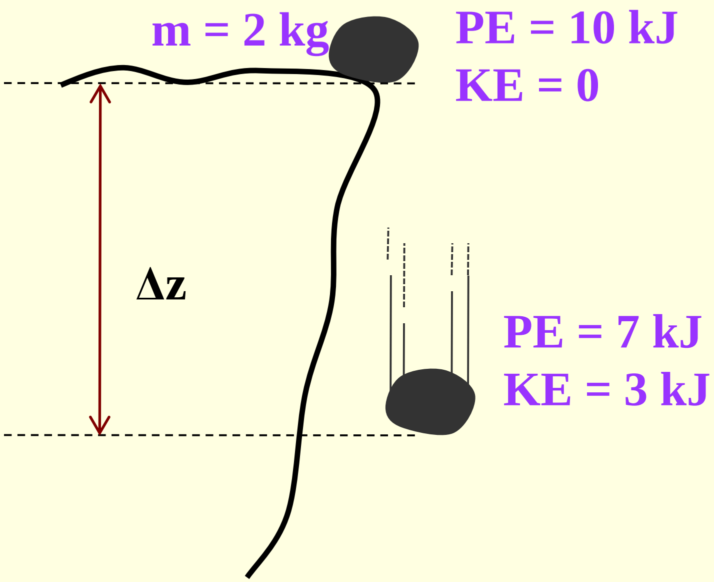
First Law of Thermodynamics

Also known as Law of Conservation of Energy

Important due to its ability to provide a sound basis to study between different forms of Energy and their interactions.



STATEMENT :

Energy can neither be created nor destroyed during a process; but can be only converted from one form to another.

$$m\ g\ \Delta z = \tfrac{1}{2}\ m\ (\ v_1^2 - v_2^2\ )$$

First Law of Thermodynamics

This forms the basis for Heat Balance / Energy Balance.

Net change (increase / decrease) in the total Energy of the System during a Process = Difference between Total Energy entering and Total Energy leaving the System during that Process.

Total Energy entering the System	−	Total Energy leaving the System	=	Change in Total Energy of the System
(E_{IN})		(E_{OUT})		(ΔE)

Second Law of Thermodynamics

Hot cup of coffee gets cooled off when exposed to surrounding.

Energy lost by coffee = Energy gained by Surroundings.

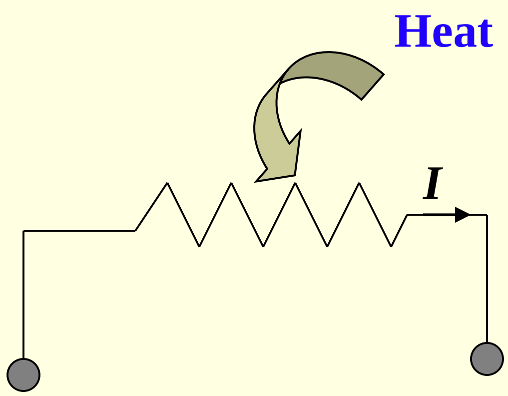
Here, First Law of Thermodynamics is satisfied.

HOWEVER, converse is NOT true.

i.e. Taking out Heat Energy from Surroundings ≠ Coffee getting hot.

Still, First Law of Thermodynamics is satisfied !

Second Law of Thermodynamics



Heating of a room by Electric heater; by passing Electric Current through the Resistor.

Electric Energy supplied to the heater =

Energy transferred to the Surroundings (room air).

Here, First Law of Thermodynamics is satisfied.

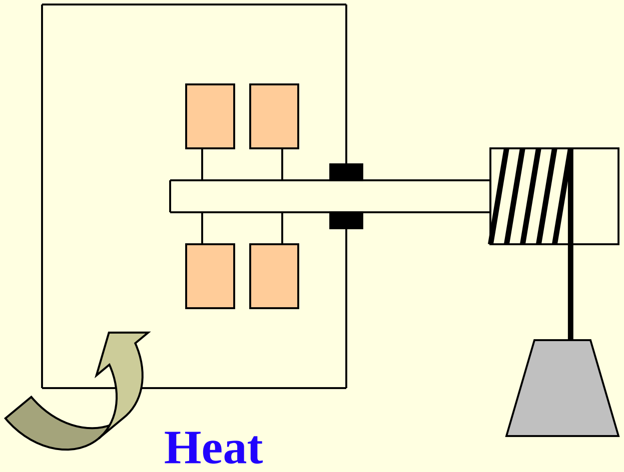
HOWEVER, converse is <u>NOT</u> true.

Transferring Heat to the wire ≠

Equivalent amount of Electric Energy generated in wire.

Still, First Law of Thermodynamics is satisfied !

Second Law of Thermodynamics



Paddle Wheel mechanism operated by falling mass.

Paddle wheel rotates as mass falls down and stirs the fluid inside the container.

Decrease in Potential Energy of the mass = Increase in Internal Energy of the fluid.

Here, First Law of Thermodynamics is satisfied.

HOWEVER, converse is NOT true.

Transferring Heat to the Paddle Wheel ≠ Raising the mass.

Still, First Law of Thermodynamics is satisfied !

Second Law of Thermodynamics

From these day – to – day life examples, it can be clearly seen that;

Satisfying the First Law of Thermodynamics does not ensure for a Process to occur actually.

Processes proceed in certain direction; but may not in Reverse direction.

First Law of Thermodynamics has no restriction on the DIRECTION of a Process to occur.

This inadequacy of the First Law of Thermodynamics; to predict whether the Process can occur is solved by introduction of the Second Law of Thermodynamics.

Second Law of Thermodynamics

SIGNIFICANCE :

1. **Second Law of Thermodynamics is <u>not just limited</u> to identify the direction of the Process.**
2. **It also asserts that Energy has quantity as well as *Quality*.**
3. **It helps to determine the *Degree of Degradation* of Energy during the Process.**
4. **It is also used to determine the *Theoretical Limits* for the performance of the commonly used engineering systems, such as Heat Engines and Refrigerators.**

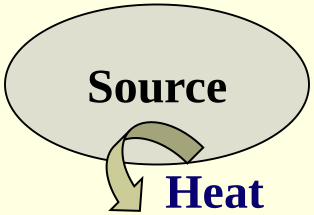
Second Law of Thermodynamics

Thermal Energy Reservoir :

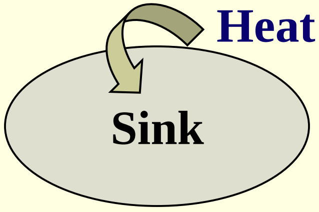
Hypothetical body with relatively very large *Thermal Energy Capacity* (mass x Sp. Heat) that can supply or absorb finite amount of Heat without undergoing change in Temperature.

e.g. ocean, lake, atmosphere, two-phase system, industrial furnace, etc.

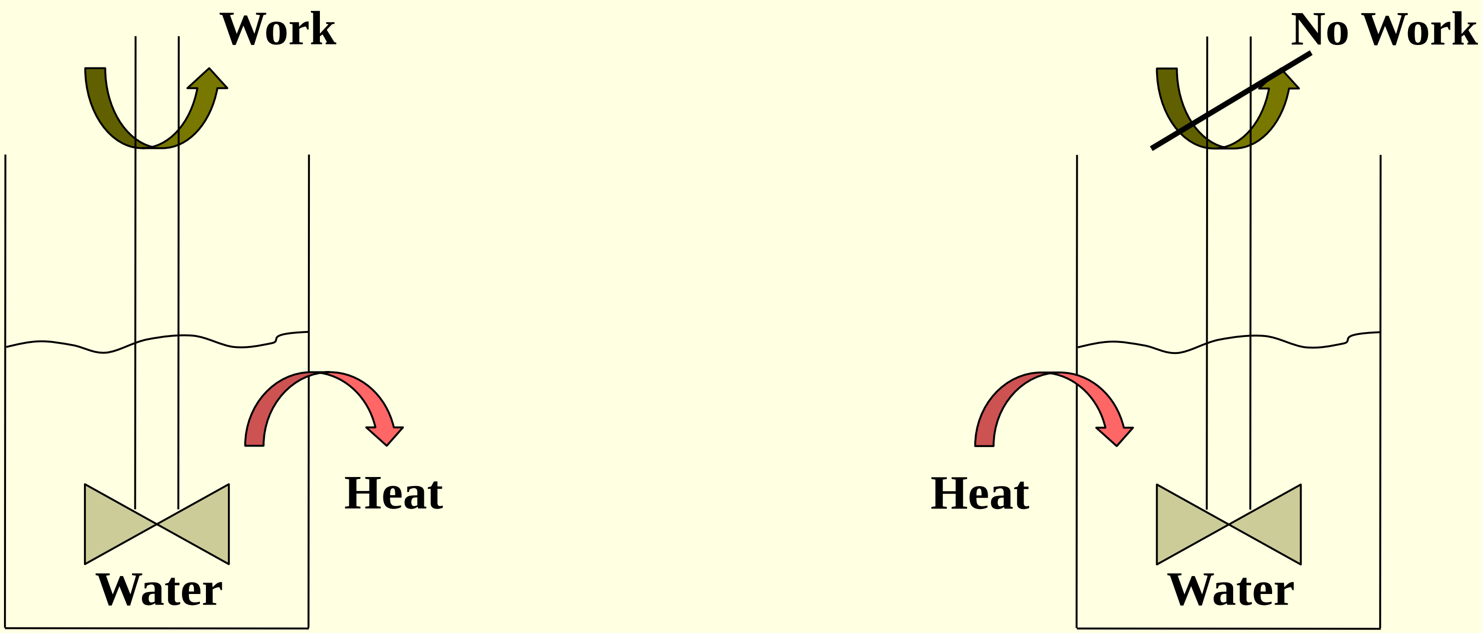
Reservoir that <u>supplies</u> Energy in form of Heat is known as SOURCE.



Reservoir that <u>absorbs</u> Energy in form of Heat is known as SINK.



Second Law of Thermodynamics



From such examples, it can be concluded that,

1. Work can be converted to Heat.
2. BUT, Converting Heat to Work requires *special devices*.

These devices are known as **Heat Engines**.

Second Law of Thermodynamics

Characteristics of Heat Engines :

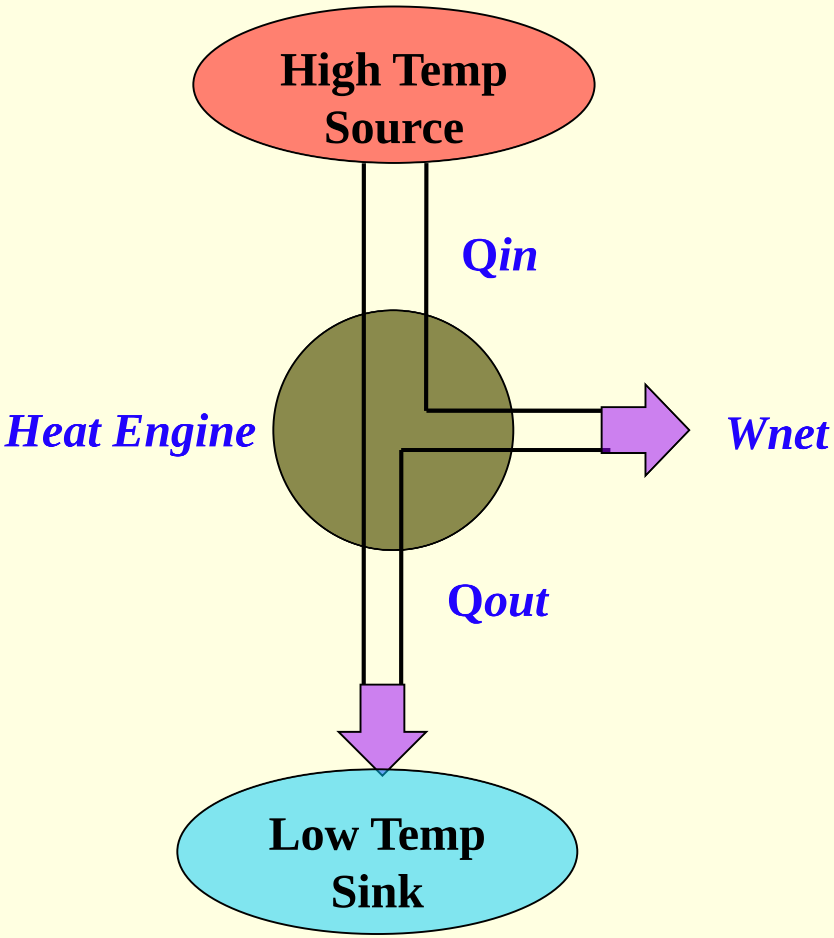
1. **They receive the Heat from High-Temp Reservoir (i.e. Source)**
   (e.g. Solar Energy, Oil Furnace, Nuclear Reactor, etc.).
2. **They convert part of this Heat to Work**
   (Usually in form of rotating shaft).
3. **They reject the remaining Heat to Low-Temp Reservoir (i.e. Sink)**
   (e.g. Atmosphere, River, etc.)
4. **They operate on a CYCLE.**

Heat Engines are generally Work – Producing devices,

e.g. Gas Turbines, I.C. Engines, Steam Power Plants, etc.

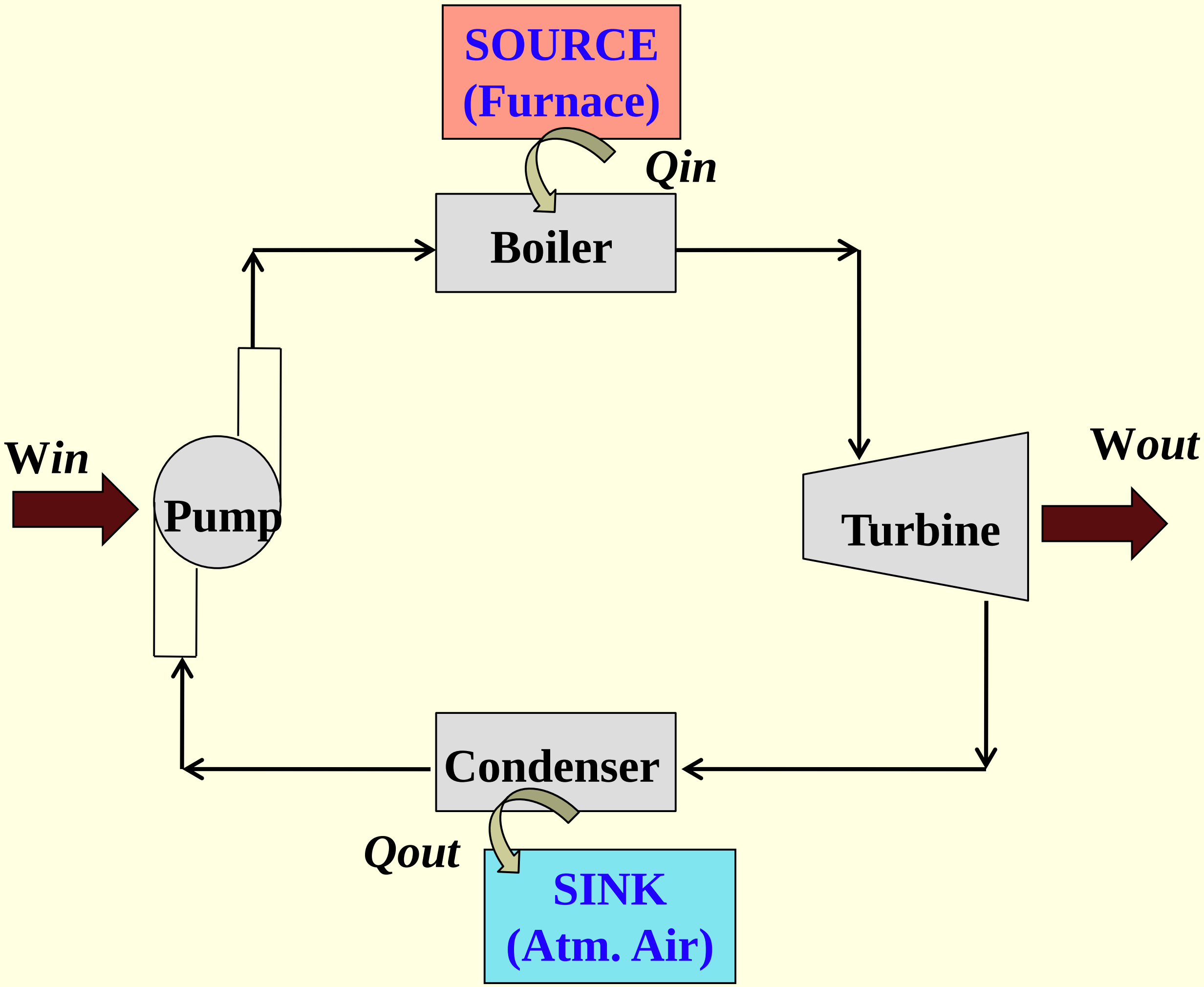
Second Law of Thermodynamics

HEAT ENGINE :



Second Law of Thermodynamics

STEAM POWER PLANT :

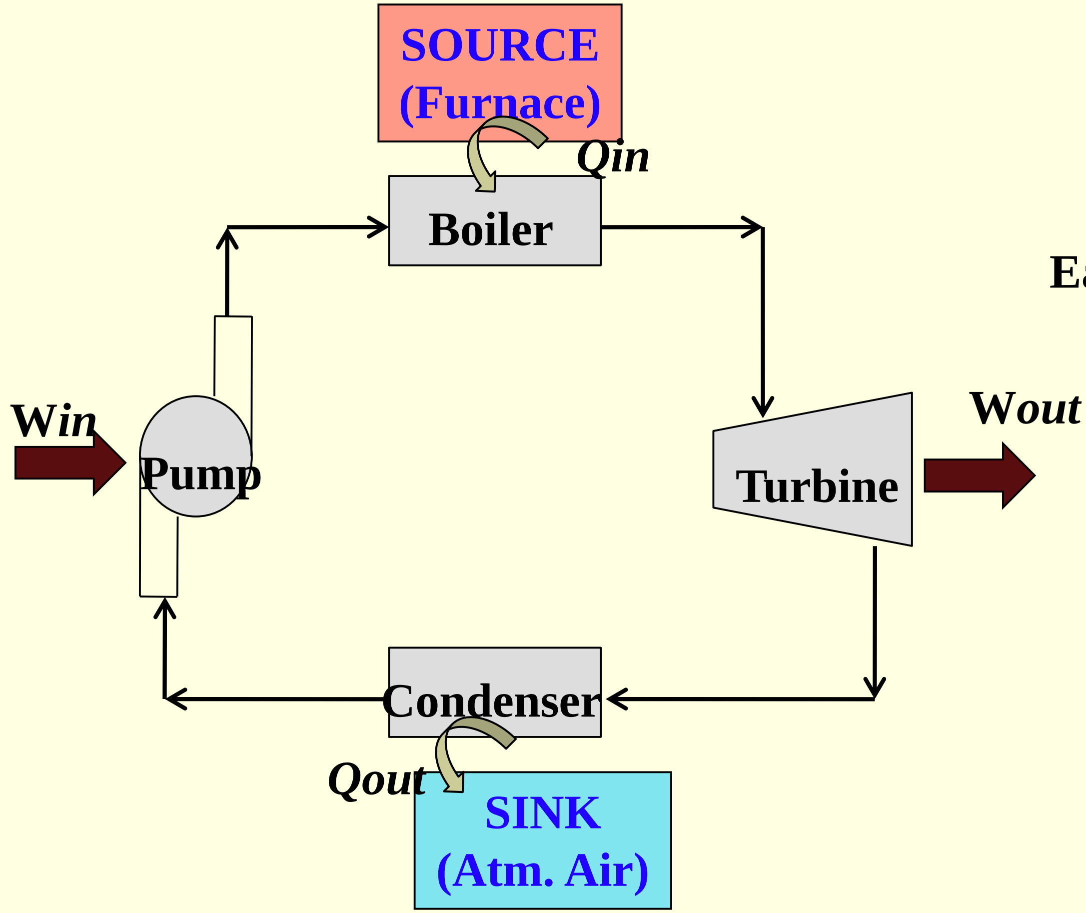


Can Q*out* be eliminated ?

ANS : NO.

Without a Heat Rejection Process, the Cycle can not be completed.

Second Law of Thermodynamics



Net Work Output =

$$Work_{net,out} = W_{out} - W_{in}$$

Each component is an OPEN SYSTEM

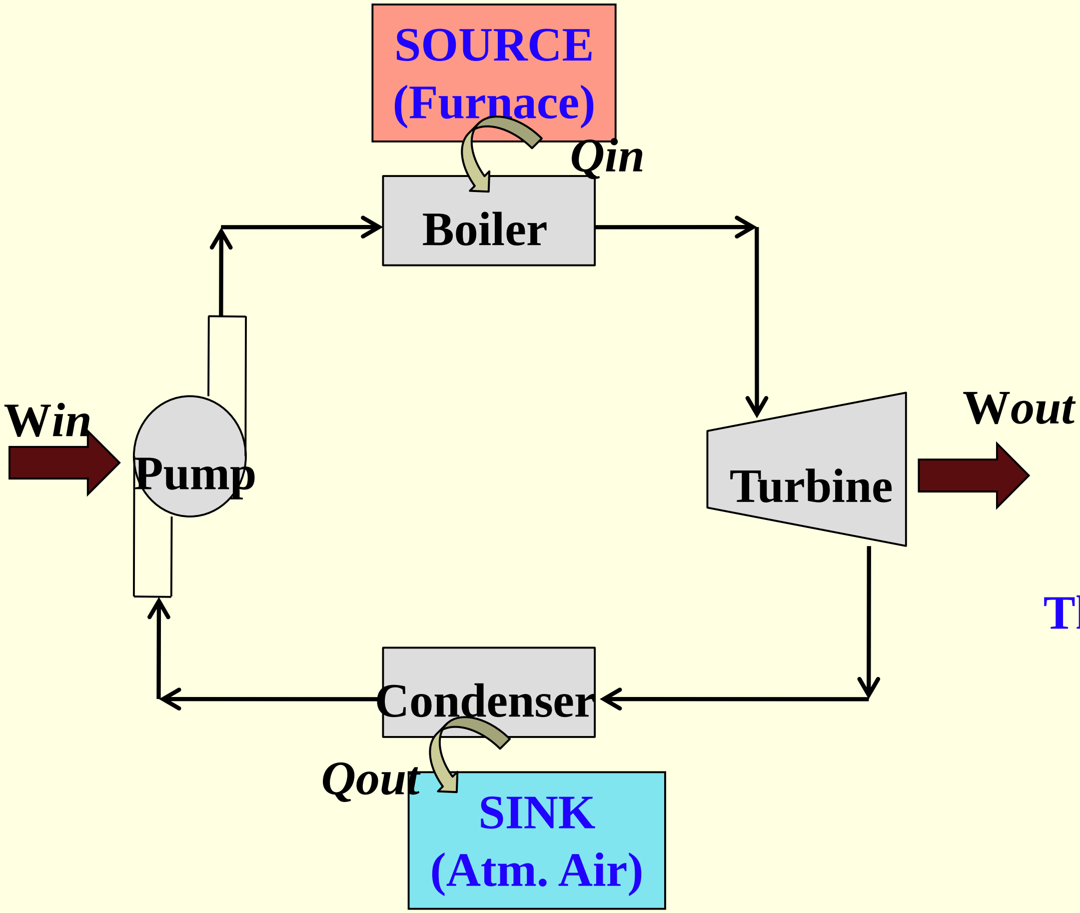
However, as a <u>complete set of components</u>, no mass flows in / out of the system

Hence, it can be treated as a CLOSED SYSTEM → $\Delta U = 0$

Thus,

$$Work_{net,out} = Q_{out} - Q_{in}$$

Second Law of Thermodynamics

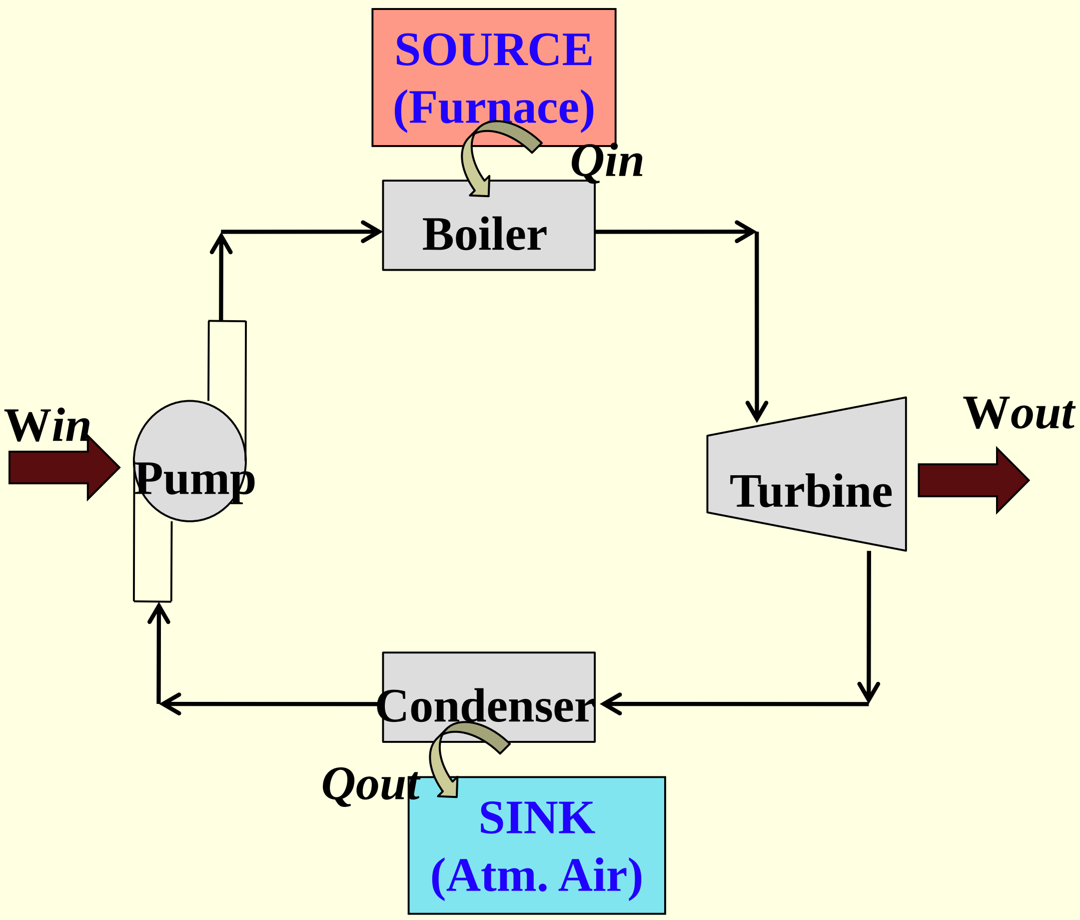


Part of Heat output that is converted to net Work output, is a measure of performance of the Heat Engine; and is known as the THERMAL EFFICIENCY of the Heat Engine.

$$\text{Thermal Efficiency} = \frac{\text{Net Work Output}}{\text{Total Heat Input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

Second Law of Thermodynamics



Q_H = Magnitude of Heat Transfer between cyclic device and Source at temperature T_H

Q_L = Magnitude of Heat Transfer between cyclic device and Sink at temperature T_L

$Work_{net,out} = Q_H - Q_L$

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Second Law of Thermodynamics

Heat Engine must *give away* some heat to the Low Temperature Reservoir (i.e. Sink) to complete the Cycle.

Thus, a Heat Engine *must* exchange Heat with at least TWO Reservoirs for continuous operation.

This forms the basis for the Kelvin – Planck expression of the Second Law of Thermodynamics.

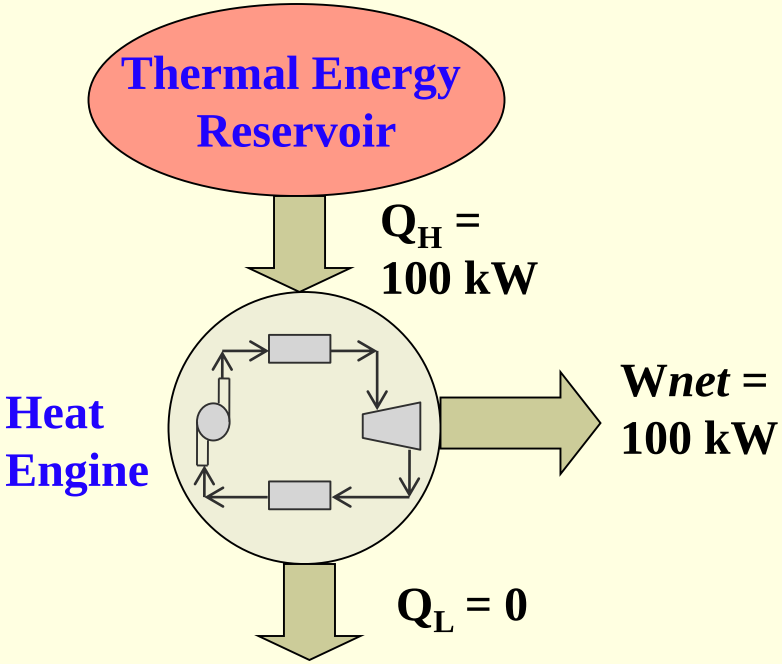
Second Law of Thermodynamics

Kelvin – Planck Statement :

It is impossible for any device that operates on a Cycle to receive Heat from a single Reservoir and produce net amount of Work.

Alternatively;

No Heat Engine can have a thermal efficiency of 100 per cent.



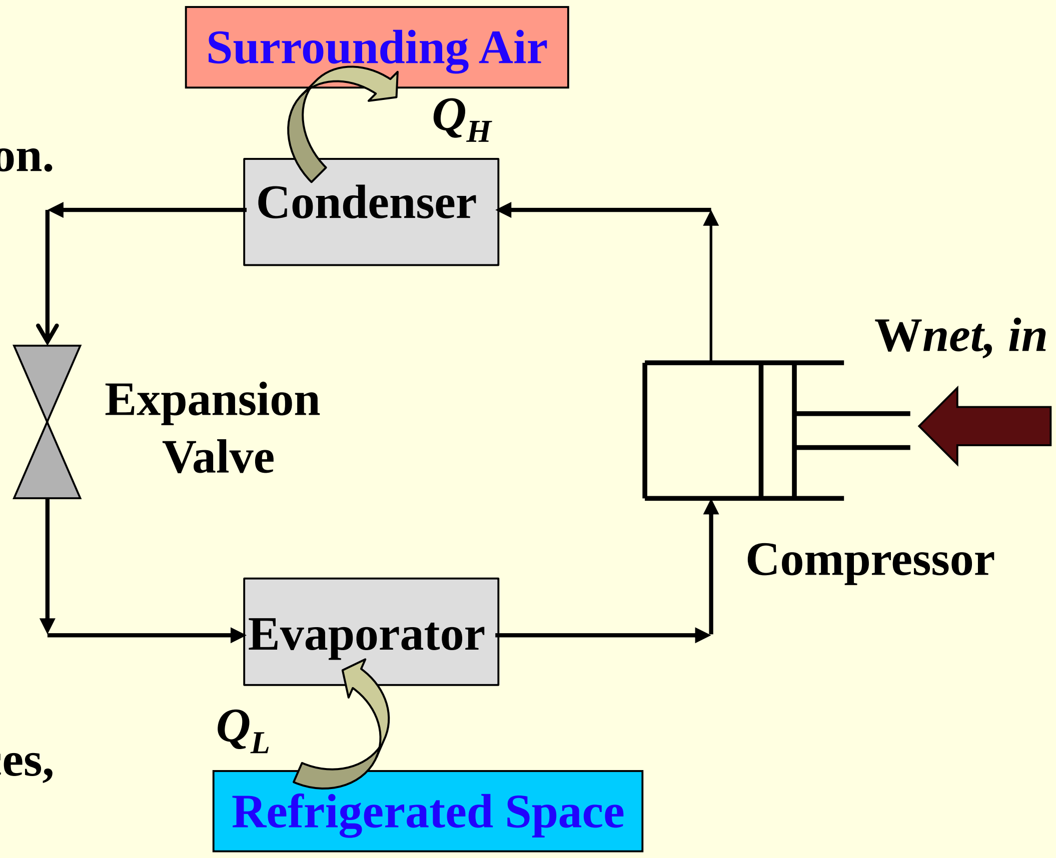
Second Law of Thermodynamics

REFRIGERATOR / HEAT PUMP :

Heat is always transferred from High Temperature to Low Temperature region.

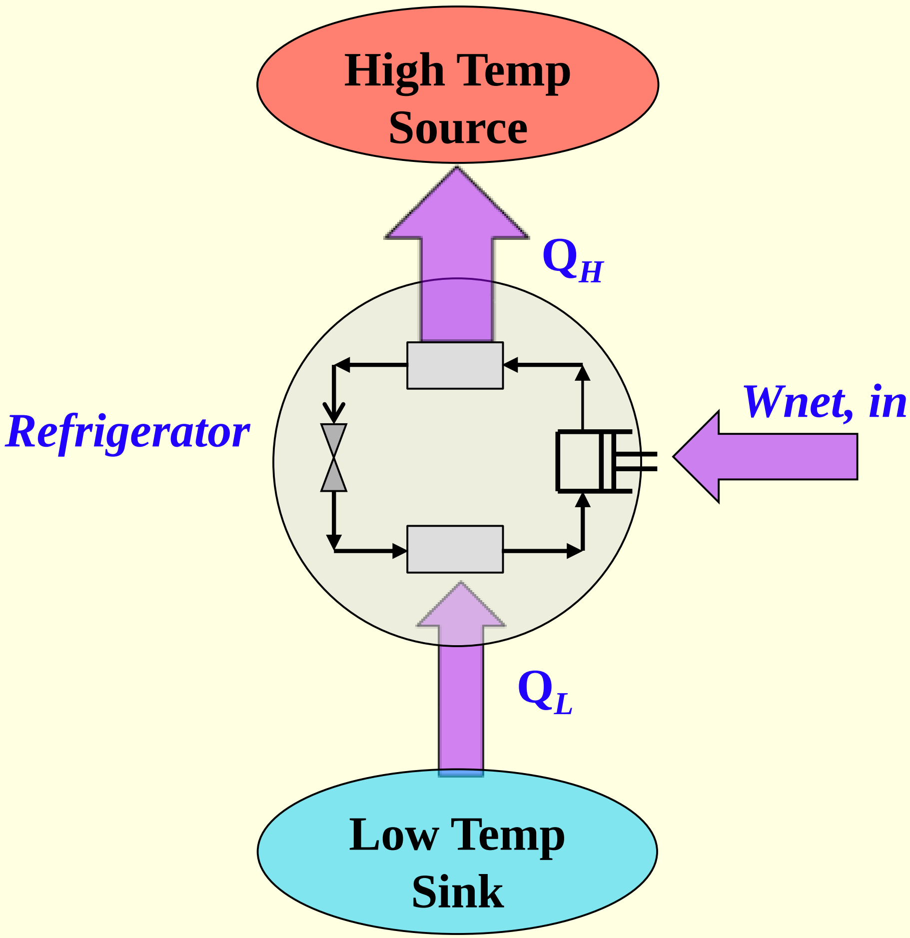
The reverse Process can not occur on itself.

Transfer of Heat from Low Temperature region to High Temperature one requires special devices, known as REFRIGERATORS.

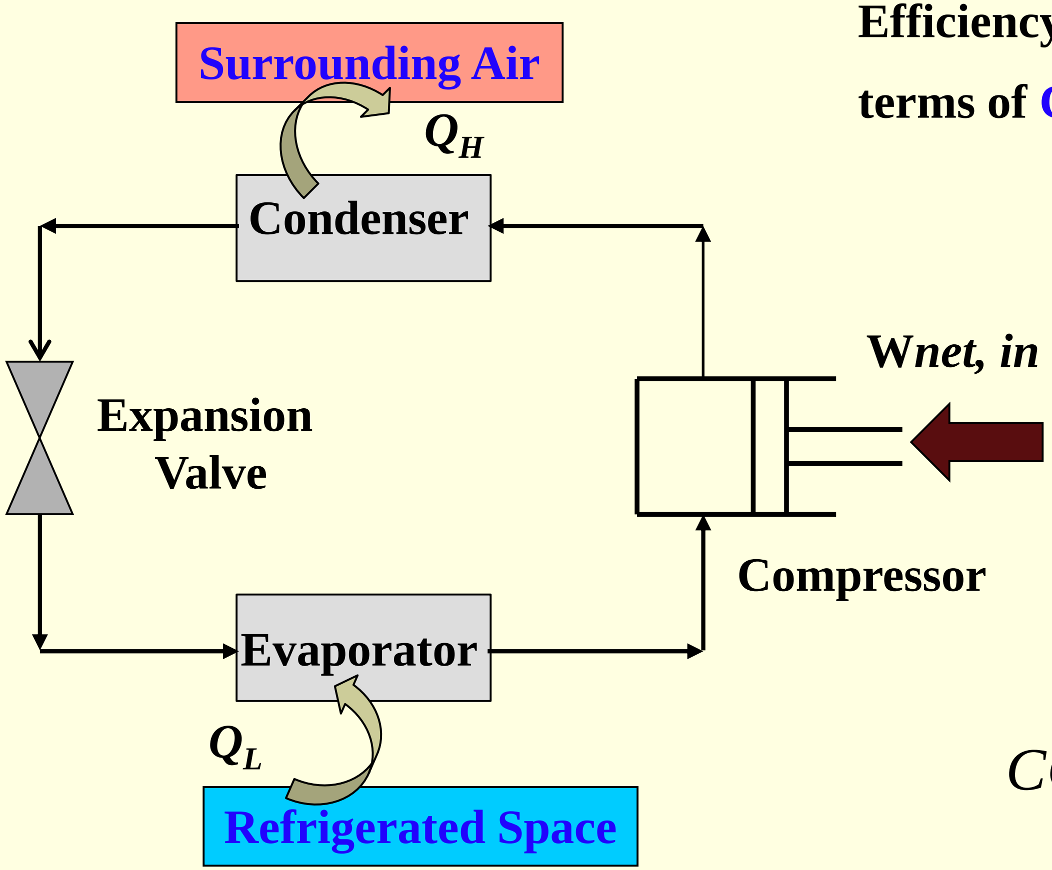


Second Law of Thermodynamics

REFRIGERATOR / HEAT PUMP :



Second Law of Thermodynamics



Efficiency of a Refrigerator is expressed in terms of Coefficient of Performance $(COP)_R$.

$$COP_R = \frac{Desired\ Output}{Required\ Input} = \frac{Q_L}{W_{net,in}}$$

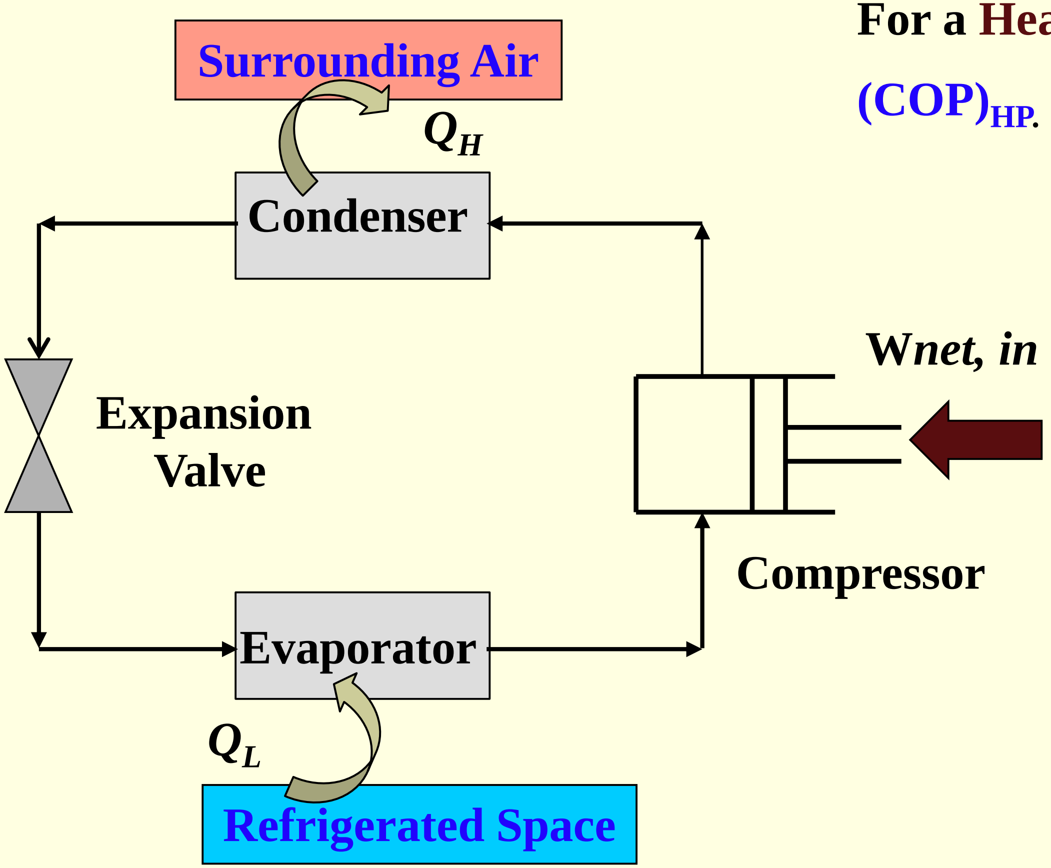
First Law of Thermodynamics gives;

$$Work_{net,in} = Q_H - Q_L$$

$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\left(Q_H / Q_L \right) - 1}$$

Thus, COP_R can be > 1

Second Law of Thermodynamics



For a **Heat Pump,** COP is expressed as

$(COP)_{HP}$.

$$COP_{HP} = \frac{Desired\ Output}{Required\ Input} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \left(Q_L / Q_H \right)}$$

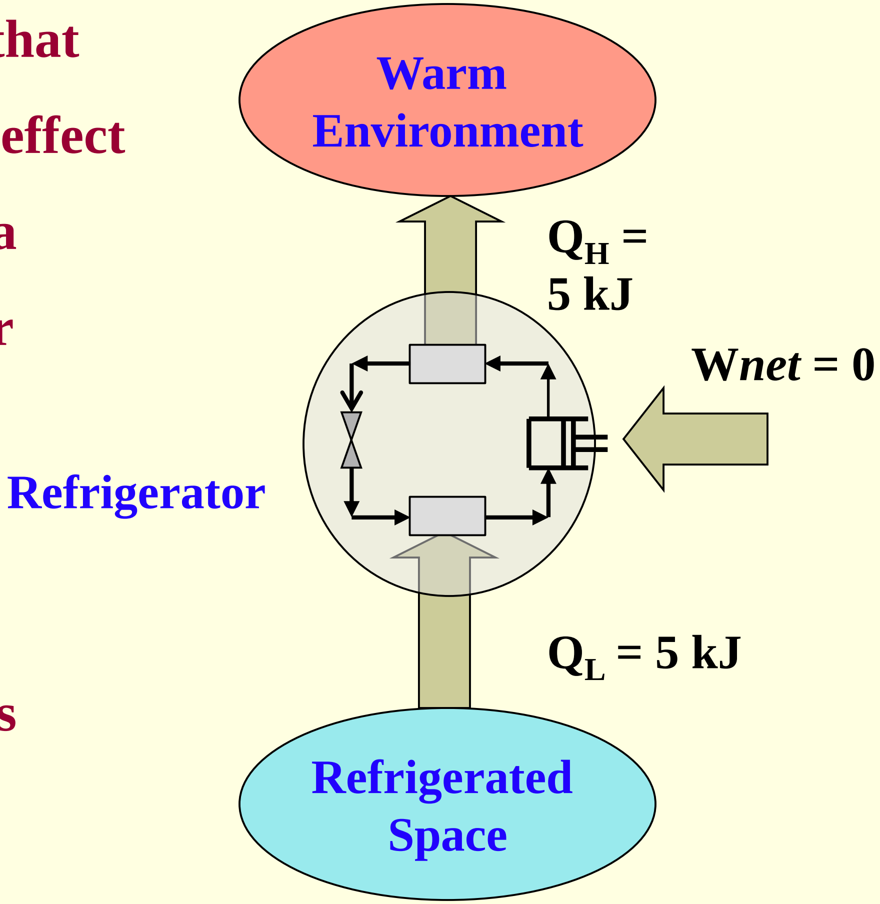
Thus;

$$COP_{HP} = COP_R + 1$$

Second Law of Thermodynamics

Clausius Statement :

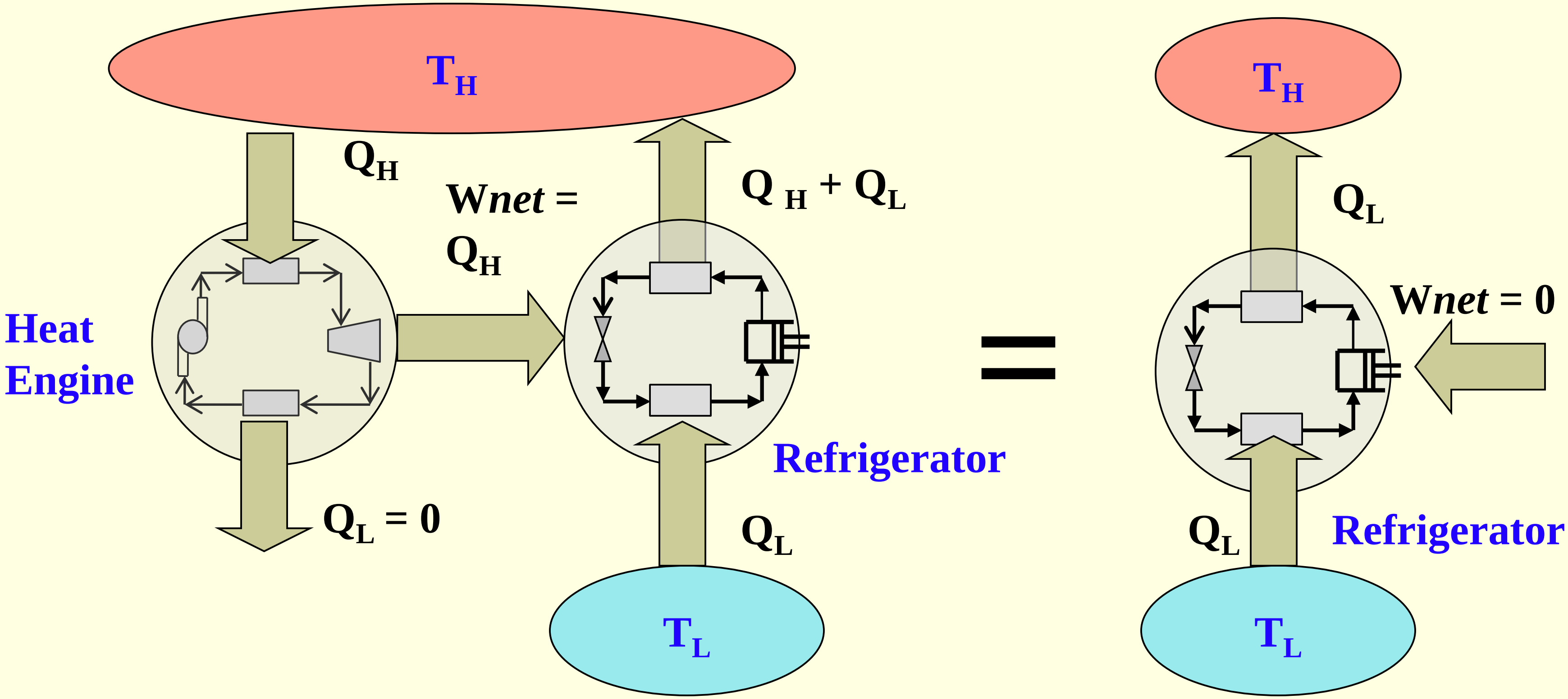
It is impossible to construct a device that operates in a Cycle, and produces no effect other than the transfer of Heat from a Lower Temperature Body to a Higher Temperature body.



Alternatively;

No Refrigerator can operate unless its compressor is supplied with external Power source.

Second Law of Thermodynamics



This Proves that;

Violation of Kelvin – Planck Statement results in violation of Clausius Statement.

Converse is also True.