Chapter 20 In-Class Solutions

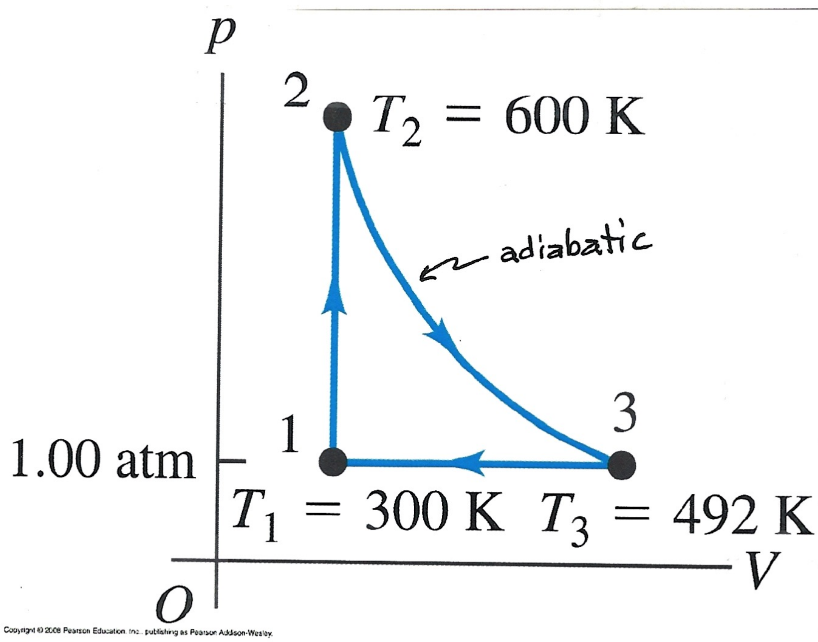
Ex. 1 A diesel engine performs 2200 J of mechanical work and discards 4300 J of heat each cycle.

Thermal efficiency $= e = \frac{W}{Q_H} = \frac{W}{Q_c + W} = \frac{2200\text{ J}}{(4300+2200)\text{ J}} = 0.3385$

$\boxed{Q_H = Q_c + W = 6500\text{ J}}$

$\boxed{e = 33.8\%}$

Ex. 34 A heat engine takes 0.350 mol of a diatomic gas around the cycle shown in the p-V diagram in Fig. P 20.34.



a.) Find the pressure and volume at points 1, 2, & 3.

$V_1 = \frac{nRT_1}{P_1} = \frac{(0.350)(8.31)(300)}{1.013\times10^5}$

$\boxed{\begin{aligned} V_1 &= 8.61\times10^{-3}\text{ m}^3 \\ P_1 &= 1.013\times10^5\text{ Pa} \end{aligned}}$

$V_3 = \frac{nRT_3}{P_3} = \frac{(0.350)(8.31)(492)}{1.013\times10^5}$

$\boxed{\begin{aligned} V_3 &= 14.1\times10^{-3}\text{ m}^3 \\ P_3 &= 1.013\times10^5\text{ Pa} \end{aligned}}$

$\boxed{\begin{aligned} V_2 &= V_1 = 8.61\times10^{-3}\text{ m}^3 \\ P_2 &= 2.03\times10^5\text{ Pa} \end{aligned}}$

$P_2 = \frac{nRT_2}{V_2} = \frac{(0.350)(8.31)(600)}{8.61\times10^{-3}}$

b.) Calculate Q, W, and ΔU for each of the three processes.

$Q = W + \Delta U$

Chapter 20 In-Class Solutions

Ex. 34 cont'd

$1 \to 2$

$Q_V = nC_V \Delta T = 0.350\left(\frac{5}{2}(8.31)\right)(600-300) = \underline{2.18 \times 10^3 \text{ J}}$

$\underline{W = 0}$

$\Delta U = nC_V \Delta T = Q_V = \underline{2.18 \times 10^3 \text{ J}}$

$2 \to 3$

$\underline{Q = 0}$ Definition of an adiabat

$W = -\Delta U$ $\quad W = -nC_V \Delta T = -0.350\left(\frac{5}{2}(8.31)\right)(492-600) = \underline{785 \text{ J}}$

$\Delta U = nC_V \Delta T = \underline{-785 \text{ J}}$

$3 \to 1$

$Q = Q_p = nC_p \Delta T = 0.350\left(\frac{7}{2}(8.31)\right)(300-492) = \underline{-1.95 \times 10^3 \text{ J}}$

$W = p\Delta V = nR\Delta T = (0.350)(8.31)(300-492) = \underline{-558 \text{ J}}$

$\Delta U = nC_V \Delta T = (0.350)\left(\frac{5}{2}(8.31)\right)(300-492) = \underline{-1.40 \times 10^3 \text{ J}}$

c.) Find the net work done:

$W_{net} = 0 + 785 \text{ J} - 558 \text{ J} = \underline{227 \text{ J}}$

d.) Net heat flow: $Q_{net} = 2.18 \times 10^3 + 0 - 1.95 \times 10^3 = \underline{230 \text{ J}}$

e.) Thermal Efficiency: $e = \frac{W}{Q_{H_{1\to2}}} = \frac{227}{2180} = 0.104$ or $\underline{10.4\%}$

Carnot efficiency $= 1 - \frac{T_C}{T_H} = 1 - \frac{300 \text{ K}}{600 \text{ K}} = 0.50$ or $\underline{50\%}$

Ex. 8 Calculate the theoretical efficiency for an Otto-cycle engine with $\gamma = 1.40$ and $r = 9.50$.

$$e = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(9.50)^{0.4}} = 0.594 \text{ or } \underline{59.4\%}$$

b.) If this engine takes in 10,000 J of heat from burning...

$Q_C = ?$ $\quad e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$

Chapter 20 In-Class Solutions

Ex. 8 cont'd $\frac{Q_c}{Q_H} = 1 - e$ $\quad Q_c = (1-e)Q_H = (1-0.594)\,10{,}000\text{ J}$

$$\boxed{Q_c = 4{,}060\text{ J}}$$

Ex. 12 A refrigerator has a coefficient of performance of 2.10. In each cycle it absorbs 3.10×10^4 J of heat from the cold reservoir.

a.) How much mechanical energy is required for each cycle.

$K = \frac{|Q_c|}{W}$ $\quad W = \frac{|Q_c|}{K} = \frac{3.10 \times 10^4\text{ J}}{2.10} = 14{,}762\text{ J}$

$$\boxed{W = 1.48 \times 10^4\text{ J}}$$

b.) How much heat is discarded to the high-temperature reservoir?

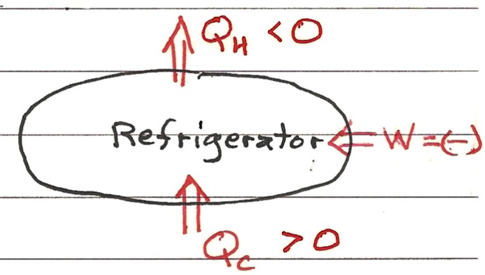
$W = Q_H + Q_c$

$Q_H = W - Q_c$

$= -1.48 \times 10^4\text{ J} - 3.10 \times 10^4\text{ J}$

$\boxed{Q_H = -4.58 \times 10^4\text{ J}}$ per cycle

(-)... because heat is being discarded from the system.

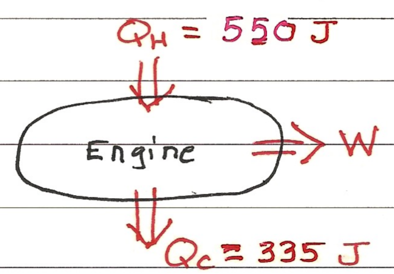


Ex. 15 A Carnot engine whose high-temperature reservoir is at 620 K takes in 550 J of heat and gives up 335 J to the low-temperature reservoir.

a.) $W = ?$ for each cycle

$W = Q_H - Q_c = 550\text{ J} - 335\text{ J}$

$\boxed{W = 215\text{ J}}$ per cycle



b.) In a Carnot engine $\Rightarrow \frac{|Q_c|}{|Q_H|} = \frac{T_c}{T_H}$

$T_c = T_H \, |Q_c| / |Q_H|$

$T_c = (620\text{ K}) \frac{335\text{ J}}{550\text{ J}}$

$$\boxed{T_c = 378\text{ K}}$$

Chapter 20 In-Class Solutions

Ex. 15 cont'd.

c.) Thermal efficiency $e_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{378\ K}{620\ K}$

$\boxed{e_{carnot} = 0.390}$ or 39.0%

Ex. 23 A sophomore with nothing better to do adds heat to 0.350 kg of ice at 0.00°C until it is all melted.

Table 17.4

Latent heat of fusion ice ↔ water @ 0°C $= 334 \times 10^3\ J/kg$

Total $Q = (334 \times 10^3\ J/kg)(0.350\ kg) = \underline{1.17 \times 10^5\ J}$

a.) $\Delta S_{water} = \frac{Q}{T} = \frac{1.17 \times 10^5\ J}{273\ K} = \boxed{428\ J/K}$ $Q > 0,\ \Delta S > 0$

b.) The source of heat is a very massive body at a temperature of 25°C. $T = 273 + 25 = 298\ K$

$\Delta S_{body} = \frac{Q}{T} = \frac{-1.17 \times 10^5\ J}{298\ K}$ $\boxed{\Delta S_{body} = -393\ J/K}$

c.) The total change in entropy $= \Delta S_{Total} = \Delta S_{water} + \Delta S_{body}$

$\Delta S_{TOTAL} = 428\ J/K - 393\ J/K$ $\boxed{\Delta S_{TOTAL} = 35\ J/K}$

$\Delta S > 0$ for this isolated system.

The process is irreversible.