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2nd Law

The Second Law of Thermodynamics: Processes occur in a certain direction and energy has quality as well as quantity.
Thermal Energy Reservoirs: A hypothetical body with a relatively large thermal energy capacity (mass x specific heat) that can supply or absorb finite amounts of heat without undergoing any change in temperature.

Heat Engines

- Devices that convert heat to work
- Receive heat from high-temp source
- Convert part of this heat to work
- Reject remaining waste heat to low-temperature sink - Kelvin-Plank Statement
- Operate on a cycle
- MUST waste some energy by transferring to low-temperature reservoir in order to complete cycle

Notation:

- $Q_{in} = Q_H$ = amount of heat supplied from a high-temp source
- $Q_{out} = Q_L$ = amount of heat rejected to a low temperature sink
- W_{out} = amount of work delivered out of system by working fluid
- W_{in} = amount of work input to system

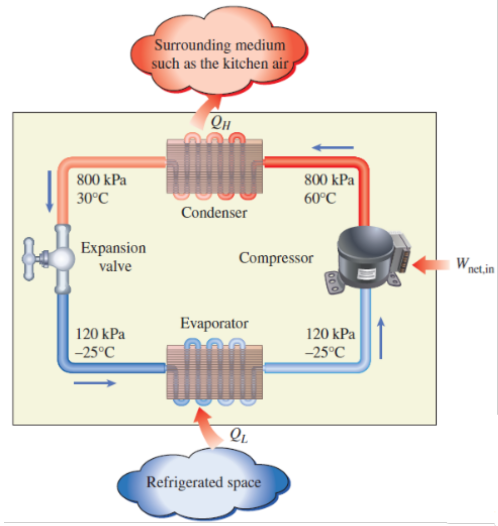
$W_{net,out} = W_{out} - W_{in}$ (kJ)
$W_{net,out} = Q_{in} - Q_{out}$ (kJ)

Thermal Efficiency

$\eta = \frac{W_{net,out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{Q_L}{Q_H}$

Refrigerators and Heat Pumps

Coefficient of Performance: efficiency of a refrigerator.
$\mathrm{COP}_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$
Clausius Statement: It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.



Reversible and Irreversible Processes

Reversible Process: A process that can be reversed without leaving any trace on the surroundings - theoretical to find limits.
Irreversible Process: A process that is not reversible.
Ierreversibilities:

- Friction
- Unrestrained expansion
- Mixing of two fluids
- Heat transfer across a finite temperature difference
- Electric resistance
- Inelastic deformation of solids
- Chemical reactions

The Carnot Cycle

The Carnot Cycle is composed of four reversible processes - two isothermal and two adiabatic - and it can be executed either in a closed or steady-flow system.

- Reversible Isothermal Expansion - process 1-2, T_H = constant
- Reversible Adiabatic Expansion - process 2-3, $T_H \to T_L$
- Reversible Isothermal Compression - process 3-4, T_L = constant
- Reversible Adiabtic Compression - process 4-1, $T_L \to T_H$

The Carnot Cycle is completely reversible - in which case it becomes the carnot refrigeration cycle.

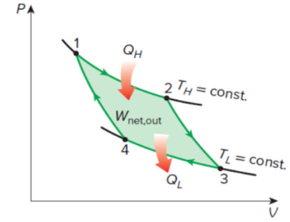


FIGURE 7-35
P-V diagram of the Carnot cycle.

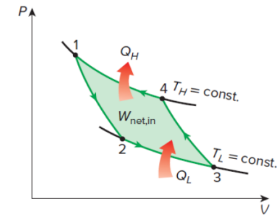


FIGURE 7-36
P-V diagram of the reversed Carnot cycle.

The Carnot Principles: The efficiency of an irreversible heat engine is always less than the efficiency of a reversible one operating between the same two reservoirs and the efficiencies of all reversible heat engines operating between the same two reservoirs are the same.
The Thermodynamic Temperature Scale: A temperature scale that is independent of the properties of the substances that are used to measure temperature.
$T_H = T_L \frac{Q_H}{Q_L}$

The Carnot Heat Engine

Any heat engine: $\eta_{th} = 1 - \frac{Q_L}{Q_H}$
Carnot heat engine: $\eta_{th,rev} = 1 - \frac{T_L}{T_H}$

$$\eta_{th} \begin{cases} < \eta_{th,rev} & \text{irreversible heat engine} \\ = \eta_{th,rev} & \text{reversible heat engine} \\ > \eta_{th,rev} & \text{impossible heat engine} \end{cases}$$

Amount of heat rejected per cycle: $Q_{L,rev} = \frac{T_L}{T_H} Q_{H,rev}$
Quality of Energy: The higher the temperature of the thermal energy, the higher its quality. Directly relates to face that you can use temperature to measure efficiency in $\eta_{th,rev}$.

The Carnot Refrigerator and Heat Pump

Any refrigerator or heat pump:
$\mathrm{COP}_R = \frac{1}{Q_H/Q_L - 1}$ and $\mathrm{COP}_{HP} = \frac{1}{1 - Q_L/Q_H}$
Carnot refrigerator or heat pump:
$\mathrm{COP}_{R,rev} = \frac{1}{T_H/T_L - 1}$ and $\mathrm{COP}_{HP,rev} = \frac{1}{1 - T_L/T_H}$

$$\mathrm{COP}_R \begin{cases} < \mathrm{COP}_{R,rev} & \text{irreversible refrigerator} \\ = \mathrm{COP}_{R,rev} & \text{reversible refrigerator} \\ > \mathrm{COP}_{R,rev} & \text{impossible refrigerator} \end{cases}$$