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# THE CARNOT CYCLE SELF STUDY MODULE

## Objective

The objective of this module is to derive the heat and work interactions of a hypothetical cycle

known as the Carnot cycle. The cycle runs around a gas confined in the piston and cylinder arrangement

undergoing the following process steps:

I.      Reversible isothermal expansion

II.     Reversible adiabatic expansion

III.    Reversible isothermal compression

IV.     Reversible adiabatic compression

This cycle steps can be shown on PV and TS diagrams as follows (The figure is from Sandler)

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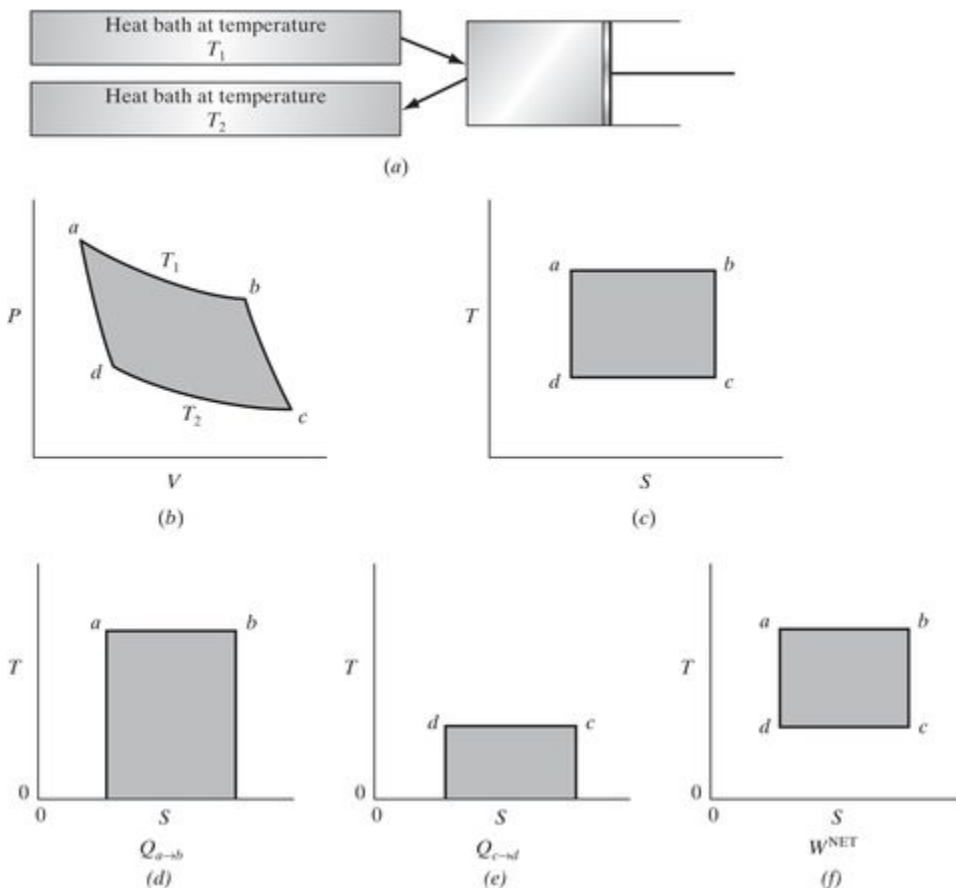
The tables below summarize the states, and the changes during the processes between

these states.

| State | T | P | V | S |
|-------|-----|-------|-------|-------|
| 1 | $T_H$ | $P_1$ | $V_1$ | $S_2$ |
| 2 | $T_H$ | $P_2$ | $V_2$ | $S_1$ |
| 3 | $T_C$ | $P_3$ | $V_3$ | $S_1$ |
| 4 | $T_C$ | $P_4$ | $V_4$ | $S_2$ |

$$\Delta S = n\, C_v \ln\left(\frac{T_2}{T_1}\right) + n\, R \ln\left(\frac{V_2}{V_1}\right)$$

| Path | ΔU | Q | W | ΔS |
|------|------|------|------|------|
| 1 | 0 | $nRT_H\ln(V_2/V_1)$ | $-nRT_H\ln(V_2/V_1)$ | $nR\ln(V_2/V_1)$ |
| 2 | $nC_v(T_C-T_H)$ | 0 | $nC_v(T_C-T_H)$ | 0 |
| 3 | 0 | $nRT_c\ln(V_4/V_3)$ | $-nRT_c\ln(V_4/V_3)$ | $nR\ln(V_4/V_3)$ |
| 4 | $nC_v(T_H-T_c)$ | 0 | $nC_v(T_H-T_c)$ | 0 |
| Overall cycle | 0 | $nR(T_H-T_c)\ln(V_2/V_1)$ | $-nR(T_H-T_c)\ln(V_2/V_1)$ | 0 |

For the overall cycle $\Delta S=0= nR\ln(V_2/V_1)+ nR\ln(V_4/V_3)=0$

$Q_{overall}= nRT_H\ln(V_2/V_1)+ nRT_c\ln(V_4/V_3)$

$\ln(V_4/V_3)=-\ln(V_2/V_1)$;  $Q_{overall}=nR(T_H-T_c)\ln(V_2/V_1)$;

$W_{overall}=-Q_{overall}$ such that the substitution yields

$\eta=-W_{net}/Q_H=\dfrac{T_H-T_C}{T_H}$

This expression is known as the Carnot cycle efficiency and is a very important identifier

about the power cycle performances.

## *Reading assignment*

Read Chapter 5 of Sandler's thermodynamics, 5th edition. Also read about other power cycles, such

as the Steam engine, the Otto engine, the Diesel engine etc.

## *Derive*

Derive the efficiency of a hypothetical power cycle that operates between $T_H$ and $T_C$ to generate

work.  Observe the similarity between the efficiency terms of this cycle and the Carnot cycle.

## *Evaluate yourself*

What are the muddiest points, what are the points that you understood well? What should you do

to clarify the parts that are not at all clear.