Chapter 18

The Laws of Thermodynamics

Answers to Even-numbered Conceptual Questions

2.   From Equation 18-3, we can see that 300 J of heat must be added to this system.

4.   **(a)** Yes. Heat can flow into the system if at the same time the system expands, as in an isothermal expansion of a gas. **(b)** Yes. Heat can flow out of the system if at the same time the system is compressed, as in an isothermal compression of a gas.

6.   No. The heat might be added to a gas undergoing an isothermal expansion. In this case, there is no change in the temperature.

8.   Yes. In an isothermal expansion, all the heat added to the system to keep its temperature constant appears as work done by the system.

10.   The final temperature of an ideal gas in this situation is *T*; that is, there is no change in temperature. The reason is that as the gas expands into the vacuum is does no work – it has nothing to push against. The gas is also insulated, so no heat can flow into or out of the system. It follows that the internal energy of the gas is unchanged, which means that its temperature is unchanged as well.

12.   This would be a violation of the second law of thermodynamics, which states that heat always flows from a high-temperature object to a low-temperature object. If heat were to flow spontaneously between objects of equal temperature, the result would be objects at different temperatures. These objects could then be used to run a heat engine until they were again at the same temperature, after which the process could be repeated indefinitely.

14.   The work done from A to B is negative; the work done from B to C is positive; the work done from C to A is negative.

16.   Yes, this would be possible. The problem is that you would need low-temperature reservoirs of ever lower temperature to keep the process going.

18.   In principle, less energy would be required if the kitchen is cooler. The reason is that in this case the heat extracted from the water can be expelled at a lower temperature, which means that less work must be done by the refrigerator's engine.

20.   The entropy of the universe will increase if you rub your hands together, as in all frictional processes.

22.   Assuming a reversible, adiabatic expansion, there will be no increase in entropy because there is no heat exchange.

24.   The law of thermodynamics most pertinent to this situation is the second law, which states that physical processes move in the direction of increasing disorder. To decrease the disorder in one region of space requires work to be done, and a larger increase in disorder in another region of space.

Solutions to Problems

1. $Q = \boxed{-4.1 \times 10^5 \text{ J}}$

$W = \boxed{6.7 \times 10^5 \text{ J}}$

$\Delta U = Q - W = -4.1 \times 10^5 \text{ J} - 6.7 \times 10^5 \text{ J} = \boxed{-10.8 \times 10^5 \text{ J}}$

2. $W = Q - \Delta U$

$\quad = Q - \dfrac{3}{2} nR\Delta T$

$\quad = 1210 \text{ J} - \dfrac{3}{2}(1\,\text{mol})\left(8.31 \dfrac{\text{J}}{\text{mol}\cdot\text{k}}\right)(276\,\text{K} - 272\,\text{K})$

$\quad = \boxed{1160 \text{ J}}$

3. (a) $\Delta U = Q - W = 77 \text{ J} - (-42 \text{ J}) = \boxed{119 \text{ J}}$

   (b) $\Delta U = Q - W = 77 \text{ J} - 42 \text{ J} = \boxed{35 \text{ J}}$

   (c) $Q = \Delta U + W = -120 \text{ J} + 120 \text{ J} = \boxed{0}$

4. $\Delta U_{\text{AB}} + \Delta U_{\text{BC}} + \Delta U_{\text{CD}} + \Delta U_{\text{DA}} = 0$

$\Delta U_{\text{CD}} = -\Delta U_{\text{AB}} - \Delta U_{\text{BC}} - \Delta U_{\text{DA}} = -82 \text{ J} - 15 \text{ J} - (-56 \text{ J}) = \boxed{-41 \text{ J}}$

5. (a) $W_{\text{AB}} = P\Delta V_{\text{AB}} = P(0) = \boxed{0}$

   (b) $\Delta U_{\text{AB}} = Q_{\text{AB}} - W_{\text{AB}} = -53 \text{ J} - 0 = \boxed{-53 \text{ J}}$

   (c) $\Delta U_{\text{BC}} = Q_{\text{BC}} - W_{\text{BC}} = -280 \text{ J} - (-130 \text{ J}) = \boxed{-150 \text{ J}}$

   (d) $\Delta U_{\text{AB}} + \Delta U_{\text{BC}} + \Delta U_{\text{CA}} = 0$

$\qquad\qquad\quad \Delta U_{\text{CA}} = -\Delta U_{\text{AB}} - \Delta U_{\text{BC}}$

$\qquad\qquad\qquad\quad = -(-53 \text{ J}) - (-150 \text{ J})$

$\qquad\qquad\qquad\quad = \boxed{200 \text{ J}}$

   (e) $Q_{\text{CA}} = \Delta U_{\text{CA}} + W_{\text{CA}} = 200 \text{ J} + 150 \text{ J} = \boxed{350 \text{ J}}$

6. (a) $\qquad\qquad \Delta U = Q - W$

$\dfrac{3}{2} nR(T_{\text{f}} - T_{\text{i}}) = Q - W$

$T_{\text{f}} = \dfrac{2(Q - W)}{3nR} + T_{\text{i}} = \dfrac{2(3280 \text{ J} - 722 \text{ J})}{3(1\,\text{mol})\left(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)} + 283 \text{ K} = \boxed{488 \text{ K}}$

   (b) When there are more molecules to share the energy, the average energy gained per molecule is smaller, resulting in a $\boxed{\text{decrease}}$ in the final temperature found in part (a).

7. (a) Let Q', $\Delta U'$, and W' represent heat per mile, change in internal energy per mile, and work per mile, respectively.

$$Q'_{atm} = \Delta U'_g - W'_g = -\left(\frac{-1.19 \times 10^8 \frac{J}{gal}}{25.0 \frac{mi}{gal}}\right) - 5.20 \times 10^5 \frac{J}{mi} = \boxed{4.24 \text{ MJ/mi}}$$

   (b) Increasing miles per gallon improves efficiency, resulting in a $\boxed{\text{decrease}}$ of heat released to the atmosphere.

8. $Q = W + \Delta U = W + \frac{3}{2}nR\Delta T = -560 \text{ J} + \frac{3}{2}(4 \text{ mol})\left(8.31 \frac{J}{mol \cdot K}\right)(130\,^\circ C) = \boxed{5.9 \text{ kJ}}$

9. (a) $\Delta U = Q - W = -mL - W = -(0.110 \text{ kg})\left(2.26 \times 10^6 \frac{J}{kg}\right) - 2.13 \times 10^5 \text{ J} = \boxed{-462 \text{ kJ}}$

   (b) $(4.62 \times 10^5 \text{ J})\left(\frac{0.2389 \text{ cal}}{1 \text{ J}}\right) = \boxed{110 \text{ kcal}}$

10.
$$W = Q - \Delta U$$
$$P\Delta V = Q - \Delta U$$
$$\Delta V = \frac{Q - \Delta U}{P}$$

   (a) $\Delta V = \frac{820 \text{ J} - 820 \text{ J}}{110 \times 10^3 \text{ Pa}} = \boxed{0}$

   (b) $\Delta V = \frac{820 \text{ J} - 360 \text{ J}}{110 \times 10^3 \text{ Pa}} = \boxed{4.2 \times 10^{-3} \text{ m}^3}$

11.
$$P\Delta V = W$$
$$P(V_f - V_i) = W$$
$$P\left(\frac{V_i}{2} - V_i\right) = W$$
$$V_i = \frac{-2W}{P}$$
$$= \frac{-2(-760 \text{ J})}{120 \times 10^3 \text{ Pa}}$$
$$= \boxed{1.3 \times 10^{-2} \text{ m}^3}$$

12. $P(V_f - V_i) = W$
$$P = \frac{W}{V_f - V_i}$$
$$= \frac{93 \text{ J}}{2.3 \text{ m}^3 - 0.74 \text{ m}^3}$$
$$= \boxed{60 \text{ Pa}}$$

13. $P_i V_i^\gamma = P_f V_f^\gamma$

$$\frac{P_f}{P_i} = \left(\frac{V_i}{V_f}\right)^\gamma = \left(\frac{V_i}{2V_i}\right)^\gamma = \left(\frac{1}{2}\right)^{5/3} = \boxed{0.315}$$

14. **(a)** $W_{AB} = \sum P\Delta V$

$\qquad$ = area under P-V curve from A to B

$\qquad$ = $A_{rect} + A_{tri}$

$\qquad A_{rect} = lw$

$\qquad\qquad = \left(6\text{ m}^3 - 2\text{ m}^3\right)(200\text{ kPa})$

$\qquad\qquad = 800\text{ kJ}$

$\qquad A_{tri} = \dfrac{1}{2}bh$

$\qquad\qquad = \dfrac{1}{2}\left(6\text{ m}^3 - 4\text{ m}^3\right)(600\text{ kPa}-200\text{ kPa})$

$\qquad\qquad = 400\text{ kJ}$

$\qquad W_{AB} = 800\text{ kJ} + 400\text{ kJ} = \boxed{1200\text{ kJ}}$

$\quad$ **(b)** $\boxed{\text{No}}$, it only depends on the *P-V* curve.

15. **(a)** $W_{AC} = \sum P\Delta V$ = area under P-V curve from A to C = $A_{rect} + A_{tri,1} + A_{tri,2} + A_{square}$

$\qquad A_{rect} = lw = (10\text{ m}^3 - 2\text{ m}^3)(200\text{ kPa}) = 1600\text{ kJ}$

$\qquad A_{tri,1} = \dfrac{1}{2}bh = \dfrac{1}{2}(6\text{ m}^3 - 4\text{ m}^3)(600\text{ kPa} - 200\text{ kPa}) = 400\text{ kJ}$

$\qquad A_{tri,2} = \dfrac{1}{2}bh = \dfrac{1}{2}(8\text{ m}^3 - 6\text{ m}^3)(600\text{ kPa} - 400\text{ kPa}) = 200\text{ kJ}$

$\qquad A_{square} = wh = (8\text{ m}^3 - 6\text{ m}^3)(400\text{ kPa} - 200\text{ kPa}) = 400\text{ kJ}$

$\qquad W_{AC} = 1600\text{ kJ} + 400\text{ kJ} + 200\text{ kJ} + 400\text{ kJ} = \boxed{2.6\text{ MJ}}$

$\quad$ **(b)** $\dfrac{V_i}{T_i} = \dfrac{V_f}{T_f}$

$\qquad T_f = \dfrac{V_f}{V_i}T_i$

$\qquad\quad = \dfrac{10\text{ m}^3}{2\text{ m}^3}(220\text{ K})$

$\qquad\quad = \boxed{1100\text{ K}}$

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

$\quad = \dfrac{3}{2}nR\Delta T + W$

$\quad = \dfrac{3}{2}\left(\dfrac{P_iV_i}{RT_i}\right)R\Delta T + W$

$\quad = \dfrac{3}{2}\left[\dfrac{(200\text{ kPa})(2\text{ m}^3)}{220\text{ K}}\right](880\text{ K}) + 2.60\times10^6\text{ J}$

$\quad = \boxed{5.0\text{ MJ}}$

16. (a) The expansion of the gas at constant pressure implies that work was done by the gas. Heat is required for a gas to do work, therefore heat was $\boxed{\text{added}}$ to the system.

(b) $\dfrac{V_i}{T_i} = \dfrac{V_f}{T_f}$

$\quad T_f = \left(\dfrac{V_f}{V_i}\right)T_i$

$\quad PV_i = nRT_i$

$\quad T_i = \dfrac{PV_i}{nR}$

$\quad \Delta T = T_f - T_i$

$\qquad = \left(\dfrac{V_f}{V_i} - 1\right)T_i$

$\qquad = \left(\dfrac{V_f}{V_i} - 1\right)\dfrac{PV_i}{nR}$

$\qquad = (V_f - V_i)\dfrac{P}{nR}$

$\qquad = (3.30\text{ L} - 2.15\text{ L})\dfrac{1.01\times10^5\text{ Pa}}{(2.00\text{ mol})\left(8.31\ \frac{\text{J}}{\text{mol·K}}\right)}$

$\qquad = \boxed{6990\text{ K}}$

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

$\quad = \dfrac{3}{2}nR\Delta T + P\Delta V$

$\quad = \dfrac{3}{2}(2.00\text{ mol})\left(8.31\ \dfrac{\text{J}}{\text{mol·K}}\right)(6989\text{ K}) + (101\times10^3\text{ Pa})(3.30\text{ L} - 2.15\text{ L})$

$\quad = \boxed{290\text{ kJ}}$

17. (a) $W = nRT\ln\left(\dfrac{V_f}{V_i}\right) = (5.00\text{ mol})\left(8.31\ \dfrac{\text{J}}{\text{mol·K}}\right)(245\text{ K})\ln\left(\dfrac{4.33\text{ L}}{1.12\text{ L}}\right) = \boxed{13.8\text{ kJ}}$

(b) $Q = \Delta U + W = 0 + 13.8\text{ kJ} = \boxed{13.8\text{ kJ}}$

(c) Both answers $\boxed{\text{increase by a factor of 2}}$ because work is proportional to number of moles.

18. (a) $T_i = T_f = \dfrac{P_f V_f}{nR} = \dfrac{(100 \times 10^3 \text{ Pa})(4.00 \text{ m}^3)}{(145 \text{ mol})\left(8.31 \ \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{332 \times 10^4 \text{ K}}$

(b) $W = nRT \ \ln\left(\dfrac{V_f}{V_i}\right)$

$= nR\left(\dfrac{P_i V_i}{nR}\right) \ln\left(\dfrac{V_f}{V_i}\right)$

$= P_i V_i \ \ln\left(\dfrac{V_f}{V_i}\right)$

$= (400 \text{ kPa})(1.00 \text{ m}^3) \ln\left(\dfrac{4.00 \text{ m}^3}{1.00 \text{ m}^3}\right)$

$= \boxed{555 \text{ kJ}}$

19. (a) Since the temperature and internal energy do not change, heat must $\boxed{\text{enter}}$ the gas to make up for the energy used by the gas to do work.

(b) Heat input equals the work done; work done is equal to the area under the PV. The area from 1.00 m^3 to 2.00 m^3 is $\boxed{\text{greater}}$ than the area from 3.00 m^3 to 4.00 m^3.

(c) $Q = W = nRT \ln\left(\dfrac{V_f}{V_i}\right) = nR\left(\dfrac{P_i V_i}{nR}\right) \ln\left(\dfrac{V_f}{V_i}\right)$

$= P_i V_i \ \ln\left(\dfrac{V_f}{V_i}\right)$

$= (400 \text{ kPa})(1.00 \text{ m}^3) \ln\left(\dfrac{2.00 \text{ m}^3}{1.00 \text{ m}^3}\right)$

$= \boxed{277 \text{ kJ}}$

(d) $Q = W = nRT \ln\left(\dfrac{V_f}{V_i}\right) = nR\left(\dfrac{P_f V_f}{nR}\right) \ln\left(\dfrac{V_f}{V_i}\right)$

$= P_f V_f \ \ln\left(\dfrac{V_f}{V_i}\right)$

$= (100 \text{ kPa})(4.00 \text{ m}^3) \ln\left(\dfrac{4.00 \text{ m}^3}{3.00 \text{ m}^3}\right)$

$= \boxed{115 \text{ kJ}}$

20. (a) Heat is added to the system.

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

$$= \frac{3}{2}nR\Delta T + P\Delta V$$

$$= \frac{3}{2}nR\left(\frac{P\Delta V}{nR}\right) + P\Delta V$$

$$= \left(\frac{3}{2}P + P\right)\Delta V$$

$$= \frac{5}{2}P\Delta V$$

$$= \frac{5}{2}(160 \text{ kPa})(0.93 \text{ m}^3 - 0.76 \text{ m}^3)$$

$$= \boxed{68 \text{ kJ}}$$

21. (a) $W = nRT\ln\left(\dfrac{V_f}{V_i}\right) = (3 \text{ mol})\left(8.31\ \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(273.15 \text{ K} + 21 \text{ K})\ln\left(\dfrac{4V_i}{V_i}\right) = \boxed{10 \text{ kJ}}$

(b) $Q = \Delta U + W = 0 + 10 \text{ kJ} = \boxed{10 \text{ kJ}}$

22. (a) $\Delta U = Q - W > 0$
$\Delta U = 0 - W > 0$
$W < 0$
The work is done on the system.

(b) $W = -\Delta U = -(670 \text{ J}) = \boxed{-670 \text{ J}}$

23. (a) $W = Q - \Delta U$

$$= 0 - \frac{3}{2}nR\Delta T$$

$$= -\frac{3}{2}(5.50 \text{ mol})\left(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(215\,°\text{C} - 495\,°\text{C})$$

$$= \boxed{19.2 \text{ kJ}}$$

(b) Since the process is adiabatic, $Q = \boxed{0}$.

(c) $\Delta U = -W = \boxed{-19.2 \text{ kJ}}$

24. (a) $W = W_{AB} + W_{BC} + W_{CA}$

$$= \frac{1}{2}(3 \text{ m}^3)(100 \text{ kPa}) + (3 \text{ m}^3)(50 \text{ kPa}) + (-3 \text{ m}^3)(50 \text{ kPa}) + 0$$

$$= \boxed{150 \text{ kJ}}$$

(b) $\boxed{\Delta U = 0 \text{ over a complete cycle.}}$

(c) $Q = W + \Delta U = \boxed{150 \text{ kJ}}$

25. (a) $W = P\Delta V = (210 \text{ kPa})(1.9 \text{ m}^3 - 0.75 \text{ m}^3) = \boxed{240 \text{ kJ}}$

(b) $T = \dfrac{PV}{nR}$

$T_i = \dfrac{(210 \times 10^3 \text{ Pa})(0.75 \text{ m}^3)}{(49 \text{ mol})\left(8.31\frac{\text{J}}{\text{mol·K}}\right)} = \boxed{390 \text{ K}}$

$T_f = \dfrac{(210 \times 10^3 \text{ Pa})(1.9 \text{ m}^3)}{(49 \text{ mol})\left(8.31\frac{\text{J}}{\text{mol·k}}\right)} = \boxed{980 \text{ K}}$

(c) $\Delta U = \dfrac{3}{2}nR\Delta T = \dfrac{3}{2}nR\left(\dfrac{P\Delta V}{nR}\right) = \dfrac{3}{2}P\Delta V = \dfrac{3}{2}(210 \text{ kPa})(1.9 \text{ m}^3 - 0.75 \text{ m}^3) = \boxed{360 \text{ kJ}}$

(d) $Q = \Delta U + W = \dfrac{3}{2}P\Delta V + P\Delta V = \dfrac{5}{2}P\Delta V = \dfrac{5}{2}(210 \text{ kPa})(1.9 \text{ m}^3 - 0.75 \text{ m}^3) = \boxed{600 \text{ kJ}}$

26. (a) $T_A = \dfrac{P_A V_A}{nR} = \dfrac{(150 \text{ kPa})(1.00 \text{ m}^3)}{(57.5 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{314 \text{ K}}$

$T_B = \dfrac{P_B V_B}{nR} = \dfrac{(50 \text{ kPa})(4.00 \text{ m}^3)}{(57.5 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{419 \text{ K}}$

$T_C = \dfrac{P_C V_C}{nR} = \dfrac{(50 \text{ kPa})(1.00 \text{ m}^3)}{(57.5 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{105 \text{ K}}$

(b) $A \rightarrow B$: The temperature rises and the gas does work so heat $\boxed{\text{enters}}$ the system.

$B \rightarrow C$: The temperature drops and work is done on the gas so heat $\boxed{\text{leaves}}$ the system.

$C \rightarrow A$: The temperature rises and no work is done on or by the gas so heat $\boxed{\text{enters}}$ the system.

(c) $Q = \Delta U + W = \dfrac{3}{2}nR\Delta T + W$

$A \rightarrow B$: $Q = \dfrac{3}{2}(57.5 \text{ mol})\left(8.31 \ \dfrac{\text{J}}{\text{mol} \cdot \text{K}}\right)(419 \text{ K} - 314 \text{ K}) + \dfrac{1}{2}(150 \text{ kPa} + 50 \text{ kPa})(3.00 \text{ m}^3)$

$= \boxed{375 \text{ kJ}}$

$B \rightarrow C$: $Q = \dfrac{3}{2}(57.5 \text{ mol})\left(8.31 \ \dfrac{\text{J}}{\text{mol} \cdot \text{K}}\right)(105 \text{ K} - 419 \text{ K}) + (50 \text{ kPa})(-3.00 \text{ m}^3)$

$= \boxed{-375 \text{ kJ}}$

$C \rightarrow A$: $Q = \dfrac{3}{2}(57.5 \text{ mol})\left(8.31 \ \dfrac{\text{J}}{\text{mol} \cdot \text{K}}\right)(314 \text{ K} - 105 \text{ K}) + 0$

$= \boxed{150 \text{ kJ}}$

27. (a) $W = P(V_f - V_i) = P(2V_i - V_i) = PV_i = (120 \text{ kPa})(0.66 \text{ m}^3) = \boxed{79 \text{ kJ}}$

(b) $W = P(V_f - V_i) = P\left(\dfrac{V_i}{3} - V_i\right) = -\dfrac{2}{3}PV_i = -\dfrac{2}{3}(120 \text{ kPa})(0.66 \text{ m}^3) = \boxed{-53 \text{ kJ}}$

28. (a) $Q = \Delta U + W = \Delta U + P\Delta V = 65 \text{ J} + (105 \times 10^3 \text{ Pa})(0.75 \text{ m}^3) = \boxed{79 \text{ kJ; into the gas}}$

(b) $Q = \Delta U + P\Delta V = -1850 \text{ J} + (105 \times 10^3 \text{ Pa})(0.75 \text{ m}^3) = \boxed{77 \text{ kJ; into the gas}}$

29. (a) Doing work on the system must $\boxed{\text{increase}}$ the internal energy when no heat flows into or out of the system.

(b) $\dfrac{P_i V_i}{T_i} = \dfrac{P_f V_f}{T_f}$

$$T_f = \left(\frac{P_f}{P_i}\right)\left(\frac{V_f}{V_i}\right)T_i$$

For adiabatic processes, $P_i V_i^{\gamma} = P_f V_f^{\gamma}$, where $\gamma = \dfrac{5}{3}$.

$$\frac{V_f}{V_i} = \left(\frac{P_i}{P_f}\right)^{\frac{1}{\gamma}} = \left(\frac{P_f}{P_i}\right)^{-\frac{1}{\gamma}}$$
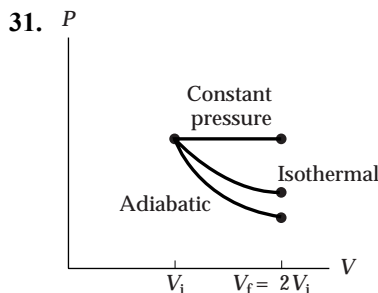
Substitute.

$$T_f = \left(\frac{P_f}{P_i}\right)\left(\frac{P_f}{P_i}\right)^{-\frac{1}{\gamma}} T_i = \left(\frac{P_f}{P_i}\right)^{1-\frac{1}{\gamma}} T_i = \left(\frac{140 \text{ kPa}}{110 \text{ kPa}}\right)^{\left(1-\frac{3}{5}\right)}(280 \text{ K}) = \boxed{310 \text{ K}}$$

30. (a) $W = \text{area under curve} = \dfrac{1}{2}(3V_i - V_i)(P_i + 2P_i) = \boxed{3P_i V_i}$

(b) $\Delta U = \dfrac{3}{2}nR\Delta T = \dfrac{3}{2}nR\left(\dfrac{\Delta(PV)}{nR}\right) = \dfrac{3}{2}\Delta(PV) = \dfrac{3}{2}\left[(2P_i)(3V_i) - P_i V_i\right] = \boxed{\dfrac{15}{2}P_i V_i}$

(c) $Q = \Delta U + W = \dfrac{15}{2}P_i V_i + 3P_i V_i = \boxed{\dfrac{21}{2}P_i V_i}$

31.

(a) The area under the $\boxed{\text{constant-pressure}}$ curve is the greatest, so that process does the most work.

(b) The area under the $\boxed{\text{adiabatic}}$ curve is the smallest, so that process does the least work.

(c) The $\boxed{\text{constant-pressure}}$ expansion, because for a given final volume, temperature varies with pressure.

(d) The $\boxed{\text{adiabatic}}$ expansion, since at final volume, temperature varies with pressure.

32. (a) $Q_p = \dfrac{5}{2} nR\Delta T = \dfrac{5}{2}(3.5 \text{ mol})\left(8.31 \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(23 \text{ K}) = \boxed{1.7 \text{ kJ}}$

(b) $Q_v = \dfrac{3}{2} nR\Delta T = \dfrac{3}{2}(3.5 \text{ mol})\left(8.31 \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(23 \text{ K}) = \boxed{1.0 \text{ kJ}}$

33. (a) $Q_v = \dfrac{3}{2} nR\Delta T$

$\Delta T = \dfrac{2Q_v}{3nR}$

$= \dfrac{2(570 \text{ J})}{3(45 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)}$

$= \boxed{1.0 \text{ K}}$

(b) $Q_p = \dfrac{5}{2} nR\Delta T$

$\Delta T = \dfrac{2Q_p}{5nR}$

$= \dfrac{2(570 \text{ J})}{5(45 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)}$

$= \boxed{0.61 \text{ K}}$

34. $\dfrac{U_i}{T_i} = \dfrac{3}{2} nR = \dfrac{U_f}{T_f}$

$T_f = \left(\dfrac{U_f}{U_i}\right) T_i = \left(\dfrac{2U_i}{U_i}\right) T_i = 2T_i$

(a) $Q_p = \dfrac{5}{2} nR(T_f - T_i)$

$= \dfrac{5}{2} nR(2T_i - T_i)$

$= \dfrac{5}{2} nRT_i$

$= \dfrac{5}{2}(2.5 \text{ mol})\left(8.31 \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(325 \text{ K})$

$= \boxed{17 \text{ kJ}}$

(b) $Q_v = \dfrac{3}{2} nR\Delta T = \dfrac{3}{2} nRT_i = \dfrac{3}{2}(2.5 \text{ mol})\left(8.31 \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(325 \text{ K}) = \boxed{10 \text{ kJ}}$

35. (a) $Q_p = \dfrac{5}{2}nR\Delta T$

$\Delta T = \dfrac{2Q_p}{5nR}$

$= \dfrac{2(130\ \text{J})}{5(2.8\ \text{mol})\left(8.31\ \frac{\text{J}}{\text{mol·K}}\right)}$

$= \boxed{2.2\ \text{K}}$

(b) $Q_v = \dfrac{3}{2}nR\Delta T$

$\Delta T = \dfrac{2Q_v}{3nR}$

$= \dfrac{2(130\ \text{J})}{3(2.8\ \text{mol})\left(8.31\ \frac{\text{J}}{\text{mol·K}}\right)}$

$= \boxed{3.7\ \text{K}}$

36. (a) No work is done by the gas so all the heat added results in an increase in internal energy. $\boxed{\text{Less}}$ heat is required.

(b) $\Delta T = \dfrac{Q_p}{\frac{5}{2}nR} = \dfrac{Q_v}{\frac{3}{2}nR}$

$Q_v = \dfrac{3}{5}Q_p = \dfrac{3}{5}(110\ \text{J}) = \boxed{66\ \text{J}}$

37. (a) $W = P\Delta V = (140\times10^3\ \text{Pa})(8600\ \text{cm}^3 - 5400\ \text{cm}^3)\left(\dfrac{1\times10^{-6}\ \text{m}^3}{\text{cm}^3}\right) = \boxed{0.45\ \text{kJ}}$

(b) Work is directly proportional to the change in volume. Therefore, the work done by the gas in the second expansion is $\boxed{\text{equal}}$ to that done in the first.

(c) $W = P\Delta V = (140\times10^3\ \text{Pa})(5400\ \text{cm}^3 - 2200\ \text{cm}^3)\left(\dfrac{1\times10^{-6}\ \text{m}^3}{\text{cm}^3}\right) = \boxed{0.45\ \text{kJ}}$

38. (a) $\dfrac{P_f}{P_i} = \left(\dfrac{V_i}{V_f}\right)^{\gamma} = \left(\dfrac{V_i}{2V_i}\right)^{5/3} = \left(\dfrac{1}{2}\right)^{5/3} = \boxed{0.315}$

(b) $\dfrac{T_f}{T_i} = \left(\dfrac{P_f}{P_i}\right)\left(\dfrac{V_f}{V_i}\right) = (0.315)(2) = \boxed{0.630}$

(c) $P_f = P_i \left(\dfrac{V_i}{V_f} \right)^{\gamma} = (330 \text{ kPa}) \left(\dfrac{1.2 \text{ m}^3}{2.4 \text{ m}^3} \right)^{5/3} = \boxed{100 \text{ kPa}}$

$\dfrac{P_f}{P_i} = \dfrac{104 \text{ kPa}}{330 \text{ kPa}} = 0.315$

$T_f = T_i \left(\dfrac{P_f}{P_i} \right) \left(\dfrac{V_f}{V_i} \right)$

$T_i = \dfrac{P_i V_i}{nR} = \dfrac{(330 \times 10^3 \text{ Pa})(1.2 \text{ m}^3)}{(135 \text{ mol}) \left(8.31 \frac{\text{J}}{\text{mol·K}} \right)} = 353 \text{ K}$

$T_f = (353 \text{ K})(0.315)(2) = \boxed{222 \text{ K}}$

39. (a) $P_i V_i^{\gamma} = P_f V_f^{\gamma}$

$\qquad V_f = \left(\dfrac{P_i}{P_f} \right)^{\frac{1}{\gamma}} V_i$

$\qquad\quad = \left(\dfrac{115 \text{ kPa}}{145 \text{ kPa}} \right)^{3/5} (0.0750 \text{ m}^3)$

$\qquad\quad = \boxed{0.0653 \text{ m}^3}$

(b) $\dfrac{P_i V_i}{T_i} = \dfrac{P_f V_f}{T_f}$

$\dfrac{T_f}{T_i} = \left(\dfrac{P_f}{P_i} \right) \left(\dfrac{V_f}{V_i} \right)$

$\qquad = \left(\dfrac{V_f}{V_i} \right)^{-\gamma} \left(\dfrac{V_f}{V_i} \right)$

$\qquad = \left(\dfrac{V_f}{V_i} \right)^{1-\gamma}$

$V_f = \left(\dfrac{T_f}{T_i} \right)^{1/(1-\gamma)} V_i$

$\qquad = \left(\dfrac{295 \text{ K}}{325 \text{ K}} \right)^{1/\left(1-\frac{5}{3}\right)} (0.0750 \text{ m}^3)$

$\qquad = \boxed{0.0867 \text{ m}^3}$

40. (a) $T = \dfrac{PV}{nR}$

$T_i = \dfrac{(106 \times 10^3 \text{ Pa})(1.00 \text{ m}^3)}{(60.0 \text{ mol}) \left(8.31 \frac{\text{J}}{\text{mol·K}} \right)} = 212.6 \text{ K}$

$T_1 = \dfrac{(212 \times 10^3 \text{ Pa})(1.00 \text{ m}^3)}{(60.0 \text{ mol}) \left(8.31 \frac{\text{J}}{\text{mol·K}} \right)} = 425.2 \text{ K}$

$$T_f = \frac{(212 \times 10^3 \text{ Pa})(3.00 \text{ m}^3)}{(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)} = 1275.6 \text{ K}$$

process 1:

$$Q_v = \frac{3}{2}nR(T_1 - T_i) = \frac{3}{2}(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(212.6 \text{ K}) = \boxed{159 \text{ kJ}}$$

process 2:

$$Q_p = \frac{5}{2}nR(T_f - T_1) = \frac{5}{2}(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(850.4 \text{ K}) = \boxed{1060 \text{ kJ}}$$

(b) $W = P\Delta V = (212 \times 10^3 \text{ Pa})(3.00 \text{ m}^3 - 1.00 \text{ m}^3) = \boxed{424 \text{ kJ}}$

(c) $\Delta U = Q - W = 159 \text{ kJ} + 1060 \text{ kJ} - 424 \text{ kJ} = \boxed{795 \text{ kJ}}$

41. (a) $T = \dfrac{PV}{nR}$

$$T_i = \frac{(106 \times 10^3 \text{ Pa})(1.00 \text{ m}^3)}{(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)} = 212.6 \text{ K}$$

$$T_2 = \frac{(106 \times 10^3 \text{ Pa})(3.00 \text{ m}^3)}{(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)} = 637.8 \text{ K}$$

$$T_f = \frac{(212 \times 10^3 \text{ Pa})(3.00 \text{ m}^3)}{(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)} = 1275.6 \text{ K}$$

process 3:

$$Q_p = \frac{5}{2}nR(T_2 - T_i) = \frac{5}{2}(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(425.2 \text{ K}) = \boxed{530 \text{ kJ}}$$

process 4:

$$Q_v = \frac{3}{2}nR(T_f - T_2) = \frac{3}{2}(60.0 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(637.8 \text{ K}) = \boxed{477 \text{ kJ}}$$

(b) $W = P\Delta V = (106 \times 10^3 \text{ Pa})(3.00 \text{ m}^3 - 1.00 \text{ m}^3) = \boxed{212 \text{ kJ}}$

(c) $\Delta U = Q - W = 530 \text{ kJ} + 477 \text{ kJ} - 212 \text{ kJ} = \boxed{795 \text{ kJ}}$

42. $W = Q_h - Q_c = 1200 \text{ J} - 680 \text{ J} = \boxed{520 \text{ J}}$

43. $e = \dfrac{W}{Q_h} = \dfrac{W}{W + Q_c} = \dfrac{340 \text{ J}}{340 \text{ J} + 870 \text{ J}} = \boxed{0.28}$

44. (a) $W = Q_h - Q_c = 690 \text{ J} - 430 \text{ J} = \boxed{260 \text{ J}}$

(b) $e = \dfrac{W}{Q_h} = \dfrac{260 \text{ J}}{690 \text{ J}} = \boxed{0.38}$

45. (a) $Q_h = \dfrac{W}{e_{max}} = \dfrac{W}{1 - \dfrac{T_c}{T_h}} = \dfrac{2500 \text{ J}}{1 - \dfrac{290 \text{ K}}{410 \text{ K}}} = \boxed{8.5 \text{ kJ}}$

(b) $Q_c = Q_h - W = 8.5 \times 10^3 \text{ J} - 2500 \text{ J} = \boxed{6.0 \text{ kJ}}$

46. (a) $Q_c = Q_h - W$

$\dfrac{Q_c}{t} = \dfrac{Q_h}{t} - \dfrac{W}{t}$

$= 820 \times 10^6 \text{ W} - 250 \times 10^6 \text{ W}$

$= \boxed{570 \text{ MW}}$

(b) $e = \dfrac{W}{Q_h} = \dfrac{\dfrac{W}{t}}{\dfrac{Q_h}{t}} = \dfrac{250 \text{ MW}}{820 \text{ MW}} = \boxed{0.30}$

47. (a) $e = \dfrac{W}{Q_h}$

$e = \dfrac{W}{W + Q_c}$

$Q_c = W\left(\dfrac{1}{e} - 1\right)$

$\dfrac{Q_c}{t} = \dfrac{W}{t}\left(\dfrac{1}{e} - 1\right)$

$= (548 \text{ MW})\left(\dfrac{1}{0.320} - 1\right)$

$= \boxed{1.16 \text{ GW}}$

(b) $Q_h = W + Q_c$

$\dfrac{Q_h}{t} = \dfrac{W}{t} + \dfrac{Q_c}{t}$

$= 548 \text{ MW} + 1165 \text{ MW}$

$= \boxed{1.71 \text{ GW}}$

48. $e_{max} = 1 - \dfrac{T_c}{T_h} = 1 - \dfrac{(273.15 + 12.0) \text{ K}}{(273.15 + 25.0) \text{ K}} = \boxed{0.0436}$

49. (a) $Q_h = \dfrac{W}{e} = \dfrac{2400 \text{ J}}{0.19} = \boxed{13 \text{ kJ}}$

(b) $Q_c = Q_h - W = 1.26 \times 10^4 \text{ J} - 2400 \text{ J} = \boxed{10 \text{ kJ}}$

(c) Higher efficiency means less heat input is needed to produce the same work, with less heat lost to the surroundings. The answers in parts (a) and (b) will decrease.

50. $e_{max} = 1 - \dfrac{T_c}{T_h}$

$$T_h = \frac{T_c}{1 - e_{max}} = \frac{295 \text{ K}}{1 - 0.210} = 373.4 \text{ K}$$

$$T_c = T_h(1 - e_{max}) = (373.4 \text{ K})(1 - 0.250) = \boxed{280 \text{ K}}$$

51. (a) $T_c = T_h(1 - e_{max}) = (545 \text{ K})(1 - 0.300) = \boxed{382 \text{ K}}$

(b) The efficiency of a heat engine increases as the difference in temperature of the hot and cold reservoirs increases. Therefore, the temperature of the low temperature reservoir must be $\boxed{\text{decreased}}$.

(c) $T_c = T_h(1 - e_{max}) = 545 \text{ K}(1 - 0.400) = \boxed{327 \text{ K}}$

52. (a) $e = \dfrac{W}{Q_h} = \dfrac{2200 \text{ J}}{2500 \text{ J}} = \boxed{0.88}$

(b) $Q_c = Q_h - W = 2500 \text{ J} - 2200 \text{ J} = \boxed{300 \text{ J}}$

(c) $e_{max} = 1 - \dfrac{T_c}{T_h}$

$$\frac{T_h}{T_c} = \frac{1}{1 - e_{max}}$$

$$= \frac{1}{1 - 0.88}$$

$$= \boxed{8.3}$$

53. $e_{max} = 1 - \dfrac{T_c}{T_h}$

$e_{max} = 1 - \dfrac{T_c}{T_c + 55}$

$T_c = \dfrac{55 \text{ K}}{e_{max}} - 55 \text{ K}$

$\quad = \dfrac{55 \text{ K}}{0.11} - 55 \text{ K}$

$\quad = \boxed{450 \text{ K}}$

$T_h = \dfrac{T_c}{1 - e_{max}} = \dfrac{445 \text{ K}}{1 - 0.11} = \boxed{500 \text{ K}}$

54. (a) $e = 1 - \dfrac{Q_c}{Q_h} = 1 - \dfrac{\frac{2Q_h}{3}}{Q_h} = \boxed{\dfrac{1}{3}}$

(b) $e_{max} = 1 - \dfrac{T_c}{T_h}$

$\dfrac{T_c}{T_h} = 1 - e_{max} = 1 - \dfrac{1}{3} = \boxed{\dfrac{2}{3}}$

55. (a) $Q_h = Q_c + W = 130 \text{ J} + 420 \text{ J} = \boxed{550 \text{ J}}$

(b) $COP = \dfrac{Q_c}{W} = \dfrac{130 \text{ J}}{420 \text{ J}} = \boxed{0.31}$

56. (a) $COP = \dfrac{Q_c}{W}$

$W = \dfrac{Q_c}{COP} = \dfrac{3.45 \times 10^4 \text{ J}}{1.75} = \boxed{19.7 \text{ kJ}}$

(b) $Q_h = Q_c + W = 3.45 \times 10^4 \text{ J} + 1.97 \times 10^4 \text{ J} = \boxed{54.2 \text{ kJ}}$

57. (a) $W = Q_h - Q_c = Q_c\left(\dfrac{Q_h}{Q_c} - 1\right) = Q_c\left(\dfrac{T_h}{T_c} - 1\right) = (1550 \text{ J})\left[\dfrac{(273.15 + 32.0) \text{ K}}{(273.15 + 21.0) \text{ K}} - 1\right] = \boxed{58.0 \text{ J}}$

(b) $Q_h = W + Q_c = 58.0 \text{ J} + 1550 \text{ J} = \boxed{1610 \text{ J}}$

58. (a) $Q_c = Q_h - W = 3240 \text{ J} - 345 \text{ J} = \boxed{2.90 \text{ kJ}}$

(b) $W = Q_h\left(1 - \dfrac{T_c}{T_h}\right)$

$T_c = \left(1 - \dfrac{W}{Q_h}\right)T_h$

$\quad = \left(1 - \dfrac{345 \text{ J}}{3240 \text{ J}}\right)(273.15 + 21.0) \text{ K}$

$\quad = 263 \text{ K}$

$\quad = (263 - 273.15)\,°\text{C}$

$\quad = \boxed{-10\,°\text{C}}$

59. $COP = \dfrac{Q_c}{W} = \dfrac{Q_c}{Q_h - Q_c} = \dfrac{Q_c}{Q_c\left(\dfrac{Q_h}{Q_c} - 1\right)} = \dfrac{1}{\dfrac{Q_h}{Q_c} - 1}$

$COP_{max} = \dfrac{1}{\dfrac{T_h}{T_c} - 1} = \dfrac{1}{\dfrac{(273.15 + 32) \text{ K}}{(273.15 + 21) \text{ K}} - 1} = 26.74$

$\dfrac{W}{t} = \dfrac{\dfrac{Q_c}{t}}{COP} = \dfrac{11 \text{ kW}}{26.74} = \boxed{0.41 \text{ kW}}$

60. $e = \dfrac{W}{Q_h} = \dfrac{W}{W + Q_c} = \dfrac{1}{1 + \dfrac{Q_c}{W}} = \dfrac{1}{1 + COP} = \dfrac{1}{1 + 10.0} = \boxed{0.0909}$

61. $Q_c = mc_w(\Delta T)_1 + mL_f + mc_{ice}(\Delta T)_2 = m[c_w(\Delta T)_1 + L_f + c_{ice}(\Delta T)_2]$

$W = \dfrac{Q_c}{COP}$

$= \dfrac{m}{COP}[c_w(\Delta T)_1 + L_f + c_{ice}(\Delta T)_2]$

$= \dfrac{1.5\text{ kg}}{4.0}\left[\left(4186\ \dfrac{\text{J}}{\text{kg}\cdot\text{C}°}\right)(15°\text{C}) + 33.5\times10^4\ \dfrac{\text{J}}{\text{kg}} + \left(2090\ \dfrac{\text{J}}{\text{kg}\cdot\text{C}°}\right)(5.0°\text{C})\right]$

$= \boxed{150\text{ kJ}}$

62. $e_{HE\text{-max}} = 1 - \dfrac{T_c}{T_h}$

$COP_{HP} = \dfrac{Q_h}{W} = \dfrac{Q_h}{Q_h - Q_c} = \dfrac{Q_h}{Q_h\left(1 - \dfrac{Q_c}{Q_h}\right)} = \dfrac{1}{1 - \dfrac{Q_c}{Q_h}}$

$COP_{HP\text{-max}} = \dfrac{1}{1 - \dfrac{T_c}{T_h}} = \dfrac{1}{e_{HP\text{-max}}} = \dfrac{1}{0.23} = \boxed{4.3}$

63. $\Delta S = \dfrac{Q}{T} = \dfrac{mL_v}{T} = \dfrac{(1.25\text{ kg})\left(22.6\times10^5\ \frac{\text{J}}{\text{kg}}\right)}{(273.15 + 100)\text{ K}} = \boxed{7.57\text{ kJ/K}}$

64. $\Delta S = \dfrac{Q}{T} = \dfrac{-mL_v}{T} = \dfrac{-(3.1\text{ kg})\left(33.5\times10^4\ \frac{\text{J}}{\text{kg}}\right)}{(273.15 + 0)\text{ K}} = \boxed{-3.8\text{ kJ/K}}$

65. $\Delta S = \left(\dfrac{Q}{T}\right)_{inside} + \left(\dfrac{Q}{T}\right)_{outside}$

$\dfrac{\Delta S}{t} = \left(\dfrac{\frac{Q}{t}}{T}\right)_{inside} + \left(\dfrac{\frac{Q}{t}}{T}\right)_{outside}$

$= \dfrac{-20.0\text{ kW}}{(273.15 + 22)\text{ K}} + \dfrac{20.0\text{ kW}}{[273.15 + (-14.5)]\text{ K}}$

$= \boxed{9.6\text{ W/K}}$

66. $\Delta S = \dfrac{Q}{T} = \dfrac{\Delta U}{T} = \dfrac{mgh}{T} = \dfrac{(82\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(350\text{ m})}{(273.15 + 21)\text{ K}} = \boxed{0.96\text{ kJ/K}}$

67. (a) The entropy of the universe stays the same, because the air conditioner has Carnot efficiency.

(b) $\dfrac{\Delta S}{t} = \left(\dfrac{\frac{Q}{t}}{T}\right)_{\text{inside}} + \left(\dfrac{\frac{Q}{t}}{T}\right)_{\text{outside}}$

$= \left(\dfrac{-\frac{Q_c}{t}}{T_c}\right) + \left(\dfrac{\frac{Q_h}{t}}{T_h}\right)$

$= \left(\dfrac{-\frac{Q_c}{t}}{T_c}\right) + \left(\dfrac{\frac{W}{t} + \frac{Q_c}{t}}{T_h}\right)$

$= \dfrac{-11\ \text{kW}}{(273.15 + 21)\ \text{K}} + \dfrac{0.4114\ \text{kW} + 11\ \text{kW}}{(273.15 + 32)\ \text{K}}$

$\boxed{\approx 0}$

68. $\Delta S = \left(\dfrac{Q}{T}\right)_h + \left(\dfrac{Q}{T}\right)_c = \left(\dfrac{-Q_h}{T_h}\right) + \left(\dfrac{Q_h - W}{T_c}\right) = \dfrac{-6400\ \text{J}}{610\ \text{K}} + \dfrac{6400\ \text{J} - 2200\ \text{J}}{320\ \text{K}} = \boxed{2.6\ \text{J/K}}$

69. Work = area enclosed by cycle.

(a) $W = (4.0\ \text{kPa})(1.0\ \text{m}^3) = \boxed{4.0\ \text{kJ}}$

(b) $W = \dfrac{1}{2}(3.0\ \text{kPa})(3.0\ \text{m}^3) = \boxed{4.5\ \text{kJ}}$

(c) $W = (1.0\ \text{kPa})(3.0\ \text{m}^3) = \boxed{3.0\ \text{kJ}}$

70. $\Delta S = \dfrac{Q}{T}$

$Q = T\Delta S = (273.15\ \text{K})\left(73\ \dfrac{\text{J}}{\text{K}}\right) = 19.9\ \text{kJ}$

$m = \dfrac{Q}{L_f} = \dfrac{19.9\ \text{kJ}}{33.5 \times 10^4\ \frac{\text{J}}{\text{kg}}} = \boxed{0.059\ \text{kg}}$

71. (a) $T = \dfrac{PV}{nR} = \dfrac{(400\ \text{kPa})(1.00\ \text{m}^3)}{(132\ \text{mol})\left(8.31\ \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{365\ \text{K}}$

(b) Heat is added to the gas, and the temperature is constant. The entropy will increase.

(c) $\Delta S = \dfrac{Q}{T} = \dfrac{\Delta U + W}{T} = \dfrac{0 + W}{T} = \dfrac{nRT \ln\left(\frac{V_f}{V_i}\right)}{T} = (132\ \text{mol})\left(8.31\ \dfrac{\text{J}}{\text{mol·K}}\right)\ln\left(\dfrac{4.00\ \text{m}^3}{1.00\ \text{m}^3}\right) = \boxed{1.52\ \text{kJ/K}}$

(d) $W = nRT \ln\left(\dfrac{V_f}{V_i}\right) = (132 \text{ mol})\left(8.31 \ \dfrac{\text{J}}{\text{mol} \cdot \text{K}}\right)(365 \text{ K}) \ln\left(\dfrac{4.00 \text{ m}^3}{1.00 \text{ m}^3}\right) = \boxed{555 \text{ kJ}}$

$T\Delta S = (365 \text{ K})\left(1.52 \ \dfrac{\text{kJ}}{\text{K}}\right) = \boxed{555 \text{ kJ}}$

72. (a) Area under the process is $\boxed{\text{positive}}$.

(b) Area under the process is $\boxed{\text{zero}}$.

(c) Area under the process is $\boxed{\text{negative}}$ since ΔV is negative.

(d) Again, ΔV is $\boxed{\text{negative}}$.

(e) $W = Q - \Delta U = Q - \dfrac{3}{2}nR\Delta T = Q - \dfrac{3}{2}(P\Delta V)$

$P\Delta V = Q - \dfrac{3}{2}P\Delta V$

$\dfrac{5}{2}P\Delta V = Q$

$W = P\Delta V = \dfrac{2}{5}Q = \dfrac{2}{5}(27 \text{ J}) = \boxed{11 \text{ J}}$

73. (a) $W = A_{\text{rectangle}} + A_{\text{triangle}}$

$= lw + \dfrac{1}{2}bh$

$= (2.00 \text{ m}^3)(106 \text{ kPa}) + \dfrac{1}{2}(2.00 \text{ m}^3)(106 \text{ kPa})$

$= \boxed{318 \text{ kJ}}$

(b) $T_f = \dfrac{P_f V_f}{nR}, \ T_i = \dfrac{P_i V_i}{nR}$

$\Delta U = \dfrac{3}{2}nR(T_f - T_i)$

$= \dfrac{3}{2}nR\left(\dfrac{P_f V_f}{nR} - \dfrac{P_i V_i}{nR}\right)$

$= \dfrac{3}{2}(P_f V_f - P_i V_i)$

$= \dfrac{3}{2}[(212 \times 10^3 \text{ Pa})(3.00 \text{ m}^3) - (106 \times 10^3 \text{ Pa})(1.00 \text{ m}^3)]$

$= \boxed{795 \text{ kJ}}$

(c) $Q = \Delta U + W = 795 \text{ kJ} + 318 \text{ kJ} = \boxed{1113 \text{ kJ}}$

74. (a) Engine B does less work than engine A since it exhausts more heat to the low temperature reservoir. Therefore, engine A has the greater efficiency.

(b)

$$e_A = \left(\frac{W}{Q_h}\right)_A$$

$$= \frac{W_A}{Q_h}$$

$$= \frac{Q_h - Q_{A,c}}{Q_h}$$

$$= 1 - \frac{Q_{A,c}}{Q_h}$$

$$\frac{Q_{A,c}}{Q_h} = 1 - e_A$$

$$e_B = \left(\frac{W}{Q_h}\right)_B$$

$$= \frac{W_B}{Q_h}$$

$$= 1 - \frac{Q_{B,c}}{Q_h}$$

$$= 1 - \frac{2Q_{A,c}}{Q_h}$$

$$= 1 - 2(1 - e_A)$$

$$= 2e_A - 1$$

$$= 2(0.66) - 1$$

$$= \boxed{0.32}$$

75. (a) $Q = mc_w(\Delta T)_1 + mL_f + mc_{ice}(\Delta T)_2$

$$= m[c_w(\Delta T)_1 + L_f + c_{ice}(\Delta T)_2]$$

$$= (1.75 \text{ kg})\left[\left(4186 \frac{J}{kg \cdot C°}\right)(20.0 \text{ C}°) + 33.5 \times 10^4 \frac{J}{kg} + \left(2090 \frac{J}{kg \cdot C°}\right)(5.00 \text{ C}°)\right]$$

$$= \boxed{751 \text{ kJ}}$$

(b) $W = \dfrac{Q_c}{COP} = \dfrac{751 \text{ kJ}}{3.88} = \boxed{194 \text{ kJ}}$

(c) $Q_h = W + Q_c = 194 \text{ kJ} + 751 \text{ kJ} = \boxed{945 \text{ kJ}}$

76. (a) $Q_p = \dfrac{5}{2}nR\Delta T$

$\Delta T = \dfrac{2Q_p}{5nR}$

$\Delta U = \dfrac{3}{2}nR\Delta T$

$\quad = \dfrac{3}{2}nR\left(\dfrac{2Q_p}{5nR}\right)$

$\quad = \dfrac{3}{5}Q_p$

$\quad = \dfrac{3}{5}(1400 \text{ J})$

$\quad = \boxed{840 \text{ J}}$

(b) $\Delta T = \dfrac{2Q_p}{5nR} = \dfrac{2(1400 \text{ J})}{5(3.5 \text{ mol})\left(8.31 \frac{\text{J}}{\text{mol·K}}\right)} = \boxed{19 \text{ K}}$

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

$P\Delta V = Q - \Delta U$

$\Delta V = \dfrac{Q - \Delta U}{P}$

$\quad = \dfrac{1400 \text{ J} - 840 \text{ J}}{120\times10^3 \text{ Pa}}$

$\quad = \boxed{4.7\times10^{-3} \text{ m}^3}$

77. $\dfrac{P_1 V_1}{T_1} = \dfrac{P_2 V_2}{T_2}$

$T_2 = \dfrac{P_2 V_2}{P_1 V_1}T_1$

$\quad = \dfrac{P_1(3V_1)}{P_1 V_1}T_1$

$\quad = 3T_1$

$Q_p = \dfrac{5}{2}nR\Delta T$

$\quad = \dfrac{5}{2}nR(3T_1 - T_1)$

$\quad = 5nRT_1$

$\quad = 5(3.5 \text{ mol})\left(8.31 \ \dfrac{\text{J}}{\text{mol}\cdot\text{K}}\right)(280 \text{ K})$

$\quad = 40.7 \text{ kJ}$

$$\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3}$$

$$T_3 = \frac{P_3 V_3}{P_2 V_2} T_2$$

$$= \frac{(2 P_2) V_2}{P_2 V_2} T_2$$

$$= 2 T_2$$

$$\Delta T = T_3 - T_2 = 2 T_2 - T_2 = T_2 = 3 T_1$$

$$Q_v = \frac{3}{2} n R \Delta T = \frac{3}{2} n R (3 T_1) = \frac{9}{2} n R T_1 = \frac{9}{2} (3.5 \text{ mol}) \left(8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}} \right) (280 \text{ K}) = 36.6 \text{ kJ}$$

$$Q_{\text{total}} = Q_p + Q_v = 40.7 \text{ kJ} + 36.6 \text{ kJ} = \boxed{77 \text{ kJ}}$$

78. (a) $\Delta S = \left(\frac{Q}{T} \right)_{\text{Sun}} + \left(\frac{Q}{T} \right)_{\text{space}}$

$$= \frac{\left(-3.80 \times 10^{26} \frac{\text{J}}{\text{s}} \right) \left(\frac{3600 \text{ s}}{\text{h}} \right) \left(\frac{24 \text{ h}}{\text{day}} \right)}{(5500°\text{C} + 273.15 \text{ K})} + \frac{\left(3.80 \times 10^{26} \frac{\text{J}}{\text{s}} \right) \left(3600 \frac{\text{s}}{\text{h}} \right) \left(\frac{24 \text{ h}}{\text{day}} \right)}{3.0 \text{ K}}$$

$$\Delta S = \boxed{1.1 \times 10^{31} \frac{\text{J}}{\text{K}}} \text{ in one day}$$

(b) $W = e_{\max} Q_h = \left(1 - \frac{T_c}{T_h} \right) Q_h = \left(1 - \frac{3.0 \text{ K}}{(5500 + 273) \text{K}} \right) (3.28 \times 10^{31} \text{ J}) = \boxed{3.28 \times 10^{31} \text{ J}}$

79. (a) $W = Q - \Delta U = \frac{5}{2} n R \Delta T - \frac{3}{2} n R \Delta T = \boxed{n R \Delta T}$

(b) $Q = \boxed{0}$

(c) $\Delta U = Q - W = 0 - \left(-\frac{3}{2} n R \Delta T \right) = \boxed{\frac{3}{2} n R \Delta T}$

(d) $W = \boxed{0}$

(e) $\Delta U = Q - W = \frac{3}{2} n R \Delta T - 0 = \boxed{\frac{3}{2} n R \Delta T}$

(f) $Q = \Delta U + W = 0 + n R T \ln(V_f / V_i) = \boxed{n R T \ln(V_f / V_i)}$

(g) $\Delta U = \boxed{0}$

80. (a) $PV = nRT$

$$V_f = \frac{nRT}{P_f}$$

$$= \frac{(2.50 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(295 \text{ K})}{121 \times 10^3 \text{ Pa}}$$

$$= \boxed{5.06 \times 10^{-2} \text{ m}^3}$$

(b) $W = nRT \ln\left(\frac{V_f}{V_i}\right)$

$$= nRT \ln\left(\frac{P_i}{P_f}\right)$$

$$= (2.50 \text{ mol})\left(8.31 \frac{J}{\text{mol·K}}\right)(295 \text{ K}) \ln\left(\frac{101 \text{ kPa}}{121 \text{ kPa}}\right)$$

$$= \boxed{-1.11 \text{ kJ}}$$

(c) $Q = \Delta U + W = 0 + (-1.11 \text{ kJ}) = \boxed{-1.11 \text{ kJ}}$

81. (a) $e = \dfrac{W}{Q_h} = \dfrac{1120 \text{ J}}{1250 \text{ J}} = \boxed{0.896}$

(b) $e_{max} = 1 - \dfrac{T_c}{T_h} = 1 - \dfrac{302 \text{ K}}{1010 \text{ K}} = \boxed{0.701}$

$\boxed{\text{Don't invest.}}$

82. (a) $\Delta S_{tot} = \left(\dfrac{Q}{T}\right)_h + \left(\dfrac{Q}{T}\right)_c$

$$= \frac{-Q_h}{T_h} + \frac{Q_c}{T_c}$$

$$= \frac{-Q_h}{T_h} + \frac{Q_h - W}{T_c}$$

$$= \frac{-660 \text{ J}}{810 \text{ K}} + \frac{660 \text{ J} - 250 \text{ J}}{320 \text{ K}}$$

$$= \boxed{0.47 \text{ J/K}}$$

(b) $W_{max} = \left(1 - \dfrac{T_c}{T_h}\right)Q_h = \left(1 - \dfrac{320 \text{ K}}{810 \text{ K}}\right)(660 \text{ J}) = \boxed{0.40 \text{ kJ}}$

(c) $\Delta W = \left(1 - \dfrac{T_c}{T_h}\right)Q_h - (Q_h - Q_c) = -\dfrac{T_c}{T_h}Q_h + Q_c = T_c\left(\dfrac{-Q_h}{T_h} + \dfrac{Q_c}{T_c}\right) = T_c \Delta S_{tot}$

83. **(a)** The entropy decreases because heat flows out of the water.

(b) $\Delta S = \dfrac{Q}{T} = \dfrac{-mL_f}{T} = -\dfrac{(0.51 \text{ kg})\left(33.5 \times 10^4 \ \frac{J}{kg}\right)}{(273.15 + 0) \text{ K}} = \boxed{-0.63 \text{ kJ/K}}$

(c) Wherever the heat flows, there will be an increase in entropy.

84. $A \rightarrow B: W = P\Delta V = P(0) = 0$

   $\qquad Q = \Delta U = -38 \text{ J}$

(a) $\boxed{-38 \text{ J}}$

(b) $\boxed{0}$

$B \rightarrow C: \ Q = \Delta U + W = -82 \text{ J} + (-89 \text{ J}) = -171 \text{ J}$

(c) $\boxed{-171 \text{ J}}$

$C \rightarrow A: \ \Delta U_{C \rightarrow A} + \Delta U_{A \rightarrow B} + \Delta U_{B \rightarrow C} = 0$

$\qquad \Delta U_{C \rightarrow A} = -(\Delta U_{A \rightarrow B} + \Delta U_{B \rightarrow C}) = -[-38 \text{ J} + (-82 \text{ J})] = 120 \text{ J}$

$\qquad W = Q - \Delta U = 332 \text{ J} - 120 \text{ J} = 212 \text{ J}$

(d) $\boxed{212 \text{ J}}$

(e) $\boxed{120 \text{ J}}$

85. Since $e = 1 - \dfrac{T_c}{T_h}$, we need to make $\dfrac{T_c}{T_h}$ smaller to increase the efficiency. We can determine which is smaller,

   $\dfrac{T_c}{T_h + \Delta T}$ or $\dfrac{T_c - \Delta T}{T_h}$ by checking the sign of their difference.

   $\dfrac{T_c}{T_h + \Delta T} - \dfrac{T_c - \Delta T}{T_h} = \dfrac{T_c T_h - (T_c - \Delta T)(T_h + \Delta T)}{(T_h + \Delta T)T_h} = \dfrac{\Delta T(T_h - T_c) + (\Delta T)^2}{(T_h + \Delta T)T_h}$

   which is > 0 since $\Delta T > 0$. So, lowering the temperature of the low temperature reservoir would result in the greater change in efficiency.

86. **(a)** $A \rightarrow B$:

   $W_{AB} = nRT_A \ln\left(\dfrac{V_B}{V_A}\right)$

   $\qquad = P_A V_A \ln\left(\dfrac{V_B}{V_A}\right)$

   $\qquad = (600 \times 10^3 \text{ Pa})(0.750 \times 10^{-3} \text{ m}^3) \ln\left(\dfrac{4.50 \times 10^{-3} \text{ m}^3}{0.750 \times 10^{-3} \text{ m}^3}\right)$

   $\qquad = 806 \text{ J}$

   $\Delta U_{AB} = 0$

   $Q_{AB} = \Delta U_{AB} + W_{AB} = 0 + 806 \text{ J} = 806 \text{ J}$

$B \rightarrow C$:

$$Q_{BC} = \frac{5}{2}nR\Delta T$$

$$= \frac{5}{2}P\Delta V$$

$$= \frac{5}{2}(100 \times 10^3 \text{ Pa})(0.750 \times 10^{-3} \text{ m}^3 - 4.50 \times 10^{-3} \text{ m}^3)$$

$$= -938 \text{ J}$$

$$W_{BC} = P\Delta V$$

$$= (100 \times 10^3 \text{ Pa})(0.750 \times 10^{-3} \text{ m}^3 - 4.50 \times 10^{-3} \text{ m}^3)$$

$$= -375 \text{ J}$$

$$\Delta U_{BC} = Q_{BC} - W_{BC} = -938 \text{ J} - (-375 \text{ J}) = -563 \text{ J}$$

$C \rightarrow A$:

$$W_{CA} = P\Delta V = 0$$

$$U_{AB} + U_{BC} + U_{CA} = 0$$

$$\Delta U_{CA} = -\Delta U_{AB} - \Delta U_{BC} = -0 - (-563) = 563 \text{ J}$$

$$Q_{CA} = \Delta U_{CA} + W_{CA} = 563 \text{ J} + 0 = 563 \text{ J}$$

	Q	W	ΔU
$A \rightarrow B$	806 J	806 J	0
$B \rightarrow C$	−938 J	−375 J	−563 J
$C \rightarrow A$	563 J	0	563 J

(b) $e = \dfrac{W}{Q_h} = \dfrac{806 \text{ J} - 375 \text{ J}}{806 \text{ J} + 563 \text{ J}} = \boxed{0.31}$

87. $\left(\dfrac{W}{Q}\right)_p = \dfrac{P\Delta V}{Q_p} = \dfrac{nR\Delta T}{\frac{5}{2}nR\Delta T} = \boxed{\dfrac{2}{5}}$

88. $P_i V_i^{\gamma} = P_f V_f^{\gamma}$

$$\left(\frac{V_i}{V_f}\right)^{\gamma} = \frac{P_f}{P_i}$$

$$\left(\frac{V_i}{V_f}\right)^{\gamma} = \frac{\frac{nRT_f}{V_f}}{\frac{nRT_i}{V_i}}$$

$$\frac{T_f}{T_f} = \left(\frac{V_i}{V_f}\right)^{\gamma-1}$$

$$= \left(\frac{V_i}{\frac{V_i}{25}}\right)^{\frac{5}{3}-1}$$

$$= 25^{\frac{2}{3}}$$

$$= \boxed{8.5}$$

89. For the adiabatic processes, starting with $P_i V_i^\gamma = P_f V_f^\gamma$ and $\dfrac{P_i V_i}{T_i} = \dfrac{P_f V_f}{T_f}$, and dividing corresponding sides,

produces $T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}$. So

$T_h V_2^{\gamma-1} = T_c V_3^{\gamma-1}$ and

$T_h V_1^{\gamma-1} = T_c V_4^{\gamma-1}$.

Dividing these equations gives $\dfrac{V_2}{V_1} = \dfrac{V_3}{V_4}$.

For the isothermal processes, $Q_h = W_1 = nRT_h = \ln\left(\dfrac{V_2}{V_1}\right)$ and $Q_c = W_3 = nRT_c \ln\left(\dfrac{V_3}{V_4}\right) = nRT_c \ln\left(\dfrac{V_2}{V_1}\right)$. Dividing

these equations gives $\dfrac{Q_h}{Q_c} = \dfrac{T_h}{T_c}$.

$e = 1 - \dfrac{Q_c}{Q_h} = 1 - \dfrac{T_c}{T_h}$

90. $e = 1 - \dfrac{T_c}{T_h}$

$\dfrac{T_h}{T_c} = \dfrac{1}{1-e}$

$COP = \dfrac{Q_c}{W} = \dfrac{Q_c}{Q_h - Q_c} = \dfrac{1}{\frac{Q_h}{Q_c} - 1} = \dfrac{1}{\frac{T_h}{T_c} - 1} = \dfrac{1}{\frac{1}{1-e} - 1} = \dfrac{1-e}{e}$