y} = \mu\frac{V}{\Delta y}$$

and hence the shear force on the cylinder, F_τ, is given by

$$F_\tau = \tau A = \left(\mu\frac{V}{\Delta y}\right)(\pi D_1 L) = \frac{\mu V\pi D_1 L}{\Delta y}$$

At the terminal speed,

$$W = F_\tau \quad\rightarrow\quad mg = \frac{\mu V\pi D_1 L}{\Delta y}$$

which gives

$$V = \frac{mg\Delta y}{\mu\pi D_1 L} = \frac{(0.8)(9.81)(0.0015)}{(0.29)\pi(0.050)(0.10)} = \boxed{2.58\,\mathrm{m/s}}$$

(b) Before reaching terminal speed, the net force, F_net, is given by

$$F_\mathrm{net} = W - F_\tau = mg - \frac{\mu V\pi D_1 L}{\Delta y} = (0.8)(9.81) - \frac{(0.29)V\pi(0.050)(0.10)}{(0.0015)} = 7.85 - 3.03V$$

Newton's law of motion gives

$$F_\mathrm{net} = ma \quad\rightarrow\quad F_\mathrm{net} = m\frac{\mathrm{d}V}{\mathrm{d}t} \quad\rightarrow\quad 7.85{-}3.03V = (0.8)\frac{\mathrm{d}V}{\mathrm{d}t} \quad\rightarrow\quad 9.81{-}3.79V = \frac{\mathrm{d}V}{\mathrm{d}t}$$

which yields

$$\int_0^{V_t}\frac{\mathrm{d}V}{9.81 - 3.79V} = \int_0^{t_t}\mathrm{d}t$$

which integrates to

$$\frac{1}{-3.79}\ln\left(\frac{9.81-3.79V_t}{9.81}\right)=t_t$$

Taking $V_t = 2.58\,\text{m/s}$ gives

$$t_t=\frac{1}{-3.79}\ln\left(\frac{9.81-3.79(2.58)}{9.81}\right)=\boxed{1.51\,\text{s}}$$

1.72. From the given data: $D_1 = 0.4\,\text{mm}$, $D_2 = 1.2\,\text{mm}$, $\mu = 1.5\,\text{Pa·s}$, $F = 84\,\text{N}$, and $V = 1.3\,\text{m/s}$. The spacing, s, between the cable and the wall of the cavity is given by

$$s=\frac{D_2-D_1}{2}=\frac{1.2\,\text{mm}-0.4\,\text{mm}}{2}=0.4\,\text{mm}$$

The shear stress, τ, on the cable can be estimated from the velocity gradient as

$$\tau=\mu\frac{V}{s}=(1.5)\frac{1.3}{0.4\times10^{-3}}=4.875\times10^{3}\,\text{Pa}$$

Let L be the limiting length of the cavity, then

$$\tau[\pi D_1 L]=F \quad\rightarrow\quad 4.875\times10^{3}[\pi(0.4\times10^{-3})L]=84 \quad\rightarrow\quad \boxed{L=13.7188\,\text{m}}$$

1.73. From the given data: $A = 1.7\,\text{m}^2$, $V = 1.5\,\text{m/s}$, $h_1 = 0.4\,\text{mm}$, $\mu_1 = 0.2\,\text{Pa·s}$, $h_2 = 0.3\,\text{mm}$, and $\mu_2 = 0.3\,\text{Pa·s}$.

(a) Let V_i be velocity at the interface between the two fluids. The shear stress at the interface can be calculated using both the gradient in the upper layer and the gradient in the lower layer, which gives

$$\mu_1\frac{V_\text{i}}{h_1}=\mu_2\frac{V-V_\text{i}}{h_2}$$

which upon rearrangement gives

$$V_\text{i}=\frac{\mu_2/h_2}{\mu_1/h_1+\mu_2/h_2}V=\frac{0.3/0.3\times10^{-3}}{0.2/0.4\times10^{-3}+0.3/0.3\times10^{-3}}(1.5)=\boxed{1.00\,\text{m/s}}$$

(b) The force, F, required to move the top plate is given by

$$F=\tau A=\mu_2\frac{V-V_\text{i}}{h_2}A=(0.3)\frac{1.5-1.0}{0.3\times10^{-3}}=\boxed{850\,\text{N}}$$

1.74. From the given data: $V = 9\,\text{m/s}$, $h_1 = 40\,\text{mm}$, $h_2 = 25\,\text{mm}$, and $A_\text{p} = 1\,\text{m}\times1.28\,\text{m} = 1.28\,\text{m}^2$. For SAE 50 oil at 20°C, $\mu = 860\,\text{mPa·s}$ (from Appendix B.4). Since the velocity profile is linear above and below the moving plate,

$$\tau_\text{top}=\mu\frac{V}{h_1}=(0.860)\frac{9}{0.04}=199.35\,\text{Pa},\qquad F_\text{top}=\tau_\text{top}A_\text{p}=(199.35)(1.28)=255.1680\,\text{N}$$

$$\tau_\text{bot}=\mu\frac{V}{h_2}=(0.860)\frac{9}{0.025}=318.96\,\text{Pa},\qquad F_\text{bot}=\tau_\text{bot}A_\text{p}=(318.96)(1.28)=408.2688\,\text{N}$$

Adding the forces on the top and bottom of the plate gives

$$F_\text{tot}=F_\text{top}+F_\text{bot}=255.1688+408.2680=\boxed{663.4368\,\text{N}}$$

1.75. For water at 20°C, $\mu = 1.00$ mPa·s $= 0.001$ Pa·s. Using Newton's law of viscosity, Equation 1.44, with the given velocity distribution, the shear stress on the bottom of the channel, τ_0, is given by

$$\tau_0 = \mu \left.\frac{\mathrm{d}u}{\mathrm{d}y}\right|_{y=0} = (0.001) \left.\frac{\mathrm{d}}{\mathrm{d}y}[1.2y(1-y)]\right|_{y=0} = (0.001)\left.[1.2 - 2.4y]\right|_{y=0} = \boxed{0.0012\,\mathrm{Pa}}$$

1.76. At equilibrium, the component of the weight down the incline equal to the shear force, Hence

$$W\sin\theta = \tau_0 A \quad\rightarrow\quad W\sin\theta = \left(\mu\frac{V}{h}\right)A \quad\rightarrow\quad \boxed{V = \frac{Wh\sin\theta}{\mu A}}$$

For SAE 30 oil at 20°C, $\mu = 0.44$ Pa·s, and from the given data: $W = mg = (6)(9.81) =$ 56.86 N, $h = 1$ mm $= 0.001$ m, $\theta = 15°$, and $A = 35$ cm^2 $= 0.0035$ m^2, which gives

$$V = \frac{(58.86)(0.001)\sin 15°}{(0.44)(0.0035)} = \boxed{9.89\,\mathrm{m/s}}$$

1.77. (a) The shear stress, τ, can be expressed as follows,

$$\tau = \mu\frac{dV}{dr} = \mu V_o\frac{d}{dr}\left(1 - \frac{r^2}{R^2}\right) = \mu V_o\left(-\frac{2r}{R^2}\right) = \boxed{-\left(\frac{2\mu V_o}{R^2}\right)r}$$

This result can also be written without the minus sign if the distance is measured from the wall of the pipe.

(b) Shear stress on pipe boundary, τ_o, is at $r = R$, hence

$$\tau_o = \frac{2\mu V_o}{R^2}\cdot R = \frac{2\mu V_o}{R}$$

The shear force, F, per unit length is therefore given by

$$F = \tau_o P$$

where P is the perimeter of the pipe. Since $P = 2\pi R$,

$$F = \tau_o P = \frac{2\mu V_o}{R}(2\pi R) = \boxed{4\pi\mu V_o}$$

1.78. The shear stress, τ, is given by Newton's law as

$$\tau = \mu\frac{\mathrm{d}u}{\mathrm{d}y} = -\mu\frac{\mathrm{d}u}{\mathrm{d}r} \tag{1}$$

From the given velocity distribution,

$$\frac{\mathrm{d}u}{\mathrm{d}r} = u_{\max} n\frac{r^{n-1}}{R^n} \tag{2}$$

Combining Equations 1 and 2 yields

$$\tau(r) = -\mu u_{\max} n \frac{r^{n-1}}{R^n}$$

At the pipe wall, $r = R$, and hence the drag force, F_{D}, per unit length of pipe is given by

$$F_{\mathrm{D}} = \tau(R) \cdot 2\pi R = -\mu u_{\max} n \frac{R^{n-1}}{R^n} 2\pi R = \boxed{-2n\pi\mu u_{\max}}$$

1.79. For SAE 10 oil: $\rho = 918$ kg/m^3, and $\mu = 82$ mPa·s; for SAE 30 oil: $\rho = 918$ kg/m^3, and $\mu = 440$ mPa·s. From the given expression for Q,

$$\Delta p = \frac{128 Q \mu L}{\pi D^4}$$

and hence for different fluids with the same Q and D,

$$\frac{\Delta p_2}{\Delta p_1} = \frac{\mu_2}{\mu_1} = \frac{440}{82} = 5.57$$

which gives

$$\% \text{ increase} = \frac{\Delta p_2 - \Delta p_1}{\Delta p_1} \times 100 = (5.37 - 1) \times 100 = \boxed{437\%}$$

The shear stress, τ_0, on the wall of the pipe can be calculated from the given velocity distribution using the following relations

$$\begin{aligned}
\tau_0 &= \mu \frac{\mathrm{d}u}{\mathrm{d}y}\bigg|_{y=0} = -\,\mu \frac{\mathrm{d}u}{\mathrm{d}r}\bigg|_{r=D/2} \\
\frac{\mathrm{d}u}{\mathrm{d}r} &= \frac{\Delta p}{16\mu L}(-8r) = \frac{\Delta p r}{2\mu L} \\
\tau_0 &= -\,\mu \frac{\mathrm{d}u}{\mathrm{d}r}\bigg|_{r=D/2} = -\,\mu \left(\frac{\Delta p r}{2\mu L}\right)\bigg|_{r=D/2} = \frac{\Delta p}{4L}
\end{aligned}$$

Based on this result,

$$\frac{\tau_{02}}{\tau_{01}} = \frac{\Delta p_2}{\Delta p_1} = 5.57$$

which gives

$$\% \text{ increase} = \frac{\tau_{02} - \tau_{01}}{\tau_{01}} \times 100 = (5.37 - 1) \times 100 = \boxed{437\%}$$

<u>Other Possible Answer:</u>
Some sources give different viscosities for oil. If $\mu_1 = 0.10$ Pa·s and $\mu_2 = 0.29$ Pa·s, then

$$\frac{\Delta p_2}{\Delta p_1} = \frac{0.29}{0.10} = 2.9$$

$$\% \text{ increase} = (2.9 - 1) \times 100 = \boxed{190\%}$$

Similarly,

$$\frac{\tau_2}{\tau_1} = \boxed{190\%}$$

1.80. Andrade's viscosity equation is Equation 1.50, and the other estimate is given in Equation 1.51. The standard equation parameters for water that are given in the text are used. The results of the calculations of viscosity, μ in mPa·s are given in the following table:

		Viscosity, μ (mPa·s)				
T (°C)	T (K)	App. B.1 (mPa·s)	Andrade (mPa·s)	Δ_1 (%)	Eq. 1.51 (mPa·s)	Δ_2 (%)
0	273.15	1.781	1.753	−1.57	1.792	0.62
5	278.15	1.518	1.501	−1.11	1.536	1.22
10	283.15	1.307	1.300	−0.57	1.330	1.76
15	288.15	1.139	1.136	−0.27	1.162	1.98
20	293.15	1.002	1.002	−0.03	1.023	2.07
25	298.15	0.89	0.890	0.05	0.907	1.96
30	303.15	0.798	0.797	−0.10	0.811	1.61
40	313.15	0.653	0.651	−0.24	0.660	1.08
50	323.15	0.547	0.544	−0.52	0.550	0.50
60	333.15	0.466	0.463	−0.62	0.467	0.23
70	343.15	0.404	0.400	−0.88	0.404	−0.05
80	353.15	0.354	0.351	−0.85	0.354	0.14
90	363.15	0.315	0.311	−1.17	0.315	0.13
100	373.15	0.282	0.279	−1.07	0.284	0.71
			Average:	−0.64		1.00

(a) The comparison of estimated viscosities for the Andrade equation is given in the above table. The maximum percentage difference is $\boxed{-1.57\% \text{ at } 0°\text{C}}$.

(a) The comparison of estimated viscosities for the alternative empirical expression is given in the above table. The maximum percentage difference is $\boxed{2.07\% \text{ at } 20°\text{C}}$. Since both the maximum and average percentage error is less for the Andrade equation, I would recommend the $\boxed{\text{Andrade equation}}$ for use in this temperature range.

1.81. From the given data: $\mu_1 = 16.40\,\mu$Pa·s, $T_1 = 0°\text{C} = 273\,\text{K}$, $\mu_2 = 20.94\,\mu$Pa·s, $T_1 = 100°\text{C} = 373\,\text{K}$, and $T_3 = 50°\text{C} = 323\,\text{K}$.

(a) Using linear interpolation,

$$\mu_3 = \mu_1 + \frac{\Delta\mu}{\Delta T}(T_3 - T_1) = 16.40 + \frac{20.94 - 16.40}{373 - 273}(323 - 273) = \boxed{18.67\,\mu\text{Pa·s}}$$

(b) Using the Sutherland equation (Equation 7.105), first determine the value of the constant e by applying this equation at $T = 0°\text{C}$ and $T = 100°\text{C}$,

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^{\frac{3}{2}} \frac{T_0 + e}{T + e} \quad \rightarrow \quad \frac{20.94}{16.40} = \left(\frac{373}{273}\right)^{\frac{3}{2}} \frac{273 + e}{373 + e} \quad \rightarrow \quad e = 125.7\,\text{K}$$

Use the Sutherland equation with $e = 125.7\,\text{K}$ to estimate the value of μ at $T = 50°\text{C}$,

$$\frac{\mu_3}{16.40} = \left(\frac{323}{273}\right)^{\frac{3}{2}} \frac{273 + 125.7}{323 + 125.7} \quad \rightarrow \quad \mu_3 = \boxed{18.76\,\mu\text{Pa·s}}$$

(c) Using the power-law equation (Equation 7.71), first determine the value of the constant n by applying this equation at $T = 0°\text{C}$ and $T = 100°\text{C}$,

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^n \quad \rightarrow \quad \frac{20.94}{16.40} = \left(\frac{373}{273}\right)^n \quad \rightarrow \quad n = 0.786$$

Use the power-law equation with $n = 0.786$ to estimate the value of μ at $T = 50°\text{C}$,

$$\frac{\mu_3}{16.40} = \left(\frac{323}{273}\right)^{0.786} \quad \rightarrow \quad \mu_3 = \boxed{18.71\,\mu\text{Pa·s}}$$

(d) Appendix B.6 gives the dynamic viscosity of nitrogen at 50°C as $18.74\,\mu$Pa·s. Comparing this value with the values estimated in Parts a–c, it is apparent that the $\boxed{\text{Sutherland equation}}$ provides the most accurate estimate, with an error of approximately 0.11%.

1.82. $\boxed{\text{No}}$. Surface tension results from the unbalanced cohesive forces acting on liquid molecules at the surface of the liquid. Since the attraction force between water and air molecules is different from the attraction force between water and oxygen molecules, the surface tension of water in contact with air is necessarily different from the surface tension of water in contact with oxygen.

1.83. For steel, SG = 7.83, and hence $\gamma_\text{steel} = 7.83 \times 9810 = 76800\,\text{N/m}^3$. For water at 20°C, $\sigma = 72.8\,\text{mN/m} = 0.0728\,\text{N/m}$. If W is the weight of the pin and L is the length of the pin, then

$$W = 2\sigma L \sin\theta \tag{1}$$

which gives the relationship between the deflection angle and the weight of the pin as

$$\boxed{\theta = \sin^{-1}\left(\frac{W}{2\sigma L}\right)}$$

The volume of the steel pin, V_pin is given by

$$V_\text{pin} = \frac{\pi D^2}{4} L$$

and substituting into Equation 1 gives

$$\gamma_\text{steel} V_\text{pin} = 2\sigma L \sin\theta$$

$$(76800)\frac{\pi D^2}{4}\cancel{L} = 2(0.0728)\cancel{L} \sin 10°$$

which yields the maximum pin diameter that can be supported by the water as $D = 0.000647$ m = $\boxed{0.647 \text{ mm}}$ for any length of pin.

1.84. For water at 20°C: $\sigma = 72.8\,\text{mN/m}$ (from Appendix B.1). The reference specific weight of water at 4°C is $\gamma_\text{w} = 9807\,\text{N/m}^3$. At the limit at which a sphere can be supported, the surface-tension force is equal to the weight of the sphere, which requires that:

$$\sigma \pi D = \gamma \frac{4}{3}\pi \left(\frac{D}{2}\right)^3 \quad \rightarrow \quad D = \sqrt{\frac{6\sigma}{\gamma}}$$

where D is the diameter of the sphere, and γ is the specific weight of the sphere.

(a) For lead, SG = 11.4 (from Table 1.4), and therefore the limiting diameter of a lead sphere that can be supported on water is

$$D = \sqrt{\frac{6(72.8\times10^{-3})}{(11.4)(9807)}} = 1.98\times10^{-3}\,\text{m} \approx \boxed{2.0\,\text{mm}}$$

(b) For concrete, SG = 2.4 (from Table 1.4), and therefore the limiting diameter of a concrete sphere that can be supported on water is

$$D = \sqrt{\frac{6(72.8\times10^{-3})}{(2.4)(9807)}} = 4.3\times10^{-3}\,\text{m} \approx \boxed{4.3\,\text{mm}}$$

1.85. From the given data: D_1 = 0.5 mm = 0.0005 m, and D_2 = 4 mm = 0.004 m. For water at 20°C, σ = 0.073 N/m. The pressure difference, Δp, between the inside and outside of the droplet is given by Equation 1.59 as

$$\Delta p = \frac{2\sigma}{R} = \frac{4\sigma}{D} = \frac{4(0.073)}{D} = \frac{0.292}{D}$$

For the given range of raindrop diameters,

$$\Delta p_1 = \frac{0.292}{D_1} = \frac{0.292}{0.0005} = 584\,\text{Pa}, \qquad \Delta p_2 = \frac{0.292}{D_2} = \frac{0.292}{0.004} = 73\,\text{Pa}$$

Therefore, the range of pressure differences is $\boxed{\text{73–584 Pa}}$.

1.86. From the given data: D = 0.6 mm = 0.0006 m, $R = D/2$ = 0.0003 m, and p_atm = 101.3 kPa. For Glycerin at 20°C, σ = 0.0633 N/m (from Appendix B.4). The pressure difference, Δp, between the inside and outside of the droplet is given by Equation 1.59 as

$$\Delta p = \frac{2\sigma}{R} = \frac{2(0.0633)}{0.0003} = 422\,\text{Pa}$$

Therefore, the absolute pressure inside the droplet is 101.3 kPa + 0.422 kPa $\simeq \boxed{101.722 \text{ kPa}}$.

1.87. (a) The sum of the forces in the vertical direction is equal to zero, hence

$$p_1\pi R^2 + \gamma\tfrac{2}{3}\pi R^3 - p_2\pi R^2 - \sigma 2\pi R = 0$$

which simplifies to

$$\boxed{p_1 - p_2 = \frac{2\sigma}{R} - \frac{2}{3}\gamma R} \qquad (1)$$

Contrasting this result with the conventional relation (Equation 1.59) shows that there is an $\boxed{\text{additional term of } \tfrac{2}{3}\gamma R}$.

(b) From the given data: D = 1.5 mm, $R = D/2$ = 0.75 mm, and T = 20°C. For SAE 30 oil, Appendix B.4 gives σ = 36 mN/m, $\rho = 918\,\text{kg/m}^3$, and $\gamma = 9003\,\text{N/m}^3$. Using Equation 1, the pressure difference is given by

$$p_1 - p_2 = \frac{2\sigma}{R} - \frac{2}{3}\gamma R = \frac{2(36\times10^{-3})}{1.5\times10^{-3}} - \frac{2}{3}(9003)(1.5\times10^{-3}) = 48\,\text{Pa} + 9\,\text{Pa} = 57\,\text{Pa}$$

Therefore, the error in using Equation 1.59 and neglecting the weight of the liquid is 9/57 × 100 = 16%. Neglecting the weight is $\boxed{\text{not justified}}$.

1.88. From the given data: D = 60 mm = 0.060 m, and σ = 0.072 N/m. The pressure difference, Δp, between the inside and outside of the bubble is given by Equation 1.60 as

$$\Delta p = \frac{4\sigma}{R} = \frac{8\sigma}{D} = \frac{8(0.072)}{0.060} = \boxed{6.84\,\text{Pa}}$$

1.89. From the given data: $h = 6\,\text{mm} = 0.006\,\text{m}$. Take $\theta_\text{w} = 0°$, $\sigma_\text{w} = 0.073\,\text{N/m}$, and $\rho_\text{w} = 998\,\text{kg/m}^3$ (Appendix B.4). Equation 1.63 gives

$$h_\text{w} = \frac{2\sigma_\text{w}\cos\theta_\text{w}}{\rho_\text{w} g r} \quad\rightarrow\quad 0.006 = \frac{2(0.073)\cos 0°}{(998)(9.807)r} \quad\rightarrow\quad r = 0.002487\,\text{m} = 2.487\,\text{mm}$$

Therefore the minimum diameter capillary tube to limit the capillary rise to 6 mm is 2(2.487) = $\boxed{5.0\,\text{mm}}$.

1.90. From the given data: D = 1.5 mm = 0.0015 m, $r = D/2$ = 0.00075 m, h = 15 mm = 0.015 m, $\theta = 15°$, and SG = 0.8. For water at 4°C, ρ_w = 1000 kg/m^3. Using the capillary-rise equation, Equation 1.63, gives

$$h = \frac{2\sigma\cos\theta}{\text{SG}\cdot\rho_\text{w} g r} \quad\rightarrow\quad 0.015 = \frac{2\sigma\cos 15°}{(0.8)(1000)(9.807)(0.00075)} \quad\rightarrow\quad \sigma = \boxed{0.0457\,\text{N/m}}$$

The surface tension would be the $\boxed{\text{same}}$ if a different tube material were used, since the surface tension is a property of the fluid, not the tube material.

1.91. From the given data: D = 1 mm = 0.001 m, and θ = 127° = 2.217 radians. For mercury at 20°C, σ = 0.51 N/m, and ρ = 13 550 Kg/m^3 (from Appendix B.4). The capillary rise or depression, h, is given by Equation 1.63 which yields

$$h = \frac{2\sigma\cos\theta}{\gamma r} = \frac{4\sigma\cos\theta}{\gamma D} = \frac{4(0.51)\cos 127°}{(13550)(9.807)(0.001)} = -0.00924\,\text{m} = -9.2\,\text{mm}$$

Therefore, the depression of mercury in the capillary tube is $\boxed{9.2\text{ mm}}$.

1.92. From the given data: $h = 4D$, and θ = 15°. For benzene at 25°C, σ = 0.029 N/m, and ρ = 876 kg/m^3 (from Appendix B.4). The capillary rise, h, is given by Equation 1.63 which yields

$$\begin{aligned} h &= \frac{2\sigma\cos\theta}{\gamma r} \rightarrow 4D = \frac{4\sigma\cos\theta}{\gamma D} \rightarrow D = \sqrt{\tfrac{4\sigma\cos\theta}{4\gamma}} = \sqrt{\tfrac{4(0.029)\cos 15°}{4(876)(9.807)}} \\ &= 0.001805\,\text{m} \simeq 1.805\,\text{mm} \end{aligned}$$

Therefore, a tube diameter less than or equal to $\boxed{1.805\text{ mm}}$ should be used if the capillary rise is to be at least four tube diameters.

1.93. For equilibrium, per unit distance along the parallel plates,

$$2\sigma(1)\cos\theta = \gamma W h(1)$$

which gives

$$\boxed{h = \frac{2\sigma\cos\theta}{\gamma W}}$$

From the given data: $W = 0.5$ mm $= 0.5 \times 10^{-3}$ m, $\sigma = 0.0727$ N/m (water at 20°C), and taking $\theta = 0$ gives

$$h = \frac{2(0.0727)(1)}{(998)(9.81)(0.5 \times 10^{-3})} = 0.0297 = \boxed{29.7\,\text{mm}}$$

1.94. From the given data: $\sigma_\text{w} = 73\,\text{mN/m}$, $\theta = 5°$, and $p_0 = 101.3\,\text{kPa}$. For water at 20°C, $\gamma = 9.789\,\text{kN/m}^3$ and $p_\text{v} = 2.337\,\text{kPa}$ (from Appendix B.1). Using the given equation for the pressure at the meniscus, the limiting condition occurs when

$$p_\text{v} = p_0 - \gamma h \quad \rightarrow \quad h = \frac{p_0 - p_\text{v}}{\gamma} = \frac{101.3 - 2.337}{9.789} = 10.11\,\text{m}$$

Using this value of h in the capillary-rise equation (Equation 1.63) for a capillary tube of diameter D gives

$$h = \frac{2\sigma_\text{w}\cos\theta}{\gamma r} \quad \rightarrow \quad 10.11 = \frac{2(73 \times 10^{-3})\cos 5°}{9789(D/2)} \quad \rightarrow \quad D = 2.93 \times 10^{-6}\,\text{m} = \boxed{2.9\ \mu\text{m}}$$

1.95. (a) Combining Equations 1.68 and 1.69 gives

$$p_0 - p = \frac{2\sigma}{R} = \gamma h \quad \rightarrow \quad \boxed{R = \frac{2\sigma}{\gamma h}} \tag{1}$$

(b) From the given data: $h = 75\,\text{mm}$. For water at 10°C, $\sigma = 74.2$ mN/m and $\gamma = \rho g = 999.7(9.807) = 9804\,\text{N/m}^3$ (from Appendix B.1). Substituting these data into Equation 1 gives

$$R = \frac{2(74.2 \times 10^{-3})}{(9804)(75 \times 10^{-3}} = 2.02 \times 10^{-4}\,\text{m} \approx \boxed{0.20\,\text{mm}}$$

1.96. For gasoline at 20°C, Appendix B.4 gives $p_\text{v} = 55.2\,\text{kPa}$. Therefore, the minimum pressure that can be attained above the gasoline in the storage tank is $\boxed{\text{55.2 kPa.}}$

1.97. From given data: T = 25°C = 273.15 + 25 = 298.15 K, p = 101.3 kPa, f_{O_2} =0.25, and f_{N_2} = 0.75. Also know: m_{O_2} = 32 g/mol, m_{N_2} = 28.02 g/mol, and R = 8.315 kJ/K·mol.

(a)

$$\rho_{\text{O}_2} = \frac{p m_{\text{O}_2}}{RT} = \frac{(101.3 \times 10^3)(0.032)}{(8.315)(298.15)} = 1.3076\,\text{kg/m}^3$$

$$\rho_{\text{N}_2} = \frac{p m_{\text{N}_2}}{RT} = \frac{(101.4 \times 10^3)(0.02802)}{(8.315)(298.15)} = 1.1441\,\text{kg/m}^3$$

$$\rho_\text{air} = 0.25(1.3076) + 0.75(1.1441) = \boxed{1.1850\,\text{kg/m}^3}$$

(b) From the ideal gas law:

$$pV = nRT \rightarrow \frac{pV}{T} = nR$$

The temperature in the tank is T = 20°C = 273.15 + 20 = 293.15 K. Putting air into the tank requires that:

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \quad \rightarrow \quad \frac{(101.3)V_1}{298.15} = \frac{(210)(1.5)}{293.15}$$

which yields $V_1 = 3.163\ \mathrm{m}^3$. Since the density of the air is 1.1850 kg/m^3, the weight of air is given by

$$\text{weight of air} = (3.163)(1.1850) = 3.748\,\text{kg} = \boxed{36.76\ \text{N}}$$

Alternative Solution:

$$\begin{aligned}
\rho_{\mathrm{O}_2} &= \frac{p_2 m_{\mathrm{O}_2}}{RT_2} = \frac{(210\times10^3)(0.032)}{(8.315)(293.15)} &&= 2.757\,\text{kg/m}^3 \\
\rho_{\mathrm{N}_2} &= \frac{p_2 m_{\mathrm{N}_2}}{RT_2} = \frac{(210\times10^3)(0.02802)}{(8.315)(293.15)} &&= 2.414\,\text{kg/m}^3 \\
\rho_{\text{air}} &= 0.25(2.757) + 0.75^*(2.414) &&= 2.50\,\text{kg/m}^3
\end{aligned}$$

So for 1.5 m^3,

$$\text{weight of air} = 3.7496\,\text{kg} = \boxed{36.77\ \text{N}}$$

(c) At 25°C, p_svp = 3.167 kPa and p_vp = 0.85(3.167) = 2.6919 kPa. Interpolating from the properties of water gives that p_svp = 2.6919 kPa when T = $\boxed{23.01°\text{C}}$.

1.98. In the morning, T = 25.6°C, and RH = 75%. From the table of water properties, the saturation vapor pressure at 25.6°C is p_svp = 3.296 kPa. Hence the actual vapor pressure at 25.6°C, p_vp, is given by

$$p_\text{vp} = \text{RH} \cdot p_\text{svp} = (0.75)(3.296) = 2.472\,\text{kPa}$$

At T = 32.2°C, p_svp = 4.933 kPa and hence the the relative humidity is given by

$$\text{RH} = \frac{2.472}{4.933} \times 100 = \boxed{50\%}$$

1.99. At 25°C, e_s = 3.167 kPa. Hence, when RH = 80% the actual vapor pressure is 0.80(3.167 kPa) = 2.534 kPa. The temperature at which the saturation vapor pressure is 2.534 kPa is 21.2°C, and therefore the temperature inside the building is $\boxed{21.2°\text{C or less}}$.

1.100. When the temperature of water is 100°C, the saturation vapor pressure is 101.3 kPa, which is approximately equal to the pressure in the water (which is at atmospheric pressure). To maintain equilibrium, vapor cavities form in the water, and hence the water boils.

From Table B.1, the temperature corresponding to a vapor pressure of 90 kPa is 96.4°C. hence, when the atmospheric pressure is 90 kPa, the boiling point of water is $\boxed{96.4°\text{C}}$.

1.101. From the given data: $T = 50°\text{C}$ and $p_\text{atm} = 101.3\,\text{kPa}$. At $T = 50°\text{C}$ Appendix B.1 gives $p_\text{v} = 12.34\,\text{kPa}$. The water boils at 50°C the the absolute pressure of the air in the tank is equal to 12.34 kPa, in which case the gauge pressure is given by

$$\text{gauge pressure} = p_\text{v} - p_\text{atm} = 12.34 - 101.3 = \boxed{-89.0\,\text{kPa}}$$

1.102. (a) The speed of the propeller surface increases with distance from the hub ($v = r\omega$), which causes the pressure to decrease with increasing distance from the hub. This makes cavitation more likely with increasing distance from the hub.

(b) At 20°C the vapor pressure of water is 2.337 kPa (from Appendix B.1). Since the water pressure is 5 kPa, which is greater than 2.337 kPa, cavitation is $\boxed{\text{unlikely to occur}}$.

1.103. From the given data: $T = 92°\text{C}$. From Appendix B.1, the saturation vapor pressure of water at 92°C is given by $p_\text{svp} = 76.35$ kPa. From Appendix B.3, the elevation in the standard atmosphere where the atmospheric pressure is 76.35 kPa is 2.34 km = 2340 m. Therefore, at any elevation above $\boxed{2340\text{ m}}$ water will boil at a temperature less than 92°C.

1.104. The saturation vapor pressure of water at 35°C can be interpolated from Table B.1 (Appendix B) as $(4.243 + 7.378)/2 = 5.811$ kPa. Hence, the (absolute) water pressure in the pipeline should be maintained above $\boxed{5.811\text{ kPa}}$ to prevent cavitation. For gasoline at 20°C, Appendix B.4 gives the saturation vapor pressure as 55.2 kPa, therefore the minimum allowable pressure in the gasoline pipeline is $\boxed{55.2\text{ kPa}}$. Clearly, much greater care should be taken in transporting gasoline via pipeline.

1.105. From the given data: $p = 7\,\text{kPa}$. Interpolating from the properties of water given in Appendix B.1, the vapor pressure is equal to 7 kPa when the water temperature is 38.8°C. Therefore the maximum allowable water temperature is $\boxed{38.8°\text{C}}$.

1.106. For gasoline at 20°C the vapor pressure is 55.2 kPa (from Appendix B.4). Hence the pressure in the space is $\boxed{55.2\text{ kPa}}$. The molecules in the space are molecules of those $\boxed{\text{compounds than constitute gasoline}}$, usually around 100 or so different compounds.

1.107. From the given data: $d = 12$ m, $T = 25°\text{C}$, $p_\text{atm} = 101$ kPa $= 101 \times 10^3$ Pa, $Q = 50$ LPM $= 8.33\ \times 10^{-4}$ m^3/sec. and $D = 50$ mm $= 0.05$ m. At 25°C, $\gamma = 62.37$ kg/m^3, and at sea level $g = 9.80665$ m/s^2. The absolute pressure in the pumped water at a distance z above the water level in the well is given by

$$p_\text{abs} = p_\text{atm} - \gamma\left[1 + 0.24\frac{Q^2}{gD^5}\right]z \tag{1}$$

The saturation vapor pressure of water at 25°C is $p_\text{sat} = 3.167\text{ kPa} = 3.167 \times 10^3$ Pa. Taking $p_\text{abs} = p_\text{sat}$ in Equation 1 and substituting the given data:

$$3.167 \times 10^3 = 101 \times 10^3 - (9.77 \times 10^3)\left[1 + 0.24\frac{(8.33 \times 10^{-4})^2}{(9.80665)(0.05)^5}\right]z$$

which yields $z = 0.152$ m. Therefore, the maximum rise height of water in this case is $\boxed{0.152\text{ m}}$. The farmer's system will $\boxed{\text{not work}}$.

1.108. The vapor pressure of seawater at 20°C is 2.34 kPa (from Appendix B.4). When the minimum pressure, p_min, on the torpedo is equal to the vapor pressure, p_v, the corresponding torpedo velocity, V_v, is derived as follows:

$$p_\text{min} = p_\text{v} = 120 - 0.402V_\text{v}^2 \quad \rightarrow \quad 2.34 = 120 - 0.402V_\text{v}^2 \quad \rightarrow \quad V_\text{v} = \boxed{17.1\,\text{m/s}}$$

1.109. From the given data: E = 20 MJ/(m^2·d), and at 20°C Table B.1 gives $\lambda = 2.452$ MJ/kg, and $\rho = 998.2$ kg/m^3. Evaporation resulting from E is

$$\frac{E}{\rho\lambda} = \frac{20}{(998.2)(2.452)} = 8.17 \times 10^{-3}\,\text{m/d} = \boxed{8.17\,\text{mm/d}}$$

1.110. At $T = 15$°C, $\rho = 999.1$ kg/m^3 and $L_\text{v} = 2.464$ MJ/kg. Therefore,

$$\frac{E}{\rho L_\text{v}} = 4.06\,\text{mm/d} = 4.06 \times 10^{-3}\,\text{m/d}$$

gives

$$E = (4.06 \times 10^{-3})(\rho L_\text{v}) = (4.06 \times 10^{-3})(999.1 \times 2.464) = \boxed{10\ \text{MJ/(m}^2\text{·d)}}$$

1.111. From the given data: condensation rate = 10 kg/s. At 5°C, the latent heat of vaporization is L_v = 2.487 MJ/kg. Therefore,

$$\text{energy generated by condensation} = 2.487\ \text{MJ/kg} \times 10\ \text{kg/s} = \boxed{24.87\ \text{MJ/s}}$$

Chapter 2

Fluid Statics

2.1. From the given data: $p_{\text{atm}} = 101\,\text{kPa}$, $h_{\text{oil}} = 0.7\,\text{m}$, and $h_{\text{gl}} = 2.25\,\text{m}$. For glycerin, $\gamma_{\text{gl}} = 12.357\ \text{kN/m}^3$, and for oil (crude), $\rho_{\text{oil}} = 856\ \text{kg/m}^3$, which gives $\gamma_{\text{oil}} = 8.395\ \text{kN/m}^3$ (from Appendix B.4). The absolute pressure on the bottom of the tank, p_{b}, is calculated as follows:

$$p_{\text{b}} = p_{\text{atm}} + \gamma_{\text{oil}} h_{\text{oil}} + \gamma_{\text{gl}} h_{\text{gl}} = 101 + 8.395(0.7) + 12.357(2.25) = \boxed{134.68\,\text{kPa}}$$

As a gauge pressure, the pressure on the bottom of the tank is $134.68\,\text{kPa} - 101\,\text{kPa} = \boxed{33.68\,\text{kPa}}$.

2.2. (a) Taking $\gamma_{\text{w}} = 9.79\ \text{kN/m}^3$ and $p = 200\ \text{kPa}$, the depth, h, below the water surface corresponding to a gauge pressure of 101.3 kPa is given by

$$h = \frac{p}{\gamma_{\text{w}}} = \frac{200}{9.79} = \boxed{20.429\,\text{m}}$$

(b) From the given data: $\Delta h = 1.55\,\text{m}$. Therefore, the pressure difference, Δp, is given by

$$\Delta p = \gamma \Delta h = (9.79)(1.55) = \boxed{15.1745\,\text{kPa}}$$

2.3. From the given data: $\text{SG}_1 = 0.98$, $z_1 = 0\,\text{m}$, $\text{SG}_2 = 1.07$, and $z_2 = -12\,\text{m}$. Since SG varies linearly,

$$\text{SG} = \text{SG}_1 + \frac{\text{SG}_2 - \text{SG}_1}{z_2 - z_1}(z - z_1) = 0.98 + \frac{1.07 - 0.98}{-12 - 0}(z - 0) = 0.98 - 0.0075z \qquad (1)$$

The relationship between specific gravity (SG) and specific weight (γ) is given by

$$\gamma\ (\text{kN/m}^3) = g \cdot \text{SG} = 9.807 \cdot \text{SG} \qquad (2)$$

Combining Equations 1 and 2 gives the following equation for the variation of specific weight with depth,

$$\gamma = 0.611 - 0.0736\, z\, \text{kN/m}^3 \qquad (3)$$

Using the hydrostatic pressure distribution (Equation 2.10) the difference in pressure between $z = -12\,\text{m}$ and $z = 0\,\text{m}$ is given by Equation 2.11 as

$$p_2 - p_1 = -\int_{z_1}^{z_2} \gamma \, \mathrm{d}z = -\int_0^{-12} (0.611 - 0.0736\, z)\, \mathrm{d}z = -\left[9.611\, z - 0.03678\, z^2\right]_0^{-12} = \boxed{121\,\text{kPa}}$$

This is a $\boxed{\text{gauge pressure}}$, relative to atmospheric pressure on the surface of the liquid.

2.4. (a) From the given data: $h = 12\,\text{m}$ and $p_\text{A} = 200\,\text{kPa}$. For water at 20°C, $\gamma = 9.789\,\text{kN/m}^3$. By definition of absolute pressure,

$$p_\text{A} = p_\text{atm} + \gamma h \quad \rightarrow \quad 200 = p_\text{atm} + (9.789)(12) \quad \rightarrow \quad \boxed{p_\text{atm} = 91.5\,\text{kPa}}$$

(b) From the given data: SG = 0.85, $\rho = 850\,\text{kg/m}^3$, $\gamma = 8.336\,\text{kN/m}^3$, and $h = 6\,\text{m}$. Since the pressure distribution is hydrostatic,

$$p_\text{g} = \gamma h = (8.336)(6) = \boxed{50.0\,\text{kPa}}, \qquad p_\text{A} = p_\text{atm} + p_\text{g} = 91.5 + 50.0 = \boxed{141.5\,\text{kPa}}$$

2.5. From the given data: $h = 12\,\text{m}$. For water at 20°C, $\gamma = 9.79\,\text{kg/m}^3$. For standard atmospheric pressure, $p_\text{atm} = 101.3\,\text{kPa}$. The gauge pressure, p, at the valve is given by

$$p = \gamma h = (9.79)(12) = \boxed{117.48\,\text{kPa}}$$

The absolute pressure, p_abs, at the valve location is given by

$$p_\text{abs} = p + p_\text{atm} = 117.48 + 101.3 = \boxed{218.78\,\text{kPa}}$$

2.6. From the given data: $p_0 = 14$ kPa, and $\gamma_\text{oil} = 0.80$, $\gamma_\text{w} = 0.80(9.79) = 7.83$ kN/m^3. Hence, at a depth $h = 1.5$ m below the surface of the oil, the pressure, p, is given by

$$p = p_0 + \gamma_\text{oil} h = 14 + (7.83)(1.5) = \boxed{25.7\,\text{kPa}}$$

2.7. From the given data: $p_\text{B} = 6\,\text{kPa}$, $\Delta z_1 = 0.35\,\text{m}$, and $\Delta z_2 = 0.72\,\text{m}$. For water at 20°C, $\gamma = 9.789\,\text{kN/m}^3$. The air pressures in tanks A and C are as follows:

$$p_\text{A} = p_\text{B} + \gamma \Delta z_1 = 6 + (9.789)(0.35) = \boxed{9.43\,\text{kPa}}$$

$$p_\text{C} = p_\text{A} - \gamma \Delta z_2 = 9.43 - (9.789)(0.72) = \boxed{2.38\,\text{kPa}}$$

2.8. From the given data: $D_1 = 6\,\text{mm}$, $h = 25\,\text{m}$, and $T = 20°\text{C}$. For water at 20°C, $\rho = 998.2\,\text{kg/m}^3$ and $\gamma = 9789\,\text{N/m}^3$. Under standard conditions, $p_\text{atm} = 101.3\,\text{kPa}$. The initial volume of the bubble, V_1, the initial pressure, p_1, and the final pressure, p_2, are given by

$$V_1 = \frac{\pi D_1^3}{6} = \frac{\pi (0.006)^3}{6} = 1.131 \times 10^{-7}\,\text{m}^3$$

$$p_1 = p_\text{atm} + \gamma h = 101.3 \times 10^3 + (9789)(25) = 3.46025 \times 10^5\,\text{Pa}$$

$$p_2 = p_\text{atm} = 1.013 \times 10^5\,\text{Pa}$$

Applying the ideal gas law to the air in the bubble and assuming isothermal conditions gives

$$p_1 V_1 = p_2 V_2 \quad \rightarrow \quad V_2 = \left(\frac{p_1}{p_2}\right) V_1 = \left(\frac{3.46025 \times 10^5}{1.013 \times 10^5}\right) (1.131 \times 10^{-7}) = 3.866 \times 10^{-7}\,\text{m}^3$$

Therefore, the diameter, D_2, at the surface is given by

$$D_2 = \left[\frac{6V_2}{\pi}\right]^{\frac{1}{3}} = \left[\frac{6(3.866 \times 10^{-7})}{\pi}\right]^{\frac{1}{3}} = 0.009038\,\text{m} \approx \boxed{9.038\,\text{mm}}$$

2.9. From the given data: $\Delta z = 20\,\text{m}$, $p_\text{atm} = 101.3\,\text{kPa}$, and $T = 20°\text{C}$. At 20°C, the density of seawater is given by Appendix B.4 as $\rho = 1023\,\text{kg/m}^3$, which corresponds to $\gamma = 10.03\,\text{kN/m}^3$. Since the pressure distribution in the ocean is hydrostatic and the pressure of the air inside the bubble is equal to the pressure of the water outside the bubble, and the temperature is constant, the ratio of densities is given by

$$\frac{\rho_1}{\rho_2} = \frac{p_1}{p_2} = \frac{p_\text{atm} + \gamma \Delta z}{p_\text{atm}} = \frac{101.3 + (10.03)(20)}{101.3} = \boxed{2.98}$$

2.10. From the given data: $h_1 = 7$ m, $\gamma_1 = 9$ kN/m^3, $h_2 = 2.3$ m, and $p_\text{bot} = 92$ kPa. For water at 4°C, $\gamma_\text{w} = 9.81$ kN/m^3. The specific gravity, SG, can be derived from the following hydrostatic pressure relationship,

$$p_\text{bot} = \gamma_1 h_1 + [\text{SG} \cdot \gamma_\text{w}] h_2 \rightarrow 92 = (9)(7) + [\text{SG} \cdot (9.81)](2.3) \quad \rightarrow \quad \text{SG} = \boxed{1.3}$$

$\boxed{\text{Yes}}$ the liquid on the bottom must necessarily be denser than the liquid on the top.

2.11. For water at 20°C, Table 1.9 gives $\gamma = 9.79$ kN/m^3. The pressure head, h, corresponding to $p = 450$ kPa is therefore

$$h = \frac{p}{\gamma} = \frac{450}{9.79} = \boxed{46.0\,\text{m}}$$

2.12. For $p = 810$ kPa, the pressure head, h, is given by

$$h = \frac{p}{\gamma_\text{w}} = \frac{810}{9.79} = \boxed{83.74\,\text{m (of water)}}$$

For mercury at 20°C, $\rho_\text{Hg} = 13550$ kg/m^3 (from Appendix B.4), which gives $\gamma_\text{Hg} = 132.89$ kN/m^3. For $p = 810$ kPa,

$$h = \frac{p}{\gamma_\text{Hg}} = \frac{810}{132.89} = \boxed{6.0953\,\text{m (of mercury)}}$$

2.13. Pressure, p_1, corresponding to $h_\text{w} = 80$ mm of water is

$$p_1 = \gamma_\text{w} h_\text{w} = (9.79)(0.080) = 0.783\,\text{kPa}$$

and the pressure, p_2, corresponding to $h_\mathrm{f} = 60$ mm of a fluid whose specific weight is $\gamma_\mathrm{f} = 2.90\gamma_\mathrm{w} = 2.90(9.79) = 28.4$ kN/m^3 is

$$p_2 = \gamma_\mathrm{f} h_\mathrm{f} = (28.4)(0.060) = 1.70\,\mathrm{kPa}$$

The total pressure, p, is therefore given by

$$p = p_1 + p_2 = 0.783 + 1.70 = 2.48\,\mathrm{kPa}$$

and the pressure head, h_Hg, in mm of mercury (taking $\gamma_\mathrm{Hg} = 133$ kN/m^3) is

$$h_\mathrm{Hg} = \frac{p}{\gamma_\mathrm{Hg}} = \frac{2.48}{133} \times 1000 = \boxed{18.6\ \mathrm{mm\ Hg}}$$

2.14. For $p_\mathrm{atm} = 101.3$ kPa, the pressure head, h_Hg, in mm of mercury ($\gamma_\mathrm{Hg} = 133$ kN/m^3) is given by

$$h_\mathrm{Hg} = \frac{p_\mathrm{atm}}{\gamma_\mathrm{Hg}} = \frac{101.3}{133} \times 1000 = \boxed{762\ \mathrm{mm\ Hg}}$$

2.15. From the given data: $D = 8\,\mathrm{mm}$, and $h' = 85\,\mathrm{mm}$. For water at 25°C, $\sigma = 72.0$ mN/m $= 0.072$ N/m, and $\gamma = 9777.7\,\mathrm{N/m^3}$ (from Appendix B.1). For water and clean glass, $\theta = 0°$.

(a) The rise height, Δh, due to surface tension is calculated as

$$\Delta h = \frac{4\sigma\cos\theta}{\gamma D} = \frac{4(0.072)\cos 0°}{(9777.7)(0.008)} = 3.682 \times 10^{-3}\,\mathrm{m} = \boxed{3.682\,\mathrm{mm}}$$

(b) In accordance with Equation 2.20, the pressure head, h, at the attachment point is given by

$$h = h' - \Delta h = 85 - 3.682 = 81.318\,\mathrm{mm} \approx \boxed{81.3\,\mathrm{mm}}$$

2.16. When the reservoir is half-full, the pipeline pressure is 350 kPa, and the height, h_0, of the mid-point of the reservoir above the pipeline is

$$h_0 = \frac{350}{\gamma_\mathrm{w}} = \frac{350}{9.79} = \boxed{35.8\,\mathrm{m}}$$

Note that the pressures of liquids in pipes are generally given as gauge pressures unless stated otherwise. When the pressure in the pipeline is 500 kPa, the height, h_1, of the water in the reservoir above the pipeline is

$$h_1 = \frac{500}{\gamma_\mathrm{w}} = \frac{500}{9.79} = 51.1\,\mathrm{m}$$

Hence the minimum space between the mid-point and top of the reservoir is 51.1 m − 35.8 m = $\boxed{15.3\ \mathrm{m}}$.

2.17. From the given data: $x = 124$ mm Hg, $y = 72$ mm Hg, $\Delta z_\mathrm{head} = 0.48$ m, $\Delta z_\mathrm{toe} = 1.46$ m, and $\rho = 1060$ kg/m^3. From the given density, $\gamma = 10.40$ kN/m^3.

(a) The following pressure differences can be calculated:

$$\begin{aligned}\text{heart-head } &= \gamma \cdot \Delta z_{\text{head}} = (10.40)(0.48) = 5\,\text{kPa} = 37.5 \text{ mm Hg}\\ \text{heart-toe } &= \gamma \cdot \Delta z_{\text{toe}} = (10.40)(1.46) = 15.184\,\text{kPa} = 113.89 \text{ mm Hg}\end{aligned}$$

The blood pressures in the head and toes are:

$$\text{head} = \frac{120 - 37.5}{70 - 37.5} = \boxed{82.5/32.5}$$

$$\text{toes} = \frac{120 + 113.89}{70 + 113.89} = \boxed{233.89/183.89}$$

(b) The maximum pressure is p = 120 mm Hg = 16.0 kPa. Therefore, the height, h, that blood would rise in the tube is given by

$$h = \frac{p}{\gamma} = \frac{16.0}{10.40} = \boxed{1.54\,\text{m}}$$

2.18. From the given data: p = 150 mm Hg = 20.00 kPa, and $\rho = 1025\,\text{kg/m}^3$. Taking $g = 9.807\,\text{m/s}^2$, the height h between arm level and fluid level is given by

$$h = \frac{p}{\rho g} = \frac{20.00 \times 10^3}{(1025)(9.807)} = \boxed{1.99\,\text{m}}$$

2.19. From the given data: Δz = 6 m, and $\rho = 1060\text{ kg/m}^3$. The specific weight of the blood is $\gamma = 10.4\text{ kN/m}^3$.

(a) When the giraffe drinks, the change in pressure in the head, Δp, is given by

$$\Delta p = \gamma \cdot \Delta z = (10.4)(6) = 67.6\,\text{kPa} = \boxed{507 \text{ mm Hg}}$$

(b) The difference in pressure between the head and the heart is 507 mm/2 = 254 mm. Since the maximum pressure at the heart level is given as 280 mm, then the maximum pressure in the head is 280 mm + 254 mm = $\boxed{534 \text{ mm Hg}}$.

2.20. From the given data: p_{air} = 310 kPa, $A_1 = 8\text{ cm}^2 = 0.0008\text{ m}^2$, W_1 = 55 N = 0.055 kN, $A_2 = 600\text{ cm}^2 = 0.06\text{ m}^2$, W_2 = 820 N = 0.82 kN, Δz = 1.2 m, Δs_1 = 12 cm, $\rho = 900\text{ kg/m}^3$, and $\gamma = \rho g = 8.83\text{ kN/m}^3$.

(a) The force, F, exerted by the compressed air on the piston is given by

$$F = p_{\text{air}} A_1 = (310)(0.0008) = \boxed{0.248\,\text{kN}}$$

(b) Let W be the weight mounted on the platform, then

$$\frac{F + W_1}{A_1} - \gamma \Delta z = \frac{W + W_2}{A_2} \rightarrow \frac{0.248 + 0.055}{0.0008} - (8.83)(1.2) = \frac{W + 0.82}{0.06} \rightarrow W = \boxed{21.27\,\text{kN}}$$

(c) If Δs_2 is the displacement of the platform, then

$$A_1 \Delta s_1 = A_2 \Delta s_2 \quad \rightarrow \quad (8)(12) = (600)\Delta s_2 \quad \rightarrow \quad \Delta s_2 = \boxed{0.16\,\text{cm}}$$

2.21. From the given data: $F_1 = 500$ N, $D_1 = 25$ mm, and $D_2 = 100$ mm. If the force on the 100-mm piston is F_2, and noting that performance of the hydraulic system will not be compromised if both pistons exert the same pressure, then

$$\frac{F_1}{D_1^2} = \frac{F_2}{D_2^2} \quad \rightarrow \quad \frac{500}{25^2} = \frac{F_2}{100^2} \quad \rightarrow \quad F_2 = \boxed{8000\,\text{N}}$$

2.22. From the given data: $z = 4342$ m $= 4.342$ km. For the standard atmosphere, $T_0 = 15$°C $= 288.2$ K, $b = 6.5$°C/km, $p_0 = 101.3$ kPa, and $g/Rb = 5.26$. The standard-atmosphere temperature, T, at the summit is calculated using Equation 2.25 as

$$T = T_0 - bz = 15 - (6.5)(4.342) = \boxed{-13.2^\circ\text{C}} = 259.9\,\text{K}$$

The standard-atmosphere pressure, p, at the summit is calculated using Equation 2.26 as

$$p = p_0 \left(\frac{T}{T_0}\right)^{\frac{g}{Rb}} = 101.3 \left(\frac{259.9}{288.2}\right)^{5.26} = \boxed{58.8\,\text{kPa}}$$

The calculated standard-atmosphere temperature and pressure are fairly close to the measured values of −11°C and 58 kPa.

2.23. From the given data: $z_1 = 11$ km, $z_2 = 20$ km, $T_0 = -56.5$°C $= 216.7$ K, and $p_1 = 22.63$ kPa. The average value of g is $\bar{g} = 9.769$ m/s^2. For air, $R = 287.1$ J/kg·K. Using Equation 2.29, the theoretical pressure, p_2, at the top of the stratosphere is given by

$$p_2 = p_1 \exp\left[-\frac{\bar{g}(z_2 - z_1)}{RT_0}\right] = (22.63)\exp\left[-\frac{(9.769)(20000 - 11000)}{(287.1)(216.7)}\right] = \boxed{5.51\,\text{kPa}}$$

The standard-atmosphere pressure at $z = 20$ km (from Appendix B.3) is $\boxed{5.529\text{ kPa}}$, so the theoretical and standard values are very close.

2.24. From the given data: $b = 6.5$°C/km, $p_0 = 101.325$ kPa, and $T_0 = 15$°C $= 288.15$ K. For air, $R = 287.1$ J/(kg·K), which gives $g/Rb = 5.255$. Assuming a uniform lapse rate and a hydrostatic pressure distribution, the temperature, T, and pressure, p, at any elevation are given by

$$T = T_0 - bz, \qquad p = p_0 \left(\frac{T}{T_0}\right)^{\frac{g}{Rb}}$$

The results of applying these equations and comparing the predictions to the standard atmosphere is given in the following table.

z (km)	T (°C)	T (K)	p (kPa)	T_{std} (°C)	p_{std} (kPa)	ΔT (°C)	Δp (kPa)
0	15.0	288.15	101.325	15.00	101.325	0.00	0.000
1	8.5	281.65	89.876	8.50	89.876	0.00	0.000
2	2.0	275.15	79.498	2.00	79.501	0.00	−0.003
3	−4.5	268.65	70.112	−4.49	70.121	−0.01	−0.009
4	−11.0	262.15	61.644	−10.98	61.660	−0.02	−0.016
5	−17.5	255.65	54.024	−17.47	54.048	−0.03	−0.024
6	−24.0	249.15	47.186	−23.96	47.217	−0.04	−0.031
7	−30.5	242.65	41.065	−30.45	41.110	−0.05	−0.045
8	−37.0	236.15	35.605	−36.94	35.651	−0.06	−0.046
9	−43.5	229.65	30.747	−43.42	30.800	−0.08	−0.053
10	−50.0	223.15	26.441	−49.90	26.499	−0.10	−0.058
11	−56.5	216.65	22.636	−56.50	22.632	0.00	0.004

Based on the results presented in the the above table, the maximum temperature difference is $\boxed{-0.10°\text{C}}$, and the maximum pressure difference is $\boxed{-0.058\,\text{kPa}}$.

2.25. Taking the pressure distribution in the atmosphere as hydrostatic,

$$\frac{\mathrm{d}p}{\mathrm{d}z} = -\rho g; \quad \rho = \frac{p}{RT}; \quad T = a + bz$$

Using these equations:

$$\begin{aligned}
\frac{\mathrm{d}p}{p} &= -\frac{g}{RT}dz = -\frac{g}{R(a+bz)}\mathrm{d}z \\
\int_1^2 \frac{\mathrm{d}p}{p} &= -\frac{g}{R}\int_1^2 \frac{\mathrm{d}z}{a+bz} \\
\frac{p_2}{p_1} &= \left(\frac{a+bz_2}{a+bz_1}\right)^{-g/Rb} \qquad (1)
\end{aligned}$$

From the given data: p_1 = 101 kPa, p_2 = 1 Pa, z_1 = 0 m, a = 273 + 20 = 293 K, b = −6.3 K/km = −0.0063 K/m, R = 287 J/kg·K (for air), which yields

$$-\frac{g}{Rb} = \frac{9.81}{(287)(0.0063)} = 5.426$$

Substituting into Equation 2.23 gives

$$\frac{0.001}{101} = \left(\frac{293 - 0.0063z_2}{293}\right)^{5.426}$$

which yields z_2 = 52,070 m = $\boxed{52.1 \text{ km}}$.

2.26. From the given data: $z = 2256$ m, $T = 5°\text{C} = 278$ K, $T_0 = 27°\text{C} = 300$ K, and $p_0 = 101$ kPa. The lapse rate, b, can be estimated as

$$b = \frac{T_0 - T}{z} = \frac{300 - 278}{2256} = 0.00975 \text{ K/m} = 9.75 \text{ K/km}$$

For the standard atmosphere, $b = 6.50$ K/km, $g/Rb = 5.26$, and so for $b = 9.75$ K/km it is estimated that

$$\frac{g}{Rb} = 5.26 \times \frac{6.50}{9.75} = 3.51$$

(a) The pressure, p, at the Peak can be calculated using Equation 2.26 which gives

$$p = p_0 \left(\frac{T}{T_0}\right)^{\frac{g}{Rb}} = (101)\left(\frac{278}{300}\right)^{3.51} = \boxed{77.3\,\text{kPa}}$$

(b) The vapor pressure of water is equal to 77.3 kPa when the temperature of the water is 92°C (from Appendix B.1). Therefore, water boils at $\boxed{92°\text{C}}$ at the Peak.

2.27. For the standard atmosphere, $b = 6.50$ K/km $= 0.00650$ K/m. For air, $M = 28.96$ g/mol $=$ 0.02896 kg/mol. Constants are $R = 8.314$ J/mol·K and $g = 9.81$ m/s^2. Therefore,

$$\frac{gM}{Rb} = \frac{(9.81)(0.02896)}{(8.314)(0.00650)} = \boxed{5.26}$$

Under standard atmospheric conditions, $p_0 = 101.3$ kPa and $T_0 = 15°\text{C} = 288.15$ K. In La Paz, $z = 3640$ m and estimated atmospheric conditions are as follows:

$$T = T_0 - bz = 288.15 - (0.00650)(3640) = 264.5\ K (= -8.66°\text{C})$$

$$p = p_0 \left(\frac{T}{T_0}\right)^{\frac{gM}{Rb}} = (101.3)\left(\frac{264.5}{288.15}\right)^{5.26} = 64.56\,\text{kPa}$$

The temperature of water at which the saturation vapor pressure is 64.56 kPa is the temperature at which water boils and is equal to approximately $\boxed{87.6°\text{C}}$.

2.28. From the given data: $\Delta z = 4000\,\text{m}$. For standard air, $R = 287.1\,\text{J/(kg·K)}$, and for a standard atmosphere at sea level, $p_1 = 101.325\,\text{kPa}$ and $T_1 = 15°\text{C} = 288.15\,\text{K}$. Assume that the temperature remains constant at 15°C over the depth of the shaft. Using Equation 2.29 gives

$$p_2 = p_1 \exp\left[-\frac{g(z_2 - z_1)}{RT_0}\right] \quad \rightarrow \quad p_2 = (101.325)\exp\left[-\frac{(9.807)(-4000)}{(287.1)(288.15)}\right] = \boxed{106.3796\,\text{kPa}}$$

2.29. From the given data: $p_0 = 100.8$ kPa, $z = 829.8\,\text{m} = 0.8298\,\text{km}$, and $T_0 = 37°\text{C} = 310.2\,\text{K}$. Assuming standard atmospheric conditions, $b = 6.5°\text{C/km}$, and $g/Rb = 5.26$. The estimated temperature, T, at the top of the building is calculated using Equation 2.25 as

$$T = T_0 - bz = 37 - (6.5)(0.8298) = 31.6063°\text{C} = 304.8\,\text{K}$$

The barometric pressure, p, at the top of the building can be estimated using Equation 2.26 as

$$p = p_0 \left(\frac{T}{T_0}\right)^{\frac{g}{Rb}} = 100.8 \left(\frac{304.8}{310.2}\right)^{5.26} = \boxed{91.9\,\text{kPa}}$$

2.30. From the given data: $p_1 = 96$ kPa, and $p_2 = 85.3$ kPa. For a standard atmosphere: $p_0 = 760$ mm, $T_0 = 15°\text{C} = 288.15$ K, $b = 6.5$ K/km, and $g/Rb = 5.26$. Using Equation 2.26,

$$p_1 = p_0 \left[1 - \frac{bz_1}{T_0}\right]^{\frac{g}{Rb}} \quad \rightarrow \quad 96 = (760)\left[1 - \frac{(6.5)z_1}{288.15}\right]^{5.26} \rightarrow z_1 = 0.4533\,\text{km}$$

$$p_2 = p_0 \left[1 - \frac{bz_2}{T_0}\right]^{\frac{g}{Rb}} \quad \rightarrow \quad 85.3 = (760)\left[1 - \frac{(6.5)z_2}{288.15}\right]^{5.26} \rightarrow z_2 = 1.4249\,\text{km}$$

Therefore the change in elevation is estimated as $1.4249\,\text{km} - 0.4533\,\text{km} = 0.9716\,\text{km} = \boxed{971.6 \text{ m}}$

2.31. From the given data: $h_\text{air} = 0.4$ m, $h_\text{k1} = 1.6$ m, $h_\text{k2} = 0.7$ m, $h_\text{k3} = 2.5$ m, and $p_\text{atm} = 101$ kPa. For kerosene at 20°C, $\rho_\text{k} = 808$ kg/m^3, which gives $\gamma_\text{k} = 7.9241$ kN/m^3. If p_0 is the pressure at the Bourdon gauge, then

$$p_0 + \gamma_\text{k} h_\text{k1} - \gamma_\text{k} h_\text{k3} = 0 \quad \rightarrow \quad p_0 + 7.9241(1.6 - 2.5) = 0 \quad \rightarrow \quad p_0 = \boxed{7.1317\,\text{kPa}}$$

Note that the Bourdon gauge reads gauge pressure, and the variation of hydrostatic pressure in the air is negligible.

2.32. From the given data: $\text{SG}_1 = 0.8$, $\Delta z_1 = 0.3\,\text{m}$, $\text{SG}_2 = 2.8$, and $\Delta z_2 = 0.3\,\text{m}$. The specific weights corresponding to the given specific gravities are determined by the relation

$$\gamma = \text{SG} \cdot \rho_0 g = \text{SG} \cdot (1000)(9.807) = 9807 \cdot \text{SG}\,\text{N/m}^3 = 9.807 \cdot \text{SG}\,\text{kN/m}^3$$

Using this relation, the specific weights of the light and dense fluids are

$$\gamma_1 = 9.807(0.8) = 7.8456\,\text{kN/m}^3, \qquad \gamma_2 = 9.807(2.8) = 27.4596\,\text{kN/m}^3$$

(a) Assuming that both the top of the light fluid and the air above the liquid are at the same atmospheric pressure, then

$$\cancel{p_\text{atm}} + \gamma_1 \Delta z_1 - \gamma_2 \Delta z = \cancel{p_\text{atm}} \quad \rightarrow \quad \Delta z = \frac{\gamma_1}{\gamma_2}\Delta z_1 = \frac{7.8456}{27.4596}(0.3) = \boxed{0.0857\,\text{m}}$$

(b) Since the pressure distribution is hydrostatic, the gauge pressure on the bottom of the tank, p_0, is given by

$$p_0 = \gamma_1 \Delta z_1 + \gamma_2 \Delta z_2 = (7.8456)(0.3) + (27.4596)(0.3) = \boxed{10.5916\,\text{kPa}}$$

2.33. From Figure 2.50,

$$p_\text{A} = p_\text{B} - \gamma_\text{f}(0.125) - \gamma_\text{w}(0.20)$$

where $p_\text{B} = 0$ kPa (gauge pressure), $\gamma_\text{f} = 45$ kN/m^3, and $\gamma_\text{w} = 9.7648$ kN/m^3. Hence,

$$p_\text{A} = 0 - 45(0.125) - 9.7648(0.20) = \boxed{-7.5666\,\text{kPa}}$$

<u>Alternative solution:</u>
In terms of absolute pressure, $p_\text{B} = 101.33$ kPa, $\gamma_\text{f} = 45$ kN/m^3, and $\gamma_\text{w} = 9.7648$ kN/m^3. Hence,

$$p_\text{A} = 101.33 - 45(0.125) - 9.7648(0.20) = \boxed{93.7634\,\text{kPa}}$$

It should be noted that the pressure of liquids in pipes is seldom given in terms of absolute pressure, so $p_\text{A} = -7.5666\,\text{kPa}$ is the preferred answer.