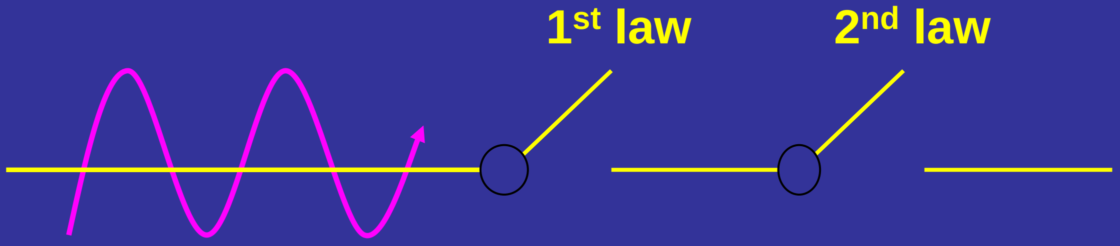
2^{nd} Law of Thermodynamics

2nd Law of Thermodynamics



A process must satisfy both the first and the second laws of thermodynamics to proceed

1st law : is concerned with the conversion of energy from one form to another.

2nd law : controls the process direction.

The first law places no restriction on the direction of a process, but satisfying the first law does not ensure that that process will actually occur

2^{nd} Law of Thermodynamics

The second law of thermodynamics states that processes occur in a certain direction, not in just any direction.

- Water flows down a waterfall.
- Gases expand from a high pressure to a low pressure.
- Heat flows from a high temperature to a low temperature.

Once it has taken place, a spontaneous process can be reversed, but it will not reverse itself spontaneously. Some external inputs, energy, must be expanded to reverse the process.

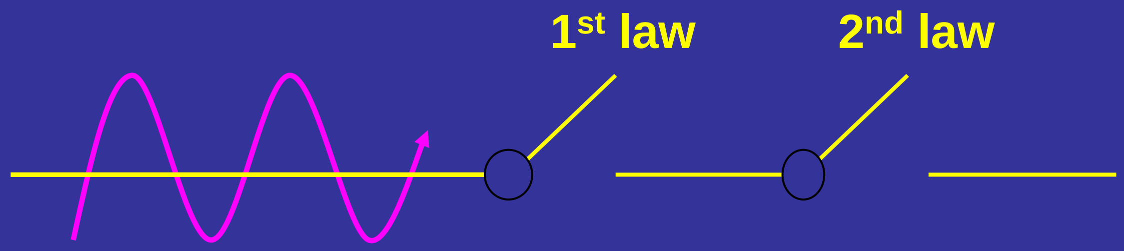
2^{nd} Law of Thermodynamics

A cup of hot cappuccino in a cooler room eventually cools off

Processes proceed in a certain direction and not in the reverse direction

A cup of cappuccino does not get hotter in a cooler room

2^{nd} Law of Thermodynamics



A process must satisfy both the first and the second laws of thermodynamics to proceed

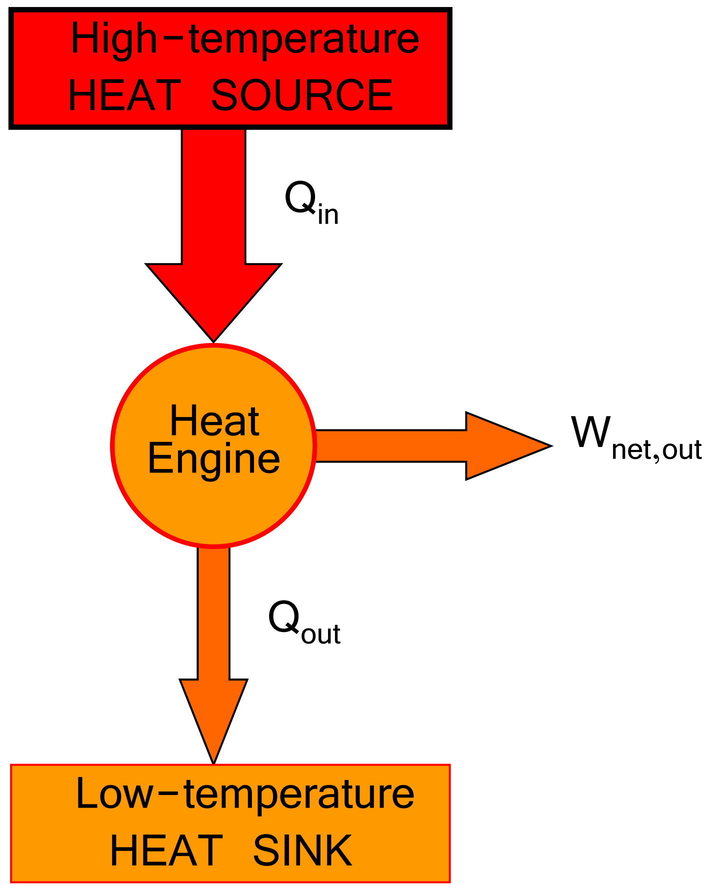
Heat Engine

Heat can be converted to work directly and completely by a device called heat engine

Heat engine is characterized by the following;

- It receives heat from a high-temperature source
- It converts part of this energy (heat to work)
- It rejects the remaining waste heat to a low-temperature sink

Heat Engines



Schematic of heat engine. Part of the heat received by heat engine is converted to work, whereas the rest is rejected to a sink

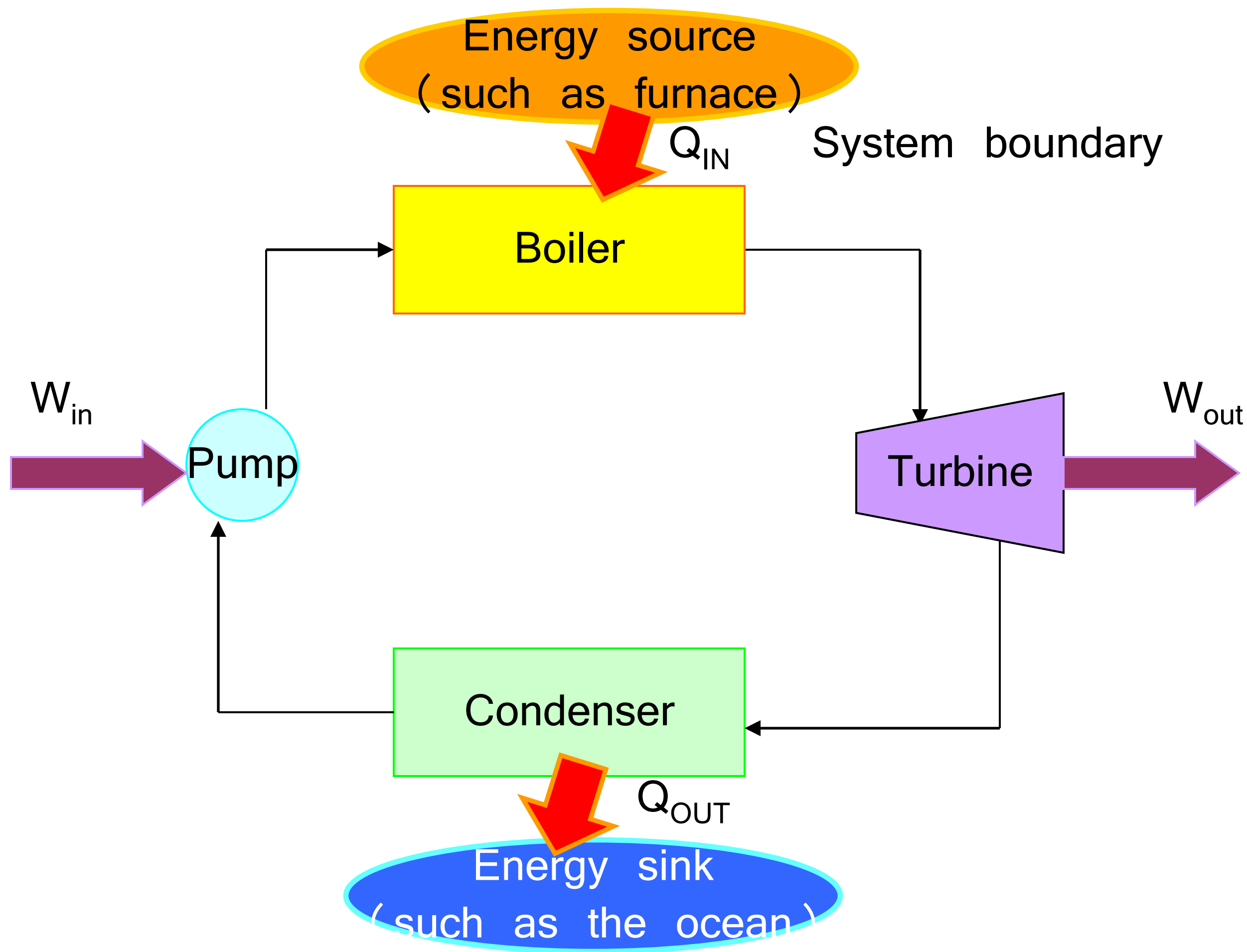
Heat engine

Steam power plant is the best example for heat engine

The main devices in steam power plant;

1) Pump
2) Boiler
3) Turbine
4) Condenser

Heat Engines



Schematic of a steam power plant

Heat Engines

Q_{in} - amount of heat supplied to steam in boiler from a high-temperature source (furnace)

Q_{out} - amount of heat rejected from steam in condenser to a low-temperature sink (the atmosphere, a river, etc)

W_{out} - amount of work delivered by steam as it expands in turbine

W_{in} - amount of work required to compress water to boiler pressure

The net work output

$$\boxed{W_{net,out} = W_{out} - W_{in}}$$

Now apply the first law to the cyclic heat engine.

$$Q_{net,\,in} - W_{net,\,out} = \cancel{\Delta U}^{\,0\ \text{(Cyclic)}}$$

$$W_{net,\,out} = Q_{net,\,in}$$

$$W_{net,\,out} = Q_{in} - Q_{out}$$

The cycle thermal efficiency may be written as

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

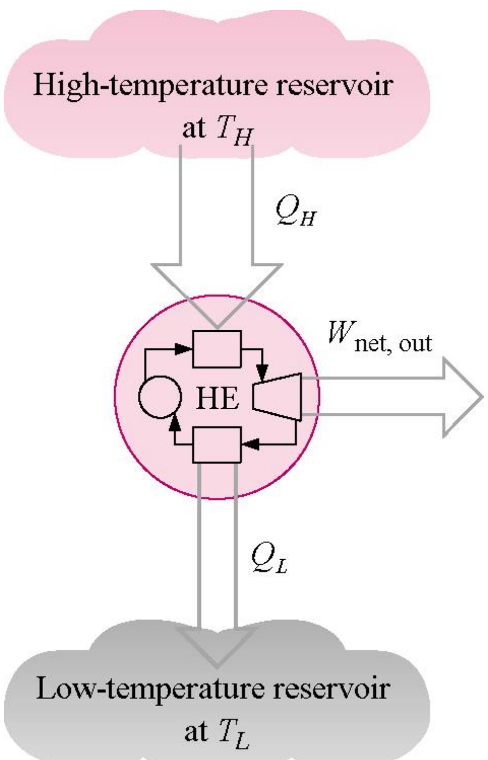
$$= \frac{Q_{in} - Q_{out}}{Q_{in}}$$

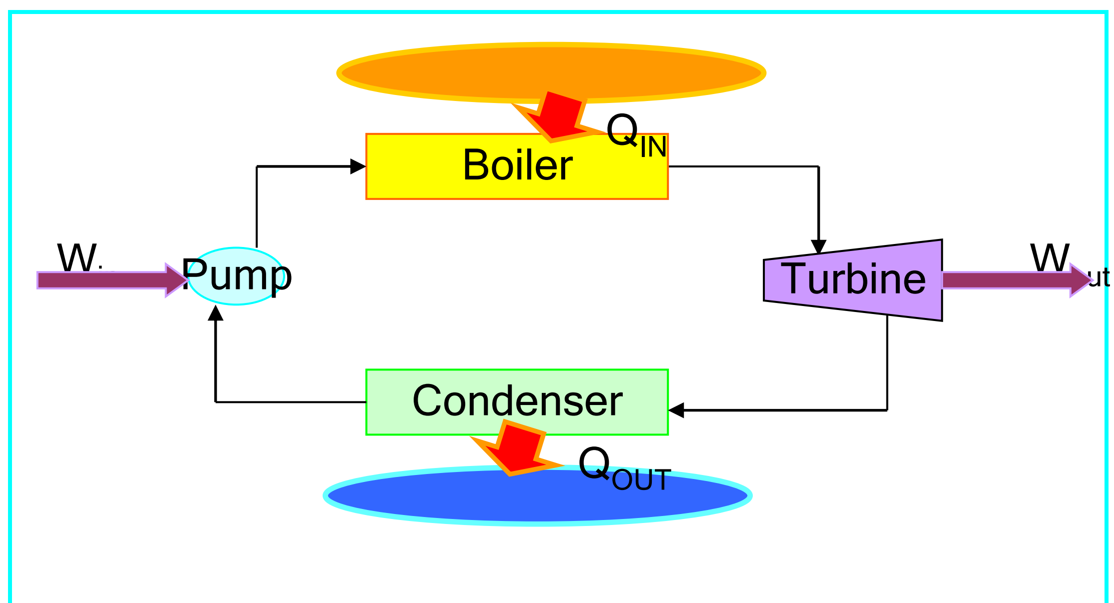
$$= 1 - \frac{Q_{out}}{Q_{in}}$$

Cyclic devices such as heat engines, refrigerators, and heat pumps often operate between a high-temperature reservoir at temperature T_H and a low-temperature reservoir at temperature T_L.

The thermal efficiency of the device becomes

$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$





LETS DO EXERCISE 1

Exercise 1

A steam power plant produces 50 MW of net work while burning fuel to produce 150 MW of heat energy at the high temperature. Determine the cycle thermal efficiency and the heat rejected by the cycle to the surroundings.

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

$$= \frac{50\ MW}{150\ MW} = 0.333 \quad \text{or} \quad 33.3\%$$

$$W_{net,\,out} = Q_H - Q_L$$

$$Q_L = Q_H - W_{net,\,out}$$

$$= 150\ MW - 50\ MW$$

$$= 100\ MW$$

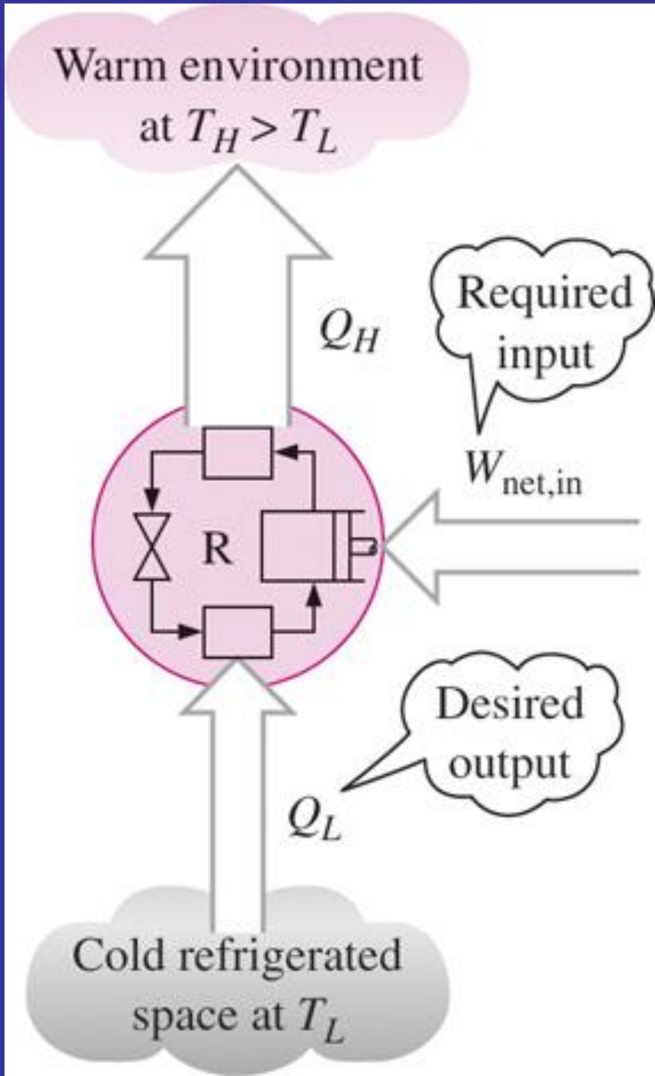
Heat Pump

A heat pump is a thermodynamic system operating in a thermodynamic cycle that removes heat from a low-temperature body and delivers heat to a high-temperature body. To accomplish this energy transfer, the heat pump receives external energy in the form of work or heat from the surroundings.

While the name "heat pump" is the thermodynamic term used to describe a cyclic device that allows the transfer of heat energy from a low temperature to a higher temperature, we use the terms "refrigerator" and "heat pump" to apply to particular devices.

Refrigerators

Reverse heat engines is a system that operates in thermodynamics cycle that transfer heat from **low-temperature** to **high-temperature** media

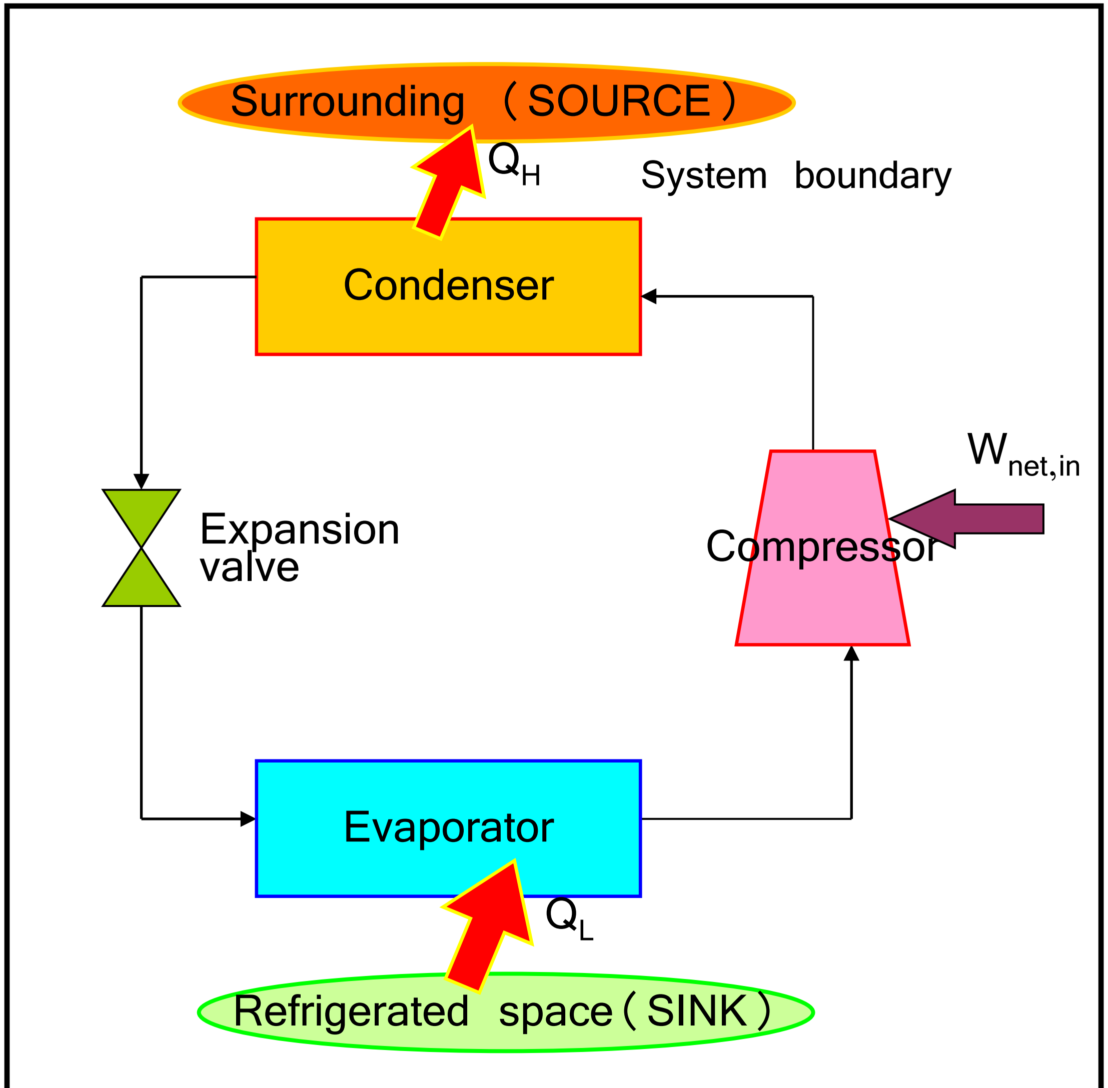


Refrigerator

Involve four main components; an evaporator, a compressor, a condenser and an expansion valve

Heat is absorbed from the-low temperature reservoir (cold enviroment) by evaporator and then the heat is rejected to the high-temperature reservoir (hot environment) by condenser

Refrigerators and Heat Pumps



Main components of a refrigeration system

Coefficient of Performance, COP

The index of performance of a refrigerator or heat pump is expressed in terms of the coefficient of performance, COP, the ratio of desired result to input. This measure of performance may be larger than 1, and we want the COP to be as large as possible.

$$COP = \frac{\text{Desired Result}}{\text{Required Input}}$$

For the refrigerator the desired result is the heat supplied at the low temperature and the input is the net work into the device to make the cycle operate.

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

Now apply the first law to the cyclic refrigerator.

$$(Q_L - Q_H) - (0 - W_{in}) = \Delta U_{cycle} = 0$$

$$W_{in} = W_{net,\,in} = Q_H - Q_L$$

and the coefficient of performance becomes

$$\boxed{COP_R = \frac{Q_L}{Q_H - Q_L}}$$

Refrigerant efficiency

Overall energy balance,

$$Q_H - Q_L = W_C$$

Efficiency is expressed in terms of coefficient of performance (COP);

$$\beta = \frac{\text{Cooling Achieved}}{\text{Energy Needed}} = \frac{Q_L}{W_C}$$

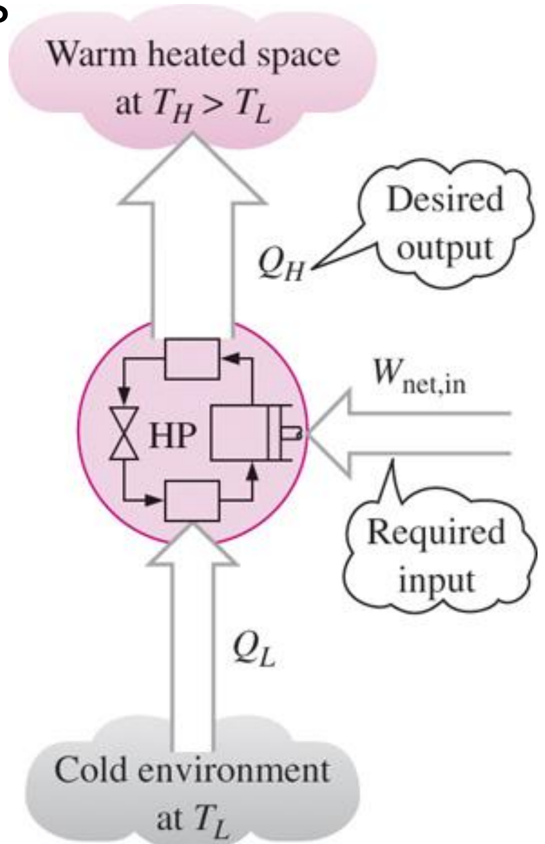
$$\beta = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$

HEAT PUMP

For the device acting like a “heat pump,” the primary function of the device is the transfer of heat from low-temperature to the high-temperature system.

The coefficient of performance for a heat pump is

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{Q_H}{Q_H - Q_L}$$



Heat pump efficiency

The heat pump efficiency is expressed as coefficient of performance (β')

$$\beta' = \frac{\text{Heating Sought}}{\text{Energy Needed}} = \frac{Q_H}{W_C}$$

$$\beta' = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - {Q_L}/{Q_H}}$$

LETS DO EXERCISE 2 & 3

LETS DO

QUIZ 1

QUIZ 2

QUIZ 3

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Kelvin-Planck statement (HE)

‘…it is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work… ’

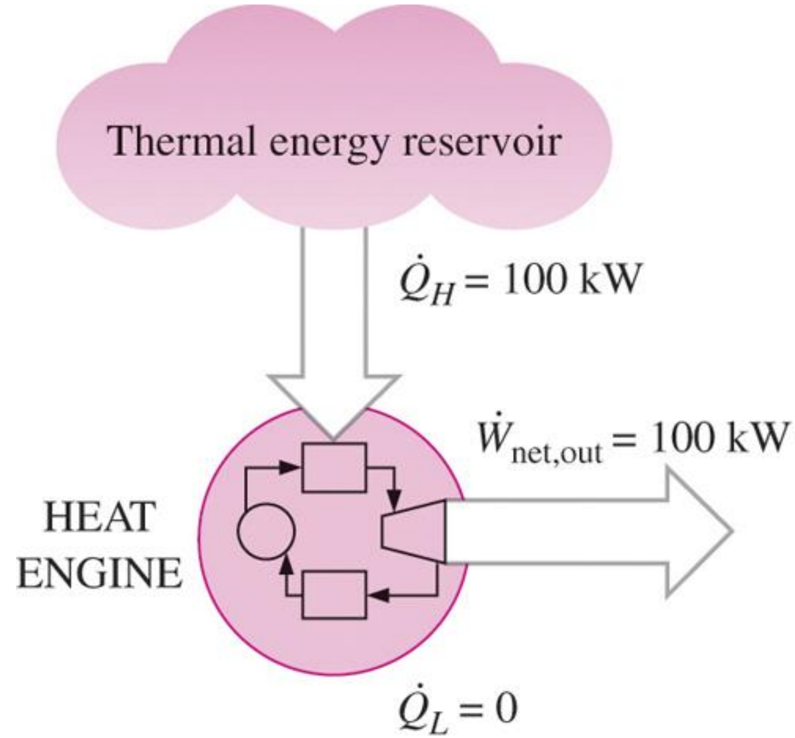
That is, a heat engine must exchange heat with low-temperature sink as well as a high-temperature source to keep operating

‘ …no heat engine can have a thermal efficiency of 100 percent , or as for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace… ‘

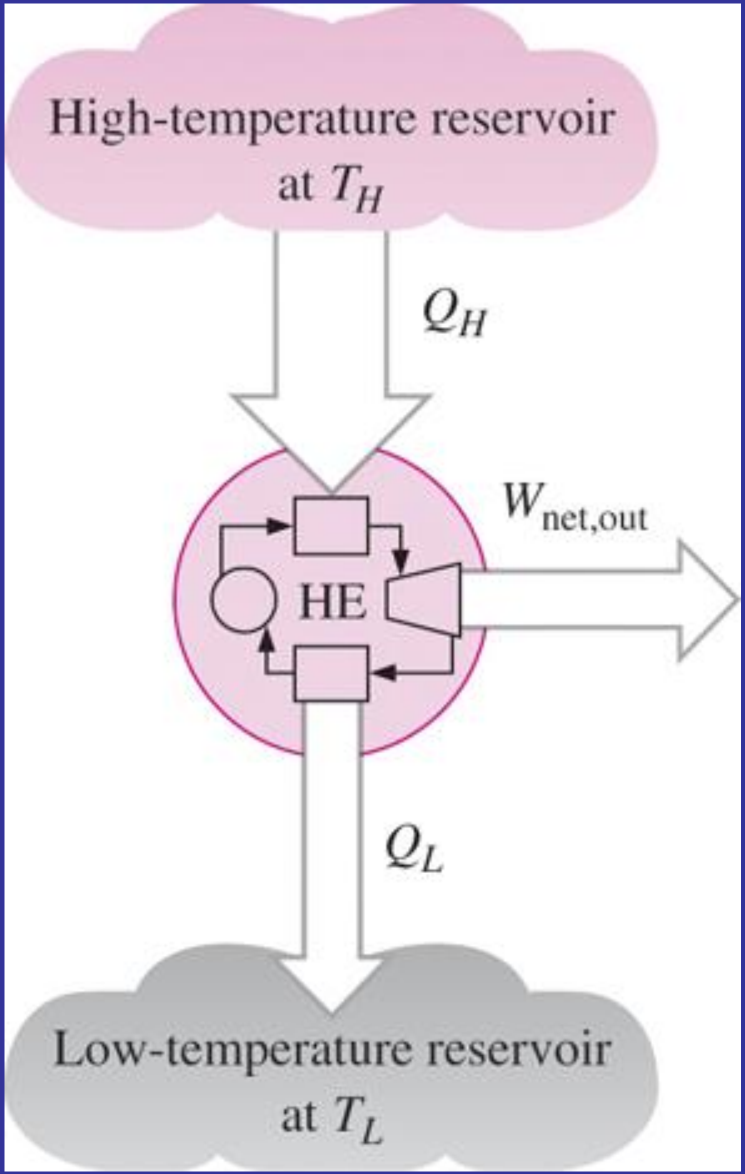
Impossible to have 100 percent efficient heat engine. This is due to limitation that applies to both the idealized and the actual heat engines

Kelvin-Planck statement (HE)

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.



Heat Engines



Clausius Statement

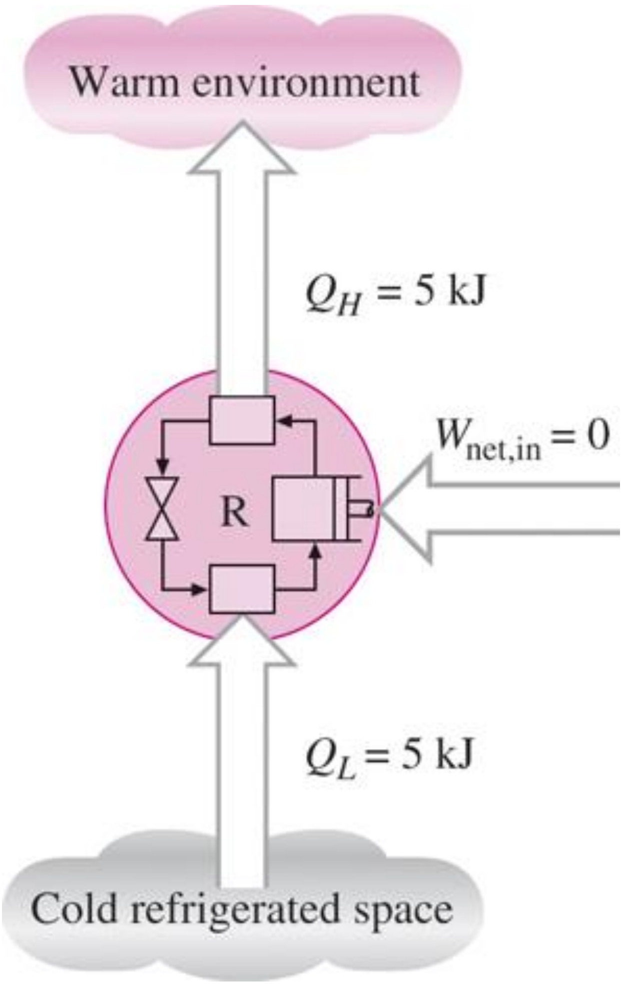
Heat Pump

It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a cooler body to a hotter body.

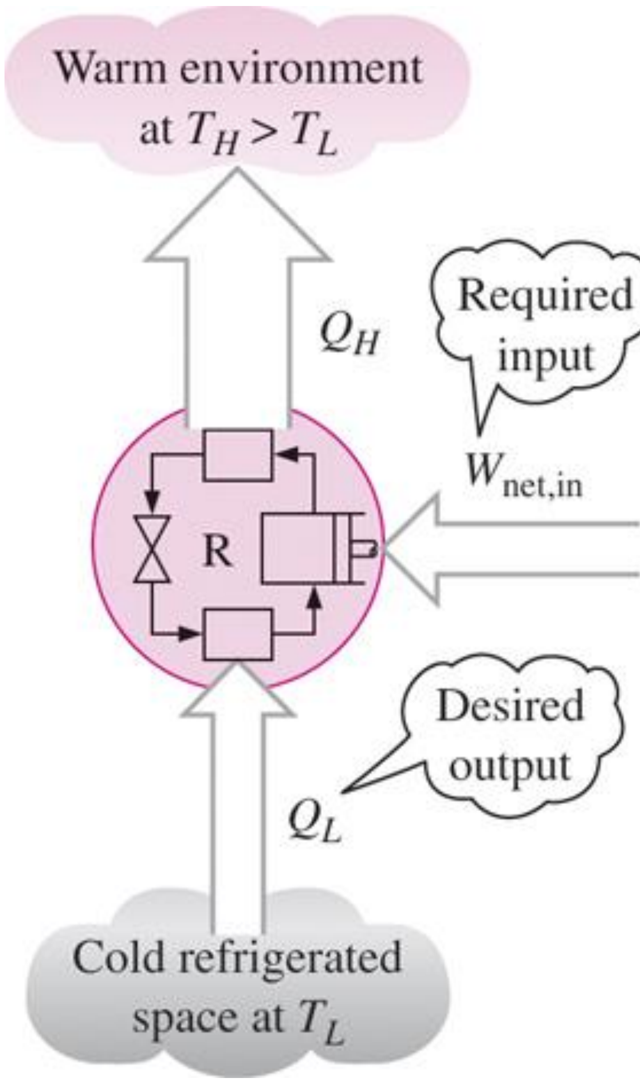
This statement simply said that a refrigerator cannot operate without a net work input from an external source (compressor)

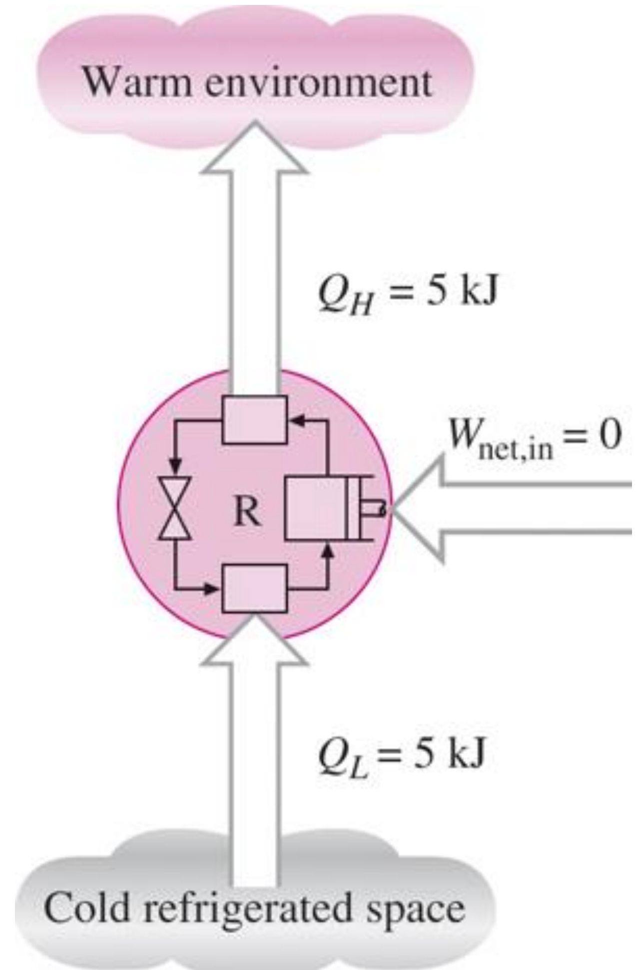
Clausius Statement

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.



Clausius Statement





Carnot cycle

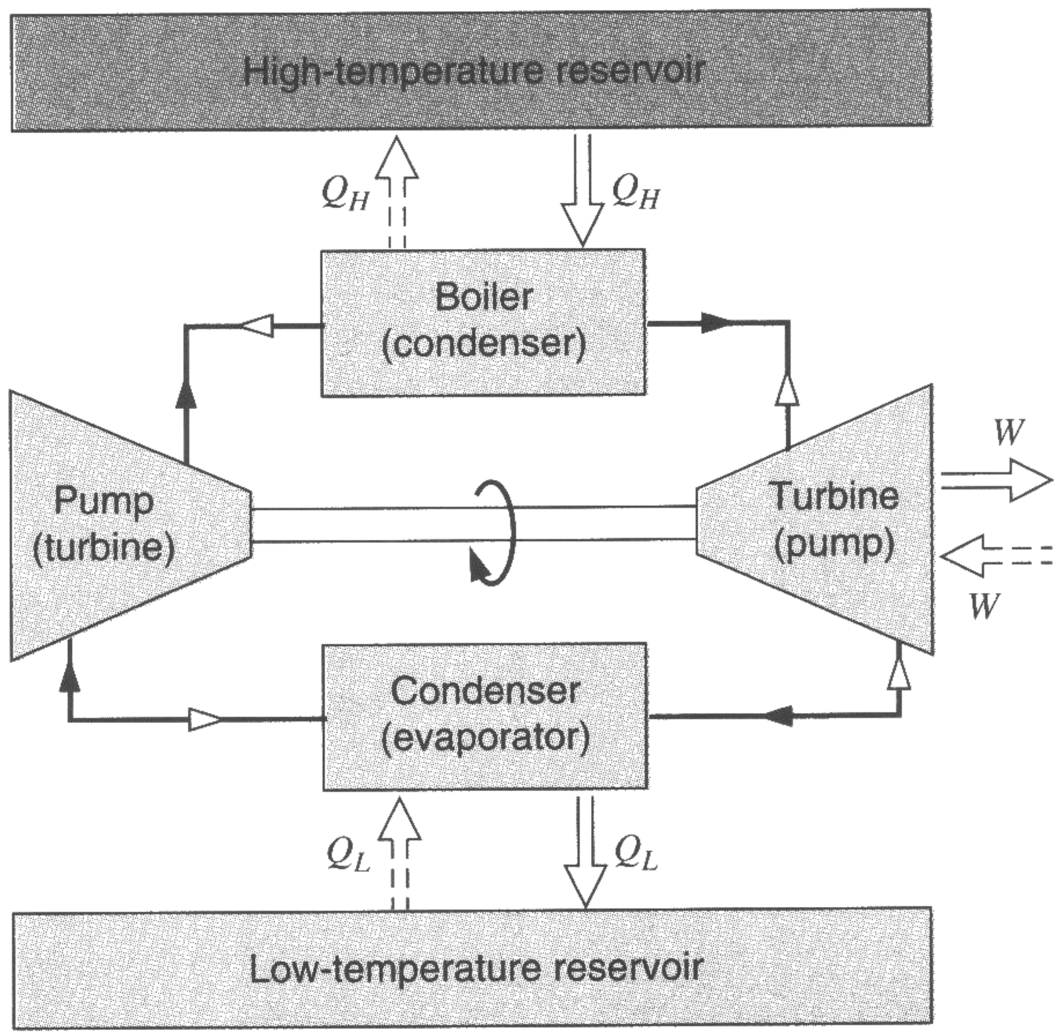
Carnot Cycle is a reversible heat engine.

It has the highest efficiency of a heat engine operating between the two thermal energy reservoirs at temperature T_L and T_H

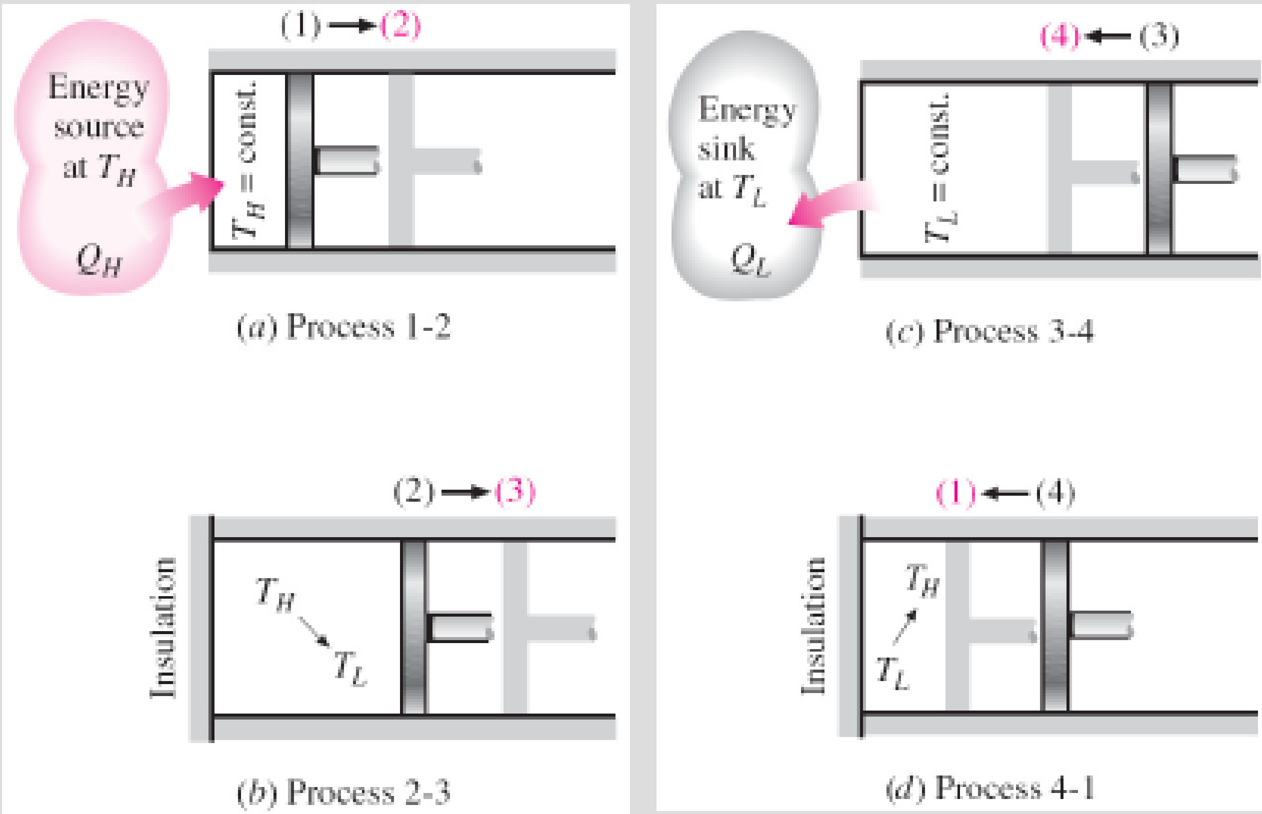
The thermal efficiency of actual heat engines can be maximized by be a Carnot engine

The Carnot cycle is composed of four reversible processes

Carnot cycle

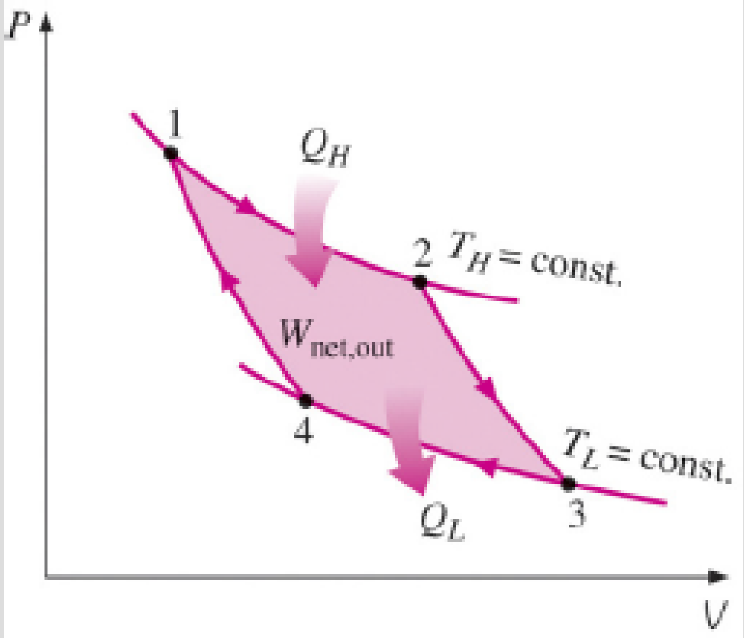


THE CARNOT CYCLE

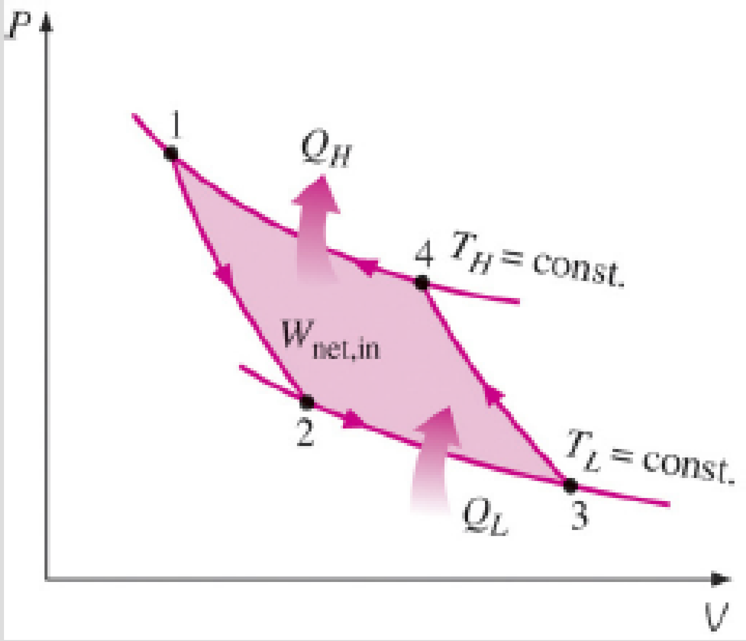


Execution of the Carnot cycle in a closed system.

Reversible Isothermal Expansion (process 1-2, T_H = constant)
Reversible Adiabatic Expansion (process 2-3, temperature drops from T_H to T_L)
Reversible Isothermal Compression (process 3-4, T_L = constant)
Reversible Adiabatic Compression (process 4-1, temperature rises from T_L to T_H)



P-V diagram of the Carnot cycle.



P-V diagram of the reversed Carnot cycle.

The Reversed Carnot Cycle

The Carnot heat-engine cycle is a totally reversible cycle.

Therefore, all the processes that comprise it can be *reversed*, in which case it becomes the **Carnot refrigeration cycle**.

Thermodynamic Temperature Scale

It is proven that Carnot engine operates between two identical thermal reservoirs will have the same efficiency.

It means that, the Carnot engine efficiency depends to the temperature.

$$\frac{Q_L}{Q_H} = \frac{(T_L)}{(T_H)} \longrightarrow \eta_{Carnot} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

Reversed Carnot Device Coefficient of Performance

If the Carnot device is caused to operate in the reversed cycle, the reversible heat pump is created. The COP of reversible refrigerators and heat pumps are given in a similar manner to that of the Carnot heat engine as

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

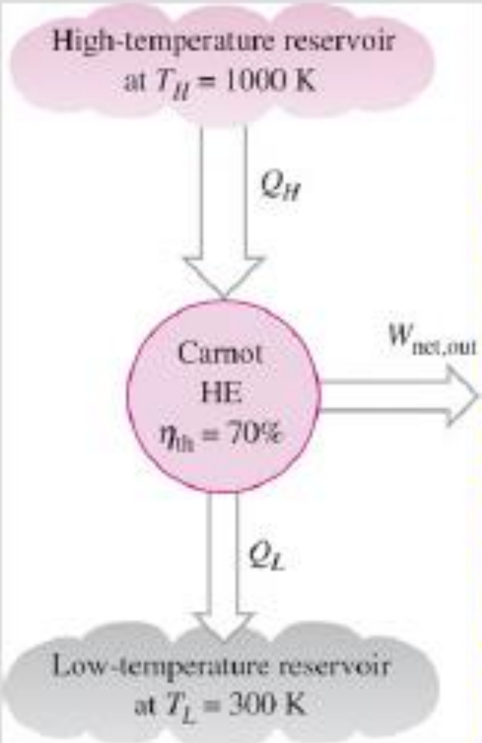
$$= \frac{T_L}{T_H - T_L} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{\frac{Q_H}{Q_L}}{\frac{Q_H}{Q_L} - 1}$$

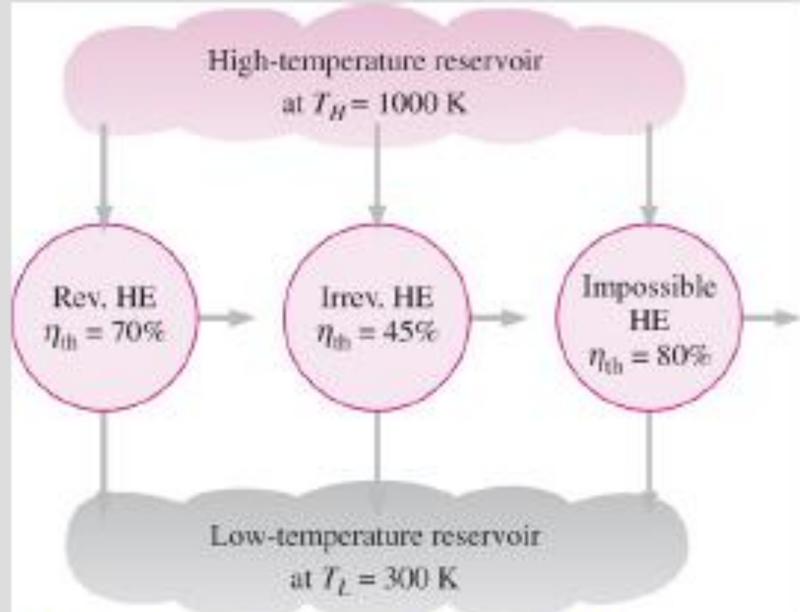
$$= \frac{T_H}{T_H - T_L} = \frac{\frac{T_H}{T_L}}{\frac{T_H}{T_L} - 1}$$

Again, these are the maximum possible COPs for a refrigerator or a heat pump operating between the temperature limits of T_H and T_L.

THE CARNOT HEAT ENGINE



The Carnot heat engine is the most efficient of all heat engines operating between the same high- and low-temperature reservoirs.



No heat engine can have a higher efficiency than a reversible heat engine operating between the same high- and low-temperature reservoirs.

Any heat engine

$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$

Carnot heat engine

$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

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

LETS DO

EXERCISE 5

EXERCISE 6

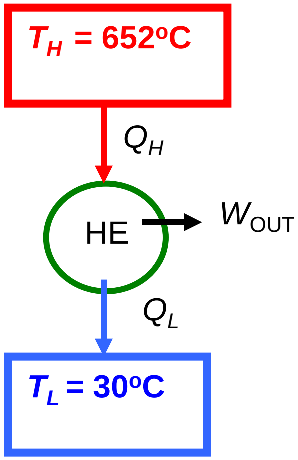
Exercise 5 (Q1)

A Carnot heat engine receives 500 kJ of heat per cycle from a high-temperature heat reservoir at 652^{o}C and rejects heat to a low-temperature heat reservoir at 30^{o}C. Determine

(a) The thermal efficiency of this Carnot engine.

(b) The amount of heat rejected to the low-temperature heat reservoir.

a.



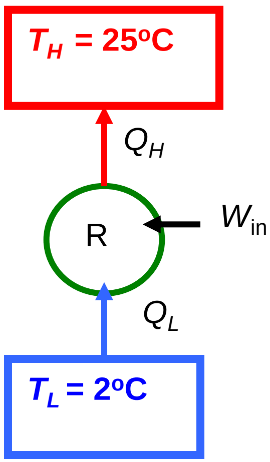
$$\eta_{th,\,rev} = 1 - \frac{T_L}{T_H}$$
$$= 1 - \frac{(30+273)K}{(652+273)K}$$
$$= 0.672 \quad or \quad 67.2\%$$

b.

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$
$$= \frac{(30+273)K}{(652+273)K} = 0.328$$
$$Q_L = 500\,kJ(0.328)$$
$$= 164\,kJ$$

Exercise 5 (Q2)

An inventor claims to have developed a refrigerator that maintains the refrigerated space at 2^{o}C while operating in a room where the temperature is 25^{o}C and has a COP of 13.5. Is there any truth to his claim?



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

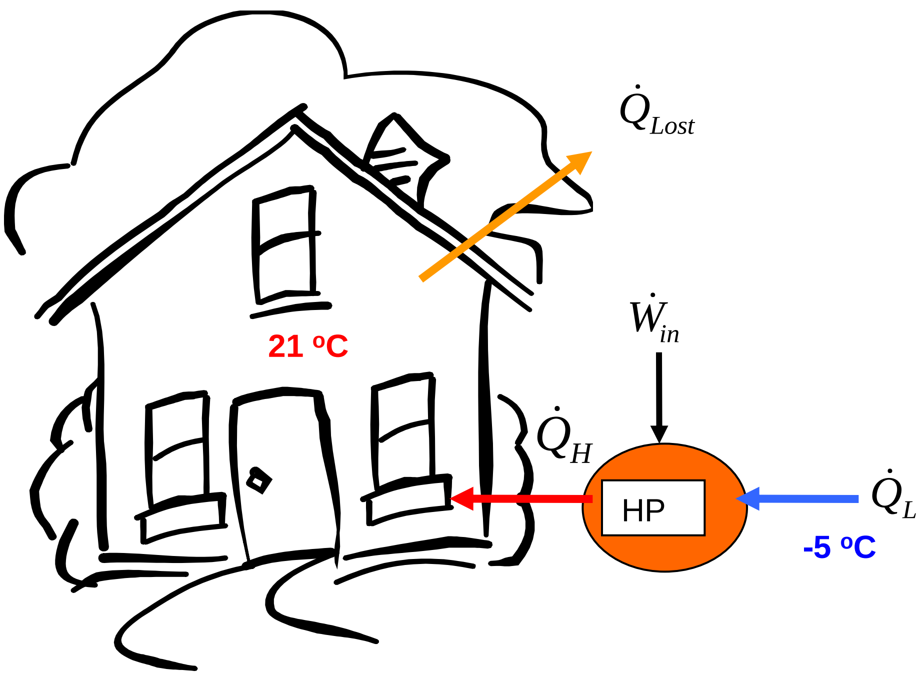
$$= \frac{(2+273)K}{(25-2)K}$$

$$= 11.96$$

The claim is false since no refrigerator may have a COP larger than the COP for the reversed Carnot device.

Exercise 6

A heat pump is to be used to heat a building during the winter. The building is to be maintained at 21°C at all times. The building is estimated to be losing heat at a rate of 135,000 kJ/h when the outside temperature drops to -5°C. Determine the minimum power required to drive the heat pump unit for this outside temperature.



The heat lost by the building has to be supplied by the heat pump.

$$\dot{Q}_H = \dot{Q}_{Lost} = 135000 \frac{kJ}{h}$$

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_L} = \frac{T_H}{T_H - T_L}$$

$$= \frac{(21+273)K}{(21-(-5))K}$$

$$= 11.31$$

Using the basic definition of the COP

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{net,\,in}}$$

$$\dot{W}_{net,\,in} = \frac{\dot{Q}_H}{COP_{HP}}$$

$$= \frac{135{,}000\, kJ/h}{11.31} \frac{1h}{3600s} \frac{1kW}{kJ/s}$$

$$= 3.316\, kW$$

LETS DO

QUIZ 4

QUIZ 6

QUIZ 8

QUIZ 9

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