PRACTICAL CENTRE

PRACTICAL CENTRE

CLASS-XII

PHYSICS

UNIT#17

SECOND LAW OF THERMODYNAMICS

2024-25

info@practicalcentre.edu.pk

021-34976530
021-34812547
021-34984762

B-14, Block-1,
Gulshan-e-Iqbal, [illegible]chi.

SECOND LAW OF THERMODYNAMICS 17

S.No.	CONTENTS	Page#
17.1	Second Law of Thermodynamics:	3
17.2	Heat Engine	4
17.3	Four Stroke Petrol Engine and Diesel Engine	5
17.4	Refrigerator	6
17.5	Reversible and Irreversible Process	6
17.6	Carnot Engine	7
17.7	Entropy	9

Introduction:

The first law of thermodynamic is a particular form of the law of conservation of energy. However, there are some *limitations regarding* the transformation of heat energy into mechanical energy, which are covered by the 2nd law of thermodynamics.

17.1- Second Law of Thermodynamics:

Lord Kelvin and Rudolf Clausius formulated the second law of thermodynamics. It consists of two statements.

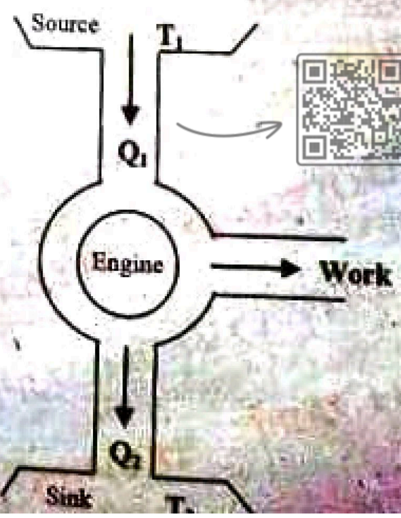
Kelvin's Statement:

STATEMENT:

"It is impossible to construct an engine, operating continuously in cycle that can take heat from a source and converts completely in to work."

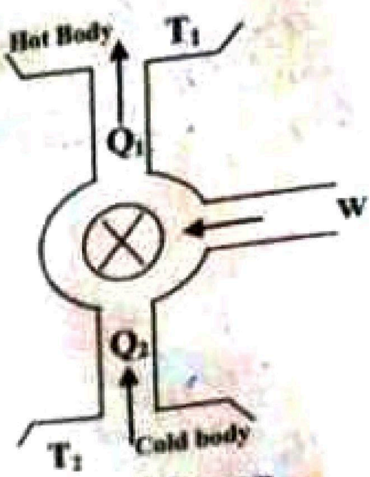
EXPLANATION:

A machine which works on Kelvin's statement is called **Heat engine**, the working of which can be understood by the following flow chart. i.e. a continuous supply of heat can never be obtained from a single supply of heat. The conversion of heat into work is possible only when the working substance works between two different temperatures. It means that a heat engine cannot convert all the heat energy into mechanical energy without giving a part of it to the cold body or the sink.



Clausius Statement:

"It is impossible to cause heat to flow from a cold body to a hot body without expenditure of energy".



REFRIGERATOR

EXPLANATION:

A **refrigerator** is the machine which conveys heat from a body at lower temperature to a body at higher temperature. This can be achieved only when it is connected with a suitable working substance or external agency which can provide it enough energy so that heat can flow in the reverse direction.

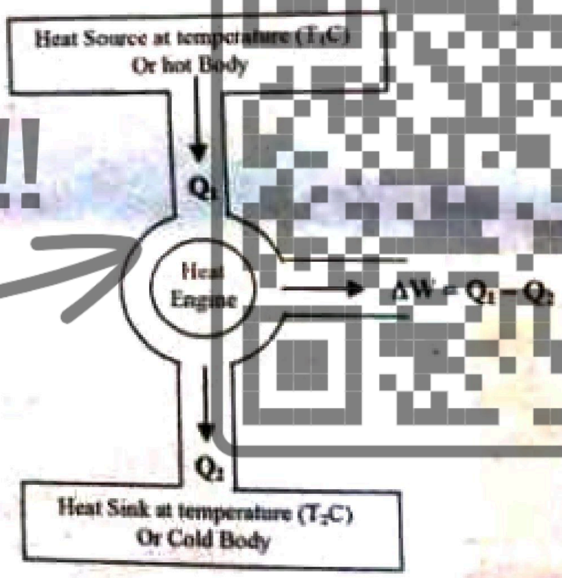
17.2 Heat Engine:

Introduction:

A heat engine is a device that converts thermal energy into mechanical work. It operates by transferring heat from a high-temperature source to a low-temperature sink, utilizing the energy difference to perform work. Heat engines are fundamental to various applications, including power generation, transportation, and industrial processes.

Principle of Heat Engine:

The basic principle of a heat engine is rooted in the laws of thermodynamics, particularly the first and second laws:



Working:

A heat engine typically operates in a cyclic process, absorbing heat ($Q_{in} = Q_1$) from a hot reservoir converting part of that heat into work (ΔW), and rejecting the remaining heat ($Q_{out} = Q_2$) to a cold reservoir.

Efficiency of Heat Engine:

The efficiency (η) of a heat engine is defined as the ratio of the work output to the heat input:

$$\eta = \frac{W}{Q_1}$$

OR

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

OR

$$\boxed{\eta = 1 - \frac{Q_2}{Q_1}}$$

But

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

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

Where:

W = Work done by the engine

Q_1 = Heat absorbed from the hot reservoir

Q_2 = Heat rejected to the cold reservoir

Practical Efficiency:

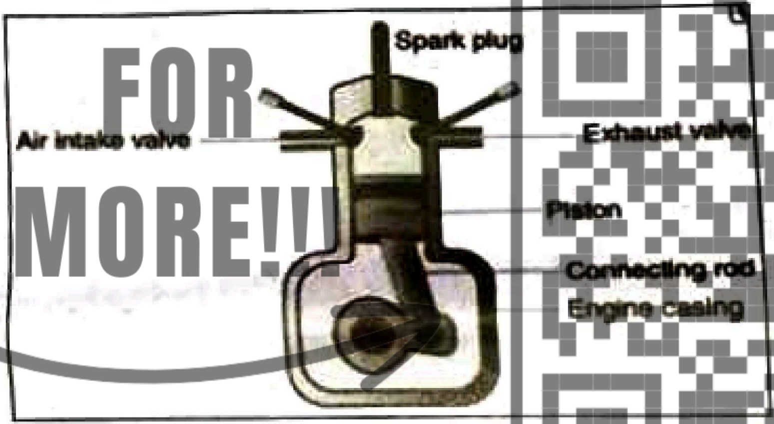
Real engines have efficiencies lower than the theoretical maximum due to irreversibility, friction, heat losses, and other factors. Typical efficiencies for internal combustion engines range from 20% to 30%, while steam turbines can achieve efficiencies of around 30% to 45%

17.3 Four Stroke Petrol Engine:

Although different engines may differ in their construction and technology but they are based on the principle of a Carnot cycle.

Construction:

Petrol engine consist of pistons, crankshaft, sparking plug and valves. It is shown in figure.



Working:

Typical four stroke petrol engine also undergoes four processes in each cycle.

1. Intake Stroke:

The cycle starts on the intake strokes in which piston moves outward and petrol air mixture is drown through and inlet valve into the cylinder from the carburetor at atmosphere pressure.

2. Compression Stroke:

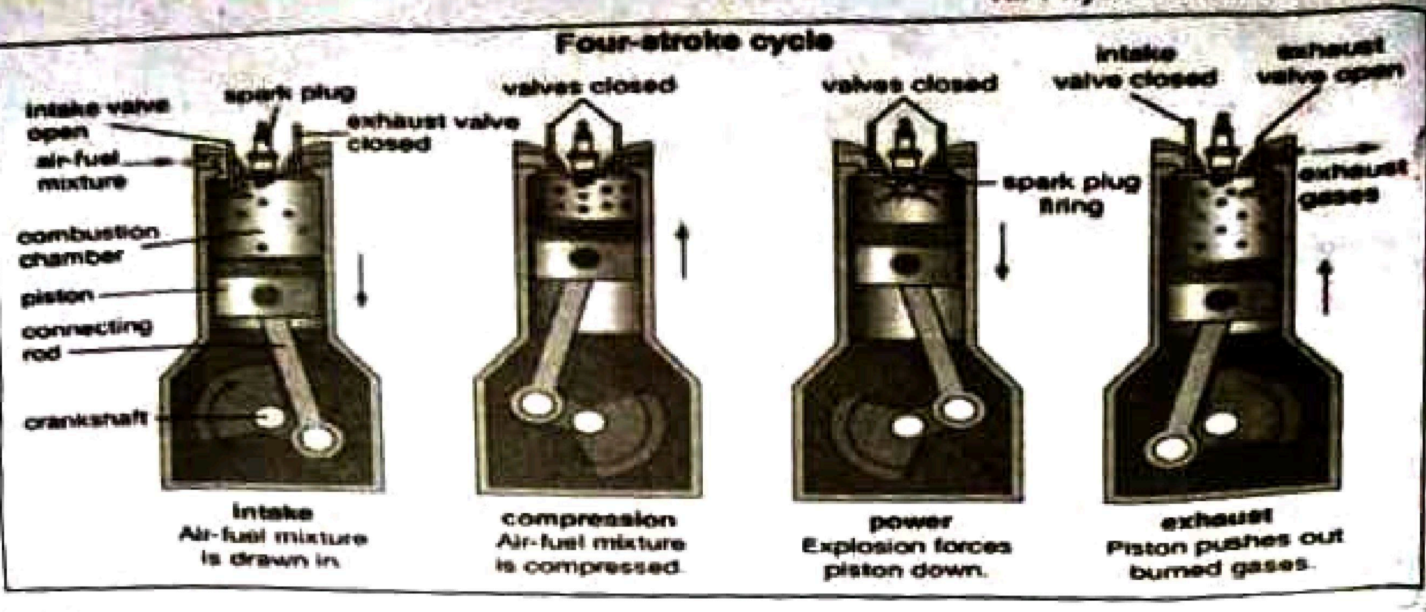
On the compression stroke into the valve closed and the mixture is compressed adiabatically by inward moment of the piston.

3. Power Stroke:

On the power stroke, a spark fires the mixture casing a rapid increase in pressure and temperature. The burning mixture expands adiabatically and forces the piston to moves outward. This is the stroke which delivers power to crankshaft to derive fly wheels.

4. Exhaust Stroke:

On the exhaust stroke the outlet valves opens. The gases are expelled and piston moves inward. Most motorbikes have one cylinder engine but cars have four cylinders on some crankshaft.



Efficiency:

The actual efficiency of tuned engine is not more than 25 to 30 % beacause of heat and friction losses.

Diesel Engine:

The construction and working of Diesel engine is almost similar to the petrol engine in diesel engine we used Fuel injector instead of spark plug.

The Fuel injector injured the mixture of air and fuel at high pressures due to friction the drops of diesel are burnout and power is produces

The efficiency of Diesel engine is about 35% to 40%.

17.4 Refrigerator

The device in which the working substance performance cycle in a direction opposite to that of a heat engine is called refrigerator.

In refrigerator heat reject into the hot reservoir by supplying some external energy (work).

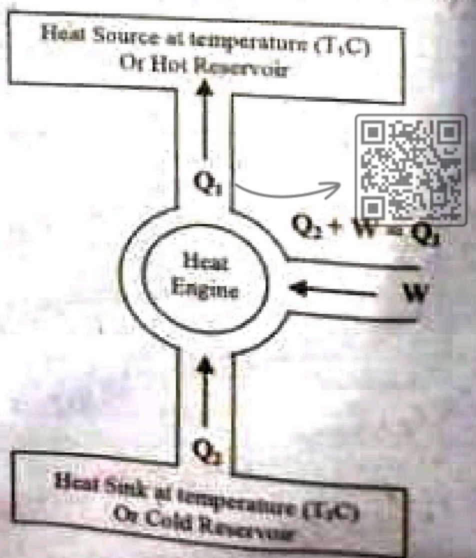
This shows that in refrigerator the work is done on the system, whereas in heat engine the work is done by the system.

When refrigerator is used for cooling in summer, it is called refrigerator, whereas when it is used for heating in winter, it is called heat pump.

Coefficient of Performance OR Energy Ratio of Refrigerator:

The performance of a heat engine is describe by its thermal efficiency. The Coefficient of performance (COP) is defined as the ratio of the amount of heat removed from the sink to the work done.

i.e. $\text{COP of Refrigerator} = \dfrac{\text{Heat Removed}}{\text{Work done}}$



$$COP = \frac{Q_2}{W}$$

$$\therefore \quad W = Q_1 - Q_2$$

$$COP = \frac{Q_2}{Q_1 - Q_2}$$

$$Q_1 = W + Q_2$$

$$\boxed{COP = \frac{T_2}{T_1 - T_2}}$$

$$\therefore \quad \frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

17.5 Reversible Process:

A process that can return to its initial condition without any change in the surroundings. It operates in equilibrium at all stages and can be retraced exactly in reverse order. For example:

Melting and Freezing:
Ice melting into water can be reversed by freezing the water back into ice.

Dissolving Sugar in Water:
Sugar dissolving in water can be reversed by evaporating the water, leaving the sugar behind.

Irreversible Process:

A process that cannot be retraced in the backward direction without affecting the surroundings. It typically involves sudden changes, friction, or energy dissipation. For example:

Cooking Food:
Cooking an egg changes its structure, and it cannot be returned to its raw state.

Burning Wood:
When wood burns, it transforms into ash and gases, which cannot be reverted back to the original wood.

17.6 Carnot Engine:

Carnot engine is an ideal heat engine which was assumed by Sadi Carnot. It is free from all imperfections of real heat engine, thus its efficiency would be an ideal efficiency and could never be obtained by any real heat engine.

Construction:

Carnot engine consists of a cylinder with ideally heat insulating frictionless piston. Further, its walls are ideally heat-insulating and base is ideally heat conducting. An ideal gas is enclosed in the cylinder. For the operation of Carnot engine, it is also supposed that the source and the sink are of infinite capacities.

Principle:

It is based upon cyclic process.

Carnot Cycle:

The operating cycle of a Carnot engine is called Carnot cycle. It consists of four following processes.

PROCESS: 1

In this process, the cylinder is placed on a hot body having temperature T_1. The gas is allowed to expand by decreasing the load on the piston slowly and at the same time, some heat Q_1, from the heat reservoir flows into the cylinder, so that its temperature remains constant and its volume changes to V_2 from V_1. This expansion is called Isothermal expansion.

PROCESS: 2

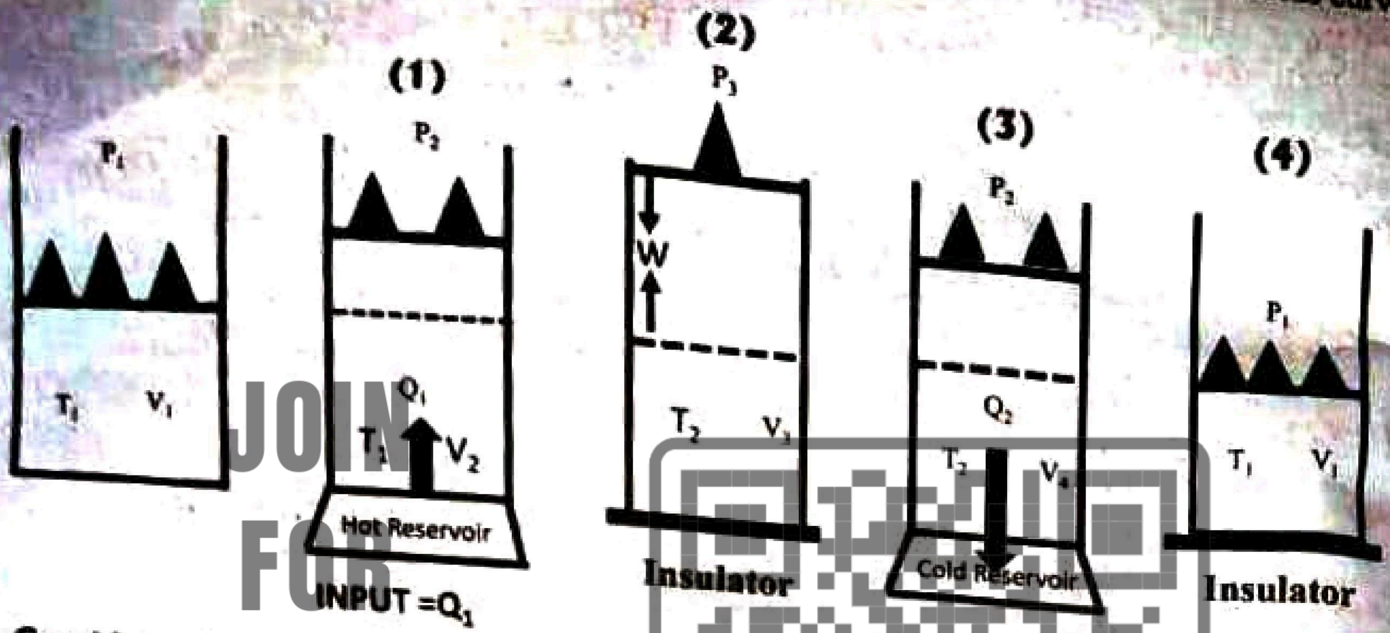
In this process, the cylinder is placed on an insulator and the gas continues to expand a little. Since no heat can enter or leave the system, this expansion is called adiabatic expansion. In this process, the temperature of the gas decreases from T_1 to T_2 and its volume changes to V_3 from V_2

PROCESS: 3

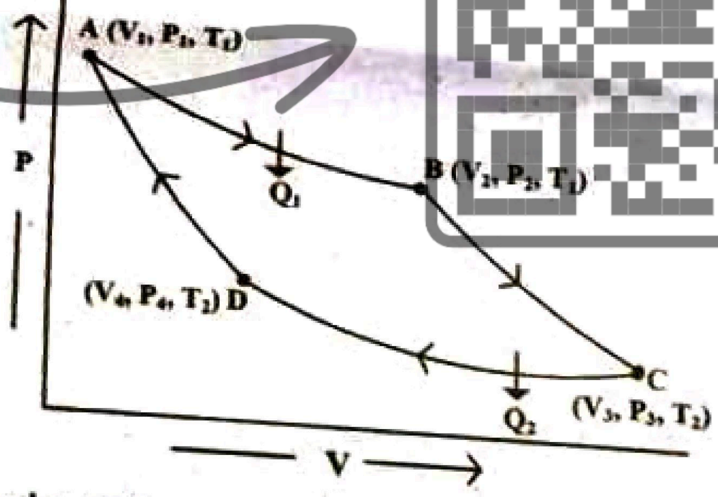
In this process, the cylinder is placed on a cold body at a temperature T_2 and the gas is compressed very slowly by increasing the load on the piston. The temperature of the gas is maintained at T_2 by the transfer of heat Q_2 from the gas to the cold reservoir and its volume changes to V_4 from V_3. This compression is called Isothermal Compression.

PROCESS: 4

In this process, the cylinder is once again placed on the insulator and the gas is compressed until it attains its initial state. In this process, no heat can enter or leave the system, therefore this compression is called adiabatic compression. The temperature of the gas increases from T_2 to T_1 and its volume comes back to V_1 from V_4. If a graph is plotted between the volume and the pressure of Carnot cycle, a loop is obtained. Curves "AB" and "CD" are isothermal whereas curves "BC" and "DA" are adiabatic.



Graphical Representation of Carnot Cycle:



Area bounded by the graph represent work done during the cycle which is

$$\text{Work} = Q_1 - Q_2$$

Efficiency of Engine:

The ratio between output and input is called efficiency. Mathematically it can be written as:

$$\text{Efficiency} = \frac{\text{output}}{\text{Input}}$$

OR

$$\text{Efficiency} = \frac{\text{Workdone}}{\text{Heat absorbed}}$$

Mathematical form:

As Carnot engine operates in a cyclic process, therefore, during the cycle, Q_1 heat is added to the system and Q_2 heat is rejected.

$$\Delta Q = Q_1 - Q_2$$

After the completion of the cycle, the system returns to its initial state, i.e.

$$U_f = U_i$$

$$\Delta U = U_f - U_i$$

OR $\Delta U = 0$

From the first law of thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$

OR $\Delta Q = \Delta W$

OR $\Delta W = Q_1 - Q_2$

The efficiency of a heat engine is given by

$$E = \left(\frac{\text{Output}}{\text{Input}}\right) \times 100$$

OR $E = \frac{W}{Q_1} \times 100$

$$E = \left(\frac{Q_1 - Q_2}{Q_1}\right) \times 100$$

$$E = \left(\frac{Q_1}{Q_1} - \frac{Q_2}{Q_1}\right) \times 100$$

$$E = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$$

Since the heat transferred to or from the Carnot engine is directly proportional to the absolute temperature of the cold and hot bodies, therefore

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

$$E = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

Thus, efficiency of Carnot engine depends only upon the temperature of hot and cold bodies.

Theoretical Limit of Efficiency of Carnot Engine:

In order to obtain 100 % efficiency of Carnot engine, factor $\frac{Q_2}{Q_1}$ in equation

$E = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$ should be zero

$$\frac{Q_2}{Q_1} = 0$$

$$\Rightarrow \quad Q_2 = 0$$

i.e. no heat is transferred to the sink, which is not possible

Also, in equation $E = \left(1 - \frac{T_2}{T_1}\right) \times 100$, for hundred percent efficiency factor $\frac{T_2}{T_1}$ should be zero.

$$\frac{T_2}{T_1} = 0$$

$$\Rightarrow \quad T_2 = 0 \text{ Kelvin}$$

i.e. sink is kept at absolute zero which is not attainable by any means. Hence, the efficiency of ideal heat engine could not be hundred percent or even Carnot engine is not a perfect heat engine.

17.7 ENTROPY:

Entropy of a system is the measure of the molecular disorder. It is also defined as ***the measure of the unavailability of useful energy in the system***. Mathematically, change in entropy is defined as ***the heat transferred to the system at constant absolute temperature***,

$$\Delta S = \frac{\Delta Q}{T}$$

S.I. unit of entropy is JK^{-1}.

The change in entropy is taken as positive when heat is added to the system and negative when heat is removed from the system.

Law of increase of Entropy or Second Law of thermodynamics in terms of entropy:

In any process, molecular disorder of the system either increases or remains constant, which is expressed in the form of a law called **"The law of increase of entropy"** which states that:

"All natural processes always take place in such a direction so as to cause increase in the entropy of the system and surroundings".

The law of increase in entropy is a direct result of the second law of thermodynamics, so the second law can be stated as:

"when an isolated system undergoes a change, the disorder of the system either increases or remains constant".