ME 266 THERMODYNAMICS 1
- The 2nd Law

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SECOND LAW OF THERMODYNAMICS

- The second law of thermodynamics continues where the first law stops, and helps us establish the direction of particular processes.
  - heat flows from a hot body to a cold one.
  - rubber bands unwind.
  - fluid flows from a high-pressure region to a low-pressure region.
- The first law of thermodynamics relates several variables involved in a physical process, but does not give any information as to the direction of the process.

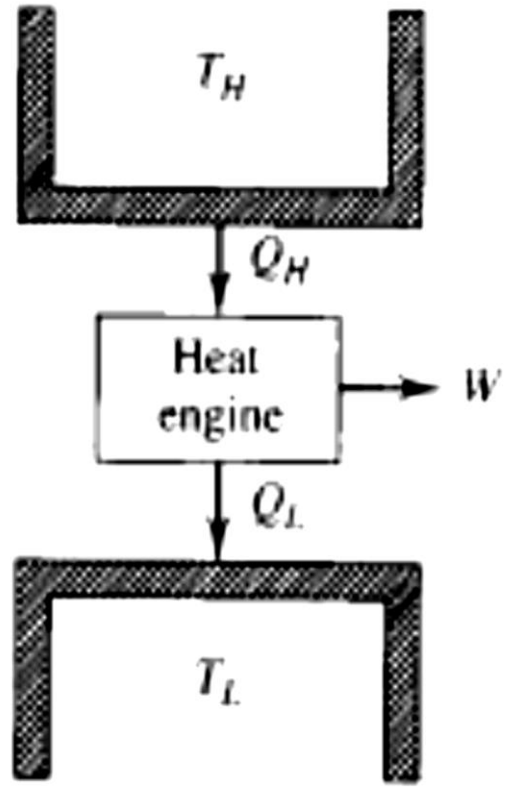
HEAT ENGINES, HEAT PUMPS, AND REFRIGERATORS

- **Cyclic devices** are either heat pumps, heat engines or refrigerators and operate between two **thermal reservoirs**.

- Thermal reservoirs are entities that are capable of providing or accepting heat without changing temperatures. E.g. atmosphere, lakes and furnaces.

HEAT ENGINES

- A heat engine is defined as a device that converts heat energy into mechanical energy.
- T_H and T_L are the temperatures of the source and sink respectively.
- $\mathbf{Q_H}$ is the heat transfer from the high temp reservoir and $\mathbf{Q_L}$ the heat transfer to the low temp reservoir.



HEAT ENGINES

- The net work output is given as:

$$W = Q_H - Q_L$$

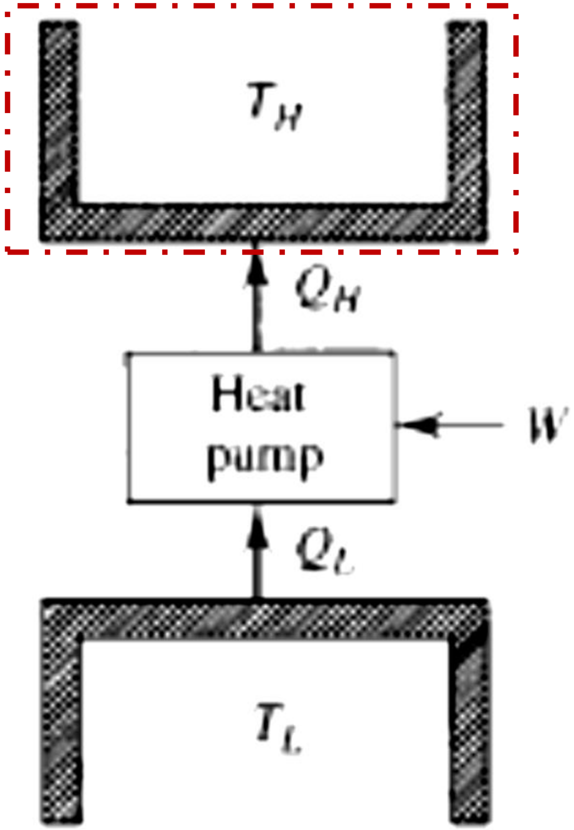
  - First law for cyclic processes, **Net Work = Net Heat**.

- The performance of a heat engine is the thermal efficiency:

$$\eta = \frac{W}{Q_H}$$

HEAT PUMPS

- A **heat pump** is a device that moves heat from one location (heat source) at a lower temperature to another location (heat sink) at a higher temperature using mechanical work.



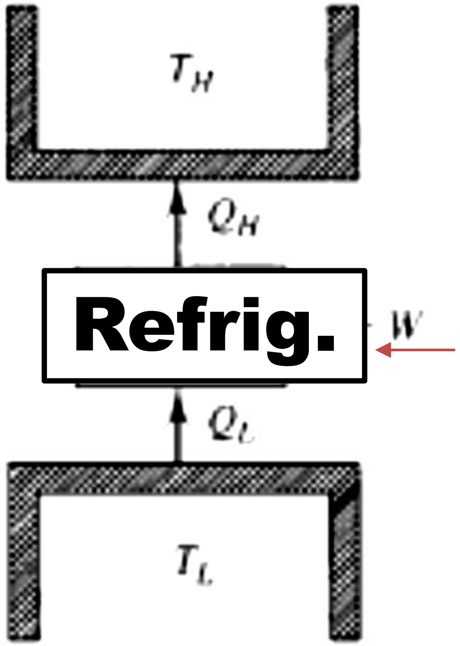
$$Q_H = W + Q_L$$

$$COP_{h.p} = \frac{Q_H}{W}$$

The measure of performance of a heat pump is the Coefficient of Performance (COP).

REFRIGERATORS

- Refrigerators, like, heat pumps move heat from a cooler region to a hotter one with the input of work.



Note - each of the performance measures represents:

$$\text{Performance} = \frac{\text{Desired Output}}{\text{Required Input}}$$

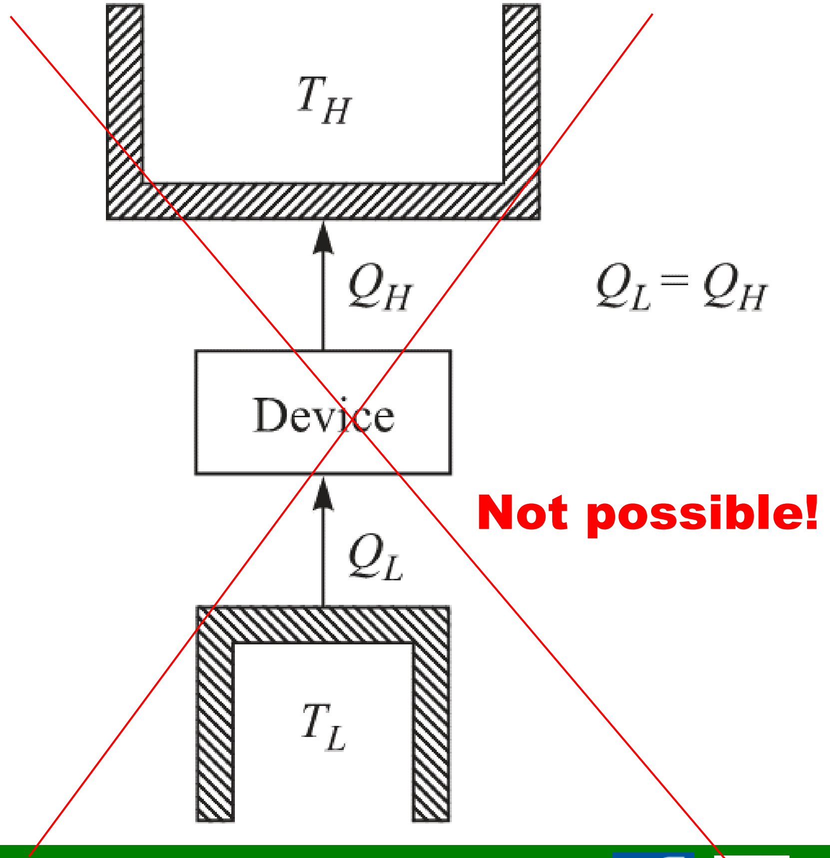
$$COP_{Refrig} = \frac{Q_L}{W}$$

$$COP_{h.p} = COP_{refrig} + 1$$

STATEMENTS OF THE SECOND LAW

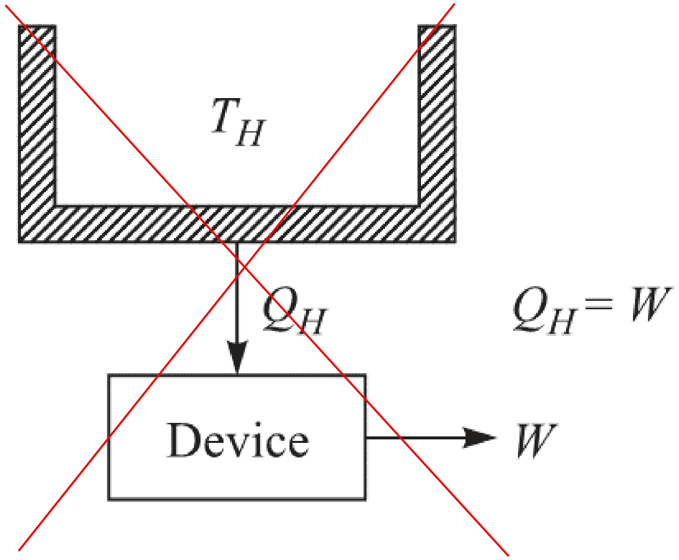
- There are a number of statements of the 2nd Law, two are presented:

Clausius Statement: It is **impossible** to construct a device that operates in a cycle and whose sole effect is the transfer of heat from a cooler body to a hotter body.



STATEMENTS OF THE SECOND LAW

- **Kelvin-Planck Statement**: It is impossible to construct a device that operates in a cycle and produces no other effect than the production of work and the transfer of heat from a single body.
  - It is impossible to construct a heat engine that extracts energy from a reservoir, does work, and does not transfer heat to a low-temperature reservoir.



Not possible!

REVERSIBILITY

- A reversible process is defined as a process which, having taken place, can be reversed and in so doing leaves no change in either the system or the surroundings.
- A reversible engine is an engine that operates with reversible processes only.
  - A reversible engine is most efficient engine that can possibly be constructed.

REVERSIBILITY

- The process has to be a quasi-equilibrium process; and:
  - No friction is involved in the process.
  - Heat transfer occurs due to an infinitesimal temperature difference only.
  - Unrestrained expansion does not occur.
- Losses such as those due to friction and others listed above are referred to as **irreversibilities**.

REVERSIBILITY

Some sources of irreversibilities:

- Friction
- Unrestrained expansion
- Mixing of two gases
- Heat transfer across finite temperature difference
- Electric resistance
- Inelastic deformation of solids, and
- Chemical reaction

THE CARNOT ENGINE

- The Carnot Engine is an ideal engine that uses reversible processes to form its cycle of operation; thus it is also called a **reversible engine**.

- The efficiency of the Carnot engine establishes the **maximum possible efficiency** of any real engine.

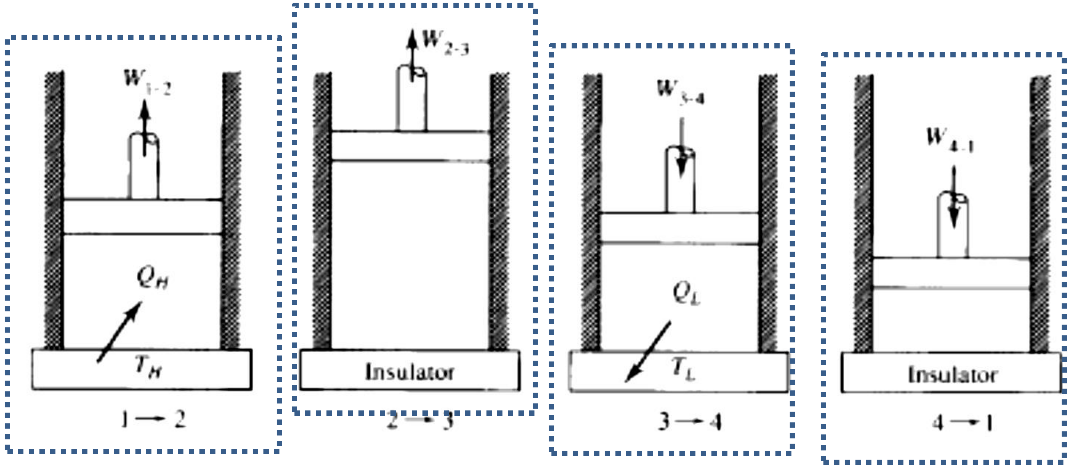
THE CARNOT ENGINE

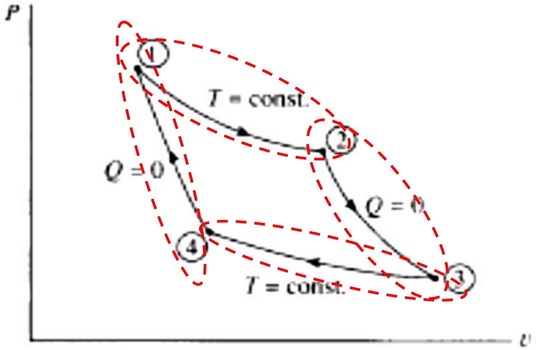
1 ⟶ 2: *Isothermal expansion.*

2 ⟶ 3: *Adiabatic reversible expansion.*

3 ⟶ 4: *Isothermal compression.*

4 ⟶ 1: *Adiabatic reversible compression.*





THE CARNOT ENGINE

Applying the first law to the cycle:

$$Q_H - Q_L = W_{net}$$

The thermal efficiency is then written as:

$$\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Postulates based on the Carnot engine:

Postulate 1: *It is impossible to construct an engine, operating between two given temperature reservoirs, that is more efficient than the Carnot engine.*

Postulate 2: *The efficiency of a Carnot engine is not dependent on the working substance used or any particular design feature of the engine.*

Postulate 3: *All reversible engines, operating between two given temperature reservoirs, have the same efficiency as a Carnot engine operating between the same two temperature reservoirs.*

THE CARNOT ENGINE

CARNOT EFFICIENCY:

$$1 \rightarrow 2:\ Q_H = W_{1-2} = \int_{V_1}^{V_2} PdV = mRT_H ln\frac{V_2}{V_1}$$

Isothermal expansion

$$2 \rightarrow 3:\ \ Q_{2-3} = 0$$

Adiabatic expansion

$$3 \rightarrow 4: Q_L = -W_{3-4} = -\int_{V_3}^{V_4} PdV = -mRT_L ln\frac{V_4}{V_3}$$

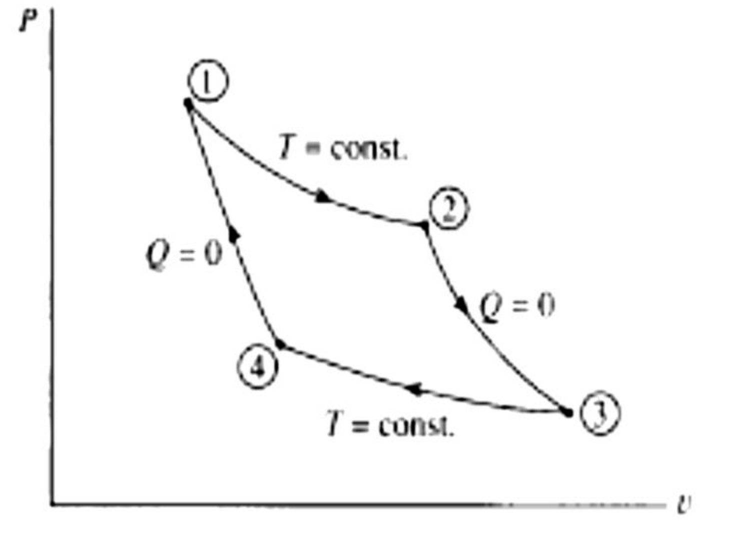
Isothermal compression

$$4 \rightarrow 1: Q_{4-1} = 0$$

Adiabatic expansion

$$\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$\eta = 1 - \frac{T_L}{T_H}$$



THE CARNOT ENGINE

The coefficient of performance for a Carnot heat pump becomes

$$COP = \frac{Q_H}{W_{net}} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

The coefficient of performance for a Carnot refrigerator takes the form

$$COP = \frac{Q_L}{W_{net}} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

The above measures of performance set limits that real devices can only approach.

Entropy Changes

- Enthropy is a quantitative measure of randomness.
- Consider an infinitesimal isothermal expansion by an ideal gas. An amount of heat ***dQ*** is added and the gas expands by a small amount **dV** such that the gas **Temperature** is kept constant.
- Recall: internal energy remains constant, since it depends only on temperature.
- From the first law, one may write:

$$dQ = dW \quad = pdV \quad = \frac{nRT}{V} dV \Rightarrow \frac{dV}{V} = \frac{dQ}{nRT}$$

- The gas is obviously more disordered after expansion than before, i.e. increased randomness due to volume for mobility.
- The fractional change in volume $\frac{dV}{V}$ is a measure of randomness and is proportional to $\frac{dQ}{T}$.
- The symbol **S** is introduced for entropy of the system. The infinitesimal entropy change ***ds*** for an infinitesimal reversible process at temperature ***T*** is given as:

$$\boxed{dS = \frac{dQ}{T}}$$

ENTROPY

Entropy is a measure of the disorder that exists in a system.

$$The\ relation\ \oint \frac{\delta Q}{T} \leq 0\ is\ termed\ Classius\ Inequality.$$

$$\oint \frac{\delta Q}{T} = 0 \qquad for\ a\ reversible\ process$$

$$\oint \frac{\delta Q}{T} < 0 \qquad for\ irreversible\ processs$$

For a given reversible process we may write:

$$\left(\frac{\delta Q}{T}\right)_{rev} = dS$$

ENTROPY

The change in entropy during a reversible process can be written as

$$\int_1^2 \left(\frac{\delta Q}{T}\right)_{rev} = \int_1^2 dS = (S_2 - S_1) = \Delta S$$

There exists a property called entropy of a system such that for any reversible process from state point 1 to state point 2, its change is given by:

$$\int_1^2 \left(\frac{\delta Q}{T}\right)_{rev} = (S_2 - S_1)$$

For a temperature – entropy diagram we have:

$$Q_{1-2} = \int_{S_1}^{S_2} T\,dS$$