Principal of Energy Conservation

Principal of Energy conservation or Law of conservation of energy states that energy can neither be created nor distroyed; rather, it can only be transformed or transferred from one form to another. For instance, chemical energy is converted in to kinetic energy when a stick of dynamite explodes.

Reversibility and Irreversibility

A reversible process is one in which is performed in such a way that at the conclusion of the process, both the system and the surroundings may be restored to their initial states, without any change in the rest of universe. A reversible process is carried out infinitely slowly with an infinitesimal gradient, so that every state passed through by the system is an equilibrium state. So a reversible process concides with a quasi-static process.

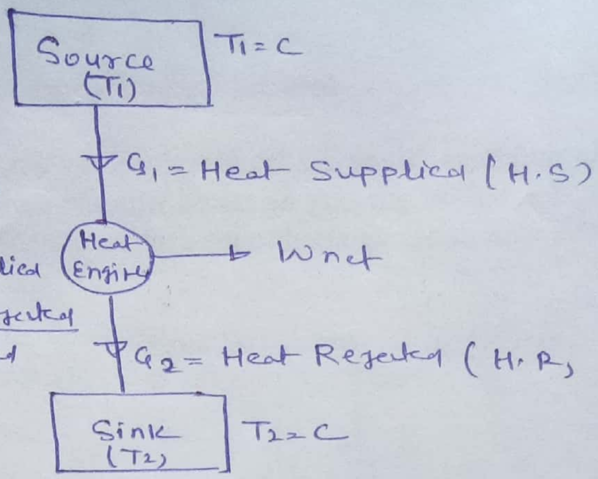
An Irreversible process is one in which the system and the surroundings can not be restored to their initial state. Any natural process carried out with a finite gradient is an Irreversible process.

Second Law of Thermodynamics

Sadi Carnot, a French Military engineer, who first studied the aspect of energy transformation in 1824 and said that work is said to be a high grade energy and heat a low grade energy. The complete conversion of low grade energy in to high grade energy in a cycle is impossible.

Energy Reservoir → A thermal energy reservoir is defined as a large body of finite heat capacity, which is capable of absorbing or rejecting an unlimited quantity of heat without change in temperature.

The thermal energy reservoir from where heat is transferred to the system operating in a heat engine cycle is called the Source. The thermal energy reservoir to which heat is rejected from the system during a cycle is known as Sink



Efficiency of Heat Engine (HE) $= \dfrac{W_{net}}{\text{Heat Supplied}}$

$= \dfrac{\text{Heat Supplied} - \text{Heat Rejected}}{\text{Heat Supplied}}$

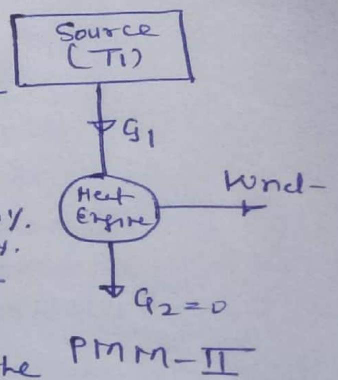
$\eta = \dfrac{HS - HR}{HS} = \dfrac{Q_1 - Q_2}{Q_1}$

$\eta = 1 - \dfrac{Q_2}{Q_1}$

Experience shows that $W_{net} < Q_1$ i.e heat Q_1 transferred to a system Cannot be completely Converted to work in a cycle. Therefore η is less than unity. A Heat engine can never be 100% efficiency i.e $Q_2 > 0$ i.e there has always to be a heat rejection.

Kelvin – Planck Statement of Second Law → It States

" It is impossible for heat engine to produce net work in a complete cycle if it exchange heat only with bodies at a sigle fixed temperature"



If $Q_2 = 0$ i.e $W_{net} = Q_1 \Rightarrow \eta = \dfrac{W_{net}}{H.S} = \dfrac{HS - HR}{HS}$

$= \dfrac{Q_1 - Q_2}{Q_1}$

$= \dfrac{Q_1 - 0}{Q_1} = 1 \times 100\% = 100\%$

In perpetual machine of second kind (PMM2) will produce net work in a complete by exchanging heat with one reservoir (Source), thus violating the Kelvin – planck statement.

A heat engine has, therefore, to exchange heat with two thermal energy reservoirs at two different temperatures to produce net work in a complete cycle.

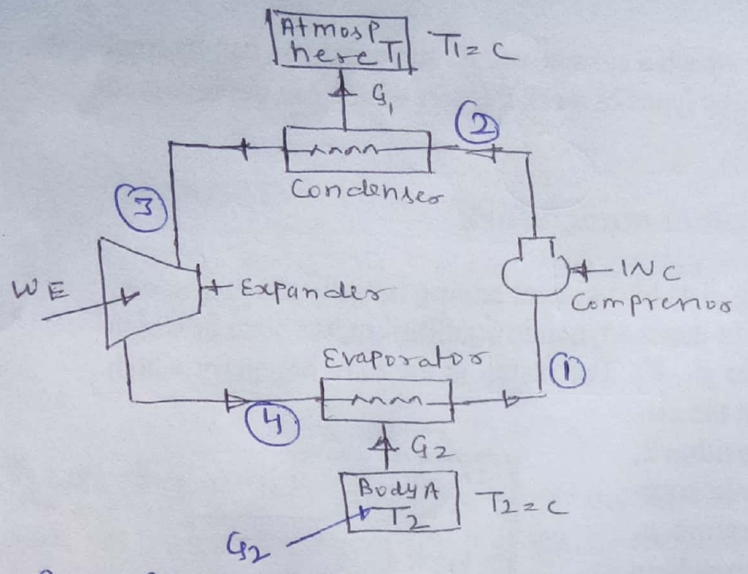
Clausius Statement of the Second Law →

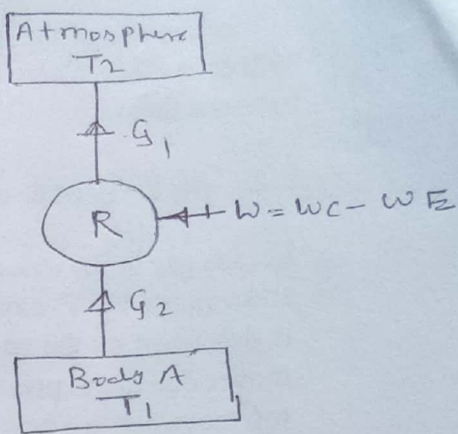
Heat always flows from a body at a higher temperature to a body at a lower temperature.

Clausius Statement of the Second law gives; It is impossible to construct a device which operating in a cycle, will produce no effect other than the transfer of heat from a Cooler to a hotter body.

Heat can not flow of itself from a body at a lower temperature to a body at a higher temp. Some work must be done on it.

Refrigerator and Heat Pump →





A refrigerator is a device which, operating in a cycle, maintain a body at a temperature lower than the temperature of the atmosphere (Ex- Freeze). Let the body A be maintained at temperature T_2, which is lower then the ambient temperature T_1. Even though A is insulated, there will always be heat leakage Q_2 into the body from the surroundings by virtue of temperature difference. In order to maintain body A at the constant temperature T_2, heat has to be removed from the body at same rate at which heat is leaking in to the body. This heat Q_2 is absorbed by a working fluid, called the refrigerant, which evaporates in the evaporator at a temperature lower than T_2 absorbing latent heat of vaporization from the body A which is ~~cool~~ cooled or refrigerated (Process 4-1). The vapour is passed through compressor driven by a motor which absorb work W_C (process 1-2), and is then condensed (vapour to liquid) in the condenser by rejecting heat of condensation Q_1 at a temperature higher than that of atmosphere (T_1). The condensate then expands adiabatically through expander (turbine) producing work W_E and temperature drops to a value ~~of~~ lower than T_2 such that heat Q_2 flows from the body A to make the refrigerant evaporate. Such a cyclic device (1-2-3-4-1) of flow is called a refrigerator. In a ~~refrigerant~~ refrigerator cycle, attention is concentrated on the body A. Q_2 are of primary interest. There is a performance parameter in a refrigerator cycle, called the coefficient of Performance (COP) which is defined as

$$COP = \frac{\text{Desired effect}}{\text{work input}}$$

In refrigerator, desired ~~output~~ effect is Q_2

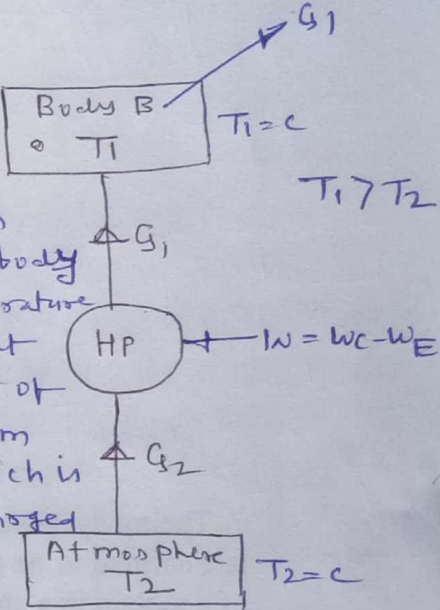
$$(COP)_{Ref} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

Net work done ~~on Compressor~~ $= W_C - W_E = Q_1 - Q_2$ [From 1st Law]

Since T_1 and T_2 are constant ~~i.e isothermal~~

i.e process 4-1 and 2-3 are isothermal

$$\therefore (COP)_{Ref} = \frac{T_2}{T_1 - T_2}$$



Heat pump – A heat pump is a device which operating in a cycle, maintains a body 'B' at a temperature higher than the temperature of surroundings. The body will be maintained at the constant temperature T_1, if heat is discharged into the body at the same rate at which heat leaks out of the body B. The heat is extracted from the low temperature reservoir, which is nothing but the atmosphere, and discharged into high temperature body B with the expenditure of work W in a cycle device is called a heat pump (Ex – winter Air Conditioning). Here Desired effect is discharging heat Q_1 into the body B.

$$(COP)_{HP} = \frac{\text{Desired effect}}{\text{work input}} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

$$(COP)_{Ref} + 1 = \frac{T_2}{T_1 - T_2} + 1 = \frac{T_2 + T_1 - T_2}{T_1 - T_2} = \frac{T_1}{T_1 - T_2} = (COP)_{HP}$$

$$\therefore \boxed{(COP)_{HP} = (COP)_{Ref} + 1}$$

Equivalence of Kelvin–Planck and Clausius Statements

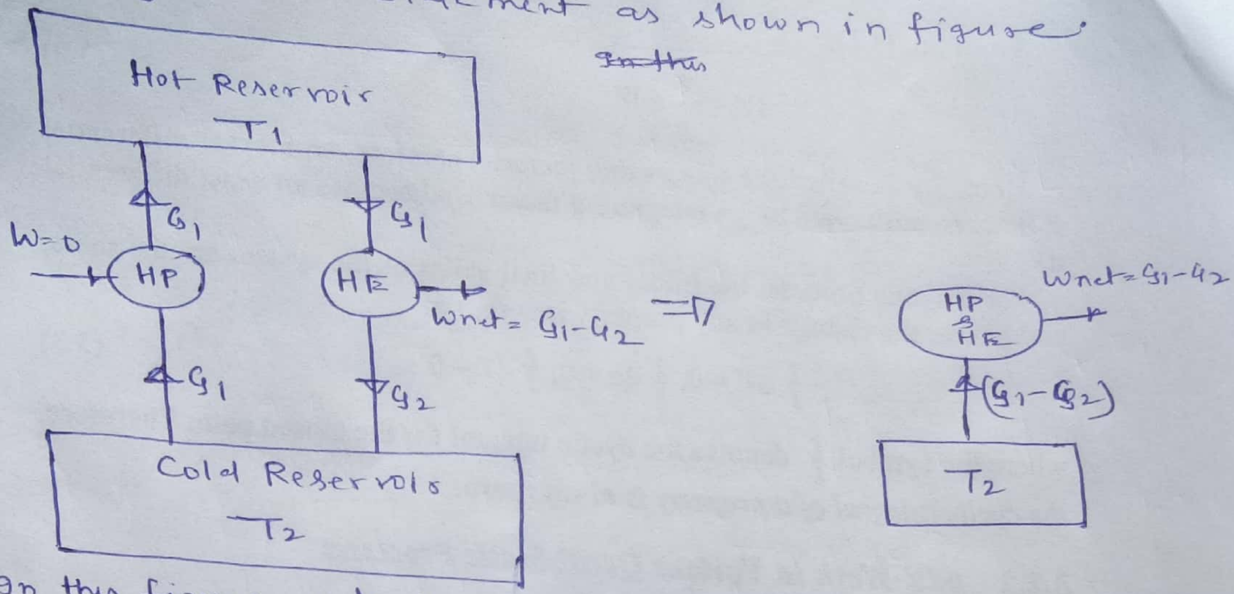
The equivalence of the two statements will be proved if it can be shown that the violation of one statement implies the violation of the second statement and vice-versa.

(a) ~~Vol~~ Violation of Clausius statement implies the ~~Vol~~ violation of Kelvin–Planck Statement. –

Consider a cyclic heat pump transfer heat from a low

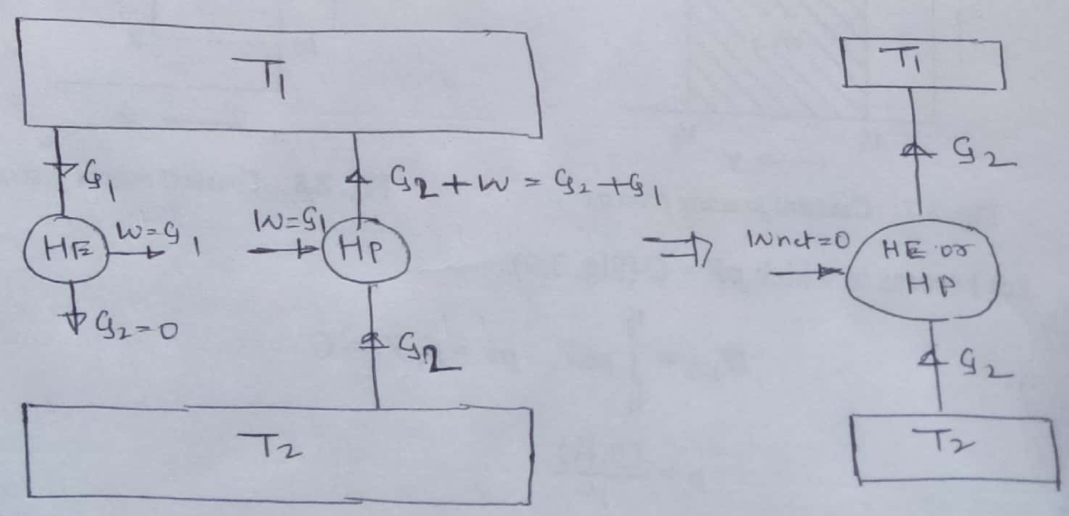
(5)

Temperature reservoir (T_2) to a high temperature reservoir (T_1) without any expenditure of work i.e violating clausius Statement as shown in figure.



In this figure a heat engine obey the kelvin-plack statement Then we find hot reservoir is eliminated. So we find that heat pump and Heat engine acting together Constitute a heat engine operating in a cycle and total heat $(G_1 - G_2)$ is converted in to work, which is violation of kelvin-plack Statement.

(b) Violation of kelvin-plack Statement implies the violation of clausius Statement



So, we find that heat engine and heat pump together Constitute a heat pump working in a cycle and transfering heat from low temperature to high temperature without any external work is thus violation of the Clausius Statement.

Perpetual Motion Machine of First kind (PMMI)

The first law states the general principle of Conservation of Energy. Energy is neither created nor destroyed, but only gets ~~transferred~~ transformed from one form to another. There can be no machine which would continuously supply mechanical work without some other form of energy disappearing simultaneously. Such a machine is called a perpetual motion machine of First kind (PMMI)