**S. S. College, Jehanabad**

**(A Constituent College of Magadh university)**

**B.Sc (H)Physics Part I**

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**Application of Second law of Thermodynamics**

**Introduction**

We can illustrate second law of thermodynamics with an application to the theory of heat engines which are machines that convert heat energy into mechanical work. To be a useful device a heat engine should operate continuously. It works by absorbing heat from a reservoir at a higher temperature and rejecting it to a reservoir at a lower temperature. Thus a heat engine has to operate between two heat reservoirs. Sadi Carnot suggested a theoretical engine which is free from all practical imperfections. It has maximum efficiency which cannot be achieved in the real world. Carnot’s engine is a perfectly reversible engine. That means all stages of operation should be carried out infinitely slowly so that there are no dissipative losses. The simplest reversible cycle is due to Carnot. In Carnot cycle any substance can be made to exchange heat from the heat reservoirs. A Carnot cycle has four processes in which two are reversible adiabatic processes and remaining two are reversible isothermal processes. A system undergoing a Carnot cycle is called a Carnot engine, although such a **'perfect' engine** is only a theoretical limit and cannot be built in practice. When the Carnot engine works in the reverse direction it works as a refrigerator. The co efficient of performance of a refrigerator is defined as the ratio of total heat extracted at lower temperature to the amount of input work done.

**Carnot cycle**

It is a cycle of expansion and compression of an idealized reversible heat engine that does work without loss of heat.

Every single thermodynamic system exists in a particular state. When a system is taken through a series of different states and finally returned to its initial state, a thermodynamic cycle is said to have occurred. In the process of going through this cycle, the system may perform work on its surroundings, thereby acting as a heat engine.

The Carnot cycle is a theoretical thermodynamic cycle proposed by Sadi Carnot. It is the most efficient cycle for converting a given amount of thermal energy into work, or conversely, creating a temperature difference by doing a given amount of work.

The various stages of the cycle executed by a reversible engine can be represented on the PV indicator diagram shown below

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**Figure 1.**

**Step 1** (Isothermal expansion): The cylinder with the working substance (perfect gas) is kept in thermal contact with the source, the temperature of which is T1. Let the initial pressure is P1 and the volume is V1. This state is represented by the point A in the diagram.

Now the gas is allowed to expand quasistatically at constant temperature(T1) from A to B i. e the process **A B** is isothermal. In this process the heat flows from the source to the system. The pressure and volume of the gas change extremely slowly (and becomes P2 ,V2 respectively at point B) but its temperature remains constant throughout the process.

Let during the process from A to B:

Q1 = the amount of heat that flows from the source into the working substance

W1= the amount of work done by the system

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For one mole of an ideal gas,

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From the first law of thermodynamics



For an isothermal process, from A to B, the amount of heat absorbed Q1 is converted into work W1 by the engine and the change in internal energy is zero (because the temperature remains constant).

So,



and



Now the work done during the isothermal process (from equation 1),

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**Step 2** (Adiabatic Expansion): Now the cylinder with the working substance is kept on the insulated stand. The gas is allowed to expand quasistatically from B to C till the temperature falls to the temperature of the sink (T2). The pressure decreases from P2 to P3 and volume increases from V2 to V3. The temperature falls from T1 to T2. The process **B C** is reversible adiabatic expansion. There is no heat flow in this process.

Let during the process from B to C:

W2 = the amount of work done by the system















Therefore

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**Step 3** (Isothermal Compression): Now cylinder with the working substance is kept in thermal contact with the sink. The gas is compressed quasistatically from C to D. The pressure increases from P3 to P4 and the volume decrease from V3 to V4 but the temperature remains the same. The process **C D** is reversible isothermal at temperature T2. In this process there is heat flow from the system to the sink.

Let, during the process from C to D:

the amount of heat rejected by the working substance to the sink

W3 = the work done on the working substance

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Here the negative sign indicates that the **work** is done **on** the working substance.

**Step 4** (Adiabatic Compression): Now the cylinder with the working substance is kept on the insulated stand. The gas is compressed quasistatically from D to A. The pressure increases from P4 to P1 and the volume decreases from V4 to V1. The temperature increases from T2 to T1. The process **D A** is adiabatic. In this process there is no heat flow. At the end of this process the system comes back to its original state (A).

Let, during the process from D to A:

W4 = the work done on the system



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So, for the complete cycle the total work done by the engine is,



Since *W2* and *W4* are equal and opposite, they cancel each other.

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The total work done per cycle in terms of area [ Figure (3)] is,

W = Area (A B G E A) + Area (B C H G B) – Area (C H F D C) – Area ( D F E A D).



Thus, the area of the Carnot’s cycle represents the net amount of work done per cycle.

In the cyclic process, net heat absorbed = net work done per cycle

So, Q1 – Q2 = W1 – W3 = W …………………….. 7

We use another adiabatic relation for an ideal gas:





Since B and C lie on the same adiabatic curve,



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Similarly, for D and A we can write,



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Comparing equations (8) and (9)

We get,



Using this result in equation (6), net work done per cycle

Efficiency:

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In general, the "efficiency" or "effectiveness" of a process is calculated by dividing the desired output by the total input. Thus, the efficiency should have a larger value.

For a heat engine, the efficiency is the ratio of useful output to the heat energy consumed from the high-temperature reservoir:



From equation (2) and (10)



Or 

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Thus the efficiency of the Carnot’s engine depends only on the temperature of the source and the sink. It does not depend on the nature of the working substance.

η= 1 i.e. 100% efficiency is possible only when the temperature of the sink is absolute zero and no heat is rejected to the sink. In practice, these two conditions are unattainable.

**Since it is not possible to reach absolute zero** (because this would be the violation of second law of thermodynamics) hence it can be concluded that 100% efficient engines are not possible.

This result is the essence of the second law of thermodynamics.

**Refrigerator and its coefficient of performance**

**Definition:** Refrigerator is a commonly used device that transfers heat from a low temperature medium to a high temperature medium and removes heat from the refrigeration space.

The main objective of the refrigerator is to remove heat from the reservoir at a low temperature.

The Carnot cycle is a totally reversible cycle. If one reverses all the processes in the Carnot cycle, we achieve Carnot refrigeration cycle.

Since Carnot cycle is perfectly reversible, it can work as a heat engine as well as a refrigerator.

When it works as a heat engine [Figure 2a], it draws heat Q1 from the source at temperature T1 and does W amount of work. Rest of the heat Q2 (Q1-W) is rejected to the sink at temperature T2.

When it works as a refrigerator [Figure 2b], it absorbs heat Q2 from the sink at lower temperature T2 and W amount of work is done on it by some external means. Total heat Q1 (Q2+W) is rejected to the source at higher temperature.

This is in accordance with Clausius statement of the second law of thermodynamics.



Figure 2a Heat Engine



Figure 2b. Refrigerator

**Co efficient of Performance**: This is the measure of the efficiency of a refrigerator

For a Carnot engine working as a refrigerator, the Co efficient of Performance (COP) is defined as the ratio of the heat extracted from the sink (which is at low temperature) to the external work, which is used by the refrigerator to transfer thermal energy from a low temperature reservoir to a high temperature reservoir.

Alternatively, we can say that it is the ratio of the amount of heat absorbed to the amount of work done on the working substance[ Figure 2(b)].



Since,



Therefore,

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Here, Q1= heat exchanged with source at higher temperature T1

Q2= heat exchanged with sink at lower temperature T2

The larger is the value of COP, the more efficient is the refrigerator.

If the value of the coefficient of performance is **1** then the temperature of the source is twice of that of the temperature of the sink. For a refrigerator the maximum amount of heat should be extracted at lower temperature for the least amount of work. The value of COP can be much higher than **1**.