CARNOT CYCLES

Sadi Carnot was a French physicist who proposed an "ideal" cycle for a heat engine in 1824.

Historical note – the idea of an ideal cycle came about because engineers were trying to develop a steam engine (a type of heat engine) where they could reject (waste) a minimal amount of heat. This would produce the best efficiency since $\eta = 1 - (Q_L/Q_H)$.

Carnot proposed that a cycle comprised of completely (internally and externally) reversible processes would give the maximum amount of net work for a given heat input, since the work done by a system in a reversible (ideal) process is always greater than that in an irreversible (real) process.

THE CARNOT HEAT ENGINE CYCLE CONSISTS OF FOUR REVERSIBLE PROCESSES IN A SEQUENCE:

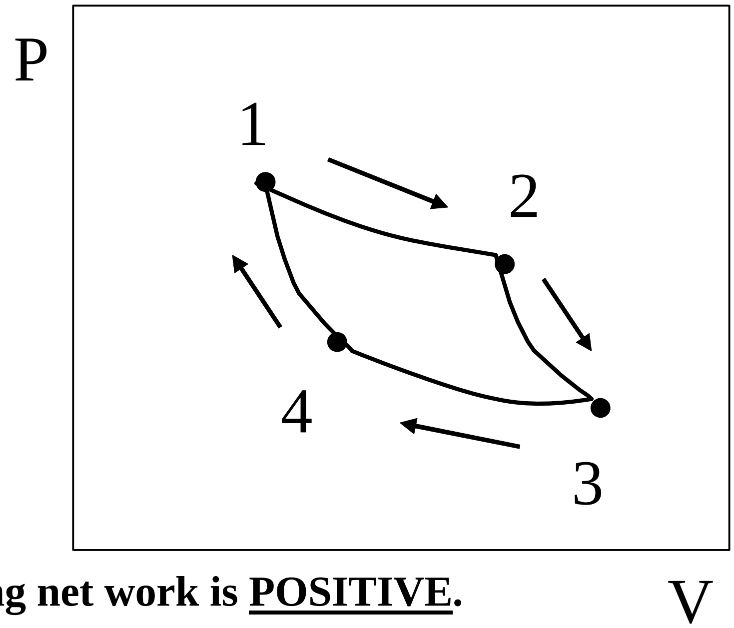
1 → 2: **Reversible <u>isothermal</u> expansion.**
Heat transfer from HTR (+) and boundary work (+) occur in closed system

2 → 3: **Reversible <u>adiabatic</u> expansion**
Work output (+), but no heat transfer

3 → 4: **Reversible <u>isothermal</u> compression**
Heat transfer (-) and boundary work (-) occur in closed system

4 → 1: **Reversible adiabatic compression**
Work input (-), but no heat transfer
AND $W_{out} >>> W_{in}$

P-V DIAGRAM FOR CARNOT HEAT ENGINE CYCLE



Showing net work is <u>POSITIVE</u>.

A useful example of an isothermal expansion is boiling (vaporization) at a constant pressure in a device such as a piston-cylinder. Similarly, an example of an isothermal compression is condensation at a constant pressure in a piston-cylinder.

Also, heat transfer can only occur in processes 1 → 2 and 3 →4.

- 1 → 2: since work is positive (expansion) and Δu is positive (e.g., boiling) then heat transfer is positive (input from HTR).
- 3 → 4: since work is negative (compression) and Δu is negative (e.g., condensation) then heat transfer is negative (output to LTR).

CARNOT PRINCIPLES FOR HEAT ENGINES

1. The efficiency of an irreversible (real) heat engine is always <u>less than</u> the efficiency for a reversible (CARNOT) heat engine operating between the same high and low temperature reservoirs, (regardless of type of devices, working fluid, etc.)

2. The efficiencies of all reversible (CARNOT) heat engines operating between the same high and low temperature reservoirs are always equal, (regardless of type of devices, working fluid, etc.)

CARNOT REFRIGERATOR IS SIMPLY A REVERSED CARNOT HEAT ENGINE, WITH A SEQUENCE OF FOUR REVERSIBLE PROCESSES

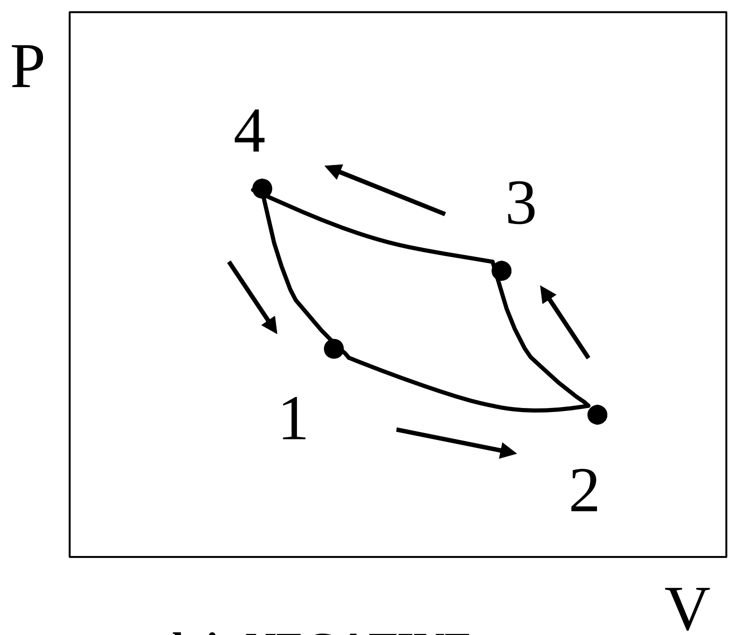
1 → 2: **Reversible isothermal expansion**
Heat transfer (+) and boundary work (+) occur in closed system

2 → 3: **Reversible adiabatic compression**
Work input (-), but no heat transfer
AND $W_{in} >>> W_{out}$

3 → 4: **Reversible isothermal compression**
Heat transfer (-) and boundary work (-) occur in closed system

4 → 1 **Reversible adiabatic expansion**
Work output (+), but no heat transfer

P-V DIAGRAM FOR CARNOT REFRIGERATOR CYCLE



Showing <u>net work is NEGATIVE</u>.

CARNOT PRINCIPLES APPLIED TO A REFRIGERATOR

1. The coefficient of performance (COP) of a refrigerator (or heat pump) comprised of reversible processes (CARNOT) is always greater than the COP for a sequence of irreversible (real) processes operating between the same high and low temperature reservoirs (regardless of type of devices, working fluid, etc.).

2. The COP's of all reversible (CARNOT) refrigerators or heat pumps operating between the same high and low temperature reservoirs are always equal, (regardless of type of devices, working fluid, etc.)

The second CARNOT principle states that the efficiency of a CARNOT heat engine is a function of high and low temperature reservoir temperatures (T_H, T_L) only when temperature is on an absolute scale (Kelvin). That is:

$$\eta_C = f(T_H, T_L)$$

then since η is by definition a function of the ratio Q_H/Q_L. For a model system of three heat engines operating between the same reservoirs, as shown in text figure 6-49, it can be proven that

for a reversible (CARNOT) heat engine:

$$\left(\frac{Q_H}{Q_L}\right)_{\text{reversible}} = \frac{T_H}{T_L}$$

and

$$\eta_C = 1 - \frac{T_L}{T_H} = 1 - \frac{Q_L}{Q_H}$$

where T_H and T_L are ALWAYS in degrees Kelvin!

Similarly for CARNOT refrigerator/heat pump cycles:

$$COP_{CR} = \frac{1}{\left(\frac{T_H}{T_L} - 1\right)} = \frac{1}{\left(\frac{Q_H}{Q_L} - 1\right)}$$

and

$$COP_{CHP} = \frac{1}{\left(1 - \frac{T_L}{T_H}\right)} = \frac{1}{\left(1 - \frac{Q_L}{Q_H}\right)}$$

where T_H and T_L are ALWAYS in degrees Kelvin!