The power output of a car engine running at 2400 rpm is 500 kW. How much (a) work and (b) heat is exhausted per cycle if the engine's thermal efficiency is 20%? Give your answers in kJ.

\[
\text{2400 cycles/minute} \times \left( \frac{1 \text{ min}}{60 \text{ sec}} \right) = \frac{40 \text{ cycles}}{\text{sec}}.
\]

\[500 \text{ kW} = \frac{500 \text{ kJ}}{s}\]

\[500 \text{ kJ/s} \times \left( \frac{1 \text{ s}}{40 \text{ cycles}} \right) = 12.5 \text{ kJ/cycle} = W_{\text{out}} \]

\[\eta = 20\% = 0.20\]

\[\eta = \frac{W_{\text{out}}}{Q_{\text{H}}}\]

\[0.20 = \frac{12.5 \text{ kJ}}{Q_{\text{H}}}\]

\[Q_{\text{H}} = 62.5 \text{ kJ} \rightarrow \text{heat from hot reservoir}\]

\[Q_{\text{c}} = ? = Q_{\text{H}} - W = 62.5 \text{ kJ} - 12.5 \text{ kJ} = 50 \text{ kJ} \]

\[Q_{\text{c}}\]
50 J of work are done per cycle on a refrigerator with a coefficient of performance of 4.0. How much heat is (a) extracted from the cold reservoir and (b) exhausted to the hot reservoir per cycle?

\[
K = 4.0 = \frac{Q_c}{W} = \frac{Q_c}{50 J}
\]

\[
4 = \frac{Q_c}{50} \quad \Rightarrow \quad Q_c = 200 J \quad (a)
\]

(b) \( Q_H = 250 J \)

\[
Q_c + W = Q_H
\]

\[
200 + 50 = 250 J
\]
Chap 19 EXAMPLE #3 Problem #14, page 592
What are (a) $W_{out}$ and $Q_H$ and (b) the thermal efficiency for the heat engine shown in the figure?

$W_{out} = \text{area enclosed by } pV \text{ curve}$

$h \times w = 200 \times 10^{-6} m^3 - 100 \times 10^{-6} m^3 = 100 \times 10^{-6} m^3$

$\frac{400000 \text{ Pa} - 100000 \text{ Pa}}{(300000 \text{ Pa})(100 \times 10^{-6} m^3)} = \frac{30 J}{W_{out}}$

$Q_H = ?$

$Q_H = Q_c + W \text{ engine}$

$Q_c = \text{Heat flowing out of engine}$

$Q_c = -90 + -25 = -115 \text{ J}$ (defined as "+" if flowing out)

$Q_H = Q_c + W = -115 + 30 = -85 J$

$\eta = \frac{W_{out}}{Q_H} = \frac{30}{145} = 0.207$
Chap 19 EXAMPLE #4 Problem #16 page 592
What are (a) the thermal efficiency and (b) the heat extracted from the hot reservoir for the heat engine shown in the figure?

\[ \eta = \frac{W}{Q_H} \]

\[ W = \text{area bounded} = \frac{1}{2} b h \]

\[ Q_c = 180\,\text{J} + 100\,\text{J} = 280\,\text{J} \]

\[ Q_H = 280 + 40 = 320\,\text{J} \]

\[ Q_H = Q_c + W \]

\[ W = \frac{1}{2} (600 - 200\,\text{cm}^3)(200\,\text{kPa}) \]

\[ = \frac{1}{2} (400 \times 10^{-6}\,\text{m}^3)(200,000) = 40\,\text{J} \]

\[ \eta = \frac{W}{Q_H} = \frac{40}{320} = 0.125 \text{ or } 12.5\% \]
Chap 19 EXAMPLE #5 Problem #20 page 592

Which, if any, of the engines shown in the figure violate the (a) first law of thermodynamics or (b) the second law of thermodynamics? EXPLAIN.

(a) 1st Law:
\[ Q_H = W + Q_C \]

\[ (a) \quad (b) \quad (c) \]

\[ 60 = 20 + 40 \quad 50 = 40 + 10 \quad 40 \neq 20 + 70 \]

(b) 2nd Law

\[ K_c = \frac{T_c}{T_H - T_c} = \frac{300}{400 - 300} \]

\[ K_c = 3.0 \]

real \[ K = \frac{Q_c}{W} \]

\[ (a) \quad (b) \quad X \]

\[ \frac{40}{20} = 2.0 \quad \frac{40}{10} = 4.0 \quad \frac{30}{20} = 1.5 \quad \checkmark \]
Chap 19 EXAMPLE #6 Problem #22 page 592
(a) A heat engine does 200 J of work per cycle while exhausting 600 J of heat to the cold reservoir. What is the engine’s thermal efficiency?
(b) A Carnot engine with a hot-reservoir temperature of 400°C has the same efficiency as the engine in part (a). What is the cold-reservoir temperature in °C?

(a) \[ W = 200\, \text{J} \quad \eta = \frac{W}{Q_h} = \frac{200}{800} = 0.25 \]
\[ Q_c = 600\, \text{J} \]
\[ Q_h = Q_c + W = 800\, \text{J} \]

(b) \[ \eta_c = 1 - \frac{T_c}{T_H} \quad \Rightarrow \quad T_H = 400^\circ C = 673 \]
\[ T_c = ? \quad ^\circ C \]
\[ \eta_{\text{max}} = 0.25 = 1 - \frac{T_c}{T_H} \quad \Rightarrow \quad 0.25 = 1 - \frac{T_c}{673} \]
\[ T_c = 504.75 \approx 505 \, \text{K} \]
\[ = 232 \, ^\circ C \]
Chap 19 EXAMPLE #7 Problem #54 page 594
The figure shows the cycle for a heat engine that uses a gas having $\kappa = 1.25$. The initial temperature is $T_1 = 300K$ and this engine operates at 20 cycles per second.

(a) What is the power output of the engine?
(b) What is the engine’s thermal efficiency?

\[
\begin{array}{cccc}
\text{find } p, V, T, n & \text{for all points} \\
p & V & T & n \\
1 & 101,300 & 6 \times 10^{-4} & 300K & 0.0241 \\
2 & 304,146 & 2 \times 10^{-4} & 300K & \\
3 & 304,146 & 6 \times 10^{-4} & 900K & \\
\end{array}
\]

\[
n = \frac{p \cdot V}{RT_1} = \frac{(101300)(6 \times 10^{-4})}{8.31 \cdot (300)} = 0.0244 \text{ mol}
\]

\[
p_2 = \frac{n_2 \cdot RT_2}{V_2} = \frac{(0.0244)(8.31)(300)}{2 \times 10^{-4}} = 304,146 \text{ Pa}
\]

\[
T_3 = \frac{p_3 \cdot V_3}{nR} = 900K
\]

Cont. \quad \text{Power} = \frac{W}{t} = \frac{54.6 \text{ J}}{(1/20)} = 1092 \text{ W}

\[
\eta = \frac{W}{Q_H} = \frac{54.6}{609} = 0.089
\]

\[
\eta_{\text{max}} = 1 - \frac{T_c}{T_H} = 1 - \frac{300}{900} = 0.67
\]

[Diagram showing the cycle with points 1, 2, 3, and annotations for pressures and temperatures]

\[\text{Isobar} \quad \text{V} (\text{cm}^3)\]

\[\text{Q}^+ = 60.8 \times 3 \, \text{J} \quad \text{Q}_c = 488.1 \, \text{J} \]

\[\text{P}_{\text{max}} \quad \text{T} = 900 \text{K} \]
Ch 19 # 54, cont.

Process: isothermal

\[ W = p \cdot V \cdot \ln \left( \frac{V_f}{V_i} \right) \]
\[ = (101300)(6 \times 10^{-4}) \ln \left( \frac{2 \times 10^{-4}}{6 \times 10^{-4}} \right) = -66.77 \text{ J} \]

\[ Q_{12} = W_{12} = -66.8 \text{ J} \]

2 → 3 isobaric

\[ W_{23} = \rho \Delta V = \rho \cdot (V_f - V_i) \]
\[ = 304146 \cdot (6 \times 10^{-4} - 2 \times 10^{-4}) = 121.66 \text{ J} \]

\[ Q_{23} = n \cdot C_p \Delta T = (0.0244)(41.55)(600) = 608.293 \text{ J} \]

\[ C_p = C_v + R = 41.55 \]

\[ C_v = \frac{R}{k-1} = \frac{8.31}{1.4} = 5.889 \text{ K} \]

3 → 1 isochoric

\[ W = 0 \]

\[ Q = n \cdot C_v \Delta T = (0.0244)(33.34)(-600) = -488.1 \text{ J} \]

Cycle:

\[ W_{net} = -66.77 + 121.66 + 0 = 54.6 \text{ J} \]

\[ Q_c = +66.77 + 488.1 = 554.87 \text{ J} \]

\[ Q_H = 608.293 \rightarrow Q_c + W = 609 \text{ J} \]

\[ \text{Now, go back to previous page} \]

@ "cont."