

19

Temperature

CHAPTER OUTLINE

- 19.1 Temperature and the Zeroth Law of Thermodynamics
- 19.2 Thermometers and the Celsius Temperature Scale
- 19.3 The Constant-Volume Gas Thermometer and the Absolute Temperature Scale
- 19.4 Thermal Expansion of Solids and Liquids
- 19.5 Macroscopic Description of an Ideal Gas

ANSWERS TO QUESTIONS

- Q19.1** Two objects in thermal equilibrium need not be in contact. Consider the two objects that are in thermal equilibrium in Figure 19.1(c). The act of separating them by a small distance does not affect how the molecules are moving inside either object, so they will still be in thermal equilibrium.
- Q19.2** The copper's temperature drops and the water temperature rises until both temperatures are the same. Then the metal and the water are in thermal equilibrium.
- Q19.3** The astronaut is referring to the temperature of the lunar surface, specifically a 400°F difference. A thermometer would register the temperature of the thermometer liquid. Since there is no atmosphere in the moon, the thermometer will not read a realistic temperature unless it is placed into the lunar soil.
- Q19.4** Rubber contracts when it is warmed.
- Q19.5** Thermal expansion of the glass bulb occurs first, since the wall of the bulb is in direct contact with the hot water. Then the mercury heats up, and it expands.
- Q19.6** If the amalgam had a larger coefficient of expansion than your tooth, it would expand more than the cavity in your tooth when you take a sip of your ever-beloved coffee, resulting in a broken or cracked tooth! As you ice down your now excruciatingly painful broken tooth, the amalgam would contract more than the cavity in your tooth and fall out, leaving the nerve roots exposed. Isn't it nice that your dentist knows thermodynamics?
- Q19.7** The measurements made with the heated steel tape will be too short—but only by a factor of 5×10^{-5} of the measured length.
- Q19.8**
- (a) One mole of H_2 has a mass of 2.016 0 g.
 - (b) One mole of He has a mass of 4.002 6 g.
 - (c) One mole of CO has a mass of 28.010 g.
- Q19.9** The ideal gas law, $PV = nRT$ predicts zero volume at absolute zero. This is incorrect because the ideal gas law cannot work all the way down to or below the temperature at which gas turns to liquid, or in the case of CO_2 , a solid.

- Q19.10** Call the process isobaric cooling or isobaric contraction. The rubber wall is easy to stretch. The air inside is nearly at atmospheric pressure originally and stays at atmospheric pressure as the wall moves in, just maintaining equality of pressure outside and inside. The air is nearly an ideal gas to start with, but $PV = nRT$ soon fails. Volume will drop by a larger factor than temperature as the water vapor liquefies and then freezes, as the carbon dioxide turns to snow, as the argon turns to slush, and as the oxygen liquefies. From the outside, you see contraction to a small fraction of the original volume.
- Q19.11** Cylinder A must be at lower pressure. If the gas is thin, it will be at one-third the absolute pressure of B.
- Q19.12** 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.
- Q19.13** (a) The water level in the cave rises by a smaller distance than the water outside, as the trapped air is compressed. Air can escape from the cave if the rock is not completely airtight, and also by dissolving in the water.
- (b) The ideal cave stays completely full of water at low tide. The water in the cave is supported by atmospheric pressure on the free water surface outside.

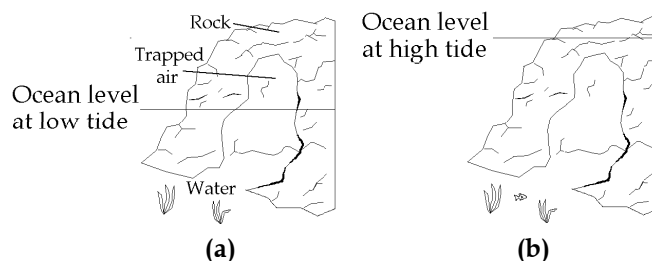


FIG. Q19.13

- Q19.14** Absolute zero is a natural choice for the zero of a temperature scale. If an alien race had bodies that were mostly liquid water—or if they just liked its taste or its cleaning properties—it is conceivable that they might place one hundred degrees between its freezing and boiling points. It is very unlikely, on the other hand, that these would be our familiar “normal” ice and steam points, because atmospheric pressure would surely be different where the aliens come from.
- Q19.15** As the temperature increases, the brass expands. This would effectively increase the distance, d , from the pivot point to the center of mass of the pendulum, and also increase the moment of inertia of the pendulum. Since the moment of inertia is proportional to d^2 , and the period of a physical pendulum is $T = 2\pi \sqrt{\frac{I}{mgd}}$, the period would increase, and the clock would run slow.
- Q19.16** As the water rises in temperature, it expands. The excess volume would spill out of the cooling system. Modern cooling systems have an overflow reservoir to take up excess volume when the coolant heats up and expands.
- Q19.17** The coefficient of expansion of metal is larger than that of glass. When hot water is run over the jar, both the glass and the lid expand, but at different rates. Since *all* dimensions expand, there will be a certain temperature at which the inner diameter of the lid has expanded more than the top of the jar, and the lid will be easier to remove.

- Q19.18** The sphere expands when heated, so that it no longer fits through the ring. With the sphere still hot, you can separate the sphere and ring by heating the ring. This more surprising result occurs because the thermal expansion of the ring is not like the inflation of a blood-pressure cuff. Rather, it is like a photographic enlargement; every linear dimension, including the hole diameter, increases by the same factor. The reason for this is that the atoms everywhere, including those around the inner circumference, push away from each other. The only way that the atoms can accommodate the greater distances is for the circumference—and corresponding diameter—to grow. This property was once used to fit metal rims to wooden wagon and horse-buggy wheels. If the ring is heated and the sphere left at room temperature, the sphere would pass through the ring with more space to spare.

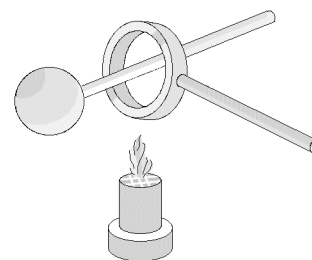


FIG. Q19.18

SOLUTIONS TO PROBLEMS

Section 19.1 Temperature and the Zeroth Law of Thermodynamics

No problems in this section

Section 19.2 Thermometers and the Celsius Temperature Scale

Section 19.3 The Constant-Volume Gas Thermometer and the Absolute Temperature Scale

- P19.1** Since we have a linear graph, the pressure is related to the temperature as $P = A + BT$, where A and B are constants. To find A and B , we use the data

$$0.900 \text{ atm} = A + (-80.0^\circ\text{C})B \quad (1)$$

$$1.635 \text{ atm} = A + (78.0^\circ\text{C})B \quad (2)$$

Solving (1) and (2) simultaneously,

we find $A = 1.272 \text{ atm}$

and $B = 4.652 \times 10^{-3} \text{ atm}/^\circ\text{C}$

Therefore, $P = 1.272 \text{ atm} + (4.652 \times 10^{-3} \text{ atm}/^\circ\text{C})T$

(a) At absolute zero $P = 0 = 1.272 \text{ atm} + (4.652 \times 10^{-3} \text{ atm}/^\circ\text{C})T$

which gives $T = -274^\circ\text{C}$.

(b) At the freezing point of water $P = 1.272 \text{ atm} + 0 = 1.27 \text{ atm}$.

(c) And at the boiling point $P = 1.272 \text{ atm} + (4.652 \times 10^{-3} \text{ atm}/^\circ\text{C})(100^\circ\text{C}) = 1.74 \text{ atm}$.

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P19.2 $P_1V = nRT_1$

and $P_2V = nRT_2$

imply that $\frac{P_2}{P_1} = \frac{T_2}{T_1}$

(a) $P_2 = \frac{P_1 T_2}{T_1} = \frac{(0.980 \text{ atm})(273 \text{ K} + 45.0 \text{ K})}{(273 + 20.0) \text{ K}} = \boxed{1.06 \text{ atm}}$

(b) $T_3 = \frac{T_1 P_3}{P_1} = \frac{(293 \text{ K})(0.500 \text{ atm})}{0.980 \text{ atm}} = 149 \text{ K} = \boxed{-124^\circ \text{C}}$

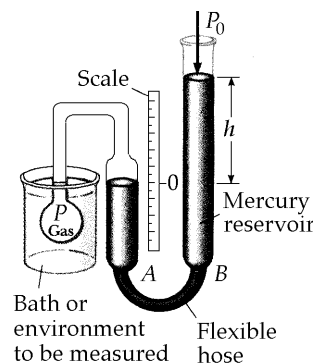


FIG. P19.2

P19.3 (a) $T_F = \frac{9}{5}T_C + 32.0^\circ \text{F} = \frac{9}{5}(-195.81) + 32.0 = \boxed{-320^\circ \text{F}}$

(b) $T = T_C + 273.15 = -195.81 + 273.15 = \boxed{77.3 \text{ K}}$

P19.4 (a) To convert from Fahrenheit to Celsius, we use $T_C = \frac{5}{9}(T_F - 32.0) = \frac{5}{9}(98.6 - 32.0) = \boxed{37.0^\circ \text{C}}$

and the Kelvin temperature is found as $T = T_C + 273 = \boxed{310 \text{ K}}$

(b) In a fashion identical to that used in (a), we find $T_C = \boxed{-20.6^\circ \text{C}}$

and $T = \boxed{253 \text{ K}}$

P19.5 (a) $\Delta T = 450^\circ \text{C} = 450^\circ \text{C} \left(\frac{212^\circ \text{F} - 32.0^\circ \text{F}}{100^\circ \text{C} - 0.00^\circ \text{C}} \right) = \boxed{810^\circ \text{F}}$

(b) $\Delta T = 450^\circ \text{C} = \boxed{450 \text{ K}}$

P19.6 Require $0.00^\circ \text{C} = a(-15.0^\circ \text{S}) + b$

$100^\circ \text{C} = a(60.0^\circ \text{S}) + b$

Subtracting, $100^\circ \text{C} = a(75.0^\circ \text{S})$

$a = 1.33 \text{ } ^\circ \text{C}/^\circ \text{S}.$

Then $0.00^\circ \text{C} = 1.33(-15.0^\circ \text{S}) + b$

$b = 20.0^\circ \text{C}.$

So the conversion is $T_C = (1.33 \text{ } ^\circ \text{C}/^\circ \text{S})T_S + 20.0^\circ \text{C}.$

P19.7 (a) $T = 1064 + 273 = \boxed{1337 \text{ K}}$ melting point

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

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

Section 19.4 Thermal Expansion of Solids and Liquids

P19.8 $\alpha = 1.10 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}$ for steel

$$\Delta L = 518 \text{ m} (1.10 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}) [35.0^\circ\text{C} - (-20.0^\circ\text{C})] = \boxed{0.313 \text{ m}}$$

P19.9 The wire is 35.0 m long when $T_C = -20.0^\circ\text{C}$.

$$\Delta L = L_i \bar{\alpha} (T - T_i)$$

$$\bar{\alpha} = \alpha (20.0^\circ\text{C}) = 1.70 \times 10^{-5} \text{ (} ^\circ\text{C)}^{-1} \text{ for Cu.}$$

$$\Delta L = (35.0 \text{ m}) (1.70 \times 10^{-5} \text{ (} ^\circ\text{C)}^{-1}) (35.0^\circ\text{C} - (-20.0^\circ\text{C})) = \boxed{+3.27 \text{ cm}}$$

P19.10 $\Delta L = L_i \alpha \Delta T = (25.0 \text{ m}) (12.0 \times 10^{-6} / ^\circ\text{C}) (40.0^\circ\text{C}) = \boxed{1.20 \text{ cm}}$

P19.11 For the dimensions to increase, $\Delta L = \alpha L_i \Delta T$

$$1.00 \times 10^{-2} \text{ cm} = 1.30 \times 10^{-4} \text{ } ^\circ\text{C}^{-1} (2.20 \text{ cm}) (T - 20.0^\circ\text{C})$$

$$T = \boxed{55.0^\circ\text{C}}$$

***P19.12** $\Delta L = \alpha L_i \Delta T = (22 \times 10^{-6} / ^\circ\text{C}) (2.40 \text{ cm}) (30^\circ\text{C}) = \boxed{1.58 \times 10^{-3} \text{ cm}}$

P19.13 (a) $\Delta L = \alpha L_i \Delta T = 9.00 \times 10^{-6} \text{ } ^\circ\text{C}^{-1} (30.0 \text{ cm}) (65.0^\circ\text{C}) = \boxed{0.176 \text{ mm}}$

(b) $\Delta L = \alpha L_i \Delta T = 9.00 \times 10^{-6} \text{ } ^\circ\text{C}^{-1} (1.50 \text{ cm}) (65.0^\circ\text{C}) = \boxed{8.78 \times 10^{-4} \text{ cm}}$

(c) $\Delta V = 3\alpha V_i \Delta T = 3 (9.00 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}) \left(\frac{30.0(\pi)(1.50)^2}{4} \text{ cm}^3 \right) (65.0^\circ\text{C}) = \boxed{0.0930 \text{ cm}^3}$

***P19.14** The horizontal section expands according to $\Delta L = \alpha L_i \Delta T$.

$$\Delta x = (17 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}) (28.0 \text{ cm}) (46.5^\circ\text{C} - 18.0^\circ\text{C}) = 1.36 \times 10^{-2} \text{ cm}$$

The vertical section expands similarly by

$$\Delta y = (17 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}) (134 \text{ cm}) (28.5^\circ\text{C}) = 6.49 \times 10^{-2} \text{ cm}.$$

The vector displacement of the pipe elbow has magnitude

$$\Delta r = \sqrt{\Delta x^2 + \Delta y^2} = \sqrt{(0.136 \text{ mm})^2 + (0.649 \text{ mm})^2} = 0.663 \text{ mm}$$

and is directed to the right below the horizontal at angle

$$\theta = \tan^{-1} \left(\frac{\Delta y}{\Delta x} \right) = \tan^{-1} \left(\frac{0.649 \text{ mm}}{0.136 \text{ mm}} \right) = 78.2^\circ$$

$$\boxed{\Delta r = 0.663 \text{ mm to the right at } 78.2^\circ \text{ below the horizontal}}$$

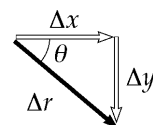


FIG. P19.14

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P19.15 (a) $L_{\text{Al}}(1 + \alpha_{\text{Al}}\Delta T) = L_{\text{Brass}}(1 + \alpha_{\text{Brass}}\Delta T)$

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

$$\Delta T = \frac{(10.01 - 10.00)}{(10.00)(19.0 \times 10^{-6}) - (10.01)(24.0 \times 10^{-6})}$$

$$\Delta T = -199^\circ\text{C} \text{ so } T = \boxed{-179^\circ\text{C. This is attainable.}}$$

(b)
$$\Delta T = \frac{(10.02 - 10.00)}{(10.00)(19.0 \times 10^{-6}) - (10.02)(24.0 \times 10^{-6})}$$

$$\Delta T = -396^\circ\text{C} \text{ so } T = \boxed{-376^\circ\text{C which is below 0 K so it cannot be reached.}}$$

P19.16 (a) $\Delta A = 2\alpha A_i \Delta T$: $\Delta A = 2(17.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1})(0.080 \text{ m})^2 (50.0^\circ\text{C})$

$$\Delta A = 1.09 \times 10^{-5} \text{ m}^2 = \boxed{0.109 \text{ cm}^2}$$

(b) The length of each side of the hole has increased. Thus, this represents an increase in the area of the hole.

P19.17 $\Delta V = (\beta - 3\alpha)V_i\Delta T = (5.81 \times 10^{-4} - 3(11.0 \times 10^{-6}))(50.0 \text{ gal})(20.0) = \boxed{0.548 \text{ gal}}$

P19.18 (a) $L = L_i(1 + \alpha\Delta T)$: $5.050 \text{ cm} = 5.000 \text{ cm}[1 + 24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1}(T - 20.0^\circ\text{C})]$

$$T = \boxed{437^\circ\text{C}}$$

(b) We must get $L_{\text{Al}} = L_{\text{Brass}}$ for some ΔT , or

$$L_{i, \text{Al}}(1 + \alpha_{\text{Al}}\Delta T) = L_{i, \text{Brass}}(1 + \alpha_{\text{Brass}}\Delta T)$$

$$5.000 \text{ cm}[1 + (24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1})\Delta T] = 5.050 \text{ cm}[1 + (19.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1})\Delta T]$$

Solving for ΔT , $\Delta T = 2080^\circ\text{C}$,

so $T = \boxed{3000^\circ\text{C}}$

This will not work because aluminum melts at 660°C .

P19.19 (a) $V_f = V_i(1 + \beta\Delta T) = 100[1 + 1.50 \times 10^{-4}(-15.0)] = \boxed{99.8 \text{ mL}}$

(b) $\Delta V_{\text{acetone}} = (\beta V_i \Delta T)_{\text{acetone}}$

$$\Delta V_{\text{flask}} = (\beta V_i \Delta T)_{\text{Pyrex}} = (3\alpha V_i \Delta T)_{\text{Pyrex}}$$

for same V_i , ΔT ,

$$\frac{\Delta V_{\text{acetone}}}{\Delta V_{\text{flask}}} = \frac{\beta_{\text{acetone}}}{\beta_{\text{flask}}} = \frac{1.50 \times 10^{-4}}{3(3.20 \times 10^{-6})} = \frac{1}{6.40 \times 10^{-2}}$$

The volume change of flask is

$$\boxed{\text{about } 6\% \text{ of the change in the acetone's volume}}.$$

P19.20 (a),(b) The material would expand by $\Delta L = \alpha L_i \Delta T$,

$$\begin{aligned}\frac{\Delta L}{L_i} &= \alpha \Delta T, \text{ but instead feels stress} \\ \frac{F}{A} &= \frac{Y \Delta L}{L_i} = Y \alpha \Delta T = (7.00 \times 10^9 \text{ N/m}^2) 12.0 \times 10^{-6} (\text{C}^\circ)^{-1} (30.0^\circ \text{C}) \\ &= \boxed{2.52 \times 10^6 \text{ N/m}^2}. \text{ This will } \boxed{\text{not break}} \text{ concrete.}\end{aligned}$$

P19.21 (a) $\Delta V = V_i \beta_i \Delta T - V_{\text{Al}} \beta_{\text{Al}} \Delta T = (\beta_i - 3\alpha_{\text{Al}}) V_i \Delta T$

$$= (9.00 \times 10^{-4} - 0.720 \times 10^{-4})^\circ \text{C}^{-1} (2000 \text{ cm}^3) (60.0^\circ \text{C})$$

$\Delta V = \boxed{99.4 \text{ cm}^3}$ overflows.

(b) The whole new volume of turpentine is

$$2000 \text{ cm}^3 + 9.00 \times 10^{-4}^\circ \text{C}^{-1} (2000 \text{ cm}^3) (60.0^\circ \text{C}) = 2108 \text{ cm}^3$$

so the fraction lost is $\frac{99.4 \text{ cm}^3}{2108 \text{ cm}^3} = 4.71 \times 10^{-2}$

and this fraction of the cylinder's depth will be empty upon cooling:

$$4.71 \times 10^{-2} (20.0 \text{ cm}) = \boxed{0.943 \text{ cm}}.$$

***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

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

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

$$\begin{aligned}\text{overflow} &= [(\beta_{\text{Hg}} - \beta_{\text{glass}}) V_{\text{Hg}} + (\beta_{\text{Pb}} - \beta_{\text{glass}}) V_{\text{Pb}}] \Delta T = [(\beta_{\text{Hg}} - 3\alpha_{\text{glass}}) V_{\text{Hg}} + (3\alpha_{\text{Pb}} - 3\alpha_{\text{glass}}) V_{\text{Pb}}] \Delta T \\ &= \left[(182 - 27) 10^{-6} \frac{1}{\text{C}^\circ} 118 \text{ cm}^3 + (87 - 27) 10^{-6} \frac{1}{\text{C}^\circ} 33.5 \text{ cm}^3 \right] 40^\circ \text{C} = \boxed{0.812 \text{ cm}^3}\end{aligned}$$

P19.23 In $\frac{F}{A} = \frac{Y \Delta L}{L_i}$ require $\Delta L = \alpha L_i \Delta T$

$$\frac{F}{A} = Y \alpha \Delta T$$

$$\Delta T = \frac{F}{A Y \alpha} = \frac{500 \text{ N}}{(2.00 \times 10^{-4} \text{ m}^2) (20.0 \times 10^{10} \text{ N/m}^2) (11.0 \times 10^{-6} / \text{C}^\circ)}$$

$$\Delta T = \boxed{1.14^\circ \text{C}}$$

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***P19.24** Model the wire as contracting according to $\Delta L = \alpha L_i \Delta T$ and then stretching according to

$$\text{stress} = \frac{F}{A} = Y \frac{\Delta L}{L_i} = \frac{Y}{L_i} \alpha L_i \Delta T = Y \alpha \Delta T.$$

$$(a) \quad F = Y A \alpha \Delta T = (20 \times 10^{10} \text{ N/m}^2) 4 \times 10^{-6} \text{ m}^2 11 \times 10^{-6} \frac{1}{\text{C}^\circ} 45^\circ \text{C} = \boxed{396 \text{ N}}$$

$$(b) \quad \Delta T = \frac{\text{stress}}{Y \alpha} = \frac{3 \times 10^8 \text{ N/m}^2}{(20 \times 10^{10} \text{ N/m}^2) 11 \times 10^{-6} / \text{C}^\circ} = 136^\circ \text{C}$$

$$\text{To increase the stress the temperature must decrease to } 35^\circ \text{C} - 136^\circ \text{C} = \boxed{-101^\circ \text{C}}.$$

(c) The original length divides out, so the answers would not change.

***P19.25** The area of the chip decreases according to $\Delta A = \gamma A_i \Delta T = A_f - A_i$

$$A_f = A_i(1 + \gamma \Delta T) = A_i(1 + 2\alpha \Delta T)$$

The star images are scattered uniformly, so the number N of stars that fit is proportional to the area.

$$\text{Then } N_f = N_i(1 + 2\alpha \Delta T) = 5\,342 \left[1 + 2(4.68 \times 10^{-6} \text{ }^\circ \text{C}^{-1})(-100^\circ \text{C} - 20^\circ \text{C}) \right] = \boxed{5\,336 \text{ star images}}.$$

Section 19.5 Macroscopic Description of an Ideal Gas

$$\text{P19.26 (a)} \quad n = \frac{PV}{RT} = \frac{(9.00 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm})(8.00 \times 10^{-3} \text{ m}^3)}{(8.314 \text{ N} \cdot \text{mol K})(293 \text{ K})} = \boxed{2.99 \text{ mol}}$$

$$(b) \quad N = nN_A = (2.99 \text{ mol})(6.02 \times 10^{23} \text{ molecules/mol}) = \boxed{1.80 \times 10^{24} \text{ molecules}}$$

$$\begin{array}{ll} \text{P19.27 (a)} & \text{Initially, } P_i V_i = n_i R T_i \quad (1.00 \text{ atm}) V_i = n_i R (10.0 + 273.15) \text{ K} \\ & \text{Finally, } P_f V_f = n_f R T_f \quad P_f (0.280 V_i) = n_i R (40.0 + 273.15) \text{ K} \\ & \text{Dividing these equations,} \quad \frac{0.280 P_f}{1.00 \text{ atm}} = \frac{313.15 \text{ K}}{283.15 \text{ K}} \\ & \text{giving} \quad P_f = 3.95 \text{ atm} \\ & \text{or} \quad P_f = \boxed{4.00 \times 10^5 \text{ Pa(abs.)}}. \end{array}$$

$$(b) \quad \text{After being driven} \quad P_d (1.02)(0.280 V_i) = n_i R (85.0 + 273.15) \text{ K} \\ P_d = 1.121 P_f = \boxed{4.49 \times 10^5 \text{ Pa}}$$

$$\text{P19.28} \quad PV = NP'V' = \frac{4}{3} \pi r^3 NP': \quad N = \frac{3PV}{4\pi r^3 P'} = \frac{3(150)(0.100)}{4\pi(0.150)^3(1.20)} = \boxed{884 \text{ balloons}}$$

If we have no special means for squeezing the last 100 L of helium out of the tank, the tank will be full of helium at 1.20 atm when the last balloon is inflated. The number of balloons is then reduced

$$\text{to to } 884 - \frac{(0.100 \text{ m}^3) 3}{4\pi(0.15 \text{ m})^3} = 877.$$

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 .

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

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

***P19.30** (a) $P_i V_i = n_i R T_i = \frac{m_i}{M} R T_i$

$$m_i = \frac{M P_i V_i}{R T_i} = \frac{4.00 \times 10^{-3} \text{ kg} \cdot 1.013 \times 10^5 \text{ N} \cdot 4\pi (6.37 \times 10^6 \text{ m})^3 \text{ mole} \cdot \text{K}}{\text{mole} \cdot \text{m}^2 \cdot 3 \cdot 8.314 \text{ Nm} \cdot 50 \text{ K}}$$

$$= \boxed{1.06 \times 10^{21} \text{ kg}}$$

(b) $\frac{P_f V_f}{P_i V_i} = \frac{n_f R T_f}{n_i R T_i}$

$$2 \cdot 1 = \left(\frac{1.06 \times 10^{21} \text{ kg} + 8.00 \times 10^{20} \text{ kg}}{1.06 \times 10^{21} \text{ kg}} \right) \frac{T_f}{50 \text{ K}}$$

$$T_f = 100 \text{ K} \left(\frac{1}{1.76} \right) = \boxed{56.9 \text{ K}}$$

P19.31 $P = \frac{nRT}{V} = \left(\frac{9.00 \text{ g}}{18.0 \text{ g/mol}} \right) \left(\frac{8.314 \text{ J}}{\text{mol K}} \right) \left(\frac{773 \text{ K}}{2.00 \times 10^{-3} \text{ m}^3} \right) = \boxed{1.61 \text{ MPa}} = 15.9 \text{ atm}$

P19.32 (a) $T_2 = T_1 \frac{P_2}{P_1} = (300 \text{ K})(3) = \boxed{900 \text{ K}}$

(b) $T_2 = T_1 \frac{P_2 V_2}{P_1 V_1} = 300(2)(2) = \boxed{1200 \text{ K}}$

P19.33 $\sum F_y = 0: \quad \rho_{\text{out}} g V - \rho_{\text{in}} g V - (200 \text{ kg})g = 0$

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

The density of the air outside is 1.25 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

$$\rho_{\text{in}} = \left(1.25 \text{ kg/m}^3 \right) \left(\frac{283 \text{ K}}{T_{\text{in}}} \right)$$

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

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

$$0.600 = \frac{283 \text{ K}}{T_{\text{in}}} \quad T_{\text{in}} = \boxed{472 \text{ K}}$$

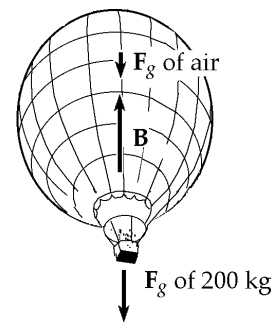


FIG. P19.33

***P19.34** Consider the air in the tank during one discharge process. We suppose that the process is slow enough that the temperature remains constant. Then as the pressure drops from 2.40 atm to 1.20 atm, the volume of the air doubles. During the first discharge, the air volume changes from 1 L to 2 L. Just 1 L of water is expelled and 3 L remains. In the second discharge, the air volume changes from 2 L to 4 L and 2 L of water is sprayed out. In the third discharge, only the last 1 L of water comes out. Were it not for male pattern dumbness, each person could more efficiently use his device by starting with the tank half full of water.

P19.35 (a) $PV = nRT$

$$n = \frac{PV}{RT} = \frac{(1.013 \times 10^5 \text{ Pa})(1.00 \text{ m}^3)}{(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K})} = \boxed{41.6 \text{ mol}}$$

(b) $m = nM = (41.6 \text{ mol})(28.9 \text{ g/mol}) = \boxed{1.20 \text{ kg}}$, in agreement with the tabulated density of 1.20 kg/m^3 at 20.0°C .

***P19.36** The void volume is $0.765V_{\text{total}} = 0.765\pi r^2 \ell = 0.765\pi(1.27 \times 10^{-2} \text{ m})^2 0.2 \text{ m} = 7.75 \times 10^{-5} \text{ m}^3$. Now for the gas remaining $PV = nRT$

$$n = \frac{PV}{RT} = \frac{12.5(1.013 \times 10^5 \text{ N/m}^2)7.75 \times 10^{-5} \text{ m}^3}{(8.314 \text{ Nm/mole K})(273 + 25) \text{ K}} = \boxed{3.96 \times 10^{-2} \text{ mol}}$$

P19.37 (a) $PV = nRT$ $n = \frac{PV}{RT}$

$$m = nM = \frac{PVM}{RT} = \frac{1.013 \times 10^5 \text{ Pa}(0.100 \text{ m})^3(28.9 \times 10^{-3} \text{ kg/mol})}{(8.314 \text{ J/mol} \cdot \text{K})(300 \text{ K})}$$

$$m = \boxed{1.17 \times 10^{-3} \text{ kg}}$$

(b) $F_g = mg = 1.17 \times 10^{-3} \text{ kg}(9.80 \text{ m/s}^2) = \boxed{11.5 \text{ mN}}$

(c) $F = PA = (1.013 \times 10^5 \text{ N/m}^2)(0.100 \text{ m})^2 = \boxed{1.01 \text{ kN}}$

(d) The molecules must be moving very fast to hit the walls hard.

P19.38 At depth, $P = P_0 + \rho gh$ and $PV_i = nRT_i$
 At the surface, $P_0 V_f = nRT_f$: $\frac{P_0 V_f}{(P_0 + \rho gh)V_i} = \frac{T_f}{T_i}$

Therefore $V_f = V_i \left(\frac{T_f}{T_i} \right) \left(\frac{P_0 + \rho gh}{P_0} \right)$

$$V_f = 1.00 \text{ cm}^3 \left(\frac{293 \text{ K}}{278 \text{ K}} \right) \left(\frac{1.013 \times 10^5 \text{ Pa} + (1025 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(25.0 \text{ m})}{1.013 \times 10^5 \text{ Pa}} \right)$$

$$V_f = \boxed{3.67 \text{ cm}^3}$$

P19.39 $PV = nRT :$ $\frac{m_f}{m_i} = \frac{n_f}{n_i} = \frac{P_f V_f}{RT_f} \frac{RT_i}{P_i V_i} = \frac{P_f}{P_i}$

so $m_f = m_i \left(\frac{P_f}{P_i} \right)$

$$|\Delta m| = m_i - m_f = m_i \left(\frac{P_i - P_f}{P_i} \right) = 12.0 \text{ kg} \left(\frac{41.0 \text{ atm} - 26.0 \text{ atm}}{41.0 \text{ atm}} \right) = \boxed{4.39 \text{ kg}}$$

P19.40 My bedroom is 4 m long, 4 m wide, and 2.4 m high, enclosing air at 100 kPa and $20^\circ\text{C} = 293 \text{ K}$. Think of the air as 80.0% N_2 and 20.0% O_2 .

Avogadro's number of molecules has mass

$$(0.800)(28.0 \text{ g/mol}) + (0.200)(32.0 \text{ g/mol}) = 0.0288 \text{ kg/mol}$$

Then $PV = nRT = \left(\frac{m}{M} \right) RT$

gives $m = \frac{PVM}{RT} = \frac{(1.00 \times 10^5 \text{ N/m}^2)(38.4 \text{ m}^3)(0.0288 \text{ kg/mol})}{(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K})} = 45.4 \text{ kg} \quad \boxed{\sim 10^2 \text{ kg}}$

***P19.41** The CO_2 is far from liquefaction, so after it comes out of solution it behaves as an ideal gas. Its molar mass is $M = 12.0 \text{ g/mol} + 2(16.0 \text{ g/mol}) = 44.0 \text{ g/mol}$. The quantity of gas in the cylinder is

$$n = \frac{m_{\text{sample}}}{M} = \frac{6.50 \text{ g}}{44.0 \text{ g/mol}} = 0.148 \text{ mol}$$

Then $PV = nRT$

gives $V = \frac{nRT}{P} = \frac{0.148 \text{ mol}(8.314 \text{ J/mol} \cdot \text{K})(273 \text{ K} + 20 \text{ K})}{1.013 \times 10^5 \text{ N/m}^2} \left(\frac{1 \text{ N} \cdot \text{m}}{1 \text{ J}} \right) \left(\frac{10^3 \text{ L}}{1 \text{ m}^3} \right) = \boxed{3.55 \text{ L}}$

P19.42 $N = \frac{PVN_A}{RT} = \frac{(10^{-9} \text{ Pa})(1.00 \text{ m}^3)(6.02 \times 10^{23} \text{ molecules/mol})}{(8.314 \text{ J/K} \cdot \text{mol})(300 \text{ K})} = \boxed{2.41 \times 10^{11} \text{ molecules}}$

P19.43 $P_0 V = n_1 RT_1 = \left(\frac{m_1}{M} \right) RT_1$

$$P_0 V = n_2 RT_2 = \left(\frac{m_2}{M} \right) RT_2$$

$$\boxed{m_1 - m_2 = \frac{P_0 VM}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right)}$$

P19.44 (a) Initially the air in the bell satisfies $P_0 V_{\text{bell}} = nRT_i$

$$\text{or } P_0 [(2.50 \text{ m})A] = nRT_i \quad (1)$$

When the bell is lowered, the air in the bell satisfies

$$P_{\text{bell}} (2.50 \text{ m} - x)A = nRT_f \quad (2)$$

where x is the height the water rises in the bell. Also, the pressure in the bell, once it is lowered, is equal to the sea water pressure at the depth of the water level in the bell.

$$P_{\text{bell}} = P_0 + \rho g(82.3 \text{ m} - x) \approx P_0 + \rho g(82.3 \text{ m}) \quad (3)$$

The approximation is good, as $x < 2.50 \text{ m}$. Substituting (3) into (2) and substituting nR from (1) into (2),

$$[P_0 + \rho g(82.3 \text{ m})](2.50 \text{ m} - x)A = P_0 V_{\text{bell}} \frac{T_f}{T_i}.$$

Using $P_0 = 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$ and $\rho = 1.025 \times 10^3 \text{ kg/m}^3$

$$\begin{aligned} x &= (2.50 \text{ m}) \left[1 - \frac{T_f}{T_0} \left(1 + \frac{\rho g(82.3 \text{ m})}{P_0} \right)^{-1} \right] \\ &= (2.50 \text{ m}) \left[1 - \frac{277.15 \text{ K}}{293.15 \text{ K}} \left(1 + \frac{(1.025 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(82.3 \text{ m})}{1.013 \times 10^5 \text{ N/m}^2} \right)^{-1} \right] \\ x &= \boxed{2.24 \text{ m}} \end{aligned}$$

(b) If the water in the bell is to be expelled, the air pressure in the bell must be raised to the water pressure at the bottom of the bell. That is,

$$\begin{aligned} P_{\text{bell}} &= P_0 + \rho g(82.3 \text{ m}) \\ &= 1.013 \times 10^5 \text{ Pa} + (1.025 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(82.3 \text{ m}) \\ P_{\text{bell}} &= 9.28 \times 10^5 \text{ Pa} = \boxed{9.16 \text{ atm}} \end{aligned}$$

Additional Problems

P19.45 The excess expansion of the brass is $\Delta L_{\text{rod}} - \Delta L_{\text{tape}} = (\alpha_{\text{brass}} - \alpha_{\text{steel}})L_i \Delta T$

$$\Delta(\Delta L) = (19.0 - 11.0) \times 10^{-6} (\text{°C})^{-1} (0.950 \text{ m})(35.0^\circ \text{C})$$

$$\Delta(\Delta L) = 2.66 \times 10^{-4} \text{ m}$$

(a) The rod contracts more than tape to

$$\text{a length reading } 0.950 \text{ m} - 0.000 \text{ 266 m} = \boxed{0.949 \text{ 7 m}}$$

(b) $0.950 \text{ m} + 0.000 \text{ 266 m} = \boxed{0.950 \text{ 3 m}}$

P19.46 At 0°C , 10.0 gallons of gasoline has mass,

from $\rho = \frac{m}{V}$

$$m = \rho V = (730 \text{ kg/m}^3)(10.0 \text{ gal})\left(\frac{0.00380 \text{ m}^3}{1.00 \text{ gal}}\right) = 27.7 \text{ kg}$$

The gasoline will expand in volume by

$$\Delta V = \beta V_i \Delta T = 9.60 \times 10^{-4} \text{ }^\circ\text{C}^{-1} (10.0 \text{ gal})(20.0^\circ\text{C} - 0.0^\circ\text{C}) = 0.192 \text{ gal}$$

At 20.0°C , $10.192 \text{ gal} = 27.7 \text{ kg}$

$$10.0 \text{ gal} = 27.7 \text{ kg} \left(\frac{10.0 \text{ gal}}{10.192 \text{ gal}} \right) = 27.2 \text{ kg}$$

The extra mass contained in 10.0 gallons at 0.0°C is

$$27.7 \text{ kg} - 27.2 \text{ kg} = \boxed{0.523 \text{ kg}}.$$

P19.47 Neglecting the expansion of the glass,

$$\Delta h = \frac{V}{A} \beta \Delta T$$

$$\Delta h = \frac{\frac{4}{3} \pi (0.250 \text{ cm}/2)^3}{\pi (2.00 \times 10^{-3} \text{ cm})^2} (1.82 \times 10^{-4} \text{ }^\circ\text{C}^{-1})(30.0^\circ\text{C}) = \boxed{3.55 \text{ cm}}$$

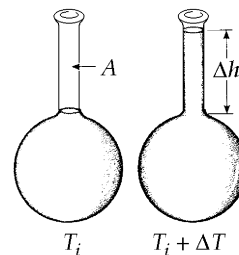


FIG. P19.47

P19.48 (a) The volume of the liquid increases as $\Delta V_\ell = V_i \beta \Delta T$. The volume of the flask increases as $\Delta V_g = 3\alpha V_i \Delta T$. Therefore, the overflow in the capillary is $V_c = V_i \Delta T (\beta - 3\alpha)$; and in the capillary $V_c = A \Delta h$.

Therefore, $\boxed{\Delta h = \frac{V_i}{A} (\beta - 3\alpha) \Delta T}.$

(b) For a mercury thermometer $\beta(\text{Hg}) = 1.82 \times 10^{-4} \text{ }^\circ\text{C}^{-1}$

and for glass, $3\alpha = 3 \times 3.20 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$

Thus $\beta - 3\alpha \approx \beta$

or $\boxed{\alpha \ll \beta}.$

P19.49 The frequency played by the cold-walled flute is $f_i = \frac{v}{\lambda_i} = \frac{v}{2L_i}$.

When the instrument warms up

$$f_f = \frac{v}{\lambda_f} = \frac{v}{2L_f} = \frac{v}{2L_i(1 + \alpha\Delta T)} = \frac{f_i}{1 + \alpha\Delta T}.$$

The final frequency is lower. The change in frequency is

$$\begin{aligned}\Delta f &= f_i - f_f = f_i \left(1 - \frac{1}{1 + \alpha\Delta T} \right) \\ \Delta f &= \frac{v}{2L_i} \left(\frac{\alpha\Delta T}{1 + \alpha\Delta T} \right) \approx \frac{v}{2L_i} (\alpha\Delta T) \\ \Delta f &\approx \frac{(343 \text{ m/s})(24.0 \times 10^{-6} / \text{C}^\circ)(15.0^\circ \text{C})}{2(0.655 \text{ m})} = \boxed{0.0943 \text{ Hz}}\end{aligned}$$

This change in frequency is imperceptibly small.

P19.50 (a) $\frac{P_0 V}{T} = \frac{P' V'}{T'}$

$$\begin{aligned}V' &= V + Ah \\ P' &= P_0 + \frac{kh}{A} \\ \left(P_0 + \frac{kh}{A} \right) (V + Ah) &= P_0 V \left(\frac{T'}{T} \right) \\ (1.013 \times 10^5 \text{ N/m}^2 + 2.00 \times 10^5 \text{ N/m}^3 h) & \\ (5.00 \times 10^{-3} \text{ m}^3 + (0.0100 \text{ m}^2) h) & \\ &= (1.013 \times 10^5 \text{ N/m}^2) (5.00 \times 10^{-3} \text{ m}^3) \left(\frac{523 \text{ K}}{293 \text{ K}} \right) \\ 2000h^2 + 2013h - 397 &= 0 \\ h = \frac{-2013 \pm 2689}{4000} &= \boxed{0.169 \text{ m}}\end{aligned}$$

(b) $P' = P + \frac{kh}{A} = 1.013 \times 10^5 \text{ Pa} + \frac{(2.00 \times 10^3 \text{ N/m})(0.169)}{0.0100 \text{ m}^2}$

$$P' = \boxed{1.35 \times 10^5 \text{ Pa}}$$

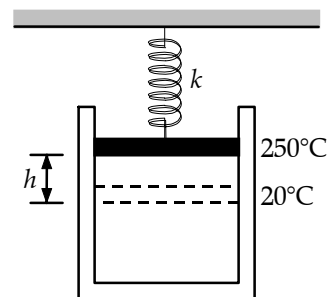


FIG. P19.50

P19.51 (a) $\rho = \frac{m}{V}$ and $d\rho = -\frac{m}{V^2} dV$

For very small changes in V and ρ , this can be expressed as

$$\Delta\rho = -\frac{m}{V} \frac{\Delta V}{V} = -\rho\beta\Delta T.$$

The negative sign means that any increase in temperature causes the density to decrease and vice versa.

(b) For water we have $\beta = \left| \frac{\Delta\rho}{\rho\Delta T} \right| = \left| \frac{1.000\,0\text{ g/cm}^3 - 0.999\,7\text{ g/cm}^3}{(1.000\,0\text{ g/cm}^3)(10.0^\circ\text{C} - 4.0^\circ\text{C})} \right| = \boxed{5 \times 10^{-5} \text{ }^\circ\text{C}^{-1}}.$

***P19.52** The astronauts exhale this much CO_2 :

$$n = \frac{m_{\text{sample}}}{M} = \frac{1.09\text{ kg}}{\text{astronaut} \cdot \text{day}} \left(\frac{1\,000\text{ g}}{1\text{ kg}} \right) (3\text{ astronauts})(7\text{ days}) \left(\frac{1\text{ mol}}{44.0\text{ g}} \right) = 520\text{ mol}.$$

Then 520 mol of methane is generated. It is far from liquefaction and behaves as an ideal gas.

$$P = \frac{nRT}{V} = \frac{520\text{ mol}(8.314\text{ J/mol} \cdot \text{K})(273\text{ K} - 45\text{ K})}{150 \times 10^{-3}\text{ m}^3} = \boxed{6.57 \times 10^6\text{ Pa}}$$

P19.53 (a) We assume that air at atmospheric pressure is above the piston.

In equilibrium $P_{\text{gas}} = \frac{mg}{A} + P_0$

Therefore, $\frac{nRT}{hA} = \frac{mg}{A} + P_0$

or $\boxed{h = \frac{nRT}{mg + P_0 A}}$

where we have used $V = hA$ as the volume of the gas.

(b) From the data given,

$$\begin{aligned} h &= \frac{0.200\text{ mol}(8.314\text{ J/K} \cdot \text{mol})(400\text{ K})}{20.0\text{ kg}(9.80\text{ m/s}^2) + (1.013 \times 10^5\text{ N/m}^2)(0.008\,00\text{ m}^2)} \\ &= \boxed{0.661\text{ m}} \end{aligned}$$

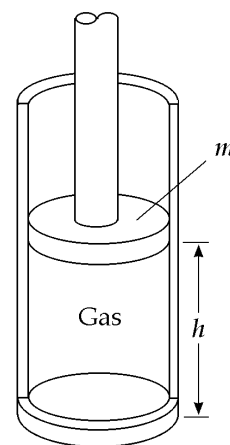


FIG. P19.53

P19.54 The angle of bending θ , between tangents to the two ends of the strip, is equal to the angle the strip subtends at its center of curvature. (The angles are equal because their sides are perpendicular, right side to the right side and left side to left side.)

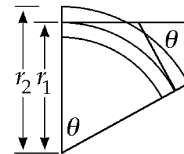


FIG. P19.54

(a) The definition of radian measure gives $L_i + \Delta L_1 = \theta r_1$

and $L_i + \Delta L_2 = \theta r_2$

By subtraction,

$$\Delta L_2 - \Delta L_1 = \theta(r_2 - r_1)$$

$$\alpha_2 L_i \Delta T - \alpha_1 L_i \Delta T = \theta \Delta r$$

$$\boxed{\theta = \frac{(\alpha_2 - \alpha_1) L_i \Delta T}{\Delta r}}$$

(b) In the expression from part (a), θ is directly proportional to ΔT and also to $(\alpha_2 - \alpha_1)$. Therefore θ is zero when either of these quantities becomes zero.

(c) The material that expands more when heated contracts more when cooled, so the bimetallic strip bends the other way. It is fun to demonstrate this with liquid nitrogen.

$$\begin{aligned} \text{(d)} \quad \theta &= \frac{2(\alpha_2 - \alpha_1) L_i \Delta T}{2\Delta r} = \frac{2((19 \times 10^{-6} - 0.9 \times 10^{-6})^\circ \text{C}^{-1})(200 \text{ mm})(1^\circ \text{C})}{0.500 \text{ mm}} \\ &= 1.45 \times 10^{-2} = 1.45 \times 10^{-2} \text{ rad} \left(\frac{180^\circ}{\pi \text{ rad}} \right) = \boxed{0.830^\circ} \end{aligned}$$

P19.55 From the diagram we see that the change in area is

$$\Delta A = \ell \Delta w + w \Delta \ell + \Delta w \Delta \ell.$$

Since $\Delta \ell$ and Δw are each small quantities, the product $\Delta w \Delta \ell$ will be very small. Therefore, we assume $\Delta w \Delta \ell \approx 0$.

Since $\Delta w = w \alpha \Delta T$ and $\Delta \ell = \ell \alpha \Delta T$,

we then have $\Delta A = \ell w \alpha \Delta T + \ell w \alpha \Delta T$

and since $A = \ell w$, $\boxed{\Delta A = 2\alpha A \Delta T}$.

The approximation assumes $\Delta w \Delta \ell \approx 0$, or $\alpha \Delta T \approx 0$. Another way of stating this is $\boxed{\alpha \Delta T \ll 1}$.

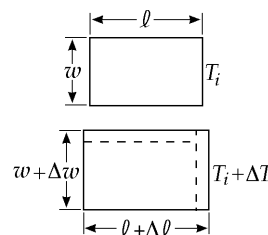


FIG. P19.55

P19.56 (a) $T_i = 2\pi \sqrt{\frac{L_i}{g}}$ so $L_i = \frac{T_i^2 g}{4\pi^2} = \frac{(1.000 \text{ s})^2 (9.80 \text{ m/s}^2)}{4\pi^2} = 0.2482 \text{ m}$

$$\Delta L = \alpha L_i \Delta T = 19.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1} (0.2482 \text{ m})(10.0^\circ\text{C}) = 4.72 \times 10^{-5} \text{ m}$$

$$T_f = 2\pi \sqrt{\frac{L_i + \Delta L}{g}} = 2\pi \sqrt{\frac{0.2483 \text{ m}}{9.80 \text{ m/s}^2}} = 1.0000950 \text{ s}$$

$$\Delta T = \boxed{9.50 \times 10^{-5} \text{ s}}$$

(b) In one week, the time lost is time lost = 1 week $(9.50 \times 10^{-5} \text{ s lost per second})$

$$\text{time lost} = (7.00 \text{ d/week}) \left(\frac{86400 \text{ s}}{1.00 \text{ d}} \right) \left(9.50 \times 10^{-5} \frac{\text{s lost}}{\text{s}} \right)$$

$$\text{time lost} = \boxed{57.5 \text{ s lost}}$$

P19.57 $I = \int r^2 dm$ and since $r(T) = r(T_i)(1 + \alpha \Delta T)$

for $\alpha \Delta T \ll 1$ we find $\frac{I(T)}{I(T_i)} = (1 + \alpha \Delta T)^2$

thus $\frac{I(T) - I(T_i)}{I(T_i)} \approx 2\alpha \Delta T$

(a) With $\alpha = 17.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$ and $\Delta T = 100^\circ\text{C}$

we find for Cu: $\frac{\Delta I}{I} = 2(17.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1})(100^\circ\text{C}) = \boxed{0.340\%}$

(b) With $\alpha = 24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$

and $\Delta T = 100^\circ\text{C}$

we find for Al: $\frac{\Delta I}{I} = 2(24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1})(100^\circ\text{C}) = \boxed{0.480\%}$

P19.58 (a) $B = \rho g V'$ $P' = P_0 + \rho g d$ $P' V' = P_0 V_i$

$$B = \frac{\rho g P_0 V_i}{P'} = \boxed{\frac{\rho g P_0 V_i}{(P_0 + \rho g d)}}$$

(b) Since d is in the denominator, B must decrease as the depth increases.
(The volume of the balloon becomes smaller with increasing pressure.)

(c) $\frac{1}{2} = \frac{B(d)}{B(0)} = \frac{\rho g P_0 V_i / (P_0 + \rho g d)}{\rho g P_0 V_i / P_0} = \frac{P_0}{P_0 + \rho g d}$

$$P_0 + \rho g d = 2P_0$$

$$d = \frac{P_0}{\rho g} = \frac{1.013 \times 10^5 \text{ N/m}^2}{(1.00 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)} = \boxed{10.3 \text{ m}}$$

- *P19.59** The effective coefficient is defined by $\Delta L_{\text{total}} = \alpha_{\text{effective}} L_{\text{total}} \Delta T$ where $\Delta L_{\text{total}} = \Delta L_{\text{Cu}} + \Delta L_{\text{Pb}}$ and $L_{\text{total}} = L_{\text{Cu}} + L_{\text{Pb}} = x L_{\text{total}} + (1-x) L_{\text{total}}$. Then by substitution

$$\begin{aligned}\alpha_{\text{Cu}} L_{\text{Cu}} \Delta T + \alpha_{\text{Pb}} L_{\text{Pb}} \Delta T &= \alpha_{\text{eff}} (L_{\text{Cu}} + L_{\text{Pb}}) \Delta T \\ \alpha_{\text{Cu}} x + \alpha_{\text{Pb}} (1-x) &= \alpha_{\text{eff}} \\ (\alpha_{\text{Cu}} - \alpha_{\text{Pb}}) x &= \alpha_{\text{eff}} - \alpha_{\text{Pb}} \\ x &= \frac{20 \times 10^{-6} \text{ } 1/\text{C}^\circ - 29 \times 10^{-6} \text{ } 1/\text{C}^\circ}{17 \times 10^{-6} \text{ } 1/\text{C}^\circ - 29 \times 10^{-6} \text{ } 1/\text{C}^\circ} = \frac{9}{12} = \boxed{0.750}\end{aligned}$$

- *P19.60** (a) No torque acts on the disk so its angular momentum is constant. Its moment of inertia decreases as it contracts so its angular speed must increase.

$$\begin{aligned}\text{(b)} \quad I_i \omega_i &= I_f \omega_f = \frac{1}{2} M R_i^2 \omega_i = \frac{1}{2} M R_f^2 \omega_f = \frac{1}{2} M [R_i + R_i \alpha \Delta T]^2 \omega_f = \frac{1}{2} M R_i^2 [1 - \alpha |\Delta T|]^2 \omega_f \\ \omega_f &= \omega_i [1 - \alpha |\Delta T|]^{-2} = \frac{25.0 \text{ rad/s}}{(1 - (17 \times 10^{-6} \text{ } 1/\text{C}^\circ) 830^\circ \text{C})^2} = \frac{25.0 \text{ rad/s}}{0.972} = \boxed{25.7 \text{ rad/s}}\end{aligned}$$

- P19.61** After expansion, the length of one of the spans is

$$L_f = L_i (1 + \alpha \Delta T) = 125 \text{ m} [1 + 12 \times 10^{-6} \text{ } ^\circ \text{C}^{-1} (20.0^\circ \text{C})] = 125.03 \text{ m}.$$

L_f , y , and the original 125 m length of this span form a right triangle with y as the altitude. Using the Pythagorean theorem gives:

$$(125.03 \text{ m})^2 = y^2 + (125 \text{ m})^2$$

yielding $y = \boxed{2.74 \text{ m}}$.

- P19.62** After expansion, the length of one of the spans is $L_f = L(1 + \alpha \Delta T)$. L_f , y , and the original length L of this span form a right triangle with y as the altitude. Using the Pythagorean theorem gives

$$L_f^2 = L^2 + y^2, \quad \text{or} \quad y = \sqrt{L_f^2 - L^2} = L \sqrt{(1 + \alpha \Delta T)^2 - 1} = L \sqrt{2\alpha \Delta T + (\alpha \Delta T)^2}$$

Since $\alpha \Delta T \ll 1$, $y \approx \boxed{L \sqrt{2\alpha \Delta T}}$.

- P19.63** (a) Let m represent the sample mass. The number of moles is $n = \frac{m}{M}$ and the density is $\rho = \frac{m}{V}$.

So $PV = nRT$ becomes $PV = \frac{m}{M} RT$ or $PM = \frac{m}{V} RT$.

$$\text{Then, } \rho = \frac{m}{V} = \boxed{\frac{PM}{RT}}.$$

$$\text{(b)} \quad \rho = \frac{PM}{RT} = \frac{(1.013 \times 10^5 \text{ N/m}^2)(0.0320 \text{ kg/mol})}{(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K})} = \boxed{1.33 \text{ kg/m}^3}$$

P19.64 (a) From $PV = nRT$, the volume is: $V = \left(\frac{nR}{P}\right)T$

Therefore, when pressure is held constant, $\frac{dV}{dT} = \frac{nR}{P} = \frac{V}{T}$

Thus, $\beta \equiv \left(\frac{1}{V}\right)\frac{dV}{dT} = \left(\frac{1}{V}\right)\frac{V}{T}, \text{ or } \beta = \boxed{\frac{1}{T}}$

(b) At $T = 0^\circ\text{C} = 273 \text{ K}$, this predicts $\beta = \frac{1}{273 \text{ K}} = \boxed{3.66 \times 10^{-3} \text{ K}^{-1}}$

Experimental values are: $\beta_{\text{He}} = 3.665 \times 10^{-3} \text{ K}^{-1}$ and $\beta_{\text{air}} = 3.67 \times 10^{-3} \text{ K}^{-1}$

They agree within 0.06% and 0.2%, respectively.

P19.65 For each gas alone, $P_1 = \frac{N_1 kT}{V}$ and $P_2 = \frac{N_2 kT}{V}$ and $P_3 = \frac{N_3 kT}{V}$, etc.

For all gases

$$P_1 V_1 + P_2 V_2 + P_3 V_3 \dots = (N_1 + N_2 + N_3 \dots)kT \text{ and}$$

$$(N_1 + N_2 + N_3 \dots)kT = PV$$

Also, $V_1 = V_2 = V_3 = \dots = V$, therefore $\boxed{P = P_1 + P_2 + P_3 \dots}$.

P19.66 (a) Using the Periodic Table, we find the molecular masses of the air components to be

$$M(\text{N}_2) = 28.01 \text{ u}, M(\text{O}_2) = 32.00 \text{ u}, M(\text{Ar}) = 39.95 \text{ u}$$

and $M(\text{CO}_2) = 44.01 \text{ u}$.

Thus, the number of moles of each gas in the sample is

$$n(\text{N}_2) = \frac{75.52 \text{ g}}{28.01 \text{ g/mol}} = 2.696 \text{ mol}$$

$$n(\text{O}_2) = \frac{23.15 \text{ g}}{32.00 \text{ g/mol}} = 0.7234 \text{ mol}$$

$$n(\text{Ar}) = \frac{1.28 \text{ g}}{39.95 \text{ g/mol}} = 0.0320 \text{ mol}$$

$$n(\text{CO}_2) = \frac{0.05 \text{ g}}{44.01 \text{ g/mol}} = 0.0011 \text{ mol}$$

The total number of moles is $n_0 = \sum n_i = 3.453 \text{ mol}$. Then, the partial pressure of N_2 is

$$P(\text{N}_2) = \frac{2.696 \text{ mol}}{3.453 \text{ mol}} (1.013 \times 10^5 \text{ Pa}) = \boxed{79.1 \text{ kPa}}.$$

Similarly,

$$P(\text{O}_2) = \boxed{21.2 \text{ kPa}} \quad P(\text{Ar}) = \boxed{940 \text{ Pa}} \quad P(\text{CO}_2) = \boxed{33.3 \text{ Pa}}$$

continued on next page

(b) Solving the ideal gas law equation for V and using $T = 273.15 + 15.00 = 288.15 \text{ K}$, we find

$$V = \frac{n_0 RT}{P} = \frac{(3.453 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(288.15 \text{ K})}{1.013 \times 10^5 \text{ Pa}} = \boxed{8.166 \times 10^{-2} \text{ m}^3}.$$

$$\text{Then, } \rho = \frac{m}{V} = \frac{100 \times 10^{-3} \text{ kg}}{8.166 \times 10^{-2} \text{ m}^3} = \boxed{1.22 \text{ kg/m}^3}.$$

(c) The 100 g sample must have an appropriate molar mass to yield n_0 moles of gas: that is

$$M(\text{air}) = \frac{100 \text{ g}}{3.453 \text{ mol}} = \boxed{29.0 \text{ g/mol}}.$$

***P19.67** Consider a spherical steel shell of inner radius r and much smaller thickness t , containing helium at pressure P . When it contains so much helium that it is on the point of bursting into two hemispheres, we have $P\pi r^2 = (5 \times 10^8 \text{ N/m}^2)2\pi rt$. The mass of the steel is

$$\rho_s V = \rho_s 4\pi r^2 t = \rho_s 4\pi r^2 \frac{Pr}{10^9 \text{ Pa}}. \text{ For the helium in the tank, } PV = nRT \text{ becomes}$$

$$P \frac{4}{3} \pi r^3 = nRT = \frac{m_{\text{He}}}{M_{\text{He}}} RT = 1 \text{ atm} V_{\text{balloon}}.$$

The buoyant force on the balloon is the weight of the air it displaces, which is described by

$1 \text{ atm} V_{\text{balloon}} = \frac{m_{\text{air}}}{M_{\text{air}}} RT = P \frac{4}{3} \pi r^3$. The net upward force on the balloon with the steel tank hanging from it is

$$+m_{\text{air}}g - m_{\text{He}}g - m_s g = \frac{M_{\text{air}} P 4\pi r^3 g}{3RT} - \frac{M_{\text{He}} P 4\pi r^3 g}{3RT} - \frac{\rho_s P 4\pi r^3 g}{10^9 \text{ Pa}}$$

The balloon will or will not lift the tank depending on whether this quantity is positive or negative, which depends on the sign of $\frac{(M_{\text{air}} - M_{\text{He}})}{3RT} - \frac{\rho_s}{10^9 \text{ Pa}}$. At 20°C this quantity is

$$\begin{aligned} &= \frac{(28.9 - 4.00) \times 10^{-3} \text{ kg/mol}}{3(8.314 \text{ J/mol} \cdot \text{K})293 \text{ K}} - \frac{7860 \text{ kg/m}^3}{10^9 \text{ N/m}^2} \\ &= 3.41 \times 10^{-6} \text{ s}^2/\text{m}^2 - 7.86 \times 10^{-6} \text{ s}^2/\text{m}^2 \end{aligned}$$

where we have used the density of iron. The net force on the balloon is downward so the helium balloon is not able to lift its tank.

P19.68 With piston alone: $T = \text{constant}$, so $PV = P_0V_0$

or $P(Ah_i) = P_0(Ah_0)$

With $A = \text{constant}$, $P = P_0 \left(\frac{h_0}{h_i} \right)$

But, $P = P_0 + \frac{m_p g}{A}$

where m_p is the mass of the piston.

Thus, $P_0 + \frac{m_p g}{A} = P_0 \left(\frac{h_0}{h_i} \right)$

which reduces to $h_i = \frac{h_0}{1 + \frac{m_p g}{P_0 A}} = \frac{50.0 \text{ cm}}{1 + \frac{20.0 \text{ kg}(9.80 \text{ m/s}^2)}{1.013 \times 10^5 \text{ Pa}[\pi(0.400 \text{ m})^2]}} = 49.81 \text{ cm}$

With the man of mass M on the piston, a very similar calculation (replacing m_p by $m_p + M$) gives:

$$h' = \frac{h_0}{1 + \frac{(m_p + M)g}{P_0 A}} = \frac{50.0 \text{ cm}}{1 + \frac{95.0 \text{ kg}(9.80 \text{ m/s}^2)}{1.013 \times 10^5 \text{ Pa}[\pi(0.400 \text{ m})^2]}} = 49.10 \text{ cm}$$

Thus, when the man steps on the piston, it moves downward by

$$\Delta h = h_i - h' = 49.81 \text{ cm} - 49.10 \text{ cm} = 0.706 \text{ cm} = \boxed{7.06 \text{ mm}}.$$

(b) $P = \text{const}$, so $\frac{V}{T} = \frac{V'}{T'}$ or $\frac{Ah_i}{T} = \frac{Ah'}{T'}$
giving $T = T_i \left(\frac{h_i}{h'} \right) = 293 \text{ K} \left(\frac{49.81}{49.10} \right) = \boxed{297 \text{ K}}$ (or 24°C)

P19.69 (a) $\frac{dL}{L} = \alpha dT$: $\int_{T_i}^{T_f} \alpha dT = \int_{L_i}^{L_f} \frac{dL}{L} \Rightarrow \ln \left(\frac{L_f}{L_i} \right) = \alpha \Delta T \Rightarrow \boxed{L_f = L_i e^{\alpha \Delta T}}$

(b) $L_f = (1.00 \text{ m}) e^{[2.00 \times 10^{-5} \text{ }^\circ\text{C}^{-1}(100^\circ\text{C})]} = 1.002002 \text{ m}$

$$L'_f = 1.00 \text{ m} [1 + 2.00 \times 10^{-5} \text{ }^\circ\text{C}^{-1}(100^\circ\text{C})] = 1.002000 \text{ m} : \frac{L_f - L'_f}{L_f} = 2.00 \times 10^{-6} = \boxed{2.00 \times 10^{-4} \%}$$

$$L_f = (1.00 \text{ m}) e^{[2.00 \times 10^{-2} \text{ }^\circ\text{C}^{-1}(100^\circ\text{C})]} = 7.389 \text{ m}$$

$$L'_f = 1.00 \text{ m} [1 + 0.020 \text{ }^\circ\text{C}^{-1}(100^\circ\text{C})] = 3.000 \text{ m} : \frac{L_f - L'_f}{L_f} = \boxed{59.4 \%}$$

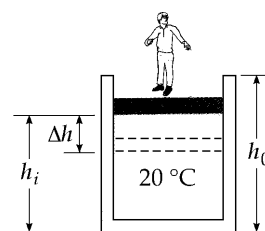


FIG. P19.68

570 Temperature

P19.70 At 20.0°C , the unstretched lengths of the steel and copper wires are

$$L_s(20.0^\circ\text{C}) = (2.000 \text{ m}) \left[1 + 11.0 \times 10^{-6} (\text{C}^\circ)^{-1} (-20.0^\circ\text{C}) \right] = 1.99956 \text{ m}$$

$$L_c(20.0^\circ\text{C}) = (2.000 \text{ m}) \left[1 + 17.0 \times 10^{-6} (\text{C}^\circ)^{-1} (-20.0^\circ\text{C}) \right] = 1.99932 \text{ m}$$

Under a tension F , the length of the steel and copper wires are

$$L'_s = L_s \left[1 + \frac{F}{YA} \right]_s \quad L'_c = L_c \left[1 + \frac{F}{YA} \right]_c \quad \text{where } L'_s + L'_c = 4.000 \text{ m}.$$

Since the tension, F , must be the same in each wire, solve for F :

$$F = \frac{(L'_s + L'_c) - (L_s + L_c)}{\frac{L_s}{Y_s A_s} + \frac{L_c}{Y_c A_c}}.$$

When the wires are stretched, their areas become

$$A_s = \pi (1.000 \times 10^{-3} \text{ m})^2 \left[1 + (11.0 \times 10^{-6})(-20.0) \right]^2 = 3.140 \times 10^{-6} \text{ m}^2$$

$$A_c = \pi (1.000 \times 10^{-3} \text{ m})^2 \left[1 + (17.0 \times 10^{-6})(-20.0) \right]^2 = 3.139 \times 10^{-6} \text{ m}^2$$

Recall $Y_s = 20.0 \times 10^{10} \text{ Pa}$ and $Y_c = 11.0 \times 10^{10} \text{ Pa}$. Substituting into the equation for F , we obtain

$$F = \frac{4.000 \text{ m} - (1.99956 \text{ m} + 1.99932 \text{ m})}{\left[1.99956 \text{ m} \right] / \left[(20.0 \times 10^{10} \text{ Pa}) (3.140 \times 10^{-6} \text{ m}^2) \right] + \left[1.99932 \text{ m} \right] / \left[(11.0 \times 10^{10} \text{ Pa}) (3.139 \times 10^{-6} \text{ m}^2) \right]}$$

$$F = \boxed{125 \text{ N}}$$

To find the x -coordinate of the junction,

$$L'_s = (1.99956 \text{ m}) \left[1 + \frac{125 \text{ N}}{(20.0 \times 10^{10} \text{ N/m}^2) (3.140 \times 10^{-6} \text{ m}^2)} \right] = 1.999958 \text{ m}$$

Thus the x -coordinate is $-2.000 + 1.999958 = \boxed{-4.20 \times 10^{-5} \text{ m}}$.

P19.71 (a) $\mu = \pi r^2 \rho = \pi (5.00 \times 10^{-4} \text{ m})^2 (7.86 \times 10^3 \text{ kg/m}^3) = \boxed{6.17 \times 10^{-3} \text{ kg/m}}$

(b) $f_1 = \frac{v}{2L}$ and $v = \sqrt{\frac{T}{\mu}}$ so $f_1 = \frac{1}{2L} \sqrt{\frac{T}{\mu}}$

Therefore, $T = \mu (2Lf_1)^2 = (6.17 \times 10^{-3}) (2 \times 0.800 \times 200)^2 = \boxed{632 \text{ N}}$

(c) First find the unstressed length of the string at 0°C:

$$L = L_{\text{natural}} \left(1 + \frac{T}{AY} \right) \text{ so } L_{\text{natural}} = \frac{L}{1 + T/AY}$$

$$A = \pi (5.00 \times 10^{-4} \text{ m})^2 = 7.854 \times 10^{-7} \text{ m}^2 \text{ and } Y = 20.0 \times 10^{10} \text{ Pa}$$

Therefore, $\frac{T}{AY} = \frac{632}{(7.854 \times 10^{-7})(20.0 \times 10^{10})} = 4.02 \times 10^{-3}$, and

$$L_{\text{natural}} = \frac{(0.800 \text{ m})}{(1 + 4.02 \times 10^{-3})} = 0.7968 \text{ m}.$$

The unstressed length at 30.0°C is $L_{30^\circ\text{C}} = L_{\text{natural}} [1 + \alpha(30.0^\circ\text{C} - 0.0^\circ\text{C})]$,

or $L_{30^\circ\text{C}} = (0.7968 \text{ m}) [1 + (11.0 \times 10^{-6})(30.0)] = 0.79706 \text{ m}.$

Since $L = L_{30^\circ\text{C}} \left[1 + \frac{T'}{AY} \right]$, where T' is the tension in the string at 30.0°C,

$$T' = AY \left[\frac{L}{L_{30^\circ\text{C}}} - 1 \right] = (7.854 \times 10^{-7})(20.0 \times 10^{10}) \left[\frac{0.800}{0.79706} - 1 \right] = 580 \text{ N}.$$

To find the frequency at 30.0°C, realize that

$$\frac{f'_1}{f_1} = \sqrt{\frac{T'}{T}} \text{ so } f'_1 = (200 \text{ Hz}) \sqrt{\frac{580 \text{ N}}{632 \text{ N}}} = \boxed{192 \text{ Hz}}.$$

***P19.72** Some gas will pass through the porous plug from the reaction chamber 1 to the reservoir 2 as the reaction chamber is heated, but the net quantity of gas stays constant according to

$$n_{i1} + n_{i2} = n_{f1} + n_{f2}.$$

Assuming the gas is ideal, we apply $n = \frac{PV}{RT}$ to each term:

$$\frac{P_i V_0}{(300 \text{ K})R} + \frac{P_i (4V_0)}{(300 \text{ K})R} = \frac{P_f V_0}{(673 \text{ K})R} + \frac{P_f (4V_0)}{(300 \text{ K})R}$$

$$1 \text{ atm} \left(\frac{5}{300 \text{ K}} \right) = P_f \left(\frac{1}{673 \text{ K}} + \frac{4}{300 \text{ K}} \right) \quad \boxed{P_f = 1.12 \text{ atm}}$$

P19.73 Let 2θ represent the angle the curved rail subtends. We have

$$L_i + \Delta L = 2R\theta = L_i(1 + \alpha\Delta T)$$

and
$$\sin \theta = \frac{\frac{L_i}{2}}{R} = \frac{L_i}{2R}$$

Thus,
$$\theta = \frac{L_i}{2R}(1 + \alpha\Delta T) = (1 + \alpha\Delta T)\sin \theta$$

and we must solve the transcendental equation

$$\theta = (1 + \alpha\Delta T)\sin \theta = (1.000\,005\,5)\sin \theta$$

Homing in on the non-zero solution gives, to four digits,

$$\theta = 0.018\,16 \text{ rad} = 1.040\,5^\circ$$

Now,

$$h = R - R\cos \theta = \frac{L_i(1 - \cos \theta)}{2\sin \theta}$$

This yields $h = 4.54 \text{ m}$, a remarkably large value compared to $\Delta L = 5.50 \text{ cm}$.

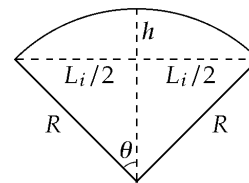


FIG. P19.73

- *P19.74** (a) Let xL represent the distance of the stationary line below the top edge of the plate. The normal force on the lower part of the plate is $mg(1-x)\cos \theta$ and the force of kinetic friction on it is $\mu_k mg(1-x)\cos \theta$ up the roof. Again, $\mu_k mgx\cos \theta$ acts down the roof on the upper part of the plate. The near-equilibrium of the plate requires $\sum F_x = 0$

$$-\mu_k mgx\cos \theta + \mu_k mg(1-x)\cos \theta - mg\sin \theta = 0$$

$$-2\mu_k mgx\cos \theta = mg\sin \theta - \mu_k mg\cos \theta$$

$$2\mu_k x = \mu_k - \tan \theta$$

$$x = \frac{1}{2} - \frac{\tan \theta}{2\mu_k}$$

and the stationary line is indeed below the top edge by $xL = \frac{L}{2}\left(1 - \frac{\tan \theta}{\mu_k}\right)$.

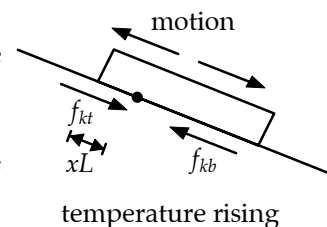


FIG. P19.74(a)

- (b) With the temperature falling, the plate contracts faster than the roof. The upper part slides down and feels an upward frictional force $\mu_k mg(1-x)\cos \theta$. The lower part slides up and feels downward frictional force $\mu_k mgx\cos \theta$. The equation $\sum F_x = 0$ is then the same as in part (a) and the stationary line is above the bottom edge by $xL = \frac{L}{2}\left(1 - \frac{\tan \theta}{\mu_k}\right)$.

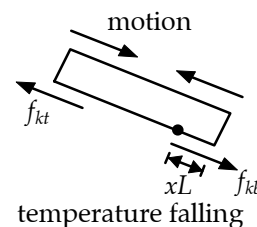


FIG. P19.74(b)

- (c) Start thinking about the plate at dawn, as the temperature starts to rise. As in part (a), a line at distance xL below the top edge of the plate stays stationary relative to the roof as long as the temperature rises. The point P on the plate at distance xL above the bottom edge is destined to become the fixed point when the temperature starts falling. As the temperature rises, this point moves down the roof because of the expansion of the central part of the plate. Its displacement for the day is

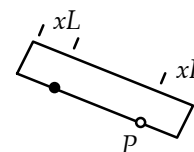


FIG. P19.74(c)

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$$\begin{aligned}
 \Delta L &= (\alpha_2 - \alpha_1)(L - xL - xL)\Delta T \\
 &= (\alpha_2 - \alpha_1) \left[L - 2\frac{L}{2} \left(1 - \frac{\tan \theta}{\mu_k} \right) \right] (T_h - T_c) \\
 &= (\alpha_2 - \alpha_1) \left(\frac{L \tan \theta}{\mu_k} \right) (T_h - T_c).
 \end{aligned}$$

At dawn the next day the point P is farther down the roof by the distance ΔL . It represents the displacement of every other point on the plate.

$$(d) \quad (\alpha_2 - \alpha_1) \left(\frac{L \tan \theta}{\mu_k} \right) (T_h - T_c) = \left(24 \times 10^{-6} \frac{1}{^\circ\text{C}} - 15 \times 10^{-6} \frac{1}{^\circ\text{C}} \right) \frac{1.20 \text{ m} \tan 18.5^\circ}{0.42} 32^\circ\text{C} = \boxed{0.275 \text{ mm}}$$

- (e) If $\alpha_2 < \alpha_1$, the diagram in part (a) applies to temperature falling and the diagram in part (b) applies to temperature rising. The weight of the plate still pulls it step by step down the roof. The same expression describes how far it moves each day.

ANSWERS TO EVEN PROBLEMS

- | | | | |
|---------------|--|---------------|--|
| P19.2 | (a) 1.06 atm; (b) -124°C | P19.32 | (a) 900 K; (b) 1 200 K |
| P19.4 | (a) $37.0^\circ\text{C} = 310 \text{ K}$; (b) $-20.6^\circ\text{C} = 253 \text{ K}$ | P19.34 | see the solution |
| P19.6 | $T_C = (1.33 \text{ } ^\circ\text{C}/^\circ\text{S})T_S + 20.0^\circ\text{C}$ | P19.36 | $3.96 \times 10^{-2} \text{ mol}$ |
| P19.8 | 0.313 m | P19.38 | 3.67 cm^3 |
| P19.10 | 1.20 cm | P19.40 | between 10^1 kg and 10^2 kg |
| P19.12 | $15.8 \mu\text{m}$ | P19.42 | $2.41 \times 10^{11} \text{ molecules}$ |
| P19.14 | 0.663 mm to the right at 78.2° below the horizontal | P19.44 | (a) 2.24 m; (b) $9.28 \times 10^5 \text{ Pa}$ |
| P19.16 | (a) 0.109 cm^2 ; (b) increase | P19.46 | 0.523 kg |
| P19.18 | (a) 437°C ; (b) $3\,000^\circ\text{C}$; no | P19.48 | (a) see the solution; (b) $\alpha \ll \beta$ |
| P19.20 | (a) $2.52 \times 10^6 \text{ N/m}^2$; (b) no | P19.50 | (a) 0.169 m; (b) $1.35 \times 10^5 \text{ Pa}$ |
| P19.22 | 0.812 cm^3 | P19.52 | 6.57 MPa |
| P19.24 | (a) 396 N; (b) -101°C ; (c) no change | P19.54 | (a) $\theta = \frac{(\alpha_2 - \alpha_1)L_i\Delta T}{\Delta r}$; (b) see the solution; (c) it bends the other way; (d) 0.830° |
| P19.26 | (a) 2.99 mol; (b) $1.80 \times 10^{24} \text{ molecules}$ | P19.56 | (a) increase by $95.0 \mu\text{s}$; (b) loses 57.5 s |
| P19.28 | 884 balloons | P19.58 | (a) $B = \rho g P_0 V_i (P_0 + \rho g d)^{-1}$ up; (b) decrease; (c) 10.3 m |
| P19.30 | (a) $1.06 \times 10^{21} \text{ kg}$; (b) 56.9 K | | |

574 *Temperature***P19.60** (a) yes; see the solution; (b) 25.7 rad/s**P19.62** $y \approx L(2\alpha\Delta T)^{1/2}$ **P19.64** (a) see the solution;
(b) $3.66 \times 10^{-3} \text{ K}^{-1}$, within 0.06% and 0.2% of the experimental values**P19.66** (a) 79.1 kPa for N_2 ; 21.2 kPa for O_2 ;
940 Pa for Ar; 33.3 Pa for CO_2 ;
(b) 81.7 L; 1.22 kg/m³; (c) 29.0 g/mol**P19.68** (a) 7.06 mm; (b) 297 K**P19.70** 125 N; $-42.0 \mu\text{m}$ **P19.72** 1.12 atm**P19.74** (a), (b), (c) see the solution; (d) 0.275 mm;
(e) see the solution