

$$17.16. \quad \Delta T = \frac{\Delta L}{\alpha L_0} = \frac{0.471 \text{ ft}}{[1.2 \times 10^{-5} (\text{C}^\circ)^{-1}][1671 \text{ ft}]} = 23.5 \text{ C}^\circ. \quad T_2 = 15.5^\circ\text{C} + 23.5 \text{ C}^\circ = 39.0^\circ\text{C}.$$

$$17.36. \quad (\text{a}) \quad Q = mc\Delta T$$

$$m = \frac{1}{2}(1.3 \times 10^{-3} \text{ kg}) = 0.65 \times 10^{-3} \text{ kg}$$

$$Q = (0.65 \times 10^{-3} \text{ kg})(1020 \text{ J/kg} \cdot \text{K})(37^\circ\text{C} - (-20^\circ\text{C})) = 38 \text{ J}$$

$$(\text{b}) \quad 20 \text{ breaths/min} \quad (60 \text{ min/1 h}) = 1200 \text{ breaths/h}$$

$$\text{So } Q = (1200)(38 \text{ J}) = 4.6 \times 10^4 \text{ J}.$$

The heat loss rate is  $Q/t = 13 \text{ W}$ .

$$17.99. \quad \text{The mass of air in the room is } m = \rho V = (1.20 \text{ kg/m}^3)(3200 \text{ m}^3) = 3840 \text{ kg}. \quad 1 \text{ W} = 1 \text{ J/s}.$$

$$(\text{a}) \quad Q = (3000 \text{ s})(90 \text{ students})(100 \text{ J/s} \cdot \text{student}) = 2.70 \times 10^7 \text{ J}.$$

$$(\text{b}) \quad Q = mc\Delta T. \quad \Delta T = \frac{Q}{mc} = \frac{2.70 \times 10^7 \text{ J}}{(3840 \text{ kg})(1020 \text{ J/kg} \cdot \text{K})} = 6.89 \text{ C}^\circ$$

$$(\text{c}) \quad \Delta T = (6.89 \text{ C}^\circ) \left( \frac{280 \text{ W}}{100 \text{ W}} \right) = 19.3 \text{ C}^\circ.$$

In the absence of a cooling mechanism for the air, the air temperature would rise significantly.

$$17.100. \quad dQ = nCdT \text{ so for the temperature change } T_1 \rightarrow T_2, \quad Q = n \int_{T_1}^{T_2} C(T)dT.$$

$$\int dT = T \text{ and } \int TdT = \frac{1}{2}T^2. \text{ Express } T_1 \text{ and } T_2 \text{ in kelvins: } T_1 = 300 \text{ K}, \quad T_2 = 500 \text{ K}.$$

Denoting  $C$  by  $C = a + bT$ ,  $a$  and  $b$  independent of temperature, integration gives  $Q = n \left( a(T_2 - T_1) + \frac{b}{2}(T_2^2 - T_1^2) \right)$ .

$$Q = (3.00 \text{ mol})(29.5 \text{ J/mol} \cdot \text{K})(500 \text{ K} - 300 \text{ K}) + (4.10 \times 10^{-3} \text{ J/mol} \cdot \text{K}^2)((500 \text{ K})^2 - (300 \text{ K})^2).$$

$$Q = 1.97 \times 10^4 \text{ J}.$$

$$18.7. \quad pV = nRT \text{ and } n, R \text{ constant implies } pV/T = nR = \text{constant} \text{ and } p_1V_1/T_1 = p_2V_2/T_2$$

$$T_1 = (27 + 273) \text{ K} = 300 \text{ K}$$

$$p_1 = 1.01 \times 10^5 \text{ Pa}$$

$$p_2 = 2.72 \times 10^6 \text{ Pa} + 1.01 \times 10^5 \text{ Pa} = 2.82 \times 10^6 \text{ Pa} \text{ (in the ideal gas equation the pressures must be absolute, not gauge, pressures)}$$

$$T_2 = T_1 \left( \frac{p_2}{p_1} \right) \left( \frac{V_2}{V_1} \right) = 300 \text{ K} \left( \frac{2.82 \times 10^6 \text{ Pa}}{1.01 \times 10^5 \text{ Pa}} \right) \left( \frac{46.2 \text{ cm}^3}{499 \text{ cm}^3} \right) = 776 \text{ K}$$

$$T_2 = (776 - 273)^\circ\text{C} = 503^\circ\text{C}$$

$$18.13. \quad pV = nRT.$$

$T$  is constant.

$$n, R, T \text{ are constant, so } pV = nRT = \text{constant}. \quad p_1V_1 = p_2V_2. \quad p_2 = p_1 \left( \frac{V_1}{V_2} \right) = (1.00 \text{ atm}) \left( \frac{6.00 \text{ L}}{5.70 \text{ L}} \right) = 1.05 \text{ atm}.$$

$$18.15. \quad (\text{a}) \quad pV = nRT. \text{ Find the initial pressure } p_1:$$

$$p_1 = \frac{nRT_1}{V} = \frac{(11.0 \text{ mol})(8.3145 \text{ J/mol} \cdot \text{K})(23.0 + 273.15 \text{ K})}{3.10 \times 10^{-3} \text{ m}^3} = 8.737 \times 10^6 \text{ Pa}$$

$$p_2 = 100 \text{ atm}(1.013 \times 10^5 \text{ Pa/1 atm}) = 1.013 \times 10^7 \text{ Pa}$$

$$p/T = nR/V = \text{constant, so } p_1/T_1 = p_2/T_2$$

$$T_2 = T_1 \left( \frac{p_2}{p_1} \right) = (296.15 \text{ K}) \left( \frac{1.013 \times 10^7 \text{ Pa}}{8.737 \times 10^6 \text{ Pa}} \right) = 343.4 \text{ K} = 70.2^\circ\text{C}$$

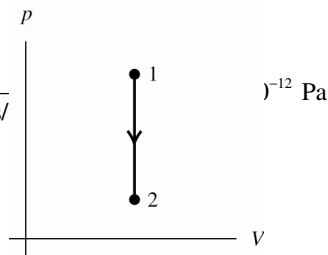
(b) The coefficient of volume expansion for a gas is much larger than for a solid, so the expansion of the tank is negligible.

$$18.25. \quad (\text{a}) \quad pV = nRT, \quad n = N/N_A \text{ so } pV = (N/N_A)RT$$

$$p = \left(\frac{N}{V}\right) \left(\frac{R}{N_A}\right) T$$

$$p = \left(\frac{80 \text{ molecules}}{1 \times 10^{-6} \text{ m}^3}\right) \left(\frac{8.3145 \text{ J/mol} \cdot \text{K}}{6.022 \times 10^{23} \text{ molecules/mol}}\right) T$$

$p = 8.2 \times 10^{-17} \text{ atm}$ . This is much lower than the laboratory pressure of  $1 \times 10^{-13} \text{ atm}$  in Exercise 18.24.



(b) The Lagoon Nebula is a very rarefied low pressure gas. The gas would exert *very* little force on an object passing through it.

18.33.  $pV = nRT = \frac{N}{N_A} RT = \frac{m_{\text{tot}}}{M} RT$ .

We know that  $V_A = V_B$  and that  $T_A > T_B$ .

(a)  $p = nRT/V$ ; we don't know  $n$  for each box, so either pressure could be higher.

(b)  $pV = \left(\frac{N}{N_A}\right) RT$  so  $N = \frac{pVN_A}{RT}$ , where  $N_A$  is Avogadro's number. We don't know how the pressures compare,

so either  $N$  could be larger.

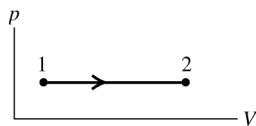
(c)  $pV = (m_{\text{tot}}/M) RT$ . We don't know the mass of the gas in each box, so they could contain the same gas or different gases.

(d)  $\frac{1}{2} m \langle v^2 \rangle_{\text{av}} = \frac{3}{2} kT$ .  $T_A > T_B$  and the average kinetic energy per molecule depends only on  $T$ , so the statement **must** be true.

(e)  $v_{\text{rms}} = \sqrt{3kT/m}$ . We don't know anything about the masses of the atoms of the gas in each box, so either set of molecules could have a larger  $v_{\text{rms}}$ .

Only statement (d) must be true. We need more information in order to determine whether the other statements are true or false.

19.1.(a) The pressure is constant and the volume increases.



(b)  $W = \int_{V_1}^{V_2} p \, dV$

Since  $p$  is constant,  $W = p \int_{V_1}^{V_2} dV = p(V_2 - V_1)$

The problem gives  $T$  rather than  $p$  and  $V$ , so use the ideal gas law to rewrite the expression for  $W$ .

$pV = nRT$  so  $p_1V_1 = nRT_1$ ,  $p_2V_2 = nRT_2$ ; subtracting the two equations gives

$p(V_2 - V_1) = nR(T_2 - T_1)$

Thus  $W = nR(T_2 - T_1)$  is an alternative expression for the work in a constant pressure process for an ideal gas.

Then  $W = nR(T_2 - T_1) = (2.00 \text{ mol})(8.3145 \text{ J/mol} \cdot \text{K})(107^\circ\text{C} - 27^\circ\text{C}) = +1330 \text{ J}$

The gas expands when heated and does positive work.

19.2.  $\Delta T = \frac{W}{nR} = \frac{1.75 \times 10^3 \text{ J}}{(6 \text{ mol})(8.3145 \text{ J/mol} \cdot \text{K})} = 35.1 \text{ K}$ .  $\Delta T_K = \Delta T_C$  and  $T_2 = 27.0^\circ\text{C} + 35.1^\circ\text{C} = 62.1^\circ\text{C}$ .

When  $W > 0$  the gas expands. When  $p$  is constant and  $V$  increases,  $T$  increases.

19.4. (a) The  $pV$  diagram is given in Figure 19.4.

(b) Since  $\Delta V = 0$ ,  $W = 0$ .

For any constant volume process the work done is zero.

Figure 19.4

- 19.10.** The type of process is not specified. We can use  $\Delta U = Q - W$  because this applies to all processes. Calculate  $\Delta U$  and then from it calculate  $\Delta T$ .  $Q$  is positive since heat goes into the gas;  $Q = +1200$  J

$W$  positive since gas expands;  $W = +2100$  J

$$\Delta U = 1200 \text{ J} - 2100 \text{ J} = -900 \text{ J}$$

We can also use  $\Delta U = n\left(\frac{3}{2}R\right)\Delta T$  since this is true for any process for an ideal gas.

$$\Delta T = \frac{2\Delta U}{3nR} = \frac{2(-900 \text{ J})}{3(5.00 \text{ mol})(8.3145 \text{ J/mol} \cdot \text{K})} = -14.4\text{C}^\circ$$

$$T_2 = T_1 + \Delta T = 127\text{C}^\circ - 14.4\text{C}^\circ = 113\text{C}^\circ$$

- 19.12.** (a)  $W = \int_{V_1}^{V_2} p \, dV = p(V_2 - V_1)$  for this constant pressure process.

$$W = (2.3 \times 10^5 \text{ Pa})(1.20 \text{ m}^3 - 1.70 \text{ m}^3) = -1.15 \times 10^5 \text{ J} \text{ (The volume decreases in the process, so } W \text{ is negative.)}$$

(b)  $\Delta U = Q - W$

$$Q = \Delta U + W = -1.40 \times 10^5 \text{ J} + (-1.15 \times 10^5 \text{ J}) = -2.55 \times 10^5 \text{ J}$$

$Q$  negative means heat flows out of the gas.

(c)  $W = \int_{V_1}^{V_2} p \, dV = p(V_2 - V_1)$  (constant pressure) and  $\Delta U = Q - W$  apply to *any* system, not just to an ideal gas.

We did not use the ideal gas equation, either directly or indirectly, in any of the calculations, so the results are the same whether the gas is ideal or not.

- 19.16.** Apply  $\Delta U = Q - W$ .  $|W|$  is the area under the path in the  $pV$ -plane.

$W > 0$  when  $V$  increases.

(a) The greatest work is done along the path that bounds the largest area above the  $V$ -axis in the  $p$ - $V$  plane, which is path 1. The least work is done along path 3.

(b)  $W > 0$  in all three cases;  $Q = \Delta U + W$ , so  $Q > 0$  for all three, with the greatest  $Q$  for the greatest work, that along path 1. When  $Q > 0$ , heat is absorbed.

$\Delta U$  is path independent and depends only on the initial and final states.  $W$  and  $Q$  are path independent and can have different values for different paths between the same initial and final states.

- 19.29.** (a)  $W = \int_{V_1}^{V_2} p \, dV$

$$pV = nRT \text{ so } p = nRT/V$$

$$W = \int_{V_1}^{V_2} (nRT/V) \, dV = nRT \int_{V_1}^{V_2} dV/V = nRT \ln(V_2/V_1) \text{ (work done during an isothermal process).}$$

$$W = (0.150 \text{ mol})(8.3145 \text{ J/mol} \cdot \text{K})(350 \text{ K}) \ln(0.25V_1/V_1) = (436.5 \text{ J}) \ln(0.25) = -605 \text{ J.}$$

$W$  for the gas is negative, since the volume decreases.

(b)  $\Delta U = nC_V\Delta T$  for any ideal gas process.

$$\Delta T = 0 \text{ (isothermal) so } \Delta U = 0.$$

$\Delta U = 0$  for any ideal gas process in which  $T$  doesn't change.

(c)  $\Delta U = Q - W$

$$\Delta U = 0 \text{ so } Q = W = -605 \text{ J. (} Q \text{ is negative; the gas liberates 605 J of heat to the surroundings.)}$$

$Q = nC_V\Delta T$  is only for a constant volume process so doesn't apply here.

$Q = nC_p\Delta T$  is only for a constant pressure process so doesn't apply here.

- 20.1.** For a heat engine,  $W = |Q_H| - |Q_C|$ .  $e = \frac{W}{Q_H}$ .  $Q_H > 0$ ,  $Q_C < 0$ .

$$W = 2200 \text{ J. } |Q_C| = 4300 \text{ J.}$$

(a)  $Q_H = W + |Q_C| = 6500 \text{ J.}$

(b)  $e = \frac{2200 \text{ J}}{6500 \text{ J}} = 0.34 = 34\%.$

Since the engine operates on a cycle, the net  $Q$  equal the net  $W$ . But to calculate the efficiency we use the heat energy input,  $Q_H$ .

- 20.3.** (a)  $e = \frac{\text{work output}}{\text{heat energy input}} = \frac{W}{Q_H} = \frac{3700 \text{ J}}{16,100 \text{ J}} = 0.23 = 23\%.$

(b)  $W = Q = |Q_H| - |Q_C|$

Heat discarded is  $|Q_C| = |Q_H| - W = 16,100 \text{ J} - 3700 \text{ J} = 12,400 \text{ J}$ .

(c)  $Q_H$  is supplied by burning fuel;  $Q_H = mL_c$  where  $L_c$  is the heat of combustion.

$$m = \frac{Q_H}{L_c} = \frac{16,100 \text{ J}}{4.60 \times 10^4 \text{ J/g}} = 0.350 \text{ g.}$$

(d)  $W = 3700 \text{ J}$  per cycle

In  $t = 1.00 \text{ s}$  the engine goes through 60.0 cycles.

$$P = W/t = 60.0(3700 \text{ J})/1.00 \text{ s} = 222 \text{ kW}$$

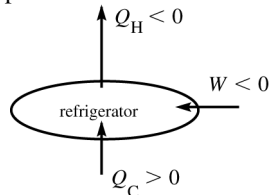
$$P = (2.22 \times 10^5 \text{ W})(1 \text{ hp}/746 \text{ W}) = 298 \text{ hp}$$

$Q_C = -12,400 \text{ J}$ . In one cycle  $Q_{\text{tot}} = Q_C + Q_H = 3700 \text{ J}$ . This equals  $W_{\text{tot}}$  for one cycle.

20.9. (a) Performance coefficient  $K = Q_C/|W|$  (Eq.20.9)

$$|W| = Q_C/K = 3.40 \times 10^4 \text{ J}/2.10 = 1.62 \times 10^4 \text{ J}$$

(b) The operation of the device is illustrated in Figure 20.9



$$W = Q_C + Q_H$$

$$Q_H = W - Q_C$$

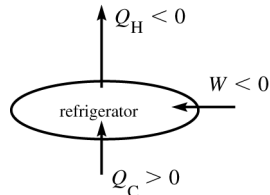
$$Q_H = -1.62 \times 10^4 \text{ J} - 3.40 \times 10^4 \text{ J} = -5.02 \times 10^4 \text{ J}$$

(negative because heat goes out of the system)

Figure 20.9

$|Q_H| = |W| + |Q_C|$ . The heat  $|Q_H|$  delivered to the high temperature reservoir is greater than the heat taken in from the low temperature reservoir.

20.16. (a) The operation of the device is sketched in Figure 20.16.



$$T_H = 24.0^\circ\text{C} = 297 \text{ K}$$

$$T_C = 0.0^\circ\text{C} = 273 \text{ K}$$

Figure 20.16

The amount of heat taken out of the water to make the liquid  $\rightarrow$  solid phase change is

$Q = -mL_f = -(85.0 \text{ kg})(334 \times 10^3 \text{ J/kg}) = -2.84 \times 10^7 \text{ J}$ . This amount of heat must go into the working substance of the refrigerator, so  $Q_C = +2.84 \times 10^7 \text{ J}$ . For Carnot cycle  $|Q_C|/|Q_H| = T_C/T_H$

$$|Q_H| = |Q_C|(T_H/T_C) = 2.84 \times 10^7 \text{ J}(297 \text{ K}/273 \text{ K}) = 3.09 \times 10^7 \text{ J}$$

(b)  $W = Q_C + Q_H = +2.84 \times 10^7 \text{ J} - 3.09 \times 10^7 \text{ J} = -2.5 \times 10^6 \text{ J}$

$W$  is negative because this much energy must be supplied to the refrigerator rather than obtained from it. Note that in Eq.(20.13) we must use Kelvin temperatures.

20.25. (a) The heat flow into the ice is  $Q = mL_f = (0.350 \text{ kg})(3.34 \times 10^5 \text{ J/kg}) = 1.17 \times 10^5 \text{ J}$ . The heat flow occurs at

$$T = 273 \text{ K, so } \Delta S = \frac{Q}{T} = \frac{1.17 \times 10^5 \text{ J}}{273 \text{ K}} = 429 \text{ J/K. } Q \text{ is positive and } \Delta S \text{ is positive.}$$

(b)  $Q = -1.17 \times 10^5 \text{ J}$  flows out of the heat source, at  $T = 298 \text{ K}$ .  $\Delta S = \frac{Q}{T} = \frac{-1.17 \times 10^5 \text{ J}}{298 \text{ K}} = -393 \text{ J/K}$ .  $Q$  is

negative and  $\Delta S$  is negative.

(c)  $\Delta S_{\text{tot}} = 429 \text{ J/K} + (-393 \text{ J/K}) = +36 \text{ J/K}$ .

For the total isolated system,  $\Delta S > 0$  and the process is irreversible.