The horizontal section expands according to
\[ \Delta L = \alpha L \Delta T. \]
\[ \Delta x = \left( 17 \times 10^{-6} \text{°C}^{-1} \right) \left( 28 \text{ cm} \right) \left( 46.5 \text{°C} - 18 \text{°C} \right) = 1.36 \times 10^{-2} \text{ cm} \]

The vertical section expands similarly by
\[ \Delta y = \left( 17 \times 10^{-6} \text{°C}^{-1} \right) \left( 134 \text{ cm} \right) \left( 28.5 \text{°C} \right) = 6.49 \times 10^{-2} \text{ cm} . \]

The vector displacement of the pipe elbow has magnitude
\[ \Delta r = \sqrt{\Delta x^2 + \Delta y^2} = \sqrt{\left(0.136 \text{ m m} \right)^2 + \left(0.649 \text{ m m} \right)^2} = 0.663 \text{ m m} \]
and is directed to the right below the horizontal at angle
\[ \theta = \arctan \left( \frac{\Delta y}{\Delta x} \right) = \arctan \left( \frac{0.649 \text{ m m}}{0.136 \text{ m m}} \right) = 78.2^\circ \]
\[ \Delta r = 0.663 \text{ m m to the right at 78.2° below the horizontal} \]

P19.15 (a) \[ I_{A1} (1 + \alpha_A \Delta T) = I_{B\text{max}} (1 + \alpha_B \Delta T) \]
\[ \Delta T = \frac{I_{A1} - I_{B\text{max}}}{I_{B\text{max}} \alpha_B - I_A \alpha_A} \]
\[ \Delta T = \frac{10 \Delta 1 - 10 \Delta 0}{10 \Delta 0 \left( 19 \Delta \times 10^{-6} \right) - (10 \Delta 1) \left( 24 \Delta \times 10^{-6} \right)} \]
\[ \Delta T = -199^\circ C \text{ so } T = -179^\circ C \text{. This is attainable.} \]

(b) \[ \Delta T = \frac{10 \Delta 02 - 10 \Delta 0}{10 \Delta 0 \left( 19 \Delta \times 10^{-6} \right) - (10 \Delta 2) \left( 24 \Delta \times 10^{-6} \right)} \]
\[ \Delta T = -396^\circ C \text{ so } T = -376^\circ C \text{ which is below 0 K so it cannot be reached.} \]
P19.22

The volume of the sphere is

$$V_{\text{Pb}} = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (2 \text{ cm})^3 = 33.5 \text{ cm}^3.$$ 

The amount of mercury overflowing is

$$\text{overflow} = \Delta V_{\text{Hg}} + \Delta V_{\text{Pb}} - \Delta V_{\text{glass}} = \left( \beta_{\text{Hg}} V_{\text{Hg}} + \beta_{\text{Pb}} V_{\text{Pb}} - \beta_{\text{glass}} V_{\text{glass}} \right) \Delta T$$

where $V_{\text{glass}} = V_{\text{Hg}} + V_{\text{Pb}}$ is the initial volume. Then

$$\text{overflow} = \left( \beta_{\text{Hg}} - \beta_{\text{glass}} \right) V_{\text{Hg}} + \left( \beta_{\text{Pb}} - \beta_{\text{glass}} \right) V_{\text{Pb}} \Delta T = \left( \beta_{\text{Hg}} - 3 \alpha_{\text{glass}} \right) V_{\text{Hg}} + \left( 3 \alpha_{\text{Pb}} - 3 \alpha_{\text{glass}} \right) V_{\text{Pb}} \Delta T$$

$$= \left[ (182 - 27) \times 10^{-6} \frac{1}{\text{C}^2} 118 \text{ cm}^3 + (87 - 27) \times 10^{-6} \frac{1}{\text{C}^2} 33.5 \text{ cm}^3 \right] \Delta T$$

$$= \left[ 100 \times 10^{-6} \frac{1}{\text{C}^2} 150 \text{ cm}^3 \right] \Delta T$$

$$= 100 \times 10^{-6} \frac{1}{\text{C}^2} 150 \text{ cm}^3 \times 40^\circ C = 0.812 \text{ cm}^3$$

P19.29

The equation of state of an ideal gas is $PV = nRT$ so we need to solve for the number of moles to find $N$.

$$n = \frac{PV}{RT} = \frac{\left( 1.01 \times 10^5 \text{ N/m}^2 \right) \left( (10.0 \text{ m})(20.0 \text{ m})(30.0 \text{ m}) \right)}{8.314 \text{ J/m} \cdot \text{mol} \cdot \text{K}(293 \text{ K})} = 2.49 \times 10^5 \text{ mol}$$

$$n = nN_A = 2.49 \times 10^5 \text{ mol} \left( 6.022 \times 10^{23} \text{ molecules/mol} \right) = 1.50 \times 10^{29} \text{ molecules}$$

P19.33

$$\sum F_y = 0: \quad \rho_{\text{out}} g V - \rho_n g V - (200 \text{ kg}) g = 0$$

$$(\rho_{\text{out}} - \rho_n)(400 \text{ m}^3) = 200 \text{ kg}$$

The density of the air outside is $1.25 \text{ kg/m}^3$.

From $PV = nRT$, $\frac{n}{V} = \frac{P}{RT}$

The density is inversely proportional to the temperature, and the density of the hot air is

$$\rho_n = \left( 1.25 \text{ kg/m}^3 \right) \left( \frac{283 \text{ K}}{T_n} \right)$$

Then

$$\left( 1.25 \text{ kg/m}^3 \right) \left( 1 - \frac{283 \text{ K}}{T_n} \right) \left( 400 \text{ m}^3 \right) = 200 \text{ kg}$$

$$1 - \frac{283 \text{ K}}{T_n} = 0.400$$

$$0.600 = \frac{283 \text{ K}}{T_n} \quad T_n = 472 \text{ K}$$
P19.45 The excess expansion of the brass is \[ \Delta L_{\text{rod}} - \Delta L_{\text{tape}} = (\alpha_{\text{brass}} - \alpha_{\text{steel}}) L \Delta T \]

\[ \Delta(\Delta L) = (19.0 - 11.0) \times 10^{-6} \ (°C)^{-1} (0.950 \ m) (35 \ °C) \]
\[ \Delta(\Delta L) = 2.66 \times 10^{-4} \ m \]

(a) The rod contracts more than tape to a length reading 0.950 m - 0.000 266 m = \boxed{0.9497 \ m} 

(b) 0.950 m + 0.000 266 m = \boxed{0.9503 \ m} 

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