2nd LAW of THERMODYNAMICS

1st Law – Energy Conservation
- amount, quantity

2nd Law – Direction of process
- quality

For a process to occur, 1st and 2nd Laws must be obeyed

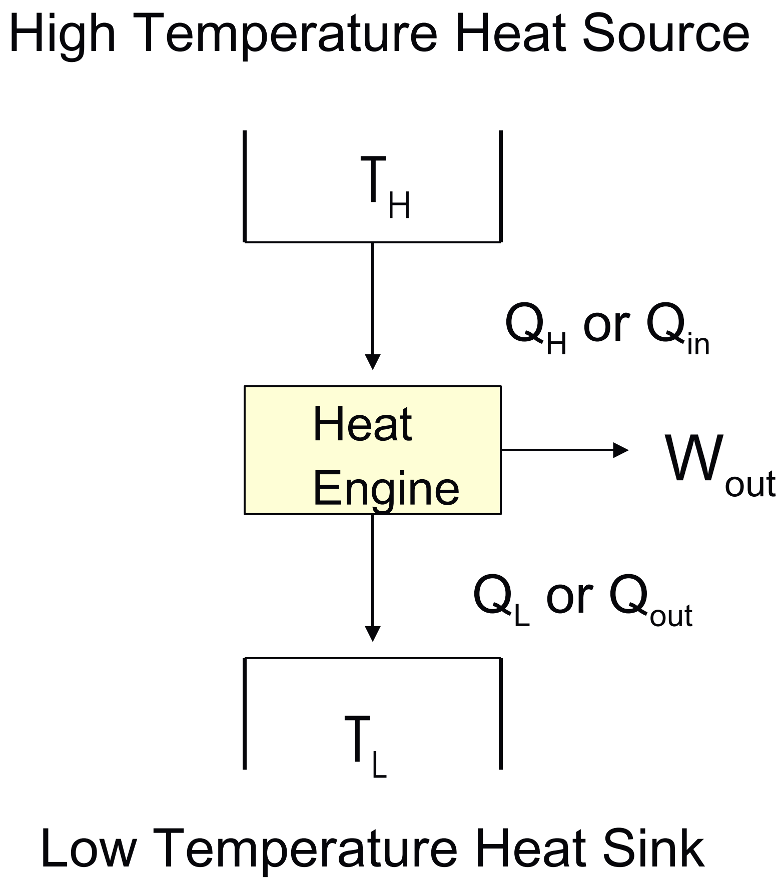
Heat – Low quality energy
Work – High quality energy

Heat Reservoir

- A body which can receive/reject heat without resulting in temperature change
- Source - reservoir supplies heat (heat leaves reservoir)
- Sink - reservoir receives heat (heat enters reservoir)

Heat Engine

- To convert *heat* into *work*
- Characteristics
  - Receives heat from a heat source at high temperature, T_H
  - Only part of the heat is converted into work
  - The rest is rejected to another heat sink at low temperature, T_L
  - Engine works continuously (in a cycle)



$$\text{Thermal Efficiency} = \eta = \frac{\text{Net Work Output}}{\text{Heat Supplied}} = \frac{W_{out,net}}{Q_{\text{in}}}$$

$$\text{Efficiency} \equiv \frac{\text{Purpose Achieved}}{\text{Effort Supplied}}$$

2 factors limit efficiency

- Irreversibilities
- Side effect of heat transfer

Irreversibility

- Friction
- Electrical resistance
- Mixing of different substances
- Free expansion
- Non-isothermal heat transfer
- Etc.

Irreversible Process

- Process where the above factors are present

Reversible Process

- After forward and reverse processes are done (system back to initial state), there is no change on the universe (system and surrounding)
- Reversible because there is no irreversibilities
- Internally reversible - irreversibilities assumed to exist only outside the system
- Externally reversible - irreversibilities assumed to exist only inside the system

2^{nd} Law of Thermodynamics

- Kelvin-Planck Statement (Heat Engine)

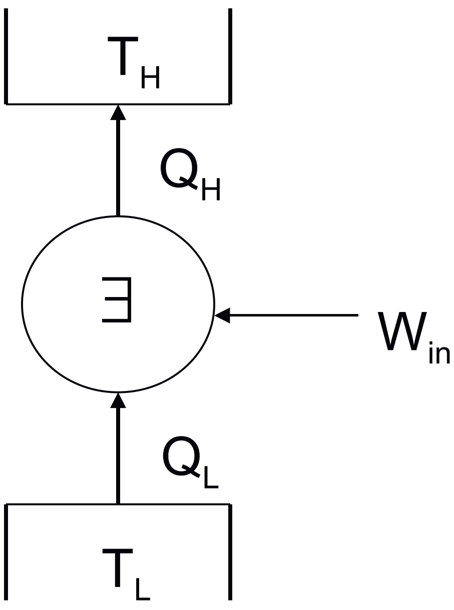
  "It is impossible for a device that works in a cycle (continuously) to receive heat supply from one heat reservoir and produces the same amount of work"

- Clausius Statement (Heat Pump)

  "It is impossible to construct a device that works in a cycle which does not produce any other effect except the transfer of an amount of heat from a cold to a hot body"

Refrigerator & Heat Pump (Reversed Heat Engine)

- To force heat at T_L to flow to T_H (work must be supplied)



Coefficient of Performance for Refrigerators

$$COP_R = \frac{Q_L}{W_{in}}$$

Coefficient of Performance for Heat Pump

$$COP_{HP} = \frac{Q_H}{W_{in}}$$

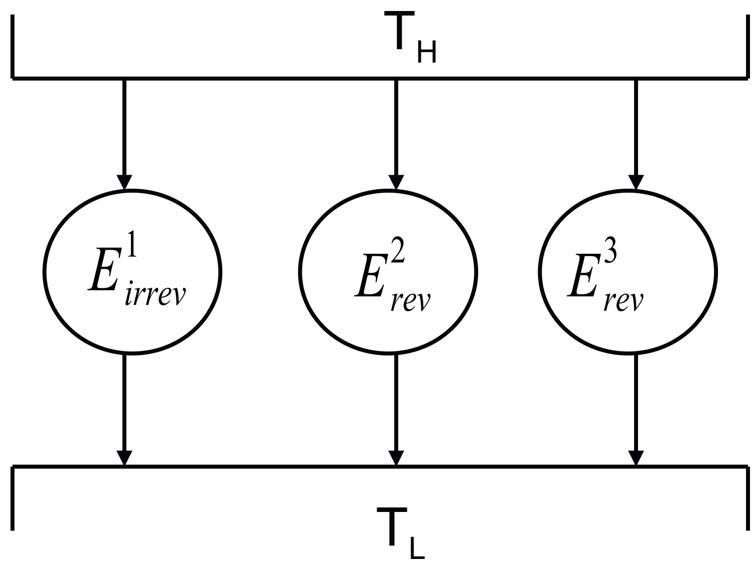
Reversible Heat Engine/Reversed H.E

- No irreversibilities in the engine (friction etc.)
- All processes within the cycle are reversible processes (heat transfer done isothermally, etc.)

Real Heat Engine

- There exist irreversibilities (friction etc.)

Carnot Principles



3 heat engines between the same T_H, T_L

$$(a)\ \eta_{irrev} < \eta_{rev}$$

$$(b)\ \eta_{rev,2} = \eta_{rev,3}$$

$$(c)\ \eta_{rev} < 1$$

(due to heat rejection requirement)

Thermodynamic Temperature Scale

- From Carnot Principle (b)

$$\eta_{rev} = f\left(T_H, T_L\right)$$

also $\eta_{rev} = 1 - \frac{Q_L}{Q_H}$

so $\frac{Q_L}{Q_H} = 1 - \eta_{rev} = 1 - f\left(T_H, T_L\right)$

$$\frac{Q_L}{Q_H} = g\left(T_H, T_L\right)$$

take $g\left(T_H, T_L\right) = \frac{T_L}{T_H}$

thus $\boxed{\left[\frac{Q_L}{Q_H}\right]_{rev} = \frac{T_L}{T_H}}$

Maximum Performance

General **Ideal/Max/Carnot/Reversible**

$$\frac{Q_H - Q_L}{Q_H} = \eta = \frac{T_H - T_L}{T_H}$$

$$\frac{Q_L}{Q_H - Q_L} = \mathrm{COP}_R = \frac{T_L}{T_H - T_L}$$

$$\frac{Q_H}{Q_H - Q_L} = \mathrm{COP}_{\mathrm{HP}} = \frac{T_H}{T_H - T_L}$$

Same T_H, same T_L

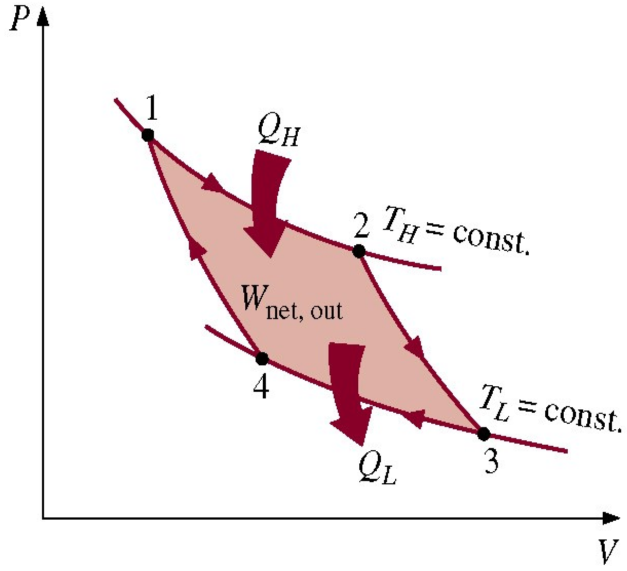
$$\mathrm{COP}_{\mathrm{HP,rev}} = \mathrm{COP}_{\mathrm{R,rev}} + 1$$

$$\eta, \mathrm{COP} = \eta_{\max}, \mathrm{COP}_{\max} \quad (\mathrm{Ideal})$$

$$< \eta_{\max}, \mathrm{COP}_{\max} \quad (\mathrm{Real})$$

$$> \eta_{\max}, \mathrm{COP}_{\max} \quad (\mathrm{Impossible})$$

Carnot Cycle (Reversible Heat Engine)



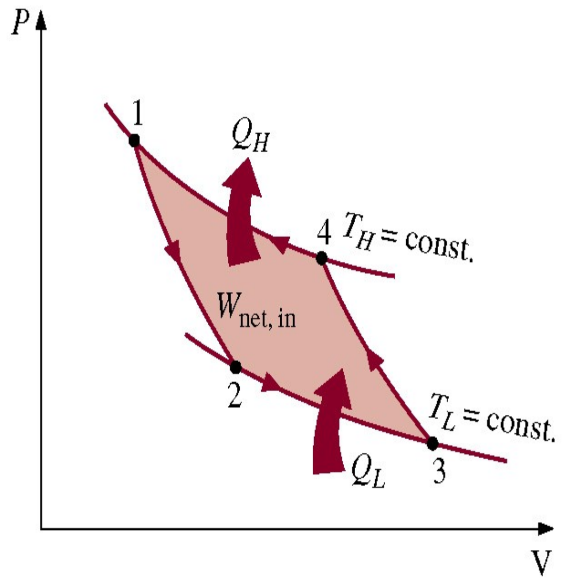
2 isothermal processes (heat transfers)

2 reversible adiabatic processes

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

Reversed Carnot Cycle (for refrigerators/heat pumps)

- Same processes, but reversed direction



Refrigerators

$$COP_{R,rev} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

Heat Pumps

$$COP_{HP,rev} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$