Chapter 10
Thermal Physics

Quick Quizzes

1. (c). When two objects having different temperatures are in thermal contact, energy is transferred from the higher temperature object to the lower temperature object. As a result, the temperature of the hotter object decreases and that of the cooler object increases until thermal equilibrium is reached at some intermediate temperature.

2. (b). The glass surrounding the mercury expands before the mercury does, causing the level of the mercury to drop slightly. The mercury rises after it begins to get warmer and approach the temperature of the hot water, because its coefficient of expansion is greater than that for glass.

3. (c). Gasoline has the highest coefficient of expansion so it undergoes the greatest change in volume per degree change in temperature.

4. (c). A cavity in a material expands in exactly the same way as if the cavity were filled with material. Thus, both spheres will expand by the same amount.

5. (a). It expands. Imagine the balloon rising into air at uniform temperature. The air cannot be uniform in pressure because the lower layers support the weight of all the air above them. The rubber in a typical balloon stretches or contracts until interior and exterior pressures are nearly equal. So as the balloon rises, it expands; this can be considered as constant temperature expansion with V increasing as P decreases by the same factor in $PV = nRT$. If the rubber wall is strong enough, the buoyant force will eventually match the total weight of the balloon and helium so the balloon will stop rising. It is more likely that the rubber will stretch and rupture, releasing the helium, which in turn will escape from Earth's atmosphere.

6. (b). Since the two containers are at the same temperature, the average kinetic energy per molecule is the same for the argon and helium gases. However, helium has a lower molar mass than does argon, so the rms speed of the helium atoms must be higher than that of the argon atoms.

Answers to Even Numbered Conceptual Questions

2. As the moment of inertia of the balance wheel increases, the angular acceleration the spring can give the wheel will decrease. Thus, the wheel will not oscillate as rapidly as it should, causing the watch to run slow.

4. This is very good advice. As the engine heats, pressure builds up in the radiator causing most of the water in the system to remain liquid even at temperatures above the normal boiling point of water. Opening the radiator cap while the engine is still hot would result in an explosive release of this pressure and very rapid boiling of the water. This will cause steam and superheated water to spew from the radiator, and can result in serious burns to the person opening the cap.

6. The temperature of the bearing can be increased until its diameter becomes large enough to slip over the axle.

8. The lower temperature will make the power line decrease in length. This increases the tension in the line to the point that it is near breaking.

10. At high temperature and pressure, the steam inside exerts large forces on the pot and cover. Strong latches hold them together, but they would explode apart if you tried to open the hot cooker.

12. The measurements are too short. At 22°C the tape would read the width of the object accurately, but an increase in temperature causes the divisions ruled on the tape to be farther apart than they should be. This “too long” ruler will, then, measure objects to be shorter than they really are.

14. The existence of an atmosphere on a planet is due to the gravitational force holding the gas of the atmosphere to the planet. On a small planet, the gravitational force is very small, and the escape speed is correspondingly small. If a small planet starts its existence with atmosphere, the molecules of the gas will have a distribution of speeds, according to kinetic theory. Some of these molecules will have speeds higher than the escape speed of the planet and will leave the atmosphere. As the remaining atmosphere is warmed by radiation from the Sun, more molecules will attain speeds high enough to escape. As a result, the atmosphere bleeds off into space.

Answers to Even Numbered Problems

2. **(a)** $-251°C$ **(b)** 1.36 atm

4. 56.7°C, -62.1°C

6. **(a)** $-273°C$ **(b)** 1.27 atm, 1.74 atm

8. **(a)** 810°F **(b)** 450 K

10. **(a)** 263°C **(b)** $-262°C$

12. **(a)** $L = 1.3 \text{ m} - 0.49 \text{ mm}$ **(b)** fast

14. 1.39°C

18. 18.702 m

20. 1.5 km, accordion-like expansion joints at periodic intervals

22. **(a)** 0.12 mm **(b)** 96 N

24. **(a)** $2.5 \times 10^6 \text{ Pa}$ **(b)** It will not fracture.

26. **(a)** 99.4 cm^3 **(b)** 0.943 cm

28. **(a)** 3.0 mol **(b)** 1.8×10^{24} molecules

30. 884 balloons

32. 0.131 kg/m^3

34. 3.84 m

36. 36.5 kN

38. **(a)** 3.74 kJ/mol **(b)** 1.93 km/s

40. **(a)** $\left(v_{\text{rms}}\right)_{H_2} = 1.73 \text{ km/s}$ **(b)** $\left(v_{\text{rms}}\right)_{CO_2} = 0.369 \text{ km/s}$
(c) Hydrogen escapes; carbon dioxide does not.

42. $3.34 \times 10^5 \text{ Pa}$

44. 18 kPa

46. **(a)** $1.4 \times 10^{-2} \text{ cm}$ **(b)** $6.8 \times 10^{-4} \text{ cm}$ **(c)** $3.2 \times 10^{-2} \text{ cm}^3$

48. 28 m

50. 2.4 m

52. $\geq 8.0 \times 10^2$ °C

54. **(a)** 343 K **(b)** 12.5% of the original mass

56. $L_{steel} = 14.2$ cm, $L_{copper} = 9.2$ cm

58. **(a)** 16.9 cm **(b)** 1.35×10^5 Pa

60. 1.15 atm

62. **(a)** 6.0 cm

(b) The stress on the span would be 4.8×10^6 Pa, so it will not crumble

Problem Solutions

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

(b) $T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(98.6 - 32) = \boxed{37.0°\text{C}}$

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

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,

$$P = 0.700 \text{ atm when } T = 100°\text{C} \;\Rightarrow\; 0.700 \text{ atm} = A(100°\text{C}) + B \qquad (1)$$

$$P = 0.512 \text{ atm when } T = 0°\text{C} \;\Rightarrow\; 0.512 \text{ atm} = A(0) + B \qquad (2)$$

From Equation (2), $B = 0.512$ atm. Substituting this result into Equation (1) yields

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

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

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

10.3 (a) Converting from Celsius to Fahrenheit,

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5}(-252.87) + 32 = \boxed{-423°\text{F}}$$

and converting to Kelvin, $T = T_C + 273.15 = -252.87 + 273.15 = \boxed{20.28 \text{ K}}$

(b) $T_F = \frac{9}{5}T_C + 32 = \frac{9}{5}(20) + 32 = \boxed{68°\text{F}}$

and $T = T_C + 273.15 = 20 + 273.15 = \boxed{293 \text{ K}}$

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

and $T_C = \frac{5}{9}(-79.8 - 32) = \boxed{-62.1°\text{C}}$

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

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

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:

$$0.900 \text{ atm} = A + B(\text{-}80.0°\text{C}) \tag{1}$$

and

$$1.635 \text{ atm} = A + B(78.0°\text{C}) \tag{2}$$

Solving equations (1) and (2) simultaneously, we find:

$A = 1.27 \text{ atm}$, and $B = 4.65 \times 10^{-3} \text{ atm/°C}$

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

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

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

(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

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

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 $$(T_F)_1 = \frac{9}{5}(T_C)_1 + 32 \quad (1)$$

and $$(T_F)_2 = \frac{9}{5}(T_C)_2 + 32 \quad (2)$$

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 7, gives

$$\Delta T_F = (9/5)\Delta T_C = \frac{9}{5}(450) = \boxed{810°\text{F}}$$

(b) Since the only difference in the Kelvin and Celsius temperature scales is the location of their zero points, differences in temperature have the same numeric values on the two scales. Thus, $\Delta T = 450°\text{C} = \boxed{450\ \text{K}}$

10.9 (a) $T = T_C + 273 = 1064 + 273 = \boxed{1337\ \text{K}}$ melting point

$T = T_C + 273 = 2660 + 273 = \boxed{2933\ \text{K}}$ boiling point

(b) $\Delta T = \boxed{1596°\text{C}} = \boxed{1596\ \text{K}}$ The differences are the same.

10.10 (a) The temperature of the sleeve should be raised until its diameter (a linear dimension) increases from 3.196 cm to 3.212 cm. The increase in temperature required to accomplish this is

$$\Delta T = T_f - 0°\text{C} = \frac{\Delta L}{\alpha L_0} = \frac{3.212\ \text{cm} - 3.196\ \text{cm}}{\left[19 \times 10^{-6}\ (°\text{C})^{-1}\right](3.196\ \text{cm})} = 263°\text{C} \text{ or } T_f = \boxed{263°\text{C}}$$

(b) If we instead cool the shaft so its diameter contracts from 3. 212 cm to 3. 196 cm, the change in temperature required is

$$\Delta T = T_f - 0°\text{C} = \frac{\Delta L}{\alpha L_0} = \frac{3.196\ \text{cm} - 3.212\ \text{cm}}{\left[19 \times 10^{-6}\ (°\text{C})^{-1}\right](3.212\ \text{cm})} = -262°\text{C} \text{ or } T_f = \boxed{-262°\text{C}}$$

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

Thus, $$\Delta L = \alpha L_0(\Delta T) = \left[11\times10^{-6}\ (°\text{C})^{-1}\right](518\text{ m})(55°\text{C}) = 0.31\text{ m} = \boxed{31\text{ cm}}$$

10.12 (a) As the temperature drops by 20°C, the length of the pendulum changes by

$$\Delta L = \alpha L_0(\Delta T)$$

$$= \left[19\times10^{-6}\ (°\text{C})^{-1}\right](1.3\text{ m})(-20°\text{C}) = -4.9\times10^{-4}\text{ m} = -0.49\text{ mm}$$

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 $\Delta L = \alpha L_0(\Delta T)$,

$$\Delta T = T_C - 20.0°\text{C} = \frac{L - L_0}{\alpha L_0} = \frac{2.21\text{ cm} - 2.20\text{ cm}}{\left[130\times10^{-6}\ (°\text{C})^{-1}\right](2.20\text{ cm})} = 35.0°\text{C}$$

or $\quad T_C = 55.0°\text{C}$

10.14 The desired change in volume is

$$\Delta V = \left(100\text{ cm}^3\right)\left(\frac{1\text{ m}^3}{10^6\text{ cm}^3}\right) = 1.00\times10^{-4}\text{ m}^3$$

From $\Delta V = \beta V_0(\Delta T) = (3\alpha)V_0(\Delta T)$, the required change in temperature is

$$\Delta T = \frac{\Delta V}{(3\alpha)V_0} = \frac{1.00\times10^{-4}\text{ m}^3}{3\left[24\times10^{-6}\ (°\text{C})^{-1}\right](1.00\text{ m}^3)} = \boxed{1.39°\text{C}}$$

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

$$L_{brass} = L_{al}\text{, or } (L_0)_{brass} + \alpha_{brass}(L_0)_{brass}(\Delta T) = (L_0)_{al} + \alpha_{al}(L_0)_{al}(\Delta T)$$

This gives $$\Delta T = \frac{(L_0)_{al} - (L_0)_{brass}}{\alpha_{brass}(L_0)_{brass} - \alpha_{al}(L_0)_{al}}$$

(a) If $(L_0)_{al} = 10.01\text{ cm}$,

$$\Delta T = \frac{10.01 - 10.00}{\left[19\times10^{-6}\ (°\text{C})^{-1}\right](10.00) - \left[24\times10^{-6}\ (°\text{C})^{-1}\right](10.01)} = -199°\text{C}$$

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

(b) If $(L_0)_{al} = 10.02\text{ cm}$

$$\Delta T = \frac{10.02 - 10.00}{\left[19\times10^{-6}\ (°\text{C})^{-1}\right](10.00) - \left[24\times10^{-6}\ (°\text{C})^{-1}\right](10.02)} = -396°\text{C}$$

and

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

10.16 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

$$V = \left[A_0 + 2\alpha A_0(\Delta T)\right]\left[L_0 + \alpha L_0(\Delta T)\right] = A_0L_0 + 3\alpha A_0L_0(\Delta T) + 2\alpha^2 A_0L_0(\Delta T)^2$$

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

$V = A_0L_0 + 3\alpha A_0L_0(\Delta T) = V_0 + 3\alpha V_0(\Delta T)$. This is of the form

$$\Delta V = V - V_0 = \beta V_0(\Delta T) \quad \text{where } \boxed{\beta = 3\alpha}$$

10.17 [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

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

10.18 [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 $(L_0)_{tape}$ and require that

$$L = (L_0)_{tape}\left[1 + \alpha_{steel}(\Delta T)\right] = (L_0)_{column}\left[1 + \alpha_{al}(\Delta T)\right]\text{, which gives}$$

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

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

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

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

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

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

and the tension in the band will be

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

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

$$\Delta L = \left[11\times10^{-6}\ (°\text{C})^{-1}\right]\left(1300\times10^{3}\ \text{m}\right)\left[35°\text{C-}(\text{-}73°\text{C})\right] = 1.5\times10^{3}\ \text{m} = \boxed{1.5\ \text{km}}$$

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

10.21 The initial volume of the gasoline is $V_0 = 45\ \text{L}$. As the temperature rises to 35°C, this volume will expand by

$$\Delta V = \beta V_0(\Delta T) = \left[9.6\times10^{-4}\ (°\text{C})^{-1}\right](45\ \text{L})(35°\text{C} - 10°\text{C}) = 1.1\ \text{liters}$$

Thus, if the tank does not expand, $\boxed{1.1\ \text{L}\ \ (0.29\ \text{gal})}$ of gasoline will overflow.

10.22 (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

$$\Delta L = \alpha L_0(\Delta T) = \left(17\times10^{-6}\ °\text{C}\right)(5.0\ \text{m})(46°\text{C} - 20°\text{C}) = 2.21\times10^{-3}\ \text{m}$$

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

$$\textit{movement per tick} = \Delta L/18 = \left(2.21\times10^{-3}\ \text{m}\right)/18 = 1.23\times10^{-4}\ \text{m} = \boxed{0.12\ \text{mm}}$$

(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, $Y = (F/A)/(\Delta L/L)$, as

$$F = YA\left(\frac{\Delta L}{L}\right) = \left(11\times10^{10}\ \text{Pa}\right)\left(3.55\times10^{-5}\ \text{m}^2\right)\left(\frac{1.23\times10^{-4}\ \text{m}}{5.0\ \text{m}}\right) = \boxed{96\ \text{N}}$$

10.23 Both the drum and the carbon tetrachloride expand as the temperature rises by $\Delta T = 20.0°\text{C}$. 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

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

or $$V_{spillage} = \left[5.81\times10^{-4}\ (°\text{C})^{-1} - 3\left(11\times10^{-6}\ (°\text{C})^{-1}\right)\right](50.0\ \text{gal})(20.0°\text{C}) = \boxed{0.548\ \text{gal}}$$

10.24 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

$$Stress = Y \cdot \left(\frac{\Delta L}{L_0}\right) = Y\alpha(\Delta T) = \left(7.00\times10^{9}\ \text{Pa}\right)\left[12\times10^{-6}\ (°\text{C})^{-1}\right](30.0°\text{C}),$$

or $Stress = \boxed{2.5\times10^{6}\ \text{Pa}}$

(b) Since this stress is less than the compressive strength of concrete, the sidewalk $\boxed{\text{will not fracture}}$.

10.25 (a) The gap width is a linear dimension, so it $\boxed{\text{increases}}$ 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

$$L = (1.600\ \text{cm})\left(1+\left[11\times10^{-6}\ (°\text{C})^{-1}\right](190°\text{C}-30.0°\text{C})\right) = \boxed{1.603\ \text{cm}}$$

10.26 (a) The cavity in the cylinder expands by the same amount the aluminum which was removed to form the cavity would have expanded. Since the initial volume of the cavity is identical to the initial volume of turpentine filling the cavity, the overflow is

$$V_{overflow} = \Delta V_{turp} - \Delta V_{al} = \beta_{turp}(V_0)_{turp}(\Delta T) - \beta_{al}(V_0)_{cavity}(\Delta T) = \left(\beta_{turp} - 3\alpha_{al}\right)(V_0)_{turp}(\Delta T)$$

or

$$V_{overflow} = \left[9.0\times10^{-4}\,(°\text{C})^{-1} - 3\left(24\times10^{-6}\right)(°\text{C})^{-1}\right]\left(2000\ \text{cm}^3\right)(60.0°\text{C})$$

$$= \boxed{99.4\ \text{cm}^3}$$

(b) At 80.0°C, the total volume of the turpentine is

$$V_{turp} = (V_0)_{turp} + \Delta V_{urp} = (V_0)_{turp}\left[1+\beta_{turp}(\Delta T)\right]$$

$$= \left(2000\ \text{cm}^3\right)\left(1+\left[9.0\times10^{-4}\ (^\circ\text{C})^{-1}\right](60.0^\circ\text{C})\right) = 2.11\times10^3\ \text{cm}^3$$

Thus, the fraction of the total represented by the overflow is

$$fraction\ lost = \frac{99.4\ \text{cm}^3}{2.11\times10^3\ \text{cm}^3} = 4.71\times10^{-2}$$

When the system is cooled to the original temperature, this fraction of the depth of the cavity will be empty, or

$$\Delta h = h_0(fraction\ lost) = (20.0\ \text{cm})\left(4.71\times10^{-2}\right) = \boxed{0.943\ \text{cm}}$$

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

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

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

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

10.28 (a) $n = \frac{PV}{RT}$

$$= \frac{\left[(9.0\ \text{atm})\left(1.013\times10^5\ \text{Pa/atm}\right)\right]\left[(8.0\ \text{L})\left(1\ \text{m}^3/10^3\ \text{L}\right)\right]}{(8.31\ \text{J/mol}\cdot\text{K})(293\ \text{K})} = \boxed{3.0\ \text{mol}}$$

(b) $N = n\cdot N_\text{A} = (3.0\ \text{mol})\left(6.02\times10^{23}\ \text{molecules/mol}\right) = \boxed{1.8\times10^{24}\ \text{molecules}}$

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

Thus, $N = n\cdot N_{\text{A}}$

$$= \left(4.2\times 10^{-5}\ \text{mol}\right)\left(6.02\times 10^{23}\ \frac{\text{molecules}}{\text{mol}}\right) = \boxed{2.5\times 10^{19}\ \text{molecules}}$$

(b) Since both V and T are constant, $\dfrac{n_2}{n_1} = \dfrac{P_2V_2/RT_2}{P_1V_1/RT_1} = \dfrac{P_2}{P_1}$, or

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

10.30 The volume of helium in each balloon is $V_b = \dfrac{4\pi}{3}r^3$.

The total volume of the helium at $P_2 = 1.20\ \text{atm}$ will be

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

Thus, the number of balloons that can be filled is

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

10.31 From the ideal gas law, $PV = nRT$, with $n_2 = n_1$, we have

$$T_2 = T_1\left(\frac{P_2V_2}{P_1V_1}\right) = \left(300\ \text{K}\right)\left(\frac{0.800\times 10^{5}\ \text{Pa}}{0.200\times 10^{5}\ \text{Pa}}\right)\left(\frac{0.700\ \text{m}^3}{1.50\ \text{m}^3}\right) = 560\ \text{K} = \boxed{287^\circ\text{C}}$$

10.32 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

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

10.33 With n held constant, the ideal gas law gives

$$\frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right) = \left(\frac{0.030\ \text{atm}}{1.0\ \text{atm}}\right)\left(\frac{300\ \text{K}}{200\ \text{K}}\right) = 4.5\times10^{-2}$$

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

Thus, $r_1 = \left(\dfrac{V_1}{V_2}\right)^{1/3} r_2 = \left(4.5\times10^{-2}\right)^{1/3}(20\ \text{m}) = \boxed{7.1\ \text{m}}$

10.34 The pressure at a depth of 220 m in the ocean is

$$P_2 = P_{atm} + \rho g h$$

$$= 1.013\times10^5\ \text{Pa} + \left(1\,025\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)(220\ \text{m}) = 2.31\times10^6\ \text{Pa}$$

At pressure $P_1 = 1\ \text{atm} = 1.013\times10^5\ \text{Pa}$, the air in the bell occupies a volume

$$V_1 = \left(\pi r^2\right)h_1 = \pi(1.50\ \text{m})^2(4.00\ \text{m}) = 28.3\ \text{m}^3$$

At the ocean bottom, the volume of this air will be

$$V_2 = \left(\frac{P_1}{P_2}\right)\left(\frac{T_2}{T_1}\right)V_1 = \left(\frac{1.013\times10^5\ \text{Pa}}{2.31\times10^6\ \text{Pa}}\right)\left(\frac{278\ \text{K}}{298\ \text{K}}\right)\left(28.3\ \text{m}^3\right) = 1.16\ \text{m}^3$$

The height of this cylindrical volume is $h_2 = \dfrac{V_2}{\pi r^2} = \dfrac{1.16 \text{ m}^3}{\pi(1.50 \text{ m})^2} = 0.164 \text{ m}$

so the height the water will rise inside the bell as it sinks to the bottom is

$$\Delta h = h_1 - h_2 = 4.00 \text{ m} - 0.164 \text{ m} = \boxed{3.84 \text{ m}}$$

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

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

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

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

10.36 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

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

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

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

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

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

10.38 (a) One mole of any gas contains Avogadro's number of molecules and the total random kinetic energy of these molecules at $T = 300$ K is

$$KE = N_A\left(\frac{3}{2}k_B T\right) = \frac{3}{2}RT = \frac{3}{2}\left(8.31 \ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(300 \text{ K}) = \boxed{3.74 \times 10^3 \text{ J/mol}}$$

(b) The mass of 1 mole of hydrogen is

$$m = nM = (1\text{ mol})(2.00\text{ g/mol}) = 2.00\times10^{-3}\text{ kg}$$

When this mass has a translational kinetic energy of $3.74\times10^{3}\text{ J}$, the speed is

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2\left(3.74\times10^{3}\text{ J}\right)}{2.00\times10^{-3}\text{ kg}}} = 1.93\times10^{3}\text{ m/s} = \boxed{1.93\text{ km/s}}$$

10.39 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, $M = 4.00\text{ g/mol} = 4.00\times10^{-3}\text{ kg/mol}$, and the mass of a helium molecule is

$$m = \frac{4.00\times10^{-3}\text{ kg/mol}}{6.02\times10^{23}\text{ molecule/mol}} = 6.64\times10^{-27}\text{ kg/molecule}$$

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

$$m_{atom} = \boxed{6.64\times10^{-27}\text{ kg}}$$

10.40 From $KE_{molecule} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}k_B T$

the rms speed of a molecule is $v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3k_B T}{m}}$

The mass of the molecule is $m = \frac{molar\ mass}{N_A} = \frac{M}{N_A}$

(a) For hydrogen (H_2), $m = \frac{2.00\times10^{-3}\text{ kg/mol}}{6.02\times10^{23}\text{ molecule/mol}} = 3.32\times10^{-27}\text{ kg}$

At $T = 240\text{ K}$, $\left(v_{rms}\right)_{H_2} = \sqrt{\frac{3\left(1.38\times10^{-23}\text{ J/K}\right)(240\text{ K})}{3.32\times10^{-27}\text{ kg}}} = \boxed{1.73\text{ km/s}}$

(b) For carbon dioxide, $m = \dfrac{44.0 \times 10^{-3}\ \text{kg/mol}}{6.02 \times 10^{23}\ \text{molecule/mol}} = 7.31 \times 10^{-26}\ \text{kg}$, and

at $T = 240\ \text{K}$, $\quad \left(v_{\text{rms}}\right)_{CO_2} = \sqrt{\dfrac{3\left(1.38 \times 10^{-23}\ \text{J/K}\right)\left(240\ \text{K}\right)}{7.31 \times 10^{-26}\ \text{kg}}} = \boxed{0.369\ \text{km/s}}$

(c) Since, on Venus, $\dfrac{v_{escape}}{6} = \dfrac{10.3\ \text{km/s}}{6} = 1.71\ \text{km/s}$, we should expect that $\boxed{\text{hydrogen will escape but carbon dioxide will not}}$. Indeed, it is found that carbon dioxide is the predominant component in the atmosphere of Venus and hydrogen is present only in combination with other elements.

10.41 (a) Since each gas is at temperature $T = 423\ \text{K}$, the average kinetic energy of a molecule in either gas is

$$KE_{molecule} = \frac{3}{2}k_{\text{B}}T = \frac{3}{2}\left(1.38 \times 10^{-23}\ \frac{\text{J}}{\text{K}}\right)\left(423\ \text{K}\right) = \boxed{8.76 \times 10^{-21}\ \text{J}}$$

(b) The rms speed of the molecules in a gas is $v_{\text{rms}} = \sqrt{\dfrac{2KE_{molecule}}{m}}$

For helium, $m = \dfrac{M}{N_{\text{A}}} = \dfrac{4.00 \times 10^{-3}\ \text{kg/mol}}{6.02 \times 10^{23}\ \text{molecules/mol}} = 6.64 \times 10^{-27}\ \text{kg}$

and $\quad v_{\text{rms, He}} = \sqrt{\dfrac{2\left(8.76 \times 10^{-21}\ \text{J}\right)}{6.64 \times 10^{-27}\ \text{kg}}} = \boxed{1.62\ \text{km/s}}$

For argon, $m = \dfrac{M}{N_{\text{A}}} = \dfrac{39.9 \times 10^{-3}\ \text{kg/mol}}{6.02 \times 10^{23}\ \text{molecules/mol}} = 6.63 \times 10^{-26}\ \text{kg}$,

and $\quad v_{\text{rms, Ar}} = \sqrt{\dfrac{2\left(8.76 \times 10^{-21}\ \text{J}\right)}{6.63 \times 10^{-26}\ \text{kg}}} = \boxed{514\ \text{m/s}}$

10.42 From the ideal gas law, the pressure the gas exerts will be

$$P = \frac{nRT}{V} = \frac{(3.00\ \text{mol})\left(8.31\ \text{J/mol}\cdot\text{K}\right)\left(300\ \text{K}\right)}{(22.4\ \text{L})\left(10^{-3}\ \text{m}^3/1\ \text{L}\right)} = \boxed{3.34 \times 10^{5}\ \text{Pa}}$$

10.43 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

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

$$= \frac{150\left(8.0\times10^{-3}\text{ kg}\right)\left[\left(400\text{ m/s}\right)-\left(-400\text{ m/s}\right)\right]}{60\text{ s}} = \boxed{16\text{ N}}$$

10.44 From the impulse-momentum theorem, the average force exerted on the wall is

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

$$F_{\text{av}} = \frac{\left(5.0\times10^{23}\right)\left(4.68\times10^{-26}\text{ kg}\right)\left[\left(300\text{ m/s}\right)-\left(-300\text{ m/s}\right)\right]}{1.0\text{ s}} = 14\text{ N}$$

The pressure on the wall is then

$$P = \frac{F_{\text{av}}}{A} = \frac{14\text{ N}}{8.0\text{ cm}^2}\left(\frac{10^4\text{ cm}^2}{1\text{ m}^2}\right) = 1.8\times10^4\text{ N/m}^2 = \boxed{18\text{ kPa}}$$

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

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

$$= \left[17\times10^{-6}\ (°\text{C})^{-1}\right]\left(28.0\text{ cm}\right)\left(28.5°\text{C}\right) = 1.36\times10^{-2}\text{ cm} = 0.136\text{ mm}$$

The expansion of the vertical section is

$$\Delta L_y = \alpha L_{0y}\left(\Delta T\right) = \left[17\times10^{-6}\ (°\text{C})^{-1}\right]\left(134\text{ cm}\right)\left(28.5°\text{C}\right) = 0.649\text{ mm}$$

The total displacement of the pipe elbow is

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

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

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

10.46 (a) $\Delta L = \alpha L_0(\Delta T) = \left[9.0\times10^{-6}\ (°\text{C})^{-1}\right](20\text{ cm})(75\text{ °C}) = \boxed{1.4\times10^{-2}\text{ cm}}$

(b) $\Delta D = \alpha D_0(\Delta T) = \left[9.0\times10^{-6}\ (°\text{C})^{-1}\right](1.0\text{ cm})(75\text{ °C}) = \boxed{6.8\times10^{-4}\text{ cm}}$

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

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

$$= 3\alpha V_0(\Delta T) = 3\left[9.0\times10^{-6}\ (°\text{C})^{-1}\right](16\text{ cm}^3)(75\text{ °C}) = \boxed{3.2\times10^{-2}\text{ cm}^3}$$

10.47 The number of moles of CO_2 present is $n = \frac{6.50\text{ g}}{44.0\text{ g/mol}} = 0.148\text{ mol}$. Thus, at the given temperature and pressure, the volume will be

$$V = \frac{nRT}{P} = \frac{(0.148\text{ mol})(8.31\text{ J/mol}\cdot\text{K})(293\text{ K})}{1.013\times10^5\text{ Pa}} = 3.55\times10^{-3}\text{ m}^3 = \boxed{3.55\text{ L}}$$

10.48 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

$$P_2 = \left(\frac{V_1}{V_2}\right)P_1 = \left(\frac{L_1}{L_2}\right)P_1 = \left(\frac{1.5\text{ m}}{0.40\text{ m}}\right)(1.013\times10^5\text{ Pa}) = 3.8\times10^5\text{ Pa}$$

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

$$h = \frac{P_2 - P_{atm}}{\rho g} = \frac{(3.8 - 1.013)\times10^5\text{ Pa}}{(10^3\text{ kg/m}^3)(9.80\text{ m/s}^2)} = \boxed{28\text{ m}}$$

10.49 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

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

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 $T = -45.0°\text{C} = 228 \text{ K}$, the pressure of the stored methane is

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

10.50 When gas the supports the piston in equilibrium, the gauge pressure of the gas is $P_{gauge} = \frac{F}{A} = \frac{mg}{A} = \frac{(5.0 \text{ kg})(9.80 \text{ m/s}^2)}{0.050 \text{ m}^2} = 9.8 \times 10^2 \text{ Pa}$, and the absolute pressure is $P = P_{atm} + P_{gauge} = (1.013 \times 10^5 + 9.8 \times 10^2) \text{ Pa}$

The ideal gas law gives the volume as $V = nRT/P$, so the height of the cylindrical space is

$$h = \frac{V}{A} = \frac{nRT}{P \cdot A} = \frac{(3.0 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{(1.013 \times 10^5 \text{ Pa} + 9.8 \times 10^2 \text{ Pa})(0.050 \text{ m}^2)} = \boxed{2.4 \text{ m}}$$

10.51 (a) The volume of the liquid expands by $\Delta V_{liquid} = \beta V_0 (\Delta T)$ and the volume of the glass flask expands by $\Delta V_{flask} = (3\alpha) V_0 (\Delta T)$. The amount of liquid that must overflow into the capillary is $V_{overflow} = \Delta V_{liquid} - \Delta V_{flask} = V_0 (\beta - 3\alpha)(\Delta T)$. The distance the liquid will rise into the capillary is then

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

(b) For a mercury thermometer, $\beta_{\text{Hg}} = 1.82 \times 10^{-4} \ (°\text{C})^{-1}$ and (assuming Pyrex glass), $3\alpha_{glass} = 3\left(3.2 \times 10^{-6} \ (°\text{C})^{-1}\right) = 9.6 \times 10^{-6} \ (°\text{C})^{-1}$. 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.

10.52 Both diameters are linear dimensions with expansions described by $L = L_0\left[1+\alpha(\Delta T)\right]$. For the cylinder to fit over the piston, it is necessary that its diameter be at least as large as that of the piston. Thus, we require that

$$\left(d_{cylinder}\right)_0\left[1+\alpha_{al}(\Delta T)\right] \geq \left(d_{piston}\right)_0\left[1+\alpha_{steel}(\Delta T)\right]$$

Since we know that $\left(d_{cylinder}\right)_0 = 0.99\left(d_{piston}\right)_0$, this reduces to

$$0.99\left[1+\alpha_{al}(\Delta T)\right] \geq 1+\alpha_{steel}(\Delta T), \text{ or } \left(0.99\,\alpha_{al}-\alpha_{steel}\right)(\Delta T) \geq 1-0.99$$

This yields $\Delta T \geq \dfrac{1-0.99}{\left[0.99(24)-11\right]\times 10^{-6}\ (^\circ\text{C})^{-1}} = 7.8\times 10^{2}\ ^\circ\text{C}$, and

$$T = T_0 + \Delta T \geq 20^\circ\text{C} + 7.8\times 10^{2}\ ^\circ\text{C} = \boxed{8.0\times 10^{2}\ ^\circ\text{C}}$$

10.53 The expansion in a 1.1-m length of steel tape as the temperature rises from 20°C to 25°C is

$$\Delta L = \alpha L_0(\Delta T) = \left[11\times 10^{-6}\ (^\circ\text{C})^{-1}\right](1.1\text{ m})(5.0^\circ\text{C}) = 6.1\times 10^{-5}\text{ m}=0.061\text{ mm}$$

Thus, at 25°C, the child fails to reach the 1.1-m mark by 0.061 mm, or the new tape reading is $\boxed{\text{shorter by 0.061 mm}}$.

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

$$P_1 = P_{atm} + \left(P_1\right)_{gauge} = 1.00\text{ atm} + 1.80\text{ atm} = 2.80\text{ atm}$$

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

The ideal gas law, with volume constant, gives

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

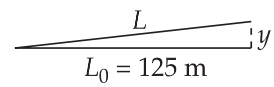
(b) When the quantity of gas varies, while volume and temperature are constant, the ideal gas law gives $\frac{n_3}{n_2} = \frac{P_3}{P_2}$. Thus, when air is released to lower the absolute pressure back to 2.80 atm, we have

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

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

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

10.55 After expansion, the increase in the length of one span is



$$\Delta L = \alpha L_{.0}(\Delta T)$$

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

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

From the Pythagorean theorem,

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

10.56 For the difference in lengths, $D = L_{steel} - L_{copper}$, to remain constant, the expansions of the two rods must always be equal, or

$$\alpha_{steel} L_{steel}(\Delta T) = \alpha_{copper} L_{copper}(\Delta T) \text{, giving } L_{copper} = \left(\frac{\alpha_{steel}}{\alpha_{copper}}\right) L_{steel}$$

Thus, $D = L_{steel} - \left(\frac{\alpha_{steel}}{\alpha_{copper}}\right) L_{steel}$, or

$$L_{steel} = \frac{D}{1 - \left(\frac{\alpha_{steel}}{\alpha_{copper}}\right)} = \frac{5.00 \text{ cm}}{1\text{-}\frac{11}{17}} = \boxed{14.2 \text{ cm}}$$

Then, $L_{copper} = L_{steel} - D = 14.2 \text{ cm} - 5.00 \text{ cm} = \boxed{9.2 \text{ cm}}$

10.57 The number of moles of water present is $n = \dfrac{m}{M} = \dfrac{9.00\text{ g}}{18.0\text{ g}} = 0.500\text{ mol}$, so the ideal gas law gives

$$P = \frac{nRT}{V} = \frac{(0.500\text{ mol})(8.31\text{ J/mol}\cdot\text{K})(773\text{ K})}{2.00\times10^{-3}\text{ m}^3} = 1.61\times10^{6}\text{ Pa} = \boxed{1.61\text{ MPa}}$$

10.58 (a) From the ideal gas law, $\dfrac{P_2V_2}{T_2} = \dfrac{P_1V_1}{T_1}$, 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:

$$P_1 = 1\text{ atm},\ V_1 = 5.00\text{ L} = 5.00\times10^{-3}\text{ m}^3,\text{ and } T_1 = 20.0°\text{C} = 293\text{ K}$$

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

or $\left(1 + \dfrac{(2.00\times10^{3}\text{ N/m})\cdot h}{(0.0100\text{ m}^2)(1.013\times10^{5}\text{ N/m}^2)}\right)\left(1 + \dfrac{(0.0100\text{ m}^2)\cdot h}{(5.00\times10^{-3}\text{ m}^3)}\right) = \left(\dfrac{523}{293}\right)$

Simplifying and using the quadratic formula yields

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

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

$$= 1.013\times10^{5}\text{ Pa} + \frac{(2.00\times10^{3}\text{ N/m})(0.169\text{ m})}{0.0100\text{ m}^2} = \boxed{1.35\times10^{5}\text{ Pa}}$$

10.59 We assume the temperature of the air in the lungs is constant at body temperature throughout. Then, the ideal gas law gives $V_2 = \left(\frac{P_1}{P_2}\right) V_1$, where

$$P_1 = 0.95(1 \text{ atm}),\ V_1 = 0.820 \text{ L, and } P_2 = 0.95\left(P_{atm} + \rho g h\right)$$

$$P_2 = 0.95\left[1.013\times10^5 \text{ Pa} + \left(10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)(10.0 \text{ m})\right] = 0.95\left(1.99\times10^5 \text{ Pa}\right)$$

Thus, $$V_2 = \left[\frac{0.95\left(1.013\times10^5 \text{ Pa}\right)}{0.95\left(1.99\times10^5 \text{ Pa}\right)}\right](0.820 \text{ L}) = \boxed{0.417 \text{ L}}$$

10.60 Let container 1 be maintained at $T_1 = T_0 = 0°\text{C} = 273 \text{ K}$, while the temperature of container 2 is raised to $T_2 = 100°\text{C} = 373 \text{ K}$. 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 $$n_2 + n_1 = (n_0)_2 + (n_0)_1 \tag{1}$$

From the ideal gas law, $n = \frac{PV}{RT}$, so equation (1) becomes

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

Thus,

$$P = \frac{2P_0}{T_0}\left(\frac{T_1T_2}{T_1 + T_2}\right) = \frac{2(1.00 \text{ atm})}{273}\left(\frac{273\cdot 373}{273 + 373}\right) = \boxed{1.15 \text{ atm}}$$

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

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

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, $\Delta r = r_2 - r_1 = \dfrac{L_2}{\theta} - \dfrac{L_1}{\theta} = \dfrac{(\alpha_2-\alpha_1)L_0(\Delta T)}{\theta}$, or $\boxed{\theta = \dfrac{(\alpha_2-\alpha_1)L_0(\Delta T)}{\Delta r}}$

(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 $\Delta T = 20°\text{C}$, the increase in length would be

$$\Delta L = \alpha L_0(\Delta T) = \left(12\times10^{-6}\ °\text{C}^{-1}\right)(250\text{ m})(20°\text{C}) = 6.0\times10^{-2}\text{ m} = \boxed{6.0\text{ cm}}$$

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

$$Y = Stress/Strain = Stress/(\Delta L/L)$$

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 $\Delta T = 20°\text{C}$, the stress in the specified bridge would be

$$Stress = \alpha Y(\Delta T) = \left(12\times10^{-6}\ °\text{C}^{-1}\right)\left(2.0\times10^{10}\text{ Pa}\right)(20°\text{C}) = \boxed{4.8\times10^{6}\text{ Pa}}$$

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 Assume that you fill a 10-gallon container with gasoline when the temperature is 20°C. When the temperature decreases to 0°C, your container will not be full because your gasoline has undergone a decrease in volume of

$$|\Delta V| = \beta V_0 |\Delta T| = \left(9.6\times10^{-4}\ {}^\circ\mathrm{C}^{-1}\right)(10\ \mathrm{gallon})(20^\circ\mathrm{C}) = 0.19\ \mathrm{gallon}$$

Had you purchased the gasoline when the temperature was 0°C, you would have gotten a full 10 gallons, or 0.19 gallons more than you now have. The increased mass of the gasoline in your container would have been

$$\Delta m = \rho(\Delta V) = \left(730\ \frac{\mathrm{kg}}{\mathrm{m}^3}\right)\left[(0.19\ \mathrm{gal})\left(\frac{3.786\ \mathrm{L}}{1\ \mathrm{gal}}\right)\left(\frac{10^{-3}\ \mathrm{m}^3}{1\ \mathrm{L}}\right)\right] = \boxed{0.53\ \mathrm{kg}}$$