PROBLEM SOLUTIONS

10.1 (a) $T_F = \dfrac{9}{5}T_C + 32 = \dfrac{9}{5}\left(-273.15\right) + 32 = \boxed{-460°F}$

(b) $T_C = \dfrac{5}{9}\left(T_F - 32\right) = \dfrac{5}{9}\left(98.6 - 32\right) = \boxed{37.0°C}$

(c) $T_F = \dfrac{9}{5}T_C + 32 = \dfrac{9}{5}\left(T - 273.15\right) + 32 = \dfrac{9}{5}\left(-173.15\right) + 32 = \boxed{-280°F}$

10.2 When the volume of a low density gas is held constant, pressure and temperature are related by a linear equation $P = AT + B$, where A and B are constants to be determined. For the given constant-volume gas thermometer,

$P = 0.700 \text{ atm}$ when $T = 100°C \Rightarrow 0.700 \text{ atm} = A\left(100°C\right) + B$ [1]

$P = 0.512 \text{ atm}$ when $T = 0°C \Rightarrow 0.512 \text{ atm} = A\left(0\right) + B$ [2]

From Equation [2], $B = 0.512 \text{ atm}$. Substituting this result into Equation [1] yields

$$A = \frac{0.700 \text{ atm} - 0.512 \text{ atm}}{100°C} = 1.88 \times 10^{-3} \text{ atm/}°C$$

so, the linear equation for this thermometer is: $P = \left(1.88 \times 10^{-3} \text{ atm/}°C\right)T + 0.512 \text{ atm}$.

(a) If $P = 0.0400 \text{ atm}$, then

$$T = \frac{P - B}{A} = \frac{0.0400 \text{ atm} - 0.512 \text{ atm}}{1.88 \times 10^{-3} \text{ atm/}°C} = \boxed{-251°C}$$

(b) If $T = 450°C$, then

$$P = \left(1.88 \times 10^{-3} \text{ atm/}°C\right)\left(450°C\right) + 0.512 \text{ atm} = \boxed{1.36 \text{ atm}}$$

10.3 (a) $T_F = \dfrac{9}{5}T_C + 32 = \dfrac{9}{5}\left(-196\right) + 32 = \boxed{-321°F}$

$T_K = T_C + 273.15 = \left(-196 + 273.15\right) \text{ K} = \boxed{77 \text{ K}}$

(b) $T_F = \dfrac{9}{5} T_C + 32 = \dfrac{9}{5} \left(37.0\right) + 32 = \boxed{98.6°\text{F}}$

$T_K = T_C + 273.15 = 37.0 + 273.15 \ \text{K} = \boxed{310 \ \text{K}}$

10.4   (a) $T_C = \dfrac{5}{9} \left(T_F - 32\right) = \dfrac{5}{9} \left(134 - 32\right) = \boxed{56.7°\text{C}}$

and

$T_C = \dfrac{5}{9} \left(-79.8 - 32\right) = \boxed{-62.1°\text{C}}$

(b) $T_K = T_C + 273.15 = 56.7 + 273.15 \ \text{K} = \boxed{330 \ \text{K}}$

and

$T_K = T_C + 273.15 = -62.1°\text{C} + 273.15 \ \text{K} = \boxed{211 \ \text{K}}$

10.5   Start with $T_F = -40°\text{F}$ and convert to Celsius.

$T_C = \dfrac{5}{9} \left(T_F - 32\right) = \dfrac{5}{9} \left(-40 - 32\right) = \boxed{-40°\text{C}}$

Since Celsius and Fahrenheit degrees of temperature change are different sizes, this is the only temperature with the same numeric value on both scales.

10.6   Since we have a linear graph, we know that the pressure is related to the temperature as $P = A + BT_C$, where A and B are constants. To find A and B, we use the given data:

0.900 atm $= A + B \left(-80.0°\text{C}\right)$ [1]

and

1.635 atm $= A + B \left(78.0°\text{C}\right)$ [2]

Solving Equations [1] and [2] simultaneously, we find:

$A = 1.27$ atm

and

$$B = 4.65 \times 10^{-3} \ \text{atm/}°\text{C}$$

Therefore,

$$P = 1.27 \ \text{atm} + \ 4.65 \times 10^{-3} \ \text{atm/}°\text{C} \ T_C$$

(a) At absolute zero the gas exerts zero pressure $P = 0$, so

$$T_C = \frac{-1.27 \ \text{atm}}{4.65 \times 10^{-3} \ \text{atm/}°\text{C}} = \boxed{-273°\text{C}}$$

(b) At the freezing point of water, $T_C = 0$ and

$$P = 1.27 \ \text{atm} + 0 = \boxed{1.27 \ \text{atm}}$$

At the boiling point of water, $T_C = 100°\text{C}$, so

$$P = 1.27 \ \text{atm} + \ 4.65 \times 10^{-3} \ \text{atm/}°\text{C} \ \ 100°\text{C} = \boxed{1.74 \ \text{atm}}$$

10.7 Apply $T_F = \frac{9}{5} T_C + 32$ to two different Celsius temperatures, T_{C_1} and T_{C_2} , to obtain

$$T_{F_1} = \frac{9}{5} T_{C_1} + 32 \qquad\qquad [1]$$

and

$$T_{F_2} = \frac{9}{5} T_{C_2} + 32 \qquad\qquad [2]$$

Subtracting Equation [1] from [2] yields

$$T_{F_2} - T_{F_1} = \frac{9}{5}\left[T_{C_2} - T_{C_1} \right]$$

or

$$\boxed{\Delta T_F = \ 9/5 \ \Delta T_C}$$

10.8 (a) Using the result of Problem 10.7 above, $\Delta T_C = \frac{5}{9} \Delta T_F = \frac{5}{9} 57.0 \ °\text{C} = \boxed{31.7°\text{C}}$.

(b) $\Delta T_K = T_{C,out} + 273.15 - T_{C,in} + 273.15 = T_{C,out} - T_{C,in} = \Delta T_C = \boxed{31.7\ \text{K}}$

10.9 $T_F = \frac{9}{5}T_C + 32 = \frac{9}{5}\ 43\ + 32 = 77 + 32\ °\text{F} = \boxed{109°\text{F}}$

$\boxed{\text{Yes}}$. The normal body temperature is $98.6°\text{F}$, so this patient has a high fever and needs immediate attention.

10.10   (a)   Since temperature differences on the Rankine and Fahrenheit scales are identical, the temperature readings on the two thermometers must differ by no more than an additive constant (i.e., $T_R = T_F + constant$). To evaluate this constant, consider the temperature readings on the two scales at absolute zero. We have $T_R = 0°\text{R}$ at absolute zero, and

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5}\ -273.15\ + 32 = -459.67°\text{F}$$

Substituting these temperatures in our Fahrenheit to Rankine conversion gives

$$0° = -459.67° + constant \quad \text{or} \quad constant = 459.67°$$

giving $\boxed{T_R = T_F + 459.67}$.

(b)   We start with the Kelvin temperature and convert to the Rankine temperature in several stages, using the Fahrenheit to Rankine conversion from part (a) above.

$$T_K = T_C + 273.15 = \frac{5}{9}\ T_F - 32\ + 273.15 = \frac{5}{9}\Big[\ T_R - 459.67\ - 32\Big] + 273.15$$

$$= \frac{5}{9}\ T_R - 491.67\ + 273.15 = \frac{5}{9}T_R - \frac{5}{9}\ 491.67\ + 273.15 = \frac{5}{9}T_R - 273.15 + 273.15 = \boxed{\frac{5}{9}T_R}$$

10.11   The increase in temperature is $\Delta T = 35°\text{C} -\ -20°\text{C}\ = 55°\text{C}$

Thus,

$$\Delta L = \alpha L_0\ \Delta T\ = \Big[11 \times 10^{-6}\ °\text{C}^{-1}\Big]\ 518\ \text{m}\ \ 55°\text{C}\ = 0.31\ \text{m} = \boxed{31\ \text{cm}}$$

10.12   (a)   As the temperature drops by 20°C, the length of the pendulum changes by $\Delta L = \alpha L_0\ \Delta T$

$$= \Big[19 \times 10^{-6}\ °\text{C}^{-1}\Big]\ 1.3\ \text{m}\ \ -20°\text{C}\ = -4.9 \times 10^{-4}\ \text{m} = -\ 0.49\ \text{mm}$$

Thus, the final length of the rod is $\boxed{L = 1.3 \text{ m} - 0.49 \text{ mm}}$.

(b) From the expression for the period, $T = 2\pi\sqrt{L/g}$, we see that as the length decreases the period decreases. Thus, the pendulum will swing too rapidly and the clock will run $\boxed{\text{fast}}$.

10.13 We choose the radius as our linear dimension. Then, from $\Delta L = \alpha L_0 \, \Delta T$,

$$\Delta T = T_C - 20.0°C = \frac{L - L_0}{\alpha L_0} = \frac{2.21 \text{ cm} - 2.20 \text{ cm}}{\left[130 \times 10^{-6} \quad °C^{-1}\right] 2.20 \text{ cm}} = 35.0°C$$

or

$$T_C = \boxed{55.0°C}$$

10.14 (a) The diameter is a linear dimension, so we consider the linear expansion of steel:

$$d = d_0\left[1 + \alpha \, \Delta T\right] = 2.540 \text{ cm} \left[1 + 11 \times 10^{-6} \quad °C^{-1} \quad 100°C - 25°C\right] = \boxed{2.542 \text{ cm}}$$

(b) If the volume increases by 1%, then $\Delta V = (1.0 \times 10^{-2}) \, V_0$. Then, using $\Delta V = \beta V_0 \, \Delta T$, where $\beta = 3\alpha$ is the volume expansion coefficient, we find

$$\Delta T = \frac{\Delta V / V_0}{\beta} = \frac{1.0 \times 10^{-2}}{3\left[11 \times 10^{-6} \quad °C^{-1}\right]} = \boxed{3.0 \times 10^2 \, °C}$$

10.15 From $\Delta L = L - L_0 = \alpha L_0 \, \Delta T$, the final value of the linear dimension is $L = L_0 + \alpha L_0 \, \Delta T$. To remove the ring from the rod, the diameter of the ring must be at least as large as the diameter of the rod. Thus, we require that

$$L_{\text{Brass}} = L_{\text{Al}}, \quad \text{or} \quad L_{0 \ \text{Brass}} + \alpha_{\text{Brass}} L_{0 \ \text{Brass}} \, \Delta T = L_{0 \ \text{Al}} + \alpha_{\text{Al}} L_{0 \ \text{Al}} \, \Delta T$$

This gives

$$\Delta T = \frac{L_{0 \ \text{Al}} - L_{0 \ \text{Brass}}}{\alpha_{\text{Brass}} L_{0 \ \text{Brass}} - \alpha_{\text{Al}} L_{0 \ \text{Al}}}$$

(a) If $L_{0 \ \text{Al}} = 10.01 \text{ cm}$,

$$\Delta T = \frac{10.01 - 10.00}{\left[19 \times 10^{-6} \ ^\circ C^{-1} \right] 10.00 - \left[24 \times 10^{-6} \ ^\circ C^{-1} \right] 10.01} = -199^\circ C$$

so

$$T = T_0 + \Delta T = 20.0^\circ C - 199^\circ C = \boxed{-179^\circ C \ \text{which is attainable}}$$

(b) If $L_{0 \ Al} = 10.02$ cm

$$\Delta T = \frac{10.02 - 10.00}{\left[19 \times 10^{-6} \ ^\circ C^{-1} \right] 10.00 - \left[24 \times 10^{-6} \ ^\circ C^{-1} \right] 10.02} = -396^\circ C$$

and $T = T_0 + \Delta T = \boxed{-376^\circ C, \text{which is below absolute zero and unattainable}}$.

10.16 $\rho = \dfrac{m}{V} = \dfrac{m}{V_0 + \Delta V} = \dfrac{m}{V_0 + \beta V_0 \ \Delta T} = \dfrac{m/V_0}{1 + \beta \ \Delta T} = \boxed{\dfrac{\rho_0}{1 + \beta \ \Delta T}}$

10.17 (a) Using the result of problem 10.16, with $\beta = 3\alpha$, gives

$$\rho = \frac{\rho_0}{1 + \beta \ \Delta T} = \frac{11.3 \times 10^3 \ \text{kg/m}^3}{1 + 3\left[29 \times 10^{-6} \ ^\circ C^{-1} \right] 90^\circ C - 0^\circ C} = \boxed{11.2 \times 10^3 \ \text{kg/m}^3}$$

(b) No. Although the density of gold would be less on a warm day, the mass of the bar would be the same, regardless of its temperature, and that is what you are paying for. (Note that the volume of the bar increases with increasing temperature, whereas its density decreases. Its mass, however, remains constant.)

10.18 When the temperature drops by 10.0°C, the wire will attempt to contract by

$$\Delta L = \alpha_{Cu} L_0 \left| \Delta T \right| = 17 \times 10^{-6} \ ^\circ C^{-1} \ 10.0 \ m \ 10.0 \ ^\circ C = 1.70 \times 10^{-3} \ m$$

If the ends of the wire are held stationary, and the wire is not allowed to contract, it will develop an additional tension force ΔF sufficient to keep it stretched by an additional 1.70×10^{-3} m beyond its natural length. The required additional tension force is $\Delta F = Y_{Cu} A (\Delta L / L_0)$, where Y_{Cu} is Young's modulus for copper and A is the cross-sectional area of the wire. Thus,

$$\Delta F = 11 \times 10^{10} \ \text{Pa} \ 2.40 \times 10^{-5} \ m^2 \left(\frac{1.7 \times 10^{-3} \ m}{10.0 \ m} \right) = 449 \ N$$

The total tension in the wire, after the decrease in temperature, is then

$$F = F_0 + \Delta F = 75.0 \text{ N} + 449 \text{ N} = \boxed{524 \text{ N}}$$

10.19   The difference in Celsius temperature in the underground tank and the tanker truck is

$$\Delta T_C = \frac{5}{9}\ \Delta T_F\ = \frac{5}{9}\ 95.0 - 52.0\ = 23.9°\text{C}$$

If $V_{52°F}$ is the volume of gasoline that fills the tank at 52.0°F, the volume this quantity of gas would occupy on the tanker truck at 95.0°F is

$$V_{95°F} = V_{52°F} + \Delta V = V_{52°F} + \beta V_{52°F}\ \Delta T = V_{52°F}\left[1 + \beta\ \Delta T\ \right]$$
$$= 1.00 \times 10^3 \text{ m}^3\ \left[1 + 9.6 \times 10^{-4}\ °\text{C}^{-1}\ 23.9°\text{C}\ \right] = \boxed{1.02 \times 10^3 \text{ m}^3}$$

10.20   Consider a regular solid with initial volume given by $V_0 = A_0 L_0$ at temperature T_0. Here, A is the cross-sectional area and L is the length of the regular solid.

As the temperature undergoes a change $\Delta T = T - T_0$, the change in the cross-sectional area is

$\Delta A = A - A_0 = \gamma A_0\ \Delta T = 2\alpha A_0\ \Delta T$, giving $A = A_0 + 2\alpha A_0\ \Delta T$. Similarly, the new length will be

$L = L_0 + \alpha L_0\ \Delta T$, so the new volume is

$$V = \left[A_0 + 2\alpha A_0\ \Delta T\ \right]\left[L_0 + \alpha L_0\ \Delta T\ \right] = A_0 L_0 + 3\alpha A_0 L_0\ \Delta T + 2\alpha^2 A_0 L_0\ \Delta T^{\ 2}$$

The term involving α^2 is negligibly small in comparison to the other terms, so

$V = A_0 L_0 + 3\alpha A_0 L_0\ \Delta T = V_0 + 3\alpha V_0\ \Delta T$. This is of the form $\Delta V = V - V_0 = \beta V_0(\Delta T)$, where

$\boxed{\beta = 3\alpha}$.

10.21   [Note that some rules concerning significant figures are deliberately violated in this solution to better illustrate the method of solution.]

When the temperature of a material is raised, the linear dimensions of any cavity in that material expands as if it were filled with the surrounding material. Thus, the final value of the inner diameter of the ring will be given by

$L = L_0 + \alpha L_0\ \Delta T$ as

$$D_{\text{inner}} = 2.168 \text{ cm} + \left[1.42 \times 10^{-5} \ \text{°C}^{-1} \right] 2.168 \text{ cm} \ 100\text{°C} - 15.0\text{°C} = \boxed{2.171 \text{ cm}}$$

10.22 [Note that some rules concerning significant figures are deliberately violated in this solution to better illustrate the method of solution.]

Let L be the final length of the aluminum column. This will also be the final length of the quantity of tape now stretching from one end of the column to the other. In order to determine what the scale reading now is, we need to find the initial length this quantity of tape had at 21.2°C (when the scale markings were presumably painted on the tape).

Thus, we let this initial length of tape be $(L_0)_{\text{tape}}$ and require that

$$L = L_0 \ _{\text{tape}} \left[1 + \alpha_{\text{steel}} \ \Delta T \right] = L_0 \ _{\text{column}} \left[1 + \alpha_{\text{Al}} \ \Delta T \right]$$

which gives

$$L_0 \ _{\text{tape}} = \frac{L_0 \ _{\text{column}} \left[1 + \alpha_{\text{Al}} \ \Delta T \right]}{1 + \alpha_{\text{steel}} \ \Delta T}$$

or

$$L_0 \ _{\text{tape}} = \frac{18.700 \text{ m} \left[1 + 24 \times 10^{-6} \ \text{°C}^{-1} \ 29.4\text{°C} - 21.2\text{°C} \right]}{1 + 11 \times 10^{-6} \ \text{°C}^{-1} \ 29.4\text{°C} - 21.2\text{°C}} = \boxed{18.702 \text{ m}}$$

10.23 The initial length of the band is $L_0 = 2\pi r_0 = 2\pi \ 5.0 \times 10^{-3} \text{ m} = 3.1 \times 10^{-2} \text{ m}$. The amount this length would contract, if allowed to do so, as the band cools to 37°C is

$$\Delta L = \alpha L_0 \left| \Delta T \right| = \left[17.3 \times 10^{-6} \ \text{°C}^{-1} \right] 3.1 \times 10^{-2} \text{ m} \ 80\text{°C} - 37\text{°C} = 2.3 \times 10^{-5} \text{ m}$$

Since the band is not allowed to contract, it will develop a tensile stress given by

$$Stress = Y\left(\frac{\Delta L}{L_0} \right) = 18 \times 10^{10} \text{ Pa} \left(\frac{2.3 \times 10^{-5} \text{ m}}{3.1 \times 10^{-2} \text{ m}} \right) = 1.3 \times 10^8 \text{ Pa}$$

and the tension in the band will be

$$F = A \ Stress = \left[4.0 \times 10^{-3} \text{ m} \ 0.50 \times 10^{-3} \text{ m} \right] 1.3 \times 10^8 \text{ Pa} = \boxed{2.7 \times 10^2 \text{ N}}$$

10.24 The expansion of the pipeline will be $\Delta L = \alpha L_0 \, \Delta T$, or

$$\Delta L = \left[11 \times 10^{-6} \; °C^{-1} \right] 1300 \times 10^3 \; m \left[35°C - \; -73°C \right] = 1.5 \times 10^3 \; m = \boxed{1.5 \; km}$$

This is accommodated by $\boxed{\text{accordion-like expansion joints}}$ placed in the pipeline at periodic intervals.

10.25 Both the drum and the carbon tetrachloride expand as the temperature rises by $\Delta T = 20.0°C$. Since the drum was completely filled when the temperature was 10.0°C, the initial volume for the drum and the carbon tetrachloride are the same. From $\Delta V = \beta V_0 \, \Delta T$, where $\beta = 3\alpha$ is the coefficient of volume expansion, we obtain

$$V_{\text{spillage}} = \Delta V_{\substack{\text{carbon} \\ \text{tetrachloride}}} - \Delta V_{\substack{\text{steel} \\ \text{drum}}} = \left(\beta_{\substack{\text{carbon} \\ \text{tetrachloride}}} - 3\alpha_{\text{steel}} \right) V_0 \, \Delta T$$

or

$$V_{\text{spillage}} = \left[5.81 \times 10^{-4} \; °C^{-1} - 3 \; 11 \times 10^{-6} \; °C^{-1} \right] 50.0 \; gal \; 20.0°C = \boxed{0.548 \; gal}$$

10.26 (a) $m_0 = \rho_0 V = 7.30 \times 10^2 \; kg/m^3 \; 10.0 \; gal \left(\dfrac{3.80 \times 10^{-3} \; m^3}{1 \; gal} \right) = \boxed{27.7 \; kg}$

(b) $V = V_0 + \Delta V = V_0 + \beta V_0 \, \Delta T = V_0 \left[1 + \beta \, \Delta T \right]$

or

$$V = 1.000 \; m^3 \left[1 + 9.60 \times 10^{-4} \; °C^{-1} \; 20.0°C \right] = \boxed{1.02 \; m^3}$$

(c) Gasoline having a mass of $m = 7.30 \times 10^2 \; kg$ occupies a volume of $V_0 = 1.000 \; m^3$ at 0°C and a volume of $V = 1.02 \; m^3$ at 20.0°C. The density of gasoline at 20.0°C is then

$$\rho_{20} = \frac{m}{V} = \frac{7.30 \times 10^2 \; kg}{1.02 \; m^3} = \boxed{716 \; kg/m^3}$$

(d) $m_{20} = \rho_{20} V = 7.16 \times 10^2 \; kg/m^3 \; 10.0 \; gal \left(\dfrac{3.80 \times 10^{-3} \; m^3}{1 \; gal} \right) = \boxed{27.2 \; kg}$

(e) $\Delta m = m_0 - m_{20} = 27.7 \; kg - 27.2 \; kg = \boxed{0.5 \; kg}$

10.27 (a) The gap width is a linear dimension, so it ⏍ increases ⏍ in "thermal enlargement" as the temperature goes up.

(b) At 190°C, the length of the piece of steel that is missing, or has been removed to create the gap, is

$L = L_0 + \Delta L = L_0 \left[1 + \alpha \ \Delta T \right]$. This gives

$$L = 1.600 \text{ cm} \left\{ 1 + \left[11 \times 10^{-6} \ °C^{-1} \right] 190°C - 30.0°C \right\} = \boxed{1.603 \text{ cm}}$$

10.28 If allowed to do so, the concrete would expand by $\Delta L = \alpha L_0 \ \Delta T$.

(a) Since it is not permitted to expand, the concrete experiences a compressive stress of

$$Stress = Y \cdot \left(\frac{\Delta L}{L_0} \right) = Y \alpha \ \Delta T = 7.00 \times 10^9 \text{ Pa} \left[12 \times 10^{-6} \ °C^{-1} \right] 30.0°C$$

or $Stress = \boxed{2.5 \times 10^6 \text{ Pa}}$.

(b) Since this stress is less than the compressive strength of concrete, the sidewalk ⏍ will not fracture ⏍.

10.29 (a) From the ideal gas law, $PV = nRT$, we find $P/T = nR/V$. Thus, if both n and V are constant as the gas is heated, the ratio P/T is constant giving

$$\frac{P_f}{T_f} = \frac{P_i}{T_i} \qquad \text{or} \qquad T_f = T_i \left(\frac{P_f}{P_i} \right) = 300 \text{ K} \left(\frac{3P_i}{P_i} \right) = 900 \text{ K} = \boxed{627°C}$$

(b) If both pressure and volume double as n is held constant, the ideal gas law gives

$$T_f = T_i \left(\frac{P_f V_f}{P_i V_i} \right) = T_i \left(\frac{2P_i \ 2V_i}{P_i V_i} \right) = 4T_i = 4 \ 300 \text{ K} = 1 \ 200 \text{ K} = \boxed{927°C}$$

10.30 (a) $T_i = T_C + 273.15 = 19.0 + 273.15 \text{ K} = \boxed{292 \text{ K}}$

(b) $n_i = \dfrac{P_i V_i}{R T_i} = \dfrac{9.50 \times 10^5 \text{ Pa} \left[20.0 \text{ L} \ 10^3 \text{ cm}^3/1 \text{ L} \ 1 \text{ m}^3/10^6 \text{ cm}^3 \right]}{8.31 \text{ J/mol} \cdot \text{K} \ 292 \text{ K}} = 7.83 \text{ mol}$

(c) $M_{CO_2} = \left[12.0 + 2\ 16.0\right]\ \dfrac{g}{mol} = \boxed{44.0\ g/mol}$

(d) $m_i = n_i M_{CO_2} = 7.83\ mol\ 44.0\ g/mol = \boxed{345\ g}$

(e) $T_f = T_i + \Delta T = 292\ K + 224\ K = \boxed{516\ K}$

$$n_f = \dfrac{m_f}{M_{CO_2}} = \dfrac{m_i - \Delta m}{M_{CO_2}} = \dfrac{345\ g - 82.0\ g}{44.0\ g/mol} = \boxed{5.98\ mol}$$

(f) Neglecting any change in volume of the tank, $V_f \approx V_i$, and we have

$$\dfrac{P_f \cancel{V_f}}{P_i \cancel{V_i}} = \dfrac{n_f \cancel{R} T_f}{n_i \cancel{R} T_i} \quad \Rightarrow \quad \boxed{P_f = \left(\dfrac{n_f T_f}{n_i T_i}\right) P_i}$$

(g) $P_f = \left(\dfrac{n_f}{n_i}\right)\left(\dfrac{T_f}{T_i}\right) P_i = \left(\dfrac{5.98\ mol}{7.83\ mol}\right)\left(\dfrac{516\ K}{292\ K}\right)\ 9.50 \times 10^5\ Pa = \boxed{1.28 \times 10^6\ Pa}$

10.31 (a) $n = \dfrac{PV}{RT} = \dfrac{1.013 \times 10^5\ Pa/atm\ \ 1.0 \times 10^{-6}\ m^3}{8.31\ J/mol \cdot K\ \ 293\ K} = 4.2 \times 10^{-5}\ mol$

Thus,

$$N = n \cdot N_A = 4.2 \times 10^{-5}\ mol\ \left(6.02 \times 10^{23}\ \dfrac{molecules}{mol}\right) = \boxed{2.5 \times 10^{19}\ molecules}$$

(b) Since both V and T are constant,

$$\dfrac{n_2}{n_1} = \dfrac{P_2 \cancel{V_2}/\cancel{RT_2}}{P_1 \cancel{V_1}/\cancel{RT_1}} = \dfrac{P_2}{P_1}$$

or

$$n_2 = \left(\dfrac{P_2}{P_1}\right) n_1 = \left(\dfrac{1.0 \times 10^{-11}\ Pa}{1.013 \times 10^5\ Pa}\right)\ 4.2 \times 10^{-5}\ mol = \boxed{4.1 \times 10^{-21}\ mol}$$

10.32 The volume of helium in each balloon is $V_b = 4\pi r^3/3$.

The total volume of the helium at $P_2 = 1.20$ atm will be

$$V_2 = \left(\frac{P_1}{P_2}\right)V_1 = \left(\frac{150 \text{ atm}}{1.20 \text{ atm}}\right) 0.100 \text{ m}^3 = 12.5 \text{ m}^3$$

Thus, the number of balloons that can be filled is

$$N = \frac{V_2}{V_b} = \frac{12.5 \text{ m}^3}{4\pi/3 \; 0.150 \text{ m}^3} = \boxed{884 \text{ balloons}}$$

10.33   The initial and final absolute temperatures are

$$T_i = T_{C,i} + 273 = 25.0 + 273 \text{ K} = 298 \text{ K} \quad \text{and} \quad T_f = T_{C,f} + 273 = 75.0 + 273 \text{ K} = 348 \text{ K}$$

The volume of the tank is assumed to be unchanged, or $V_f = V_i$. Also, since two-thirds of the gas is withdrawn, $n_f = n_i/3$. Thus, from the ideal gas law,

$$\frac{P_f \cancel{V_f}}{P_i \cancel{V_i}} = \frac{n_f \cancel{R} T_f}{n_i \cancel{R} T_i} \quad \Rightarrow \quad P_f = \left(\frac{n_f}{n_i}\right)\left(\frac{T_f}{T_i}\right)P_i = \left(\frac{1}{3}\right)\left(\frac{348 \text{ K}}{298 \text{ K}}\right) (1.0 \text{ atm}) = \boxed{4.28 \text{ atm}}$$

10.34   If the volume and the temperature are both constant, the ideal gas law gives

$$\frac{P_f \cancel{V_f}}{P_i \cancel{V_i}} = \frac{n_f R \cancel{T_f}}{n_i R \cancel{T_i}} \quad \text{or} \quad n_f = \left(\frac{P_f}{P_i}\right)n_i = \left(\frac{5.00 \text{ atm}}{25.0 \text{ atm}}\right) 1.50 \text{ mol} = 0.300 \text{ mol}$$

so the amount of gas to be withdrawn is $\Delta n = n_i - n_f = 1.50 \text{ mol} - 0.300 \text{ mol} = \boxed{1.20 \text{ mol}}$.

10.35   With n held constant, the ideal gas law gives

$$\frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right) = \left(\frac{0.030 \text{ atm}}{1.0 \text{ atm}}\right)\left(\frac{300 \text{ K}}{200 \text{ K}}\right) = 4.5 \times 10^{-2}$$

Since the volume of a sphere is $V = 4\pi/3 \; r^3$, $V_1/V_2 = r_1/r_2^{\;3}$

Thus,

$$r_1 = \left(\frac{V_1}{V_2}\right)^{1/3} r_2 = \left(4.5 \times 10^{-2}\right)^{1/3} 20 \text{ m} = \boxed{7.1 \text{ m}}$$

10.36 The mass of the gas in the balloon does not change as the temperature increases. Thus,

$$\frac{\rho_f}{\rho_i} = \frac{m/V_f}{m/V_i} = \frac{V_i}{V_f} \qquad \text{or} \qquad \rho_f = \rho_i\left(\frac{V_i}{V_f}\right)$$

From the ideal gas law with both n and P constant, we find $V_i/V_f = T_i/T_f$ and now have

$$\rho_f = \rho_i\left(\frac{T_i}{T_f}\right) = 0.179 \text{ kg/m}^3 \left(\frac{273 \text{ K}}{373 \text{ K}}\right) = \boxed{0.131 \text{ kg/m}^3}$$

10.37 The pressure 100 m below the surface is found, using $P_1 = P_{\text{atm}} + \rho g h$, to be

$$P_1 = 1.013 \times 10^5 \text{ Pa} + 10^3 \text{ kg/m}^3 \quad 9.80 \text{ m/s}^2 \quad 100 \text{ m} = 1.08 \times 10^6 \text{ Pa}$$

The ideal gas law, with T constant, gives the volume at the surface as

$$V_2 = \left(\frac{P_1}{P_2}\right)V_1 = \left(\frac{P_1}{P_{\text{atm}}}\right)V = \left(\frac{1.08 \times 10^6 \text{ Pa}}{1.013 \times 10^5 \text{ Pa}}\right) 1.50 \text{ cm}^3 = \boxed{16.0 \text{ cm}^3}$$

10.38 (a) We assume the density ρ can be written as $\rho = n^a V^b M^c$ where n is the number of moles, V is the volume, and M is the molecular weight in kilograms per mole, while a, b, and c are constants to be determined by dimensional analysis. In terms of mass (M), length (L), time (T), and number of moles (N), the fundamental units of density are $\rho = mass/volume = \text{ML}^{-3}$, those of n are $n = \text{N}$, for volume $V = \text{L}^{-3}$, and molecular weight $M = kg/mol = \text{MN}^{-1}$. In terms of basic units, our assumed equation for density becomes

$$\rho = n^a V^b M^c \qquad \text{or} \qquad \text{M}^1\text{L}^{-3} = \text{N}^a \text{L}^{3}{}^b \text{MN}^{-1}{}^c = \text{N}^{a-c}\text{L}^{3b}\text{M}^c$$

and equating the powers of each of the basic units on the two sides of the equation gives:

$$1 = c \implies c = 1; \qquad -3 = 3b \implies b = -1; \qquad 0 = a - c \implies a = c = 1$$

so our expression for density, derived by dimensional analysis, is $\rho = n^1 V^{-1} M^1$, or

$$\boxed{\rho = \frac{nM}{V}}$$ where M is in kilograms per mole.

(b) From the ideal gas law, $PV = nRT$, or $P = \left(n/V\right)RT$. But, from the result of part (a), we may write

$n/V = \rho/M$, so the ideal gas law may be written in terms of the density of the gas as

$$\boxed{P = \frac{\rho}{M}RT}$$

where M is in kilograms per mole.

(c) For carbon dioxide, $M = 44$ g/mol $= 44 \times 10^{-3}$ kg/mol. Then, if the pressure is

$P = \left(90.0 \text{ atm}\right)\left(1.013 \times 10^5 \text{ Pa/1 atm}\right) = 9.12 \times 10^6$ Pa, and $T = 7.00 \times 10^2$ K, the density of the

atmosphere on Venus is

$$\rho = \frac{PM}{RT} = \frac{\left(9.12 \times 10^6 \text{ Pa}\right)\left(44 \times 10^{-3} \text{ kg/mol}\right)}{\left(8.31 \text{ J/mol} \cdot \text{K}\right)\left(7.00 \times 10^2 \text{ K}\right)} = \boxed{69.0 \text{ kg/m}^3}$$

(d) The density of the evacuated steel shell would be

$$\rho_{\text{shell}} = \frac{M_{\text{shell}}}{V_{\text{shell}}} = \frac{2.00 \times 10^2 \text{ kg}}{4\pi \left(1.00 \text{ m}\right)^3/3} = 47.7 \text{ kg/m}^3$$

$\boxed{\text{Since } \rho_{\text{shell}} < \rho_{\text{atmosphere}}, \text{ this shell would rise in the atmosphere on Venus}}$.

10.39 The average kinetic energy of the molecules of *any* ideal gas at 300 K is

$$\overline{KE} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}k_B T = \frac{3}{2}\left(1.38 \times 10^{-23} \frac{\text{J}}{\text{K}}\right)\left(300 \text{ K}\right) = \boxed{6.21 \times 10^{-21} \text{ J}}$$

10.40 Since the sample contains three times Avogadro's number of molecules, there must be 3 moles of gas present. The ideal gas law then gives

$$P = \frac{nRT}{V} = \frac{\left(3 \text{ mol}\right)\left(8.31 \text{ J/mol} \cdot \text{K}\right)\left(293 \text{ K}\right)}{0.200 \text{ m}^3} = 9.13 \times 10^5 \text{ Pa}$$

The force this gas will exert on one face of the cubical container is

$$F = PA = 9.13 \times 10^5 \text{ Pa} \quad 0.200 \text{ m}^2 = 3.65 \times 10^4 \text{ N} = \boxed{36.5 \text{ kN}}$$

10.41 One mole of any substance contains Avogadro's number of molecules and has a mass equal to the molar mass, M. Thus, the mass of a single molecule is $m = M/N_A$.

For helium, $M = 4.00 \text{ g/mol} = 4.00 \times 10^{-3} \text{ kg/mol}$, and the mass of a helium molecule is

$$m = \frac{4.00 \times 10^{-3} \text{ kg/mol}}{6.02 \times 10^{23} \text{ molecule/mol}} = 6.64 \times 10^{-27} \text{ kg/molecule}$$

Since a helium molecule contains a single helium atom, the mass of a helium atom is

$$m_{\text{atom}} = \boxed{6.64 \times 10^{-27} \text{ kg}}$$

10.42 The rms speed of molecules in a gas of molecular weight M and absolute temperature T is $v_{\text{rms}} = \sqrt{3RT/M}$.

Thus, if $v_{\text{rms}} = 625 \text{ m/s}$ for molecules in oxygen (O_2), for which $M = 32.0 \text{ g/mol} = 32.0 \times 10^{-3} \text{ kg/mol}$, the temperature of the gas is

$$T = \frac{M v_{\text{rms}}^2}{3R} = \frac{32.0 \times 10^{-3} \text{ kg/mol} \quad 625 \text{ m/s}^2}{3 \quad 8.31 \text{ J/mol} \cdot \text{K}} = \boxed{501 \text{ K}}$$

10.43 The average translational kinetic energy per molecule in an ideal gas at absolute temperature T is $\overline{KE}_{\text{molecule}} = 3k_BT/2$, where $k_B = 1.38 \times 10^{-23} \text{ J/K}$ is Boltzmann's constant. Thus, if the absolute temperature is $T = T_C + 273.15 = 77.0 + 273.15 \text{ K} = 350 \text{ K}$, we have

$$\overline{KE}_{\text{molecule}} = \frac{3}{2} \quad 1.38 \times 10^{-23} \text{ J/K} \quad 350 \text{ K} = \boxed{7.25 \times 10^{-21} \text{ J}}$$

10.44 (a) The volume occupied by this gas is

$$V = 7.00 \text{ L} \quad 10^3 \text{ cm}^3/1 \text{ L} \quad 1 \text{ m}^3/10^6 \text{ cm}^3 = 7.00 \times 10^{-3} \text{ m}^3$$

Then, the ideal gas law gives

$$T = \frac{PV}{nR} = \frac{1.60 \times 10^6 \text{ Pa} \quad 7.00 \times 10^{-3} \text{ m}^3}{3.50 \text{ mol} \quad 8.31 \text{ J/mol} \cdot \text{K}} = \boxed{385 \text{ K}}$$

(b)   The average kinetic energy per molecule in this gas is

$$\overline{KE}_{\text{molecule}} = \frac{3}{2}k_B T = \frac{3}{2}\left(1.38 \times 10^{-23} \text{ J/K}\right)\left(385 \text{ K}\right) = \boxed{7.97 \times 10^{-21} \text{ J}}$$

(c)   You would need to know the mass of the gas molecule to find its average speed, which in turn requires knowledge of $\boxed{\text{the molecular weight of the gas}}$.

10.45   Consider a time interval of 1.0 min = 60 s, during which 150 bullets bounce off Superman's chest. From the impulse–momentum theorem, the magnitude of the average force exerted on Superman is

$$F_{\text{av}} = \frac{I}{\Delta t} = \frac{150|\Delta p|_{\text{bullet}}}{\Delta t} = \frac{150\left[m\left(v - v_0\right)\right]}{\Delta t}$$

$$= \frac{150\left(8.0 \times 10^{-3} \text{ kg}\right)\left[400 \text{ m/s} - \left(-400 \text{ m/s}\right)\right]}{60 \text{ s}} = \boxed{16 \text{ N}}$$

10.46   From the impulse–momentum theorem, the average force exerted on the wall is

$$F_{\text{av}} = \frac{I}{\Delta t} = \frac{N|\Delta p|_{\text{molecule}}}{\Delta t} = \frac{N\left[m\left(v - v_0\right)\right]}{\Delta t} \quad \text{or}$$

$$F_{\text{av}} = \frac{\left(5.0 \times 10^{23}\right)\left(4.68 \times 10^{-26} \text{ kg}\right)\left[300 \text{ m/s} - \left(-300 \text{ m/s}\right)\right]}{1.0 \text{ s}} = 14 \text{ N}$$

The pressure on the wall is then

$$P = \frac{F_{\text{av}}}{A} = \frac{14 \text{ N}}{8.0 \text{ cm}^2}\left(\frac{10^4 \text{ cm}^2}{1 \text{ m}^2}\right) = 1.8 \times 10^4 \text{ N/m}^2 = \boxed{18 \text{ kPa}}$$

10.47   As the pipe undergoes a temperature change $\Delta T = 46.5°C - 18.0°C = 28.5°C$, the expansion of the horizontal segment is

$$\Delta L_x = \alpha L_{0x}\left(\Delta T\right)$$

$$= \left[17 \times 10^{-6}\left(°C\right)^{-1}\right]\left(28.0 \text{ cm}\right)\left(28.5°C\right) = 1.36 \times 10^{-2} \text{ cm} = 0.136 \text{ mm}$$

The expansion of the vertical section is

$$\Delta L_y = \alpha L_{0y}\ \Delta T\ = \left[17 \times 10^{-6}\ °C^{-1}\right]\ 134\ cm\ \ 28.5°C\ = 0.649\ mm$$

The total displacement of the pipe elbow is

$$\Delta L = \sqrt{\Delta L_x^2 + \Delta L_y^2}\ = \sqrt{\ 0.136\ mm\ ^2 +\ 0.649\ mm\ ^2}\ = 0.663\ mm$$

at

$$\theta = \tan^{-1}\left(\frac{\Delta L_y}{\Delta L_x}\right) = \tan^{-1}\left(\frac{0.649\ mm}{0.136\ mm}\right) = 78.2°$$

or

$$\vec{\Delta L} = \boxed{0.663\ mm\ at\ 78.2°\ below\ the\ horizontal}$$

10.48 (a) $\Delta L = \alpha\,L_0\ \Delta T\ = \left[9.0 \times 10^{-6}\ °C^{-1}\right]\ 20\ cm\ \ 75\ °C\ = \boxed{1.4 \times 10^{-2}\ cm}$

(b) $\Delta D = \alpha\,D_0\ \Delta T\ = \left[9.0 \times 10^{-6}\ °C^{-1}\right]\ 1.0\ cm\ \ 75\ °C\ = \boxed{6.8 \times 10^{-4}\ cm}$

(c) The initial volume is $V_0 = \left(\frac{\pi D_0^2}{4}\right) L_0 = \frac{\pi}{4}\ 1.0\ cm\ ^2\ 20\ cm\ = 16\ cm^3$.

$$\Delta V = \beta V_0\ \Delta T$$

$$= 3\alpha\,V_0\ \Delta T\ = 3\left[9.0 \times 10^{-6}\ °C^{-1}\right]\ 16\ cm^3\ \ 75\ °C\ = \boxed{3.2 \times 10^{-2}\ cm^3}$$

**10.49** The number of moles of CO_2 present is

$$n = \frac{6.50\ g}{44.0\ g/mol} = 0.148\ mol$$

Thus, at the given temperature and pressure, the volume will be

$$V = \frac{nRT}{P} = \frac{0.148\ mol\ \ 8.31\ J/mol \cdot K\ \ 293\ K}{1.013 \times 10^5\ Pa} = 3.55 \times 10^{-3}\ m^3 = \boxed{3.55\ L}$$

10.50 (a) The sketch at the right shows a thermometer marked with the Fahrenheit scale on one side and Réaumer's scale on the other. Note that 80 RE scale divisions span the range from the freezing to the boiling of water, but 180 F divisions are required to do this.
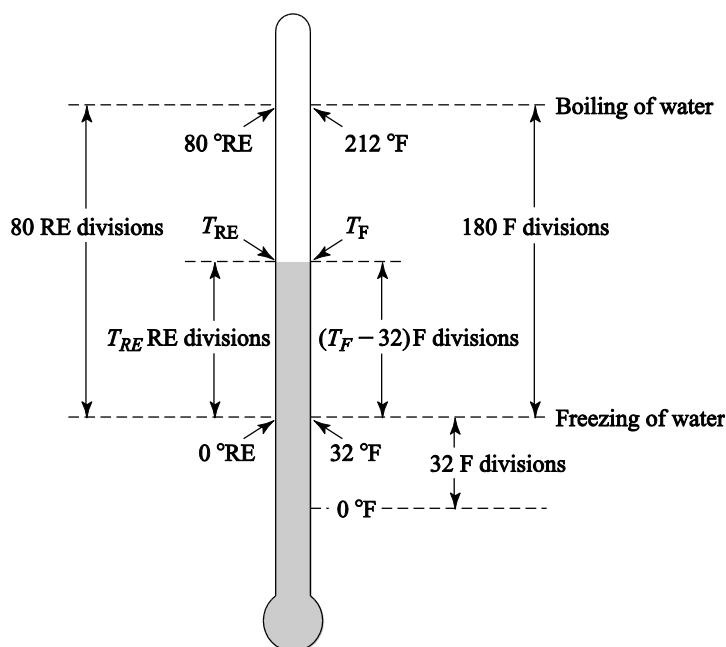
Then, note that the current temperature is T_{RE} RE divisions above the freezing point of water, but is $T_F - 32$ F divisions above this same level.

Since the range between the current temperature and the freezing of water is the same fraction of the span between freezing and boiling points of water on both sides of the thermometer, we must have

$$\frac{T_{RE}}{80} = \frac{T_F - 32}{180} \qquad \text{or} \qquad T_{RE} = \frac{80}{180}\left(T_F - 32\right) = \boxed{\frac{4}{9}T_F - 32}$$

(b) Normal body temperature $T_F = 98.6°F$ on the Réaumer scale is

$$T_{RE} = \frac{4}{9}T_F - 14.2 = \left[\frac{4}{9}\left(98.6\right) - 14.2\right]°\text{RE} = \boxed{29.6\ °\text{RE}}$$

10.51 The ideal gas law will be used to find the pressure in the tire at the higher temperature. However, one must always be careful to use absolute temperatures and absolute pressures in all ideal gas law calculations.

The initial absolute pressure is $P_i = P_{i,\text{gauge}} + P_{\text{atm}} = 2.5\ \text{atm} + 1.0\ \text{atm} = 3.5\ \text{atm}$.

The initial absolute temperature is $T_i = T_{i,C} + 273.15 = 15 + 273.15\ \ \text{K} = 288\ \text{K}$.

and the final absolute temperature is $T_f = T_{f,C} + 273.15 = 45 + 273.15\ \ \text{K} = 318\ \text{K}$.

The ideal gas law, with volume and quantity of gas constant, gives the final absolute pressure as

$$\frac{P_f \cancel{V_f}}{P_i \cancel{V_i}} = \frac{\cancel{n_f} R T_f}{\cancel{n_i} R T_i} \quad \Rightarrow \quad P_f = \left(\frac{T_f}{T_i}\right) P_i = \left(\frac{318\ K}{288\ K}\right)(3.5\ atm) = 3.9\ atm$$

The final gauge pressure in the tire is $P_{f,\text{gauge}} = P_f - P_{\text{atm}} = 3.9\ \text{atm} - 1.0\ \text{atm} = \boxed{2.9\ \text{atm}}$.

10.52 When air trapped in the tube is compressed, at constant temperature, into a cylindrical volume 0.40-m long, the ideal gas law gives its pressure as

$$P_2 = \left(\frac{V_1}{V_2}\right) P_1 = \left(\frac{L_1}{L_2}\right) P_1 = \left(\frac{1.5\ m}{0.40\ m}\right)(1.013 \times 10^5\ Pa) = 3.8 \times 10^5\ Pa$$

This is also the water pressure at the bottom of the lake. Thus, $P = P_{\text{atm}} + \rho g h$ gives the depth of the lake as

$$h = \frac{P_2 - P_{\text{atm}}}{\rho g} = \frac{(3.8 - 1.013) \times 10^5\ Pa}{(10^3\ kg/m^3)(9.80\ m/s^2)} = \boxed{28\ m}$$

10.53 The mass of CO_2 produced by three astronauts in 7.00 days is $m = 3(1.09\ \text{kg/d})(7.00\ \text{d}) = 22.9\ \text{kg}$, and the number of moles of CO_2 available is

$$n = \frac{m}{M} = \frac{22.9\ kg}{44.0 \times 10^{-3}\ kg/mol} = 520\ mol$$

The recycling process will generate 520 moles of methane to be stored. In a volume of $V = 150\ \text{L} = 0.150\ \text{m}^3$ and at temperature $T = -45.0°C = 228\ \text{K}$, the pressure of the stored methane is

$$P = \frac{nRT}{V} = \frac{(520\ mol)(8.31\ J/mol \cdot K)(228\ K)}{0.150\ m^3} = 6.57 \times 10^6\ Pa = \boxed{6.57\ MPa}$$

10.54 (a) The piston in this vertical cylinder has three forces acting on it. These are: (1) a downward gravitational force, mg, the piston's own weight; (2) a downward pressure force, $F_d = P_0 A$, due to the atmospheric pressure above the piston; and (3) an upward pressure force, $F_u = PA$, due to the absolute pressure of the gas trapped inside the cylinder. Since the piston is in equilibrium, Newton's second law requires

$$\Sigma F_y = 0 \quad \Rightarrow \quad F_u - mg - F_d = 0 \qquad \text{or} \qquad PA = mg + P_0 A \qquad [1]$$

From the ideal gas law, the absolute pressure of the trapped gas is

$$P = \frac{nRT}{V} = \frac{nRT}{Ah}$$ [2]

Substituting Equation [2] into [1] yields

$$\left(\frac{nRT}{Ah}\right) A = mg + P_0 A \quad \text{or} \quad \boxed{h = \frac{nRT}{mg + P_0 A}}$$

(b) From Equation [1] above, the absolute pressure inside the cylinder is $P = mg/A + P_0$ where P_0 is atmospheric pressure. This is $\boxed{\text{greater than atmospheric pressure}}$ because $mg/A > 0$.

(c) Observe from the result of part (a) above, if the absolute temperature T increases, $\boxed{\text{the equilibrium value of } h \text{ also increases}}$.

10.55 (a) As the acetone undergoes a change in temperature $\Delta T = 20.0 - 35.0 \ °C = -15.0 \ °C$, the final volume will be

$$V_f = V_0 + \Delta V = V_0 + \beta V_0 \ \Delta T = V_0\left[1 + \beta \ \Delta T\right]$$
$$= 100 \text{ mL} \left[1 + 1.50 \times 10^{-4} \ °C^{-1} \ -15.0 \ °C\right] = \boxed{99.8 \text{ mL}}$$

(b) When acetone at 35°C is poured into the Pyrex flask that was calibrated at 20°C, the volume of the flask temporarily expands to be larger than its calibration markings indicate. However, the coefficient of volume expansion for Pyrex $[\beta = 3\alpha = 9.6 \times 10^{-6} \ (°C)^{-1}]$ is much smaller than that of acetone $[\beta = 1.5 \times 10^{-4} \ (°C)^{-1}]$. Hence, the temporary increase in the volume of the flask will be much smaller than the change in volume of the acetone as the materials cool back to 20°C, and this change in volume of the flask $\boxed{\text{has negligible effect on the answer}}$.

10.56 If P_i is the initial gauge pressure of the gas in the cylinder, the initial absolute pressure is $P_{i,\text{abs}} = P_i + P_{\text{atm}}$, where P_f is atmospheric pressure. Likewise, the final absolute pressure in the cylinder is , where is the final gauge pressure. The initial and final masses of gas in the cylinder are $m_i = n_i M$ and $m_f = n_f M$, where n is the number of moles of gas present and M is the molecular weight of this gas. Thus, $m_f/m_i = n_f/n_i$.

We assume the cylinder is a rigid container whose volume does not vary with internal pressure. Also, since the temperature of the cylinder is constant, its volume does not expand nor contract. Then, the ideal gas law (using absolute pressures) with both temperature and volume constant gives

$$\frac{P_{f,\text{abs}}\cancel{V}}{P_{i,\text{abs}}\cancel{V}} = \frac{n_f\cancel{RT}}{n_i\cancel{RT}} = \frac{m_f}{m_i} \qquad \text{or} \qquad m_f = \left(\frac{P_{f,\text{abs}}}{P_{i,\text{abs}}}\right)m_i$$

and in terms of gauge pressures,

$$\boxed{m_f = \left(\frac{P_f + P_{\text{atm}}}{P_i + P_{\text{atm}}}\right)m_i}$$

10.57   (a)   The volume of the liquid expands by $\Delta V_{\text{liquid}} = \beta V_0\ \Delta T$ and the volume of the glass flask expands by

$\Delta V_{\text{flask}} = 3\alpha\ V_0\ \Delta T$. The amount of liquid that must overflow into the capillary is

$V_{\text{overflow}} = \Delta V_{\text{liquid}} - \Delta V_{\text{flask}} = V_0\ \beta - 3\alpha\ \Delta T$. The distance the liquid will rise into the capillary is then

$$\Delta h = \frac{V_{\text{overflow}}}{A} = \boxed{\left(\frac{V_0}{A}\right)\ \beta - 3\alpha\ \Delta T}$$

(b)   For a mercury thermometer, $\beta_{\text{Hg}} = 1.82 \times 10^{-4}\ \ °\text{C}^{-1}$ and (assuming Pyrex glass),

$3\alpha_{\text{glass}} = 3\,(3.2 \times 10^{-6}\ (°\text{C})^{-1}) = 9.6 \times 10^{-6}\ \ °\text{C}^{-1}$. Thus, the expansion of the mercury is

$\boxed{\text{almost 20 times the expansion of the flask}}$, making it a rather good approximation to neglect the expansion of the flask.

10.58   (a)   The initial absolute pressure in the tire is

$$P_1 = P_{\text{atm}} + P_{1\ \text{gauge}} = 1.00\ \text{atm} + 1.80\ \text{atm} = 2.80\ \text{atm}$$

and the final absolute pressure is $P_2 = 3.20\ \text{atm}$.

The ideal gas law, with volume constant, gives

$$T_2 = \left(\frac{P_2}{P_1}\right)T_1 = \left(\frac{3.20\ \text{atm}}{2.80\ \text{atm}}\right)\ 300\ \text{K}\ = \boxed{343\ \text{K}}$$

(b) When the quantity of gas varies, while volume and temperature are constant, the ideal gas law gives $n_3/n_2 = P_3/P_2$. Thus, when air is released to lower the absolute pressure back to 2.80 atm, we have

$$\frac{n_3}{n_2} = \frac{2.80 \text{ atm}}{3.20 \text{ atm}} = 0.875$$

At the end, we have 87.5% of the original mass of air remaining, or

$\boxed{12.5\% \text{ of the original mass}}$ was released.

10.59 After expansion, the increase in the length of one span is
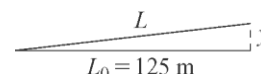
$$\Delta L = \alpha L_0 \, \Delta T$$

$$= \left[12 \times 10^{-6} \ \text{°C}^{-1} \right] 125 \text{ m} \quad 20.0\text{°C} = 0.0300 \text{ m}$$

giving a final length of $L = L_0 + \Delta L = 125 \text{ m} + 0.0300 \text{ m}$

From the Pythagorean theorem,

$$y = \sqrt{L^2 - L_0^2} = \sqrt{125 + 0.0300 \ \text{m}^2 - 125 \text{ m}^{\,2}} = \boxed{2.74 \text{ m}}$$

10.60 (a) From the ideal gas law, $\dfrac{P_2 V_2}{T_2} = \dfrac{P_1 V_1}{T_1}$, or $\left(\dfrac{P_2}{P_1} \right)\left(\dfrac{V_2}{V_1} \right) = \left(\dfrac{T_2}{T_1} \right)$

The initial conditions are

$$P_1 = 1 \text{ atm}, \ V_1 = 5.00 \text{ L} = 5.00 \times 10^{-3} \text{ m}^3, \text{ and } T_1 = 20.0\text{°C} = 293 \text{ K}$$

The final conditions are

$$P_2 = 1 \text{ atm} + \frac{F}{A} = 1 \text{ atm} + \frac{k \cdot h}{A}, \ V_2 = V_1 + A \cdot h, \text{ and } T_2 = 250 \text{ °C} = 523 \text{ K}$$

Thus,

$$\left(1 + \frac{k \cdot h}{A \ 1 \text{ atm}} \right)\left(1 + \frac{A \cdot h}{V_1} \right) = \left(\frac{523 \text{ K}}{293 \text{ K}} \right)$$

or

$$\left(1 + \frac{2.00 \times 10^3 \text{ N/m} \cdot h}{0.0100 \text{ m}^2 \quad 1.013 \times 10^5 \text{ N/m}^2}\right)\left(1 + \frac{0.0100 \text{ m}^2 \cdot h}{5.00 \times 10^{-3} \text{ m}^3}\right) = \left(\frac{523}{293}\right)$$

Simplifying and using the quadratic formula yields

$$h = 0.169 \text{ m} = \boxed{16.9 \text{ cm}}$$

(b) $P_2 = 1 \text{ atm} + \dfrac{k \cdot h}{A}$

$$= 1.013 \times 10^5 \text{ Pa} + \frac{2.00 \times 10^3 \text{ N/m} \quad 0.169 \text{ m}}{0.0100 \text{ m}^2} = \boxed{1.35 \times 10^5 \text{ Pa}}$$

10.61 (a) The two metallic strips have the same length L_0 at the initial temperature T_0. After the temperature has changed by $\Delta T = T - T_0$, the lengths of the two strips are

$$L_1 = L_0\left[1 + \alpha_1 \ \Delta T \ \right] \qquad \text{and} \qquad L_2 = L_0\left[1 + \alpha_2 \ \Delta T \ \right]$$

The lengths of the circular arcs are related to their radii by $L_1 = r_1\theta$ and $L_2 = r_2\theta$, where θ is measured in radians.

Thus,

$$\Delta r = r_2 - r_1 = \frac{L_2}{\theta} - \frac{L_1}{\theta} = \frac{\alpha_2 - \alpha_1 \ L_0 \ \Delta T}{\theta}$$

or

$$\boxed{\theta = \frac{\alpha_2 - \alpha_1 \ L_0 \ \Delta T}{\Delta r}}$$

(b) As seen in the above result, $\boxed{\theta = 0 \text{ if either } \Delta T = 0 \ \text{ or } \ \alpha_1 = \alpha_2}$.

(c) If $\Delta T < 0$, then θ is negative so $\boxed{\text{the bar bends in the opposite direction}}$.

10.62   (a)   If the bridge were free to expand as the temperature increased by $\Delta T = 20°C$, the increase in length would be

$$\Delta L = \alpha L_0 \; \Delta T \;\; = \;\; 12 \times 10^{-6} \; °C^{-1} \quad 250 \text{ m} \quad 20°C \;\; = 6.0 \times 10^{-2} \text{ m} = \boxed{6.0 \text{ cm}}$$

(b)   Combining the defining equation for Young's modulus,

$$Y = Stress/Strain = Stress\Big/ \; \Delta L/L$$

with the expression, $\Delta L = \alpha L \; \Delta T$, for the linear expansion when the temperature changes by ΔT yields

$$Stress = Y\left(\frac{\Delta L}{L}\right) = Y\left(\frac{\alpha L \; \Delta T}{L}\right) = \boxed{\alpha Y \;\; \Delta T}$$

(c)   When $\Delta T = 20°C$, the stress in the specified bridge would be

$$Stress = \alpha Y \;\; \Delta T \;\; = \;\; 12 \times 10^{-6} \; °C^{-1} \quad 2.0 \times 10^{10} \text{ Pa} \quad 20°C \;\; = \boxed{4.8 \times 10^{6} \text{ Pa}}$$

Since this considerably less than the maximum stress, 2.0×10^{7} Pa , that concrete can withstand, $\boxed{\text{the bridge will not crumble}}$.

10.63   (a)   As the temperature of the pipe increases, the original 5.0-m length between the water heater and the floor above will expand by

$$\Delta L = \alpha L_0 \; \Delta T \;\; = \;\; 17 \times 10^{-6} \; °C \quad 5.0 \text{ m} \quad 46°C - 20°C \;\; = 2.21 \times 10^{-3} \text{ m}$$

If this expansion occurs in a series of 18 "ticks," the expansion per tick is

$$movement \; per \; tick = \Delta L/18 \;\; = \;\; 2.21 \times 10^{-3} \text{ m} \Big/ 18 = 1.23 \times 10^{-4} \text{ m} = \boxed{0.12 \text{ mm}}$$

(b)   When the pipe is stuck in the hole, the floor exerts a friction force on the pipe preventing it from expanding. Just before a "tick" occurs, the pipe is compressed a distance of 0.123 mm. The force required to produce this compression is given by the equation defining Young's modulus, $Y = \; F/A \Big/ \; \Delta L/L$, as

$$F = YA\left(\frac{\Delta L}{L}\right) = 11 \times 10^{10} \text{ Pa} \quad 3.55 \times 10^{-5} \text{ m}^2 \left(\frac{1.23 \times 10^{-4} \text{ m}}{5.0 \text{ m}}\right) = \boxed{96 \text{ N}}$$

10.64 Let container 1 be maintained at $T_1 = T_0 = 0°C = 273 \text{ K}$, while the temperature of container 2 is raised to $T_2 = 100°C = 373 \text{ K}$. Both containers have the same constant volume, V, and the same initial pressures, $P_{0\,2} = P_{0\,1} = P_0$. As the temperature of container 2 is raised, gas flows from one container to the other until the final pressures are again equal, $P_2 = P_1 = P$. The total mass of gas is constant, so

$$n_2 + n_1 = n_{0\,2} + n_{0\,1} \qquad\qquad\qquad\qquad [1]$$

From the ideal gas law, $n = PV/RT$, so Equation [1] becomes

$$\frac{PV}{RT_1} + \frac{PV}{RT_2} = \frac{P_0V}{RT_0} + \frac{P_0V}{RT_0}, \quad \text{or} \quad P\left(\frac{1}{T_1} + \frac{1}{T_2}\right) = \frac{2P_0}{T_0}$$

Thus,

$$P = \frac{2P_0}{T_0}\left(\frac{T_1 T_2}{T_1 + T_2}\right) = \frac{2\ 1.00 \text{ atm}}{273}\left(\frac{273 \cdot 373}{273 + 373}\right) = \boxed{1.15 \text{ atm}}$$