18.16 Three moles of an ideal gas are in a rigid cubical box with sides of length 0.2m. (a) what is the force that the gas exerts on each of the six sides of the box when the gas temperature is 20°C? (b) What is the force when the temperature of the gas is increased to 100°C?

\[ n = 3 \text{ moles} \]
\[ T = 20^\circ C = 293 K \]
\[ V = (0.2\ m)^3 = 0.008 \ m^3 \]
\[ pV = nRT \quad R = 8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}} \]
\[ p = \frac{nRT}{V} = 913.061 \frac{\text{N} \cdot \text{m}^2}{\text{m}^3} \]

(a) \[ P = \frac{F}{A} \quad \Rightarrow \quad F = P \cdot A = (913.061 \frac{\text{N} \cdot \text{m}^2}{\text{m}^3})(0.008 \text{ m}^2) \]
\[ F = 36,522 \text{ N} \]

(b) \[ T = 100^\circ C = 373 K \]
\[ F = \frac{373}{293} (36,522 N) = 46,494 N \]
18.36 The atmosphere of Mars is mostly CO\(_2\) (molar mass 44 g/mol) under a pressure of 650 Pa, which we shall assume remains constant. In many places the temperature varies from 0\(^{\circ}\)C in summer to -100\(^{\circ}\)C in winter. Over the course of a martian year, what are the ranges of (a) the rms speeds of the CO\(_2\) molecules, and (b) the density (in mol/m\(^3\)) of the atmosphere?

Given: \[ \text{CO}_2 \quad \text{has} \quad M = 44 \frac{\text{g}}{\text{mol}} = 4.4 \times 10^{-3} \frac{\text{kg}}{\text{mol}} \]

\[ P = 650 \text{ Pa} \]

\[ T_{\text{winter}} = -100^{\circ}\text{C} = 173 \text{K} \]

\[ T_{\text{summer}} = 0^{\circ}\text{C} = 273 \text{K} \]

\(a\) RMS speed is given by \[ V_{\text{rms}} = \sqrt{\frac{3RT}{M}} \]

Using \[ R = 8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}} \]

\[ V_{\text{rms, winter}} = \sqrt{\frac{3(8.314)(173)}{4.4 \times 10^{-3}}} = 313 \frac{\text{m}}{\text{s}} \]

\[ V_{\text{rms, summer}} = \sqrt{\frac{3(8.314)(273)}{4.4 \times 10^{-3}}} = 393 \frac{\text{m}}{\text{s}} \]

\(b\) USE \[ \frac{PV}{RT} \]

We want \[ \frac{\text{moles}}{\text{m}^3} \] so solve for \[ \frac{\text{n}}{V} \]

\[ \frac{n}{V} = \frac{P}{RT} \]

Winter: \[ \frac{n}{V} = \frac{650 \text{ Pa}}{(8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}})(173 \text{K})} = 0.45 \frac{\text{mol}}{\text{m}^3} \]

Summer: \[ \frac{n}{V} = \frac{650 \text{ Pa}}{(8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}})(273 \text{K})} = 0.29 \frac{\text{mol}}{\text{m}^3} \]
18.41 (a) How much heat does it take to increase the temperature of 2.5 mol of a diatomic gas by 30K near room temperature if the gas is held at constant volume? (b) What is the answer to the question in part (a) if the gas is monatomic rather than diatomic?

\[ Q = n \cdot C_v \cdot \Delta T = (2.5 \text{ mol}) \left( \frac{5}{2} R \right) (30 \text{ K}) \]

Using \( R = 8.314 \ \text{J/mol K} \)

\[ Q = 1560 \text{ J} \]

If the gas is monatomic instead, \( C_v = \frac{3}{2} R \)

\[ Q = (2.5 \text{ mol}) \left( \frac{3}{2} R \right) (30 \text{ K}) = 935 \text{ J} \]
18.43. (a) Compute the specific heat capacity at constant volume of nitrogen \((N_2)\) gas, and compare with the specific heat capacity of liquid water. The molar mass of \(N_2\) is 28.0 g/mol. (b) You warm 1.00 kg of water at a constant volume of 1.00 L from 20.0°C to 30.0°C in a kettle. For the same amount of heat, how many kilograms of 20.0°C air would you be able to warm to 30.0°C? What volume (in liters) would this air occupy at 20.0°C and a pressure of 1.00 atm? Make the simplifying assumption that air is 100% \(N_2\).

\[
M_{N_2} = 28.014 \frac{g}{mol} = 28.014 \times 10^{-3} \frac{kg}{mol}
\]

(a) 
\[
C_v = 20.76 \frac{J}{mol \cdot K} \quad \text{(Table 18.1, pg. 626)}
\]

\[
C = \frac{20.76 \frac{J}{mol \cdot K}}{28.014 \times 10^{-3} \frac{kg}{mol}} = \boxed{741 \frac{J}{kg \cdot K}} \quad \text{for } N_2
\]

This compares to 
\[
C = 4.190 \frac{J}{kg \cdot K} \quad \text{for water}
\]

(b) 1 kg water at constant 1.00 L volume warmed from 20°C to 30°C

\[
Q = mc\Delta T = (1 \text{kg})(4190 \frac{J}{kg \cdot K})(10 \text{K}) = 41,900 \text{ J}
\]

Same \(Q\), now warm \(N_2\) instead:

\[
41,900 \text{ J} = m \left(741 \frac{J}{kg \cdot K}\right)(10 \text{K}) \Rightarrow m = 5.65 \text{ kg}
\]

What volume? (in liters)

Use \(PV = nRT\)

\[
v = \frac{5.65 \text{ kg}}{28.014 \times 10^{-3} \frac{kg}{mol}} = 202 \text{ mol}
\]

\[
r = 0.08206 \frac{L \cdot atm}{mol \cdot K}
\]

\[
V = \frac{(202)(0.08206 \times 293 \text{ K})}{1 \text{ atm}} = 48.57 \text{ L}
\]
18.62. A vertical cylindrical tank contains 1.80 mol of an ideal gas under a pressure of 1.00 atm at 20.0°C. The round part of the tank has a radius of 10.0 cm, and the gas is supporting a piston that can move up and down in the cylinder without friction. (a) What is the mass of this piston? (b) How tall is the column of gas that is supporting the piston?

(a) Mass of piston?

\[ F = \frac{P \times A}{G} = \text{weight of piston} = mg \]

\[ m = \frac{PA}{g} = \left(1.0 \times 10^5 \text{ Pa}\right) \left(\pi \times (0.1 \text{ m})^2 \right) \]

\[ m = 324 \text{ kg} \]

(b) How tall is the column of gas?

Assume ideal gas, so \( PV = nRT \)

\[ V = \frac{(1.8 \text{ mol}) (8.31 \text{ J/mol K})(293 \text{ K})}{1.01 \times 10^5 \text{ Pa}} \]

\[ V = 0.0434 \text{ m}^3 \]

\[ V_{cylinder} = \pi R^2 \cdot h \]

\[ h = \frac{0.0434 \text{ m}^3}{\pi \times (0.1 \text{ m})^2} = 1.38 \text{ m} \]
18.63. A large tank of water has a hose connected to it, as shown in Fig. 18.29. The tank is sealed at the top and has compressed air between the water surface and the top. When the water height \( h \) has the value 3.50 m, the absolute pressure \( p \) of the compressed air is \( 4.20 \times 10^5 \) Pa. Assume that the air above the water expands at constant temperature, and take the atmospheric pressure to be \( 1.00 \times 10^5 \) Pa. (a) What is the speed with which water flows out of the hose when \( h = 3.50 \) m? (b) As water flows out of the tank, \( h \) decreases. Calculate the speed of flow for \( h = 3.00 \) m and for \( h = 2.00 \) m. (c) At what value of \( h \) does the flow stop?

\[ V_2 = 26.2 \text{ m/s} \]

**Figure 18.29** Problem 18.63.

- **a)** Use Bernoulli's equation:
  - \( P_1 + \rho g y_1 + \frac{1}{2} \rho V_1^2 = P_2 + \rho g y_2 + \frac{1}{2} \rho V_2^2 \)
  - **i)** At the top, \( P_1 = 4.2 \times 10^5 \) Pa
    - \( V_1 = 0 \)
    - \( y_1 = 2.5 \) m
  - **ii)** At the hose, \( P_2 = 1 \times 10^5 \) Pa
    - \( V_2 = ? \)
    - \( y_2 = 0 \)
  - \( \rho = 1000 \text{ kg/m}^3 \) (water)

- Air above will expand at constant temp.
b) For different heights, use $PV = nRT$ to find new pressure:

$n, R, \text{ and } T$ are fixed, so $P_A = P_B V_B$

Volume $= \pi r^2(4-h)$, so $P_A (4-h_A) = P_B (4-h_B)$

Using $P_A = 4.2 \times 10^5 \text{ Pa}$ and $h_A = 3.5 \text{ m}$,

$h_B = 3.0 \text{ m}$ gives

$P_B = 2.1 \times 10^5 \text{ Pa}$ - new value for $P_1$

Using Bernoulli again, as in part a) gives:

$V_2 = 16.1 \text{ m/s}$

$V_2 = 5.44 \text{ m/s}$

18.63

c) Setting $V_2 = 0$ in Bernoulli's Eqn:

$P_1 + \rho g y_1 = P_2$

$P_1 + (1000 \frac{kg}{m^3})(9.81 \text{ m/s}^2)(4-1.8) \times 10^5$

Get $P_1 = (4.2 \times 10^5 \text{ Pa}) (4-3.5) \over 4-h$ from part b)

Substitute this and do some algebra to get a

Quadratic formula:

$h^2 - 15.2h + 23.29 = 0$

$h = 1.74 \text{ m}$