Thermodynamics
ME 1229
Credit: 3.0

Second Law of Thermodynamics

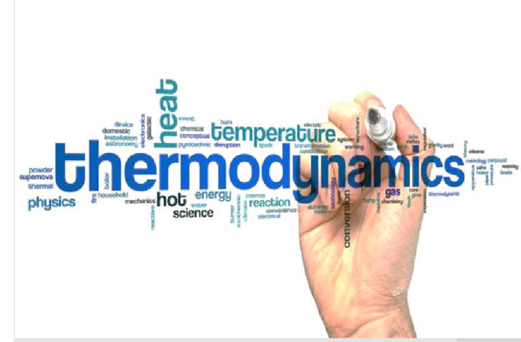
Presented By

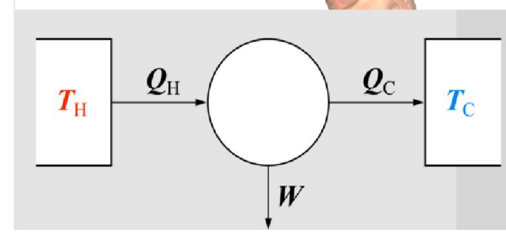
Md. Shariful Islam

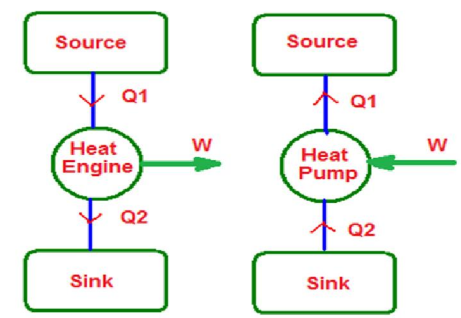
Lecturer

Department of Mechanical Engineering

Khulna University of Engineering & Technology





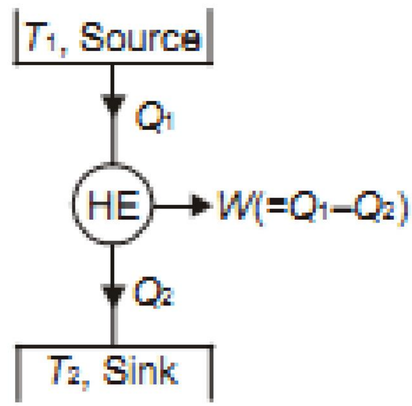


Heat Reservoir

- **Heat Reservoir** is the system having very large heat capacity i.e. it is a body capable of absorbing or rejecting finite amount of energy without any appreciable change in it's temperature. Examples: Atmosphere, Large River, Sea etc.
- Heat reservoirs can be of two types depending upon nature of heat interaction i.e. heat rejection or heat absorption from it.
- Heat reservoir which rejects heat from it is called **source**.
- While the heat reservoir which absorbs heat is called **sink**.
- Some times these heat reservoirs may also be called **Thermal Energy Reservoirs (TER).**

Heat Engine

- Heat engine is a device used for converting heat into work.
- Heat engine may be precisely defined as "a device operating in cycle between high temperature source and low temperature sink and producing work".
- Heat engine receives heat from source, transforms some portion of heat into work and rejects balance heat to sink.

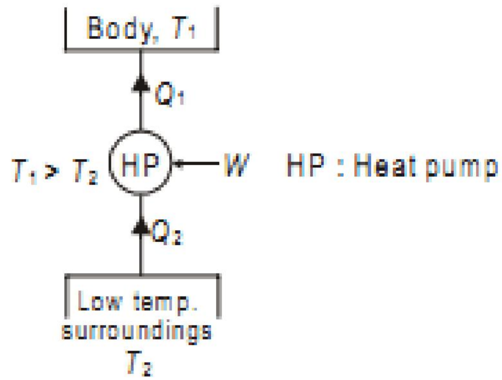


- Efficiency of heat engine can be given by the ratio of net work and heat supplied.

$$\eta_{\text{Heat Engine}} = \frac{Net\ Work}{Heat\ Supplied} = \frac{W}{Q_1}$$

Heat Pump

- Heat pump refers to a device used for extracting heat from a low temperature surroundings and sending it to high temperature body, while operating in a cycle. In other words heat pump maintains a body or system at temperature higher than temperature of surroundings, while operating in cycle.



- As heat pump transfers heat from low temperature to high temperature, which is non spontaneous process, so external work is required for realizing such heat transfer. Heat pump shown picks up heat Q_2 at temperature T_2 and rejects heat Q_1 for maintaining high temperature body at temperature T_1. For causing this heat transfer heat pump is supplied with work W as shown.

Heat Pump

- As heat pump is not a work producing machine and also its objective is to maintain a body at higher temperature, so its performance can't be defined using efficiency as in case of heat engine.
- Performance of heat pump is quantified through a parameter called coefficient of performance (C.O.P). Coefficient of performance is defined by the ratio of desired effect and net work done for getting the desired effect.

$$C.O.P. = \frac{Desired\ Effect}{Net\ Work\ Done}$$

For heat pump :

Net work = W

Desired effect = heat transferred Q_1 to high temperature body at temperature, T_1.

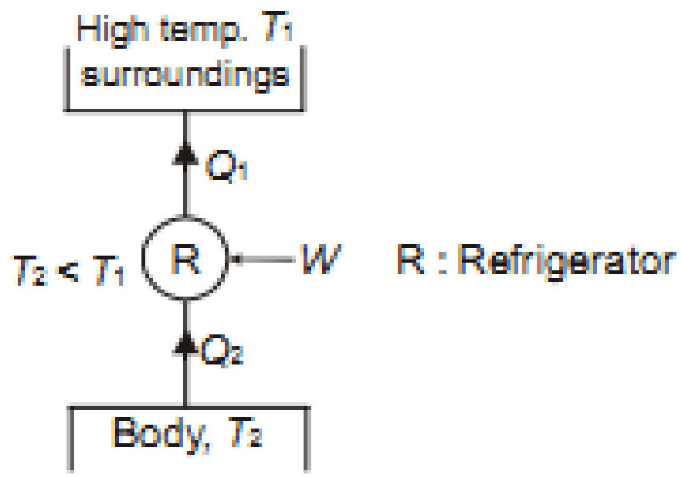
$$COP_{HP} = \frac{Q_1}{W}$$

Here $W = Q_1 - Q_2$, Hence

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$

Refrigerator

- Refrigerator is a device similar to heat pump but with reverse objective. It maintains a body at temperature lower than that of surroundings while operating in a cycle.



- Refrigerator also performs a non spontaneous process of extracting heat from low temperature body for maintaining it cool, therefore external work W is to be done for realizing it. Block diagram shows how refrigerator extracts heat Q2 for maintaining body at low temperature T2 at the expense of work W and rejects heat to high temperature surroundings.

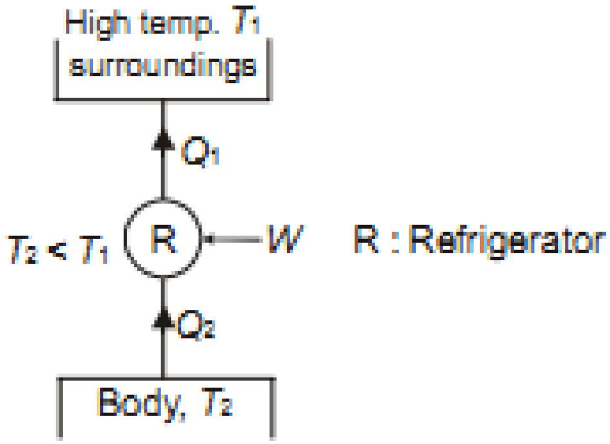
Refrigerator

- Performance of refrigerator is also quantified by coefficient of performance, which could be defined as:

$$COP_{refrigerator} = \frac{Desired\ Effect}{Net\ Work} = \frac{Q_2}{W}$$

Here $W = Q_1 - Q_2$, Hence

$$COP_{refrigerator} = \frac{Q_2}{Q_1 - Q_2}$$



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

- Performance of refrigerator is also quantified by coefficient of performance, which could be defined as:

$$COP_{refrigerator} = \frac{Desired\ Effect}{Net\ Work} = \frac{Q_2}{W}$$

Here $W = Q_1 - Q_2$, Hence

$$COP_{refrigerator} = \frac{Q_2}{Q_1 - Q_2}$$

- For heat pump :

Desired effect = heat transferred Q_1 to high temperature body at temperature, T_1.

$$COP_{HP} = \frac{Q_1}{W}$$

Also $W = Q_1 - Q_2$, Hence

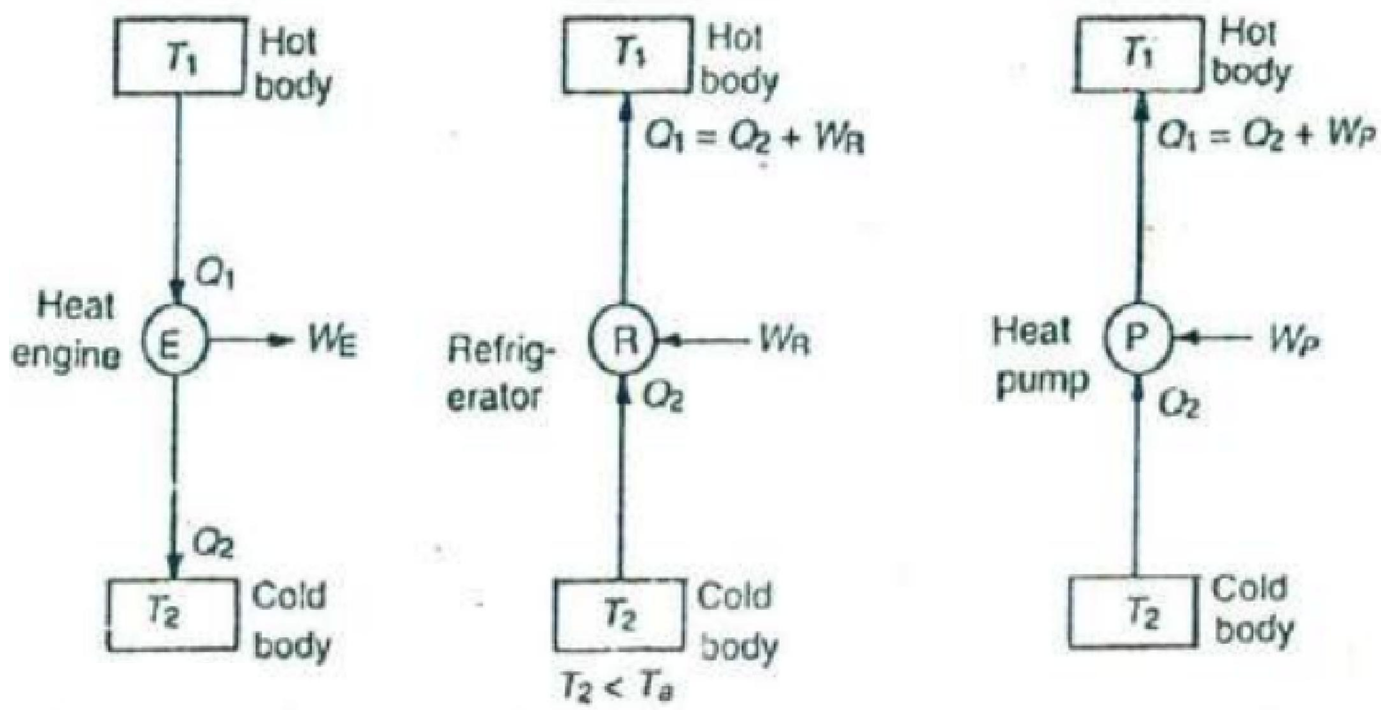
$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$

COP values of heat pump and refrigerator can be interrelated as:

$$\boldsymbol{COP_{HP} = 1 + COP_{ref}} \qquad (??= Lecture\ Note)$$

Show that the COP of a heat pump is greater than the COP of a refrigerator by unity.

Difference Between a Heat Engine, Refrigerator and Heat Pump



(a) Heat-engine. (b) Refrigerator. (c) Heat pump.

Difference Between a Heat Engine, Refrigerator and Heat Pump

- All three devices work on the basis of heat flow.
- In a heat engine, heat is transferred from a higher temperature level called source to a lower temperature level called sink. Work is obtained during this process.
- A refrigerator is a reversed heat engine. Heat is transferred from the lower temperature level to higher temperature by applying external work to maintain the temperature below atmospheric temperature.
- A heat pump is similar to a refrigerator.
- The only point of *difference between the two(Refrigerator & Heat pump)* is of the operating temperatures. The working temperatures in a refrigerator are of the colder level and atmosphere, whereas working temperatures in heat pump are of hotter level and atmosphere.

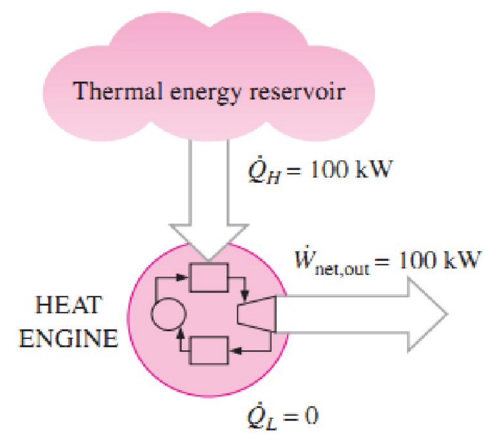
Kelvin-Planck Statement of Second Law

- A heat engine must reject some heat to a low-temperature reservoir in order to complete the cycle and can not convert all the heat it receives to useful work. This limitation is the **basis for the Kelvin–Planck** statement of the second law of thermodynamics, which is expressed as follows:

"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 a low-temperature sink as well as a high-temperature source to keep operating. The Kelvin–Planck statement can also be expressed as

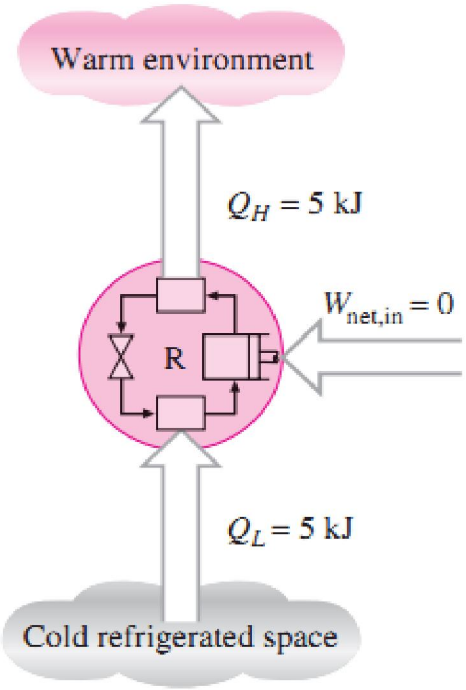
No heat engine can have a thermal efficiency of 100 percent (Fig), or as for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.



Clausius Statement of Second Law

- There are two classical statements of the second law—the Kelvin–Planck statement, which is related to heat engines and the Clausius statement, which is related to refrigerators or heat pumps. The Clausius statement is expressed as follows:

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.



Problems

Prob-1: Heat is transferred to a heat engine from a furnace at a rate of 80 MW(shown in Fig. 1). If the rate of waste heat rejection to a nearby river is 50 MW, determine the net power output and the thermal efficiency for this heat engine.

Prob-2: The food compartment of a refrigerator, shown in Fig. 2, is maintained at 4°C by removing heat from it at a rate of 360 kJ/min. If the required power input to the refrigerator is 2 kW, determine (a) the coefficient of performance of the refrigerator and (b) the rate of heat rejection to the room that houses the refrigerator.

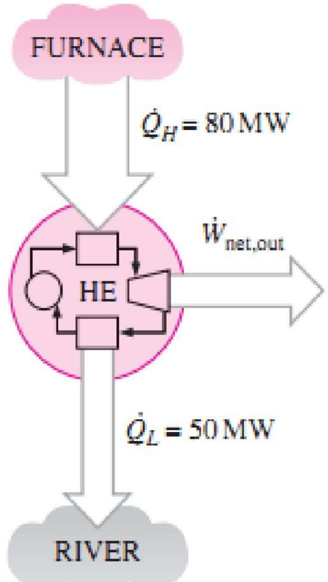


Fig. 1

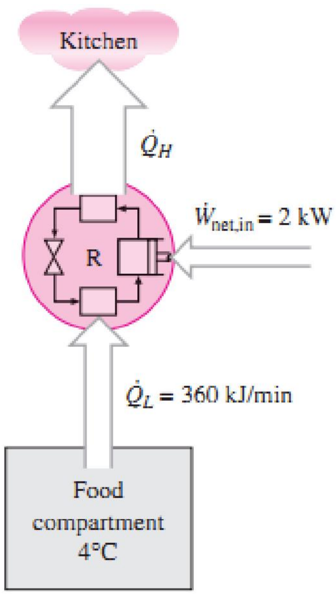
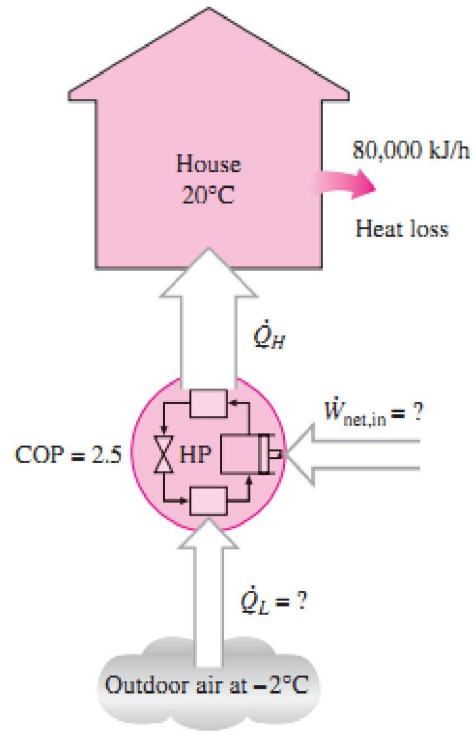


Fig. 2

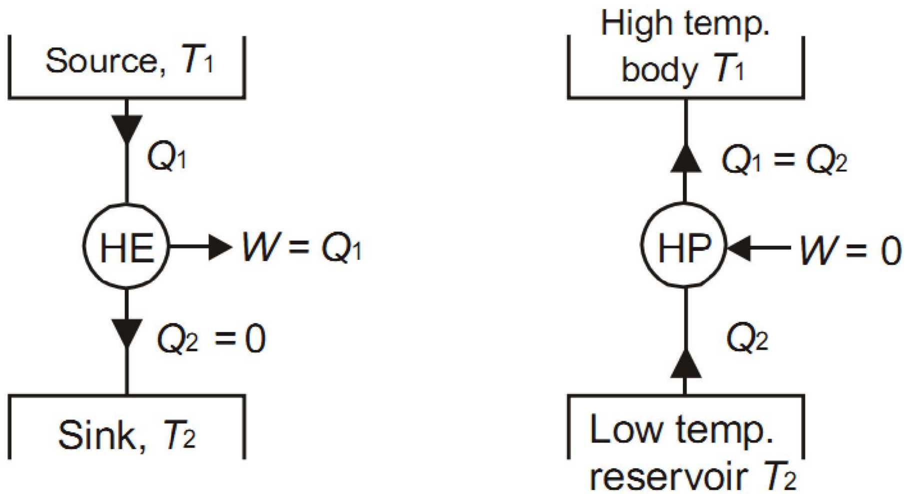
Problems

Prob-3: A heat pump is used to meet the heating requirements of a house and maintain it at 20°C. On a day when the outdoor air temperature drops to -2°C, the house is estimated to lose heat at a rate of 80,000 kJ/h. If the heat pump under these conditions has a COP of 2.5, determine (a) the power consumed by the heat pump and (b) the rate at which heat is absorbed from the cold outdoor air.



Perpetual Motion Machines of 2nd Kind (PMM-II)

- Devices based on violation of 2nd law of thermodynamics are called Perpetual motion machines of 2nd kind (PMM-II). Fig shows such PMM-II.



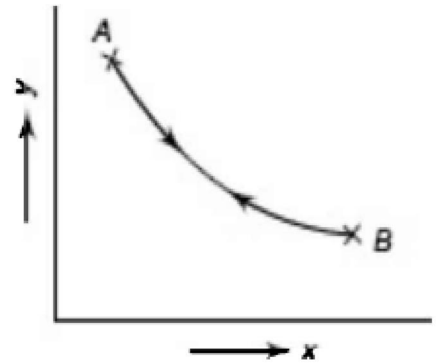
(a) (b)

- PMM-II shown in Fig (a), refers to a heat engine which produces work while interacting with only one reservoir. PMM-II shown in Fig (b), refers to the heat pump which transfers heat from low temperature to high temperature body without spending work.

Reversibility and Irreversibility

- The second law of thermodynamics enables us to divide all processes into two classes:
    - Reversible or ideal process
    - Irreversible or natural process

- *A reversible process is defined as a process that can be reversed without leaving any trace on the surroundings (Fig). That is, both the system and the surroundings are returned to their initial states at the end of the reverse process.*



A reversible process

- *Any natural process carried out with a finite gradient is an irreversible process.*

Causes of Irreversibility

The irreversibility of a process may be due to either one or both of the following:

- Lack of equilibrium during the process
- Involvement of dissipative effects

Specific examples in these regard are:

(i) Friction,

(ii) Electrical resistance,

(iii) Inelastic solid deformations,

(iv) Free expansion

(v) Heat transfer through a finite temperature difference,

(vi) Non equilibrium during the process, etc.

Entropy

- There are three important E's in the study of the thermodynamics: energy, equilibrium and entropy.
- The word entropy was first used by Rudolf Clausius. It is taken from the Greek word 'tropee' which means transformation.
- Entropy(J/K), the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work. Because work is obtained from ordered molecular motion, the amount of entropy is also a measure of the molecular disorder, or randomness, of a system.
- The entropy of the system is not measured in absolute terms; rather it is measured in relative terms. The entropy is always measured as the change in entropy of the system denoted by ΔS and not merely S.

Corollaries of 2nd Law of Thermodynamics

- Corollary 1: *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)*
- Corollary 2: *It is impossible to construct an engine operating between only two heat reservoirs which will have a higher efficiency than e reversible engine operating between the same two reservoirs.*
- Corollary 3: *All reversible engines operating between the same two reservoirs have the same efficiency.*
- Corollary 4: *A scale of temperature can be defined which is independent of any particular thermometric substance, and which provides an absolute zero of temperature.*

Corollaries of 2nd Law of Thermodynamics

- Corollary 5: *The efficiency of any reversible engine operating between more than two reservoirs must be less than that of a reversible engine operating between two reservoirs which have temperatures equal to the highest and lowest temperatures of the fluid in the original engine.*
- Corollary 6: *Whenever a system undergoes a cycle* $\oint \frac{dQ}{T}$ *is zero if the cycle is reversible and negative if irreversible, i.e. in general* $\oint \frac{dQ}{T} \leq 0$. *(Clausius Inequality)*
- Corollary 7: *There exists a property of closed system such that a change in its value is equal to* $\int_1^2 \frac{dQ}{T}$ *for any reversible process undergone by the system between state 1 and state 2.(Concept of Entropy)*
- Corollary 8: *The entropy of any closed system which is thermally isolated from the surroundings increases or, if the process undergone by the system is reversible, remains constant.*

3rd Law of Thermodynamics

- The third law of thermodynamics postulates that

"The entropy of any pure substance in thermodynamic equilibrium approaches zero as the temperature approaches zero".

- The third law of thermodynamics is also called as Nernst law.
- It provides the basis for the calculation of absolute entropy of the substances.
- Mathematically,

$$\lim_{T \to 0} S = 0$$

Thank You