6.23 Irreversible Process

The thermodynamical state of a system can be defined with the help of the thermodynamical coordinates of the system. The state of a system can be changed by altering the thermodynamical coordinates. Changing from one state to the other by changing the thermodynamical coordinates is called a *process*.

Consider two states of a system *i.e.*, state A and state B. Change of state from A to B or *vice versa* is a process and the direction of the process will depend upon a new thermodynamical coordinate called **entropy**. All processes are not possible in the universe.

Consider the following processes :

(1) Let two blocks A and B at different temperatures T_1 and T_2 ($T_1 > T_2$) be kept in contact but the system as a whole is insulated from the surroundings. Conduction of heat takes place between the blocks, the temperature of A falls and the temperature of B rises and thermodynamical equilibrium will be reached.

(2) Consider a flywheel rotating with an angular velocity ω. Its initial kinetic energy is $\frac{1}{2}I\omega^2$. After some time the wheel comes to rest and kinetic energy is utilised in overcoming friction at the bearings. The temperature of the wheel and the bearings rises and the increase in their internal energy is equal to the original kinetic energy of the fly wheel.

(3) Consider two flasks A and B connected by a glass tube provided with a stop cock. Let A contain air at high pressure and B is evacuated. The system is isolated from the surroundings. If the stop cock is opened, air rushes from A to B, the pressure in A decreases and the volume of air increases.

All the above three examples though different, are thermodynamical processes involving change in thermodynamical coordinates. Also, in accordance with the first law of thermodynamics, the principl e of conservation of energy is not violated because the total energy of the system is conserved. It is also clear that, with the initial conditions described above, the three processes will take place.

Let us consider the possibility of the above three processes taking place in the reverse direction. In the first case, if the reverse process is possible, the block B should transfer heat to A and initial conditions should be restored. In the second case, if the reverse process is possible, the heat energy must again change to kinetic energy and the fly wheel should start rotating with the initial angular velocity ω. In the third case, if the reverse process is possible the air in B must flow back to A and the initial condition should be obtained.

But, it is a matter of common experience, that none of the above conditions for the reverse processes are reached. It means that the direction of the process cannot be determined by knowing the thermodynamical coordinates in the two end states. To determine the direction of the process a new thermodynamical coordinate has been devised by Clausius and this is called the entropy of the system. Similar to internal energy, entropy is also a function of the state of a system. For any possible process, the entropy of an isolated system should increase or remain constant. The process in which there is a possibility of decrease in entropy cannot take place.

If the entropy of an isolated system is maximum, any change of state will mean decrease in entropy and hence that change of state will not take place.

To conclude, *processes in which the entropy of an isolated system decreases do not take place or for all processes taking place in an isolated system the entropy of the system should increase or remain constant.* It means a process is irreversible if the entropy decreases when the direction of the process is reversed. A process is said to be irreversible if it cannot be retraced back exactly in the opposite direction. During an irreversible process, heat energy is always used to overcome friction. Energy is also dissipated in the form of conduction and radiation. This loss of energy always takes place whether the engine works in one direction or the reverse direction. Such energy cannot be regained. In actual practice all the engines are irreversible. If electric current is passed through a wire, heat is produced. If the direction of the current is reversed, heat is again produced. This is also an example of an irreversible process. All chemical reactions are irreversible. In general, all natural processes are irreversible.

~~6·24~~ Reversible Process 5V5

From the thermodynamical point of view, a reversible process is one in which an infinitesimally small change in the external conditions will result in all the changes taking place in the direct process but exactly repeated in the reverse order and in the opposite sense. The process should take place at an extremely slow rate. In a reversible cycle, there should not be any loss of heat due to friction or radiation. In this process, the initial conditions of the working substance can be obtained.

Consider a cylinder, containing a gas at a certain pressure and temperature. The cylinder is fitted with a frictionless piston. If the pressure is decreased, the gas expands slowly and maintains a constant temperature (isothermal process). The energy required for this expansion is continuously drawn from the source (surroundings). If the pressure on the piston is increased, the gas contracts slowly and maintains constant temperature (isothermal process). The energy liberated during compression is given to the sink (surroundings). This is also true for an adiabatic process provided the process takes place infinitely slowly.

The process will not be reversible if there is any loss of heat due to friction, radiation or conduction. If the changes take place rapidly, the process will not be reversible. The energy used in overcoming friction cannot be retraced.

The conditions of reversibility for any heat engine or process can be stated as follows :—

(1) The pressure and temperature of the working substance

must not differ appreciably from those of the surroundings at any stage of the cycle of operation.

(2) All the processes taking place in the cycle of operation must be infinitely slow.

(3) The working parts of the engine must be completely free from friction.

(4) There should not be any loss of energy due to conduction or radiation during the cycle of operation.

It should be remembered that the complete reversible process or cycle of operation is only an ideal case. In an actual process, there is always loss of heat due to friction, conduction or radiation. The temperature and pressure of the working substance differ appreciably from those of the surroundings.

5·43

6·25 Second Law of Thermodynamics

A heat engine is chiefly concerned with the conversion of heat energy into mechanical work. A refrigerator is a device to cool a certain space below the temperature of its surroundings. The first law of thermodynamics is a qualitative statement which does not preclude the possibility of the existence of either a heat engine or a refrigerator. The first law does not contradict the existence of a 100% efficient heat engine or a self-acting refrigerator.

In practice, these two are not attainable. These phenomena are recognized and this led to the formulation of a law governing these two devices. It is called second law of thermodynamics.

A new term reservoir is used to explain the second law. A **reservoir** is a device having infinite thermal capacity and which can absorb, retain or reject unlimited quantity of heat without any change in its temperature.

Kelvin-Planck statement of the second law is as follows :

"It is impossible to get a continuous supply of work from a body (or engine) which can transfer heat with a single heat reservoir. This is a negative statement. According to this statement, a single reservoir at a single temperature cannot continuously transfer heat into work. It means that there should be two reservoirs for any heat engine. One reservoir (called the source) is taken at a higher temperature and the other reservoir (called the sink) is taken at a lower temperature.

According to this statement, zero degree absolute temperature is not attainable because no heat is rejected to the sink at zero degree Kelvin. If an engine works between any temperature higher than zero degree Kelvin and zero degree Kelvin, it means it uses a single reservoir which contradicts Kelvin-Planck's statement of the second law. Similarly, no engine can be 100% efficient.

In a heat engine, the engine draws heat from the source and after doing some external work, it rejects the remaining heat to the sink. The source and sink are of infinite thermal capacity and they maintain constant temperature.

First Part. According to Kelvin, the second law can also be stated as follows :

"It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than that of its surroundings".

In a heat engine the working substance does some work and rejects the remaining heat to the *sink*. The temperature of the source must be higher than the surroundings and the engine will not work when the temperatures of the source and the sink are the same. Take the case of a steam engine. The steam (working substance) at high pressure is introduced into the cylinder of the engine. Steam expands, and it does external work. The contents remaining behind after doing work are rejected to the surroundings. The temperature of the working substance rejected to the surroundings is higher than the temperature of the surroundings.

If this working substance rejected by the first engine is used in another engine, it can do work and the temperature of the working substance will fall further.

It means that the working substance can do work only if its temperature is higher than that of the surroundings.

Second Part. According to Clausius :

"It is impossible to make heat flow from a body at a lower temperature to a body at a higher temperature without doing external work on the working substance."

This part is applicable in the case of ice plants and refrigerators. Heat itself cannot flow from a body at a lower temperature to a body at a higher temperature. But, it is possible, if some external work is done on the working substance. Take the case of ammonia ice plant. Ammonia is the working substance. Liquid ammonia at low pressure takes heat from the brine solution in the brine tank and is converted to low pressure vapour. External work is done to compress the ammonia vapours to high pressure. This ammonia at high pressure is passed through coils over which water at room temperature is poured. Ammonia vapour gives heat to water at room temperature and gets itself converted into liquid again. This high pressure liquid ammonia is throttled to low pressure liquid ammonia. In the whole process ammonia (the working substance) takes heat from brine solution (at a lower temperature) and gives heat to water at room temperature (at a higher temperature). This is possible only due to the external work done on ammonia by the piston in compressing it. The only work of electricity in the ammonia ice plant is to move the piston to do external work on ammonia. If the external work is not done, no ice plant or refrigerator will work. Hence, it is possible to make heat flow from a body at a lower temperature to a body at a higher temperature by doing external work on the working substance.

Thus, the second law of thermodynamics plays an important part for practical devices *e.g.*, heat engines and refrigerators. The first law of thermodynamics only gives the relation between the work done and the heat produced. But the second law of thermodynamics gives the conditions under which heat can be converted into work.

6·26 Carnot's Reversible Engine

Heat engines are used to convert heat into mechanical work. Sadi Carnot (French) conceived a theoretical engine which is free from all the defects of practical engines. Its efficiency is maximum and it is an ideal heat engine.

For any engine, there are three essential requisites :

(1) **Source.** The source should be at a fixed high temperature T_1 from which the heat engine can draw heat. It has infinite thermal capacity and any amount of heat can be drawn from it at constant temperature T_1.

(2) **Sink.** The sink should be at a fixed lower temperature T_2 to which any amount of heat can be rejected. It also has infinite thermal capacity and its temperature remains constant at T_2.

(3) **Working Substance.** A cylinder with non-conducting sides and conducting bottom contains the perfect gas as the *working substance*.

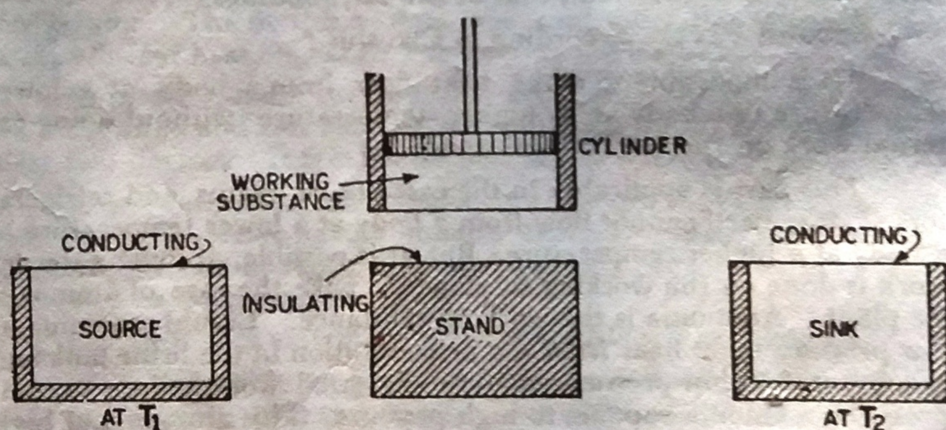

Fig. 6·12

A perfect non-conducting and frictionless piston is fitted into the cylinder. The working substance undergoes a complete cyclic operation (Fig. 6·12).

A perfectly non-conducting stand is also provided so that the working substance can undergo adiabatic operation.

Carnot's Cycle

(1) Place the engine containing the working substance over the source at temperature T_1. The working substance is also at a temperature T_1. Its pressure is P_1 and volume is V_1 as shown by the point A in Fig. 6·13. Decrease the pressure. The volume of the working substance increases. Work is done by the working substance. As the bottom is perfectly conducting to the source at temperature T_1, it absorbs heat. The process is completely isothermal. The temperature remains constant. Let the amount of heat

absorbed by the working substance be H_1 at the temperature T_1. The point B is obtained.

Consider one gram molecule of the working substance.

Work done from A to B (isothermal process)

$$W_1 = \int_{V_1}^{V_2} P.\,dV = RT_1 \log \frac{V_2}{V_1}$$

$$= \text{area } ABGE \qquad \ldots(i)$$

(2) Place the engine on the stand having an insulated top Decrease the pressure on the working substance. The volume

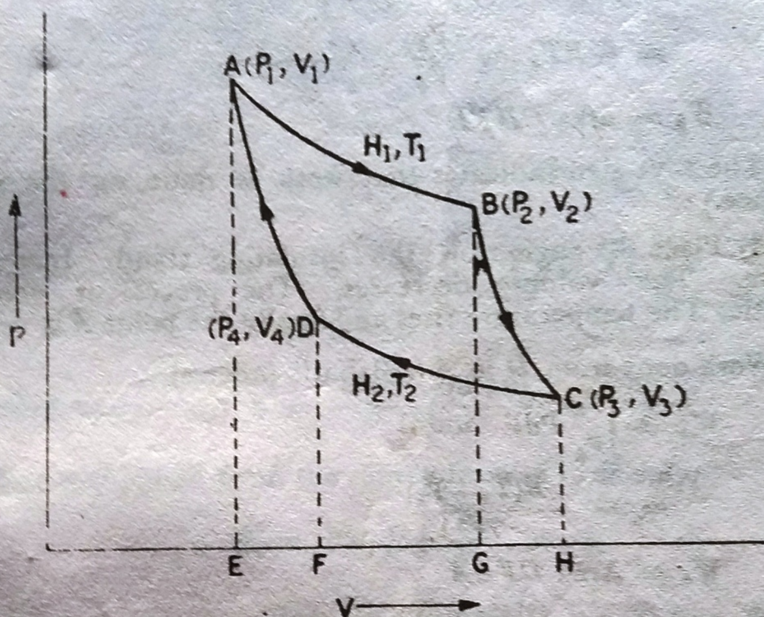

Fig. 6·13

increases. The process is completely adiabatic. Work is done by the working substance at the cost of its internal energy. The temperature falls. The working substance undergoes adiabatic change from B to C. At C the temperature is T_2 (Fig. 6·13).

Work done from B to C (adiabatic process)

$$W_2 = \int_{V_2}^{V_3} P.\,dV$$

$$= \int_{V_2}^{V_3} \frac{dV}{V^\gamma}$$

$$= \frac{KV_3^{1-\gamma} - KV_2^{1-\gamma}}{1-\gamma}$$

But $PV^\gamma = \text{constant} = K$

$P_2V_2 = RT_1$

$P_3V_3 = RT_2$

$P_3V_3^\gamma = P_2V_2^\gamma = K$

$$= \frac{P_3V_3 - P_2V_2}{1-\gamma}$$

$$= \frac{R[T_2 - T_1]}{1-\gamma} = \frac{R[T_1 - T_2]}{\gamma - 1} \qquad \ldots(ii)$$

$W_2 = \text{Area } BCHG$

(3) Place the engine on the sink at temperature T_2. Increase the pressure. The work is done on the working substance. As the base is conducting to the sink, the process is isothermal. A quantity of heat H_2 is rejected to the sink at temperature T_2. Finally the point D is reached.

Work done from C to D (isothermal process)

$$W_3 = \int_{V_3}^{V_4} PdV$$

$$= RT_2 \log \frac{V_4}{V_3}$$

$$= -RT_2 \log \frac{V_3}{V_4} \qquad ...(iii)$$

$$W_3 = \text{area } CHFD$$

(The —ve sign indicates that work is done on the working substance.)

(4) Place the engine on the insulating stand. Increase the pressure. The volume decreases. The process is completely adiabatic. The temperature rises and finally the point A is reached.

Work done from D to A (adiabatic process).

$$W_4 = \int_{V_4}^{V_1} PdV$$

$$= -\frac{R(T_1-T_2)}{\gamma-1}$$

$$W_4 = \text{Area } DFEA \qquad ...(iv)$$

[W_2 and W_4 are equal and opposite and cancel each other.]

The net work done by the working substance in one complete cycle

$$= \text{Area } ABGE + \text{Area } BCHG - \text{Area } CHFD - \text{Area } DFEA$$

$$= \text{Area } ABCD$$

The net amount of heat absorbed by the working substance

$$= H_1 - H_2$$

$$\text{Net work} = W_1 + W_2 + W_3 + W_4$$

$$= RT_1 \log\frac{V_2}{V_1} + \frac{R(T_1-T_2)}{\gamma-1} - RT_2 \log \frac{V_3}{V_4} - \frac{R[T_1-T_2]}{\gamma-1}$$

$$W = RT_1 \log\frac{V_2}{V_1} - RT_2 \log \frac{V_3}{V_4} \qquad ...(v)$$

The points A and D are on the same adiabatic

$$T_1 V_1^{\gamma-1} = T_2 V_4^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_4}\right)^{\gamma-1} \qquad ...(vi)$$

The points B and C are on the same adiabatic

$$T_1V_2^{\gamma-1} = T_2V_3^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_3}\right)^{\gamma-1} \qquad \text{...(vii)}$$

From (*vi*) and (*vii*)

$$\left(\frac{V_1}{V_4}\right)^{\gamma-1} = \left(\frac{V_2}{V_3}\right)^{\gamma-1}$$

or

$$\frac{V_1}{V_4} = \frac{V_2}{V_3}$$

or

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

From equation (*v*)

$$W = RT_1 \log\frac{V_2}{V_1} - RT_2 \log\frac{V_2}{V_1}$$

$$W = R\left[\log\frac{V_2}{V_1}\right]\left[T_1 - T_2\right]$$

$$\therefore \quad W = H_1 - H_2$$

Efficiency $\eta = \dfrac{\text{Useful output}}{\text{Input}} = \dfrac{W}{H_1}$

Heat is supplied from the source from A to B only.

$$H_1 = RT_1 \log\frac{V_2}{V_1}$$

$$\therefore \quad \eta = \frac{W}{H_1} = \frac{H_1 - H_2}{H_1}$$

$$= \frac{R[T_1 - T_2]\log\left(\frac{V_2}{V_1}\right)}{RT_1 \log\left(\frac{V_2}{V_1}\right)}$$

or

$$\eta = 1 - \frac{H_2}{H_1}$$

$$\eta = 1 - \frac{T_2}{T_1} \qquad \text{...(viii)}$$

The Carnot's engine is perfectly reversible. It can be operated in the reverse direction also. Then it works as a refrigerator. The heat H_2 is taken from the sink and external work is done on the working substance and heat H_1 is given to the source at a higher temperature.

The isothermal process will take place only when the piston moves very slowly to give enough time for the heat transfer to take place. The adiabatic process will take place when the piston moves extremely fast to avoid heat transfer. Any practical engine cannot satisfy these conditions.

All practical engines have an efficiency less than the Carnot's engine.

6·27 Carnot's Engine and Refrigerator

Carnot's cycle is perfectly reversible. It can work as a heat engine and also as a refrigerator. When it works as a heat engine, it absorbs a quantity of heat H_1 from the source at a temperature T_1, does an amount of work W and rejects an amount of heat H_2 to the sink at temperature T_2. When it works as a refrigerator, it absorbs heat H_2 from the sink at temperature T_2. W amount of work is done on it by some external means and rejects heat H_1 to the source at a temperature T_1 (Fig. 6·14). In the second case heat flows from a body at a lower temperature to a body at a higher temperature, with the help of external work done on the working substance and it works as a refrigerator. This will not be possible if the cycle is not completely reversible.

Coefficient of Performance. The amount of heat absorbed at the lower temperature is H_2. The amount of work done by the external process (input energy) $= W$ and the amount of heat rejected $= H_1$. Here H_2 is the desired refrigerating effect.

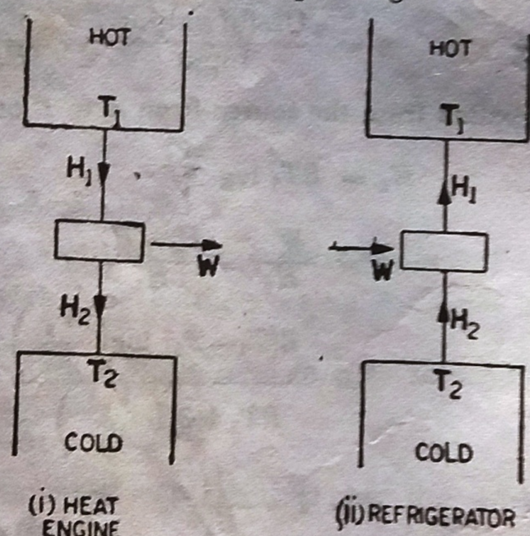

Fig. 6·14

Coefficient of performance

$$= \frac{H_2}{W} = \frac{H_2}{H_1 - H_2}$$

Suppose 200 joules of energy is absorbed at the lower temperature and 100 joules of work is done with external help. Then $200+100 = 300$ joules are rejected at the higher temperature.

The coefficient of preformance

$$= \frac{H_2}{W}$$

$$= \frac{H_2}{H_1 - H_2}$$

$$= \frac{200}{300 - 200} = 2$$

Therefore the coefficient of performance of a refrigerator = 2.

In the case of a heat engine, the efficiency cannot be more than 100% but in the case of a refrigerator, the coefficient of performance can be much higher than 100%.

Example 6·8. *Find the efficiency of the Carnot's engine working between the steam point and the ice point.*

$$T_1 = 273 + 100 = 373 \text{ K}$$

$$T_2 = 273 + 0 = 273 \text{ K}$$

$$\eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{273}{373} = \frac{100}{373}$$

$$\% \text{ efficiency} = \frac{100}{373} \times 100$$

$$= \mathbf{26{\cdot}81\%}$$

Example 6·9. *Find the efficiency of a Carnot's engine working between 127°C and 27°C.*

$$T_1 = 273 + 127 = 400 \text{ K}$$

$$T_2 = 273 + 27 = 300 \text{ K}$$

$$\eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{300}{400} = 0{\cdot}25$$

$$\% \text{ efficiency} = \mathbf{25\%}$$

Example 6·10. *A Carnot's engine whose temperature of the source is 400 K takes 200 calories of heat at this temperature and rejects 150 calories of heat to the sink. What is the temperature of the sink? Also calculate the efficiency of the engine.*

$$H_1 = 200 \text{ cal}; \qquad H_2 = 150 \text{ cal}$$

$$T_1 = 400 \text{ K}; \qquad T_2 = ?$$

$$\frac{H_1}{T_1} = \frac{H_2}{T_2}$$

$$T_2 = \frac{H_2}{H_1} \times T_1$$

$$T_2 = \frac{150}{200} \times 400 = \mathbf{300 \text{ K}}$$

$$\eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{300}{400} = 0{\cdot}25$$

% efficiency = **25%**

Example 6·11. *A Carnot's engine is operated between two reservoirs at temperatures of 450 K and 350 K. If the engine receives 1000 calories of heat from the source in each cycle, calculate the amount of heat rejected to the sink in each cycle. Calculate the efficiency of the engine and the work done by the engine in each cycle.* (1 calorie = 4·2 joules).

$T_1 = 450$ K ; $T_2 = 350$ K

$H_1 = 1000$ cal ; $H_2 = ?$

$$\frac{H_2}{H_1} = \frac{T_2}{T_1}$$

$$H_2 = H_1 \times \frac{T_2}{T_1}$$

$$= \frac{1000 \times 350}{450} = \mathbf{777{\cdot}77\ cals}$$

$$\eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{350}{450} = \frac{100}{450}$$

$$= 0{\cdot}2222$$

% efficiency = **22·22%**

Work done in each cycle

$= H_1 - H_2$

$= 1000 - 777{\cdot}77$

$= 222{\cdot}23$ cal

$= 222{\cdot}23 \times 4{\cdot}2$ joules

$=$ **933·33 joules**

Example 6·12. *A Carnot's engine working as a refrigerator between 260 K and 300 K receives 500 calories of heat from the reservoir at the lower temperature. Calculate the amount of heat rejected to the reservoir at the higher temperature. Calculate also the amount of work done in each cycle to operate the refrigerator.*

[*Delhi (Hons.) 1974*]

$H_1 = ?$ $H_2 = 500$ cal

$T_1 = 300$ K $T_2 = 260$ K

$$\frac{H_1}{H_2} = \frac{T_1}{T_2} ;$$

$$H_1 = H_2 \cdot \frac{T_1}{T_2}$$

$$H_1 = \frac{500 \times 300}{260} = 576{\cdot}92 \text{ cal}$$

$$W = H_1 - H_2 = 76{\cdot}92 \text{ cal}$$

$$= 76{\cdot}92 \times 4{\cdot}2 \text{ joules}$$

$$= \mathbf{323{\cdot}08 \text{ joules}}$$

H.W.

Example 6·13. *A Carnot's refrigerator takes heat from water at 0°C and discards it to a room at 27°C. 1 kg of water at 0°C is to be changed into ice at 0°C. How many calories of heat are discarded to the room? What is the work done by the refrigerator in this process? What is the coefficient of performance of the machine?*

[*Delhi 1974*]

$$H_1 = ?$$

$$H_2 = 1000 \times 80 = 80{,}000 \text{ cal}$$

$$T_1 = 300 \text{ K}$$

$$T_2 = 273 \text{ K}$$

(1)
$$\frac{H_1}{H_2} = \frac{T_1}{T_2}$$

$$H_1 = \frac{H_2 T_1}{T_2}$$

$$= \frac{80{,}000 \times 300}{273}$$

$$H_1 = \mathbf{87{,}900 \text{ Cal}}$$

(2) Work done by the refrigerator

$$= W = J\,(H_1 - H_2)$$

$$W = 4{\cdot}2\,(87{,}900 - 80{,}000)$$

$$W = 4{\cdot}2 \times 7900$$

or
$$W = \mathbf{3{\cdot}183 \times 10^4 \text{ joules}}$$

(3) Coefficient of performance,

$$= \frac{H_2}{H_1 - H_2}$$

$$= \frac{80{,}000}{87{,}900 - 80{,}000}$$

$$= \frac{80{,}000}{7900}$$

$$= \mathbf{10{\cdot}13}$$

Example 6·14. *A carnot engine whose low-temperature reservoir is at 7°C has an efficiency of 50%. It is desired to increase the efficiency to 70%. By how many degrees should the temperature of the high temperature reservoir be increased ?* (*Delhi 1971*)

In the first case

$$\eta = 50\% = 0{\cdot}5, \quad T_2 = 273+7 = 280 \text{ K.}$$

$$T_1 = ?$$

$$\eta = 1 - \frac{T_2}{T_1}$$

or $$0{\cdot}5 = 1 - \frac{280}{T_1}$$

or $$T_1 = 560\ K$$

In the second case

$$\eta' = 70\% = 0{\cdot}7,$$

$$T_2 = 280\ K,$$

$$T_1' = ?$$

$$\eta' = 1 - \frac{T_2}{T_1'}$$

$$0{\cdot}7 = 1 - \frac{280}{T_1'}$$

or $$T_1' = 840\ K$$ 933

Increase in temperature $= 840 - 560 =$ **280 K**

6·28 Carnot's Theorem

The efficiency of a reversible engine does not depend on the nature of the working substance. It merely depends upon the temperature limits between which the engine works.

"All the reversible engines working between the same temperature limits have the same efficiency. No engine can be more efficient than a Carnot's reversible engine working between the same two temperatures."

Consider two reversible engines A and B, working between the temperature limits T_1 and T_2 (Fig. 6·15). A and B are coupled. Suppose A is more efficient than B. The engine A works as a heat engine and B as a refrigerator. The engine A absorbs an amount of heat H_1 from the source at a temperature T_1. It does external work W and transfers it to B. The heat rejected to the sink is H_2 at a temperature T_2. The engine B absorbs heat H_2' from the sink at temperature T_2 and W amount of work is done on the working substance. The heat given to the source at temperature T_1 is H_1'.

Suppose the engine A is more efficient than B.

Efficiency of the engine A

$$= \eta = \frac{H_1 - H_2}{H_1} = \frac{W}{H_1}$$

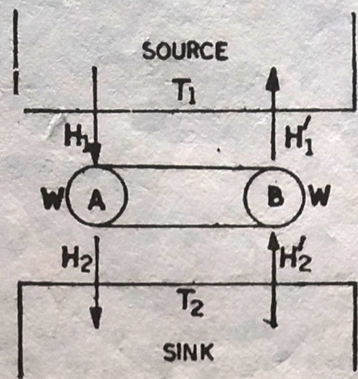

Fig. 6·15.

Efficiency of the engine B

$$= \eta' = \frac{H_1' - H_2'}{H_1'} = \frac{W}{H_1'}$$

Since $\qquad \eta > \eta' \, ; \; H_1' > H_1$

Also, $\qquad W = H_1 - H_2 = H_1' - H_2'$

$\therefore \qquad H_2' > H_2$

Thus, for the two engines A and B working as a coupled system, $(H_2' - H_2)$ is the quantity of heat taken from the sink at a temperature T_2 and $(H_1' - H_1)$ is the quantity of heat given to the source at a temperature T_1. Both $(H_2' - H_2)$ and $(H_1' - H_1)$ are positive quantities. It means heat flows from the sink at a temperature T_2 (lower temperature) to the source at a temperature T_1 (higher temperature) *i.e.*, heat flows from a body at a lower temperature to a body at a higher temperature. But, no external work has been done on the system. This is contrary to the second law of thermodynamics. Thus, η cannot be greater than η'. The two engines (reversible) working between the same two temperature limits have the same efficiency. Moreover, in the case of a Carnot's engine, there is no loss of heat due to friction, conduction or radiation (irreversible processes). Thus, the Carnot's engine has the maximum efficiency. Whatever may be the nature of the working substance, the efficiency depends only upon the two temperature limits.

In a practical engine there is always loss of energy due to friction, conduction, radiation etc. and hence its efficiency is always lower than that of a Carnot's engine.