Chapter 10

Answers to Even Numbered Problems

2. (a) \(-251^\circ C\) (b) 1.36 atm
4. 56.7°C, -62.1°C
6. (a) \(-273^\circ C\) (b) 1.27 atm, 1.74 atm
8. (a) 810°F (b) 450 K
10. (a) 263°C (b) \(-262^\circ C\)
12. (a) \(L = 1.3\ m - 0.49\ m\) (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) \(2.5 \times 10^6\ Pa\) (b) It will not fracture.
26. (a) 994 cm³ (b) 0.943 cm
28. (a) 3.0 mol (b) \(1.8 \times 10^{24}\) molecules
30. 884 balloons
32. 0.131 kg/m³
34. 3.84 m
36. 36.5 kN
38. (a) 3.74 kJ/mol (b) 1.93 km/s
40. \(\left(v_{\text{rms}}\right)_{\text{H}_2} = 1.73\ \text{km/s}\) (b) \(\left(v_{\text{rms}}\right)_{\text{CO}_2} = 0.369\ \text{km/s}\)
   (c) Hydrogen escapes; carbon dioxide does not.
42. \(3.34 \times 10^6\ Pa\)
44. 18 kPa

46. (a) $1.4 \times 10^{-2}$ cm  
    (b) $6.8 \times 10^{-4}$ cm  
    (c) $3.2 \times 10^{-2}$ 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. $L_{\text{max}} = 14.2$ cm, $L_{\text{copper}} = 9.2$ cm

58. (a) 16.9 cm  
    (b) $1.35 \times 10^5$ Pa

60. 1.15 atm

62. (a) 6.0 cm  
    (b) The stress on the span would be $4.8 \times 10^6$ Pa, so it will not crumble
10.3 (a) Converting from Celsius to Fahrenheit, 

\[ T_F = \frac{9}{5}T_c + 32 = \frac{9}{5}(-252.87) + 32 = -423.0^\circ F \]

and converting to Kelvin, 

\[ T = T_c + 273.15 = -252.87 + 273.15 = 20.28 K \]

(b) 

\[ T_F = \frac{9}{5}T_c + 32 = \frac{9}{5}(20) + 32 = 68^\circ F \]

and 

\[ T = T_c + 273.15 = 20 + 273.15 = 293 K \]

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:

\[ 0.900 \text{ atm} = A + B(-80^\circ C) \]

and

\[ 1.635 \text{ atm} = A + B(78^\circ C) \]

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

\[ A = 1.27 \text{ atm}, \quad \text{and} \quad B = 4.65 \times 10^{-3} \text{ atm} / ^\circ C \]

Therefore, 

\[ P = 1.27 \text{ atm} + (4.65 \times 10^{-3} \text{ atm} / ^\circ C)T_c \]

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

\[ T_c = \frac{-1.27 \text{ atm}}{4.65 \times 10^{-3} \text{ atm} / ^\circ C} = -273^\circ C \]

(b) At the freezing point of water, \( T_c = 0 \) and 

\[ P = 1.27 \text{ atm} + 0 = 1.27 \text{ atm} \]

At the boiling point of water, \( T_c = 100^\circ C \), so 

\[ P = 1.27 \text{ atm} + (4.65 \times 10^{-3} \text{ atm} / ^\circ C)(100^\circ C) = 1.74 \text{ atm} \]

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 

\[ L = (L_0)_{tape} \left[ 1 + \alpha_{al} (\Delta T) \right] = (L_0)_{aluminum} \left[ 1 + \alpha_{al} (\Delta T) \right], \] 

which gives 

\[ (L_0)_{tape} = \frac{(L_0)_{aluminum} \left[ 1 + \alpha_{al} (\Delta T) \right]}{1 + \alpha_{al} (\Delta T)} \]
or \( L_0 \) \(_{\text{pipe}} = \frac{18.700 \text{ m} \left[1 + \left(24 \times 10^{-6} \text{ °C}^{-1}\right)(29.4 \text{ °C} - 21.2 \text{ °C})\right]}{1 + \left(11 \times 10^{-6} \text{ °C}^{-1}\right)(29.4 \text{ °C} - 21.2 \text{ °C})} = 18.702 \text{ m}

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

\[
\Delta L = \alpha L_0 (\Delta T) = \left(17 \times 10^{-6} \text{ °C}^{-1}\right)(5.0 \text{ m})(46 \text{ °C} - 20 \text{ °C}) = 2.21 \times 10^{-3} \text{ m}
\]

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

\[
\Delta L \text{ per tick} = \Delta L/18 = \left(2.21 \times 10^{-3} \text{ m}\right)/18 = 1.23 \times 10^{-4} \text{ m} = 0.12 \text{ mm}
\]

(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, \( Y = \frac{F}{A/L} \), as

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

10.25 (a) The gap width is a linear dimension, so it increases in “thermal enlargement” as the temperature goes up.

(b) At 190°C, the length of the piece of steel that is missing, or has been removed to create the gap, is \( L = L_0 + \Delta L = L_0 \left[1 + \alpha(\Delta T)\right] \). This gives

\[
L = (1.600 \text{ cm})\left[1 + \left(11 \times 10^{-6} \text{ °C}^{-1}\right)(190 \text{ °C} - 30 \text{ °C})\right] = 1.603 \text{ cm}
\]

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

\[
\frac{P_i}{T_i} = \frac{P_f}{T_f} \quad \text{or} \quad T_f = T_i \left(\frac{P_f}{P_i}\right) = (300 \text{ K})\left(\frac{3P_i}{P_f}\right) = 900 \text{ K} = 627 \text{ °C}
\]

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

\[
T_f = T_i \left(\frac{P_fV_f}{P_iV_i}\right) = T_i \left(\frac{2P_i(2V_i)}{P_fV_i}\right) = 4T_i = 4(300 \text{ K}) = 1200 \text{ K} = 927 \text{ °C}
\]

10.29 (a) \( n = \frac{PV}{RT} = \frac{1.013 \times 10^5 \text{ Pa}/\text{atm}}{(8.31 \text{ J/mol·K})(293 \text{ K})} \left(1.0 \times 10^{-6} \text{ m}^3\right) = 4.2 \times 10^{-5} \text{ m} \cdot \text{ol} \)
Thus, \( N = n \cdot N_A \)

\[ = \left( 4.2 \times 10^{-5} \ \text{mol} \right) \left( 6.02 \times 10^{23} \ \text{molecules/mol} \right) = 2.5 \times 10^{19} \ \text{molecules} \]

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

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

10.31 From the ideal gas law, \( PV = nRT \), with \( n_2 = n_1 \), we have

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

10.33 With \( n \) held constant, the ideal gas law gives

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

Since the volume of a sphere is \( V = \frac{4}{3} \pi r^3 \), \( \frac{V_1}{V_2} = \left( \frac{r_1}{r_2} \right)^3 \)

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

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

\[ P_2 = P_{\text{atm}} + \rho g h \]

\[ = 1.013 \times 10^5 \ \text{Pa} + (1.025 \ \text{kg/m}^3)(9.80 \ \text{m/s}^2)(220 \ \text{m}) = 2.31 \times 10^6 \ \text{Pa} \]

At pressure \( P_1 = 1 \ \text{atm} = 1.013 \times 10^5 \ \text{Pa} \), the air in the bell occupies a volume

\[ V_1 = \frac{4}{3} \pi r_1^3 h_1 = \pi (1.50 \ \text{m}) \left( 4.00 \ \text{m} \right) = 28.3 \ \text{m}^3 \]

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

\[ V_2 = \left( \frac{P_2}{P_1} \right) \left( \frac{T_2}{T_1} \right) V_1 = \left( \frac{1.013 \times 10^5 \ \text{Pa}}{2.31 \times 10^6 \ \text{Pa}} \right) \left( \frac{278 \ \text{K}}{298 \ \text{K}} \right) (28.3 \ \text{m}^3) = 1.16 \ \text{m}^3 \]

The height of this cylindrical volume is \( h_2 = \frac{V_2}{\frac{4}{3} \pi r^2} = \frac{1.16 \ \text{m}^3}{\pi (1.50 \ \text{m})^2} = 0.164 \ \text{m} \)

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

\[ \Delta h = h_1 - h_2 = 4.00 \ \text{m} - 0.164 \ \text{m} = 3.84 \ \text{m} \]

10.37 The average kinetic energy of the molecules of any gas at 300 K is
\[
KE = \frac{1}{2}m v^2 = \frac{3}{2}k_b T = \frac{3}{2}\left(1.38 \times 10^{-23} \text{ J/K}\right)(300 \text{ K}) = 6.21 \times 10^{-21} \text{ J}
\]

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

\[
F_{av} = \frac{\Delta \mathbf{p}_{\text{bullet}}}{\Delta t} = \frac{150 m (v - v_0)}{\Delta t} = \frac{150(8.0 \times 10^{-3} \text{ kg})(400 \text{ m/s} - (-400 \text{ m/s})}{60 \text{ s}} = 16 \text{ N}
\]

10.45 As the pipe undergoes a temperature change \( \Delta T = 46.5^\circ \text{C} - 18^\circ \text{C} = 28.5^\circ \text{C} \), the expansion of the horizontal segment is

\[
\Delta L_x = \alpha L_{0x} (\Delta T) = \left[17 \times 10^{-6} \left(^\circ \text{C}\right)^{-1}\right](28.0 \text{ cm})(28.5^\circ \text{C}) = 1.36 \times 10^{-2} \text{ cm} = 0.136 \text{ mm}
\]

The expansion of the vertical section is

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

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

\[
\theta = \tan^{-1}\left(\frac{\Delta L}{\Delta L_x}\right) = \tan^{-1}\left(\frac{0.649 \text{ mm}}{0.136 \text{ mm}}\right) = 78.2^\circ
\]

or

\[
\Delta L = 0.663 \text{ mm at } 78.2^\circ \text{ below the horizontal}
\]

10.50 When gas supports the piston in equilibrium, the gauge pressure of the gas is

\[
P_{\text{gauge}} = \frac{F}{A} = \frac{mg}{A} = \frac{5.0 \text{ kg} \left(9.80 \text{ m/s}^2\right)}{0.050 \text{ m}^2} = 9.8 \times 10^2 \text{ Pa}, \text{ and the absolute pressure is}
\]

\[
P = P_{\text{atm}} + P_{\text{gauge}} = \left(1.013 \times 10^5 + 9.8 \times 10^2\right) \text{ Pa}
\]

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

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

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

\[
\Delta h = \frac{V_{\text{overflow}}}{A} = \left[ \frac{V_v}{A} (\beta - 3\alpha) (\Delta T) \right]
\]

(b) For a mercury thermometer, \( \beta_{\text{Hg}} = 1.82 \times 10^{-4} \text{ (°C)}^{-1} \) and (assuming Pyrex glass), \( 3\alpha_{\text{glass}} = 3 \left( 3.2 \times 10^{-6} \text{ (°C)}^{-1} \right) = 9.6 \times 10^{-6} \text{ (°C)}^{-1} \). Thus, the expansion of the mercury is almost 20 times the expansion of the flask, making it a rather good approximation to neglect the expansion of the flask.

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,

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

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

The initial conditions are:

<table>
<thead>
<tr>
<th>Initial Conditions</th>
</tr>
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<tbody>
<tr>
<td>( P_1 = 1 \text{ atm} )</td>
</tr>
<tr>
<td>( V_1 = 5.00 \text{ L} = 5.00 \times 10^{-3} \text{ m}^3 )</td>
</tr>
<tr>
<td>( T_1 = 20.0 \text{ °C} = 293 \text{ K} )</td>
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</tbody>
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The final conditions are:

<table>
<thead>
<tr>
<th>Final Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_2 = 1 \text{ atm} + \frac{F}{A} = 1 \text{ atm} + \frac{k \cdot h}{A} )</td>
</tr>
<tr>
<td>( V_2 = V_1 + A \cdot h )</td>
</tr>
<tr>
<td>( T_2 = 250 \text{ °C} = 523 \text{ K} )</td>
</tr>
</tbody>
</table>

Thus,

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

or

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

Simplifying and using the quadratic formula yields
0.169 m = 16.9 cm

(b)  
\[ P_2 = 1 \text{ atm} + \frac{k \cdot h}{A} \]

\[ = 1.013 \times 10^5 \text{ Pa} + \left( \frac{2.00 \times 10^3 \text{ N/m}}{0.0100 \text{ m}^2} \right) (0.169 \text{ m}) = 1.35 \times 10^5 \text{ Pa} \]

10.60  Let container 1 be maintained at \( T_1 = T_0 = 0^\circ \text{C} = 273 \text{ K} \), while the temperature of container 2 is raised to \( T_2 = 100^\circ \text{C} = 373 \text{ K} \). Both containers have the same constant volume, \( V \), and the same initial pressures, \( (P_0)_1 = (P_0)_2 = P_0 \). 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

\[ n_2 + n_1 = (n_0)_2 + (n_0)_1 \]

(1)

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

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

Thus,

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

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

\[ |\Delta V| = \beta V_0 |\Delta T| = (9.6 \times 10^{-4} \text{ °C}^{-1})(10 \text{ gallon})(20^\circ \text{C}) = 0.19 \text{ gallon} \]

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

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