# UNIT-17 SECOND LAW OF THERMODYNAMICS

## THE SECOND LAW OF THERMODYNAMICS

The second law of thermodynamics is a physical law based on universal empirical observation concerning heat and energy interconversions

There are two statements of this law as follows:

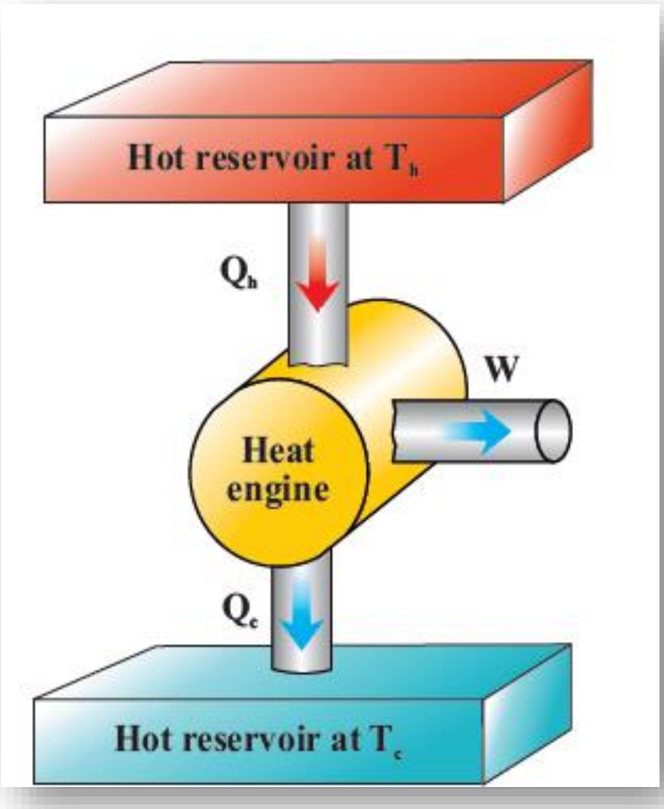
### 1. KELVIN'S STATEMENT

Lord Kelvin gave the following statement of the law as applied to heat engine.

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

### EXPLANATION

According to Kelvin's statement, the heat engine cannot convert all absorbed heat into work when converting heat into mechanical work. A part of energy must be rejected to a cooler reservoir, the exhaust as shown in the figure




A heat engine absorbs heat $Q_h$ from a high temperature or "hot" reservoir. It transforms a portion of the absorbed heat into work **W**, and the rest is given off waste heat, $Q_c$, at a relatively low temperature to the "cold" reservoir. energy conservation can be written as follows

$$W = Q_h - Q_C$$

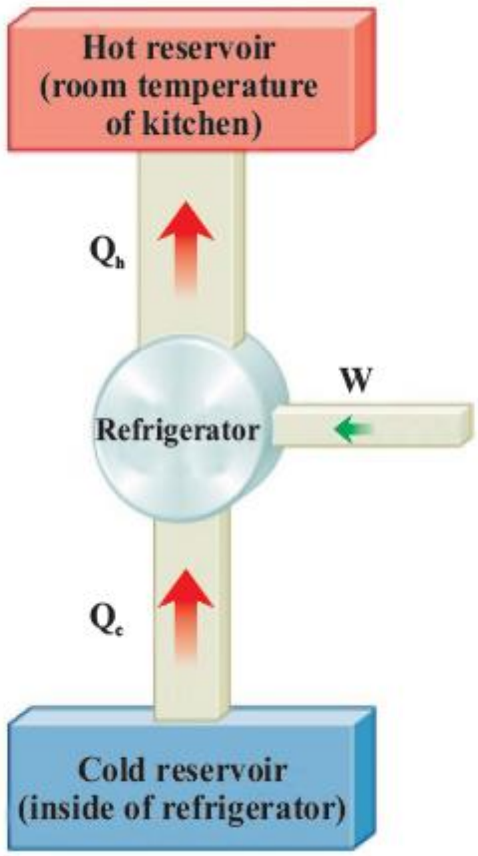
## 2. CLAUSIUS STATEMENT

Clausius gave the following statement of the law that can be applied to a refrigerator.

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

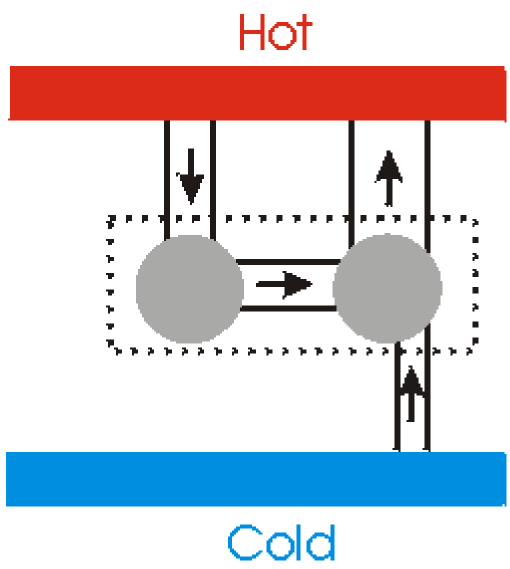
## EXPLANATION

A refrigerator absorb heat from cold body i.e., interior of the refrigerator and reject more heat to hot body i.e., atmosphere. But for this, work is done by electricity. Thus heat flows from cold to hot body by expending energy.




## EQUIVALENCE OF TWO STATEMENT

To show this, let us suppose that Kelvin's statement is incorrect and we can build a perfect engine, which will take heat $Q_H$ from source and change it completely into work (W). This work can be used to derive a real refrigerator, which converts heat from cold body to the hot body. The net result will be a transfer of heat from a cold body to hot body without expenditure of energy. This example shows that a violation of Kelvin's statement implies a violation of Clausius statement.



## WORKING PRINCIPLES OF A HEAT ENGINE

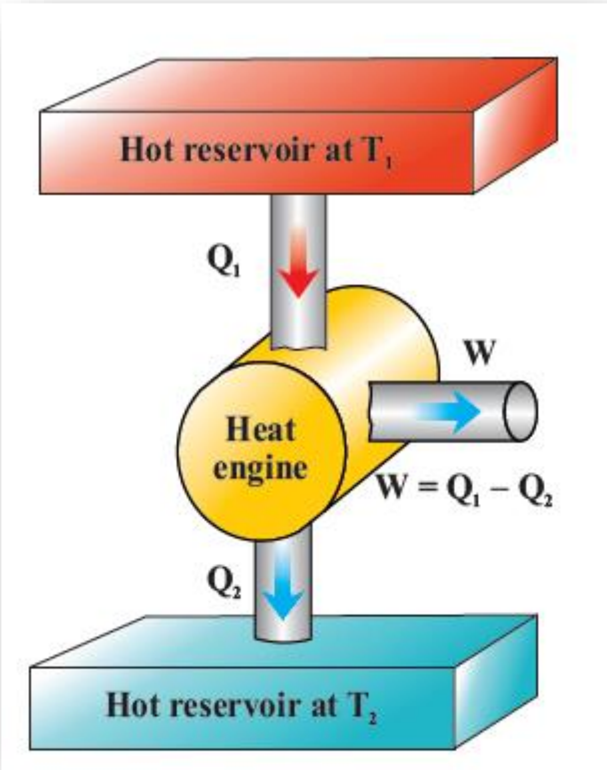
***Any device that transforms heat into mechanical energy (work) is called a heat engine.***

The essentials of a heat engine are the furnace or hot body, the working substance, and a condenser or cold body. In internal combustion engines, the working substance is the mixture of air and burnt fuel; in a steam turbine, it is water. The simplest kind of engine to discuss is one in which the working substance undergoes a cyclic process, that is, a sequence of processes that eventually leaves the substance in the same state in which it started.

The heat engines mentioned absorb heat from a source at a relatively light temperature perform some mechanical works and discard some heat at a low temperature. As far as the engine is concerned the discarded heat is wasted. In internal combustion engines, the waste heat is discarded in the hot exhaust gases and the cooling system in the analysis of heat engines.

We denote the quantities of heat transferred from the hot and cold reservoirs as $Q_1$ and $Q_2$ respectively. Thus, in a heat engine, Q1 is positive but $Q_2$ is negative, representing heat leaving the working substance.

We can represent the energy transformation in a heat engine by the flow diagram, as shown in the figure.




The engine itself is represented by the circle. The amount of heat supplied $Q_1$ to the engine by the hot reservoir is proportional to the cross-section of the incoming pipeline at the top of the diagram. The cross-section of the outgoing of the pipeline at the bottom is proportional to the magnitude $|Q_2|$of the heat discarded in the exhaust.

The branch line to the right represents that the engine converts to mechanical work W.

When an engine repeats the same cycle over and over, $Q_1$ and $Q_2$ represent the quantities of heat absorbed and rejected by the engine during one cycle. The net heat absorbed per cycle is

$$\Delta Q = Q_1 - Q_2$$

Let $Q_1$ be the heat absorbed by an engine from a high-temperature reservoir and $Q_2$ be the heat rejected by the engine to a low-temperature reservoir or sink. The rest of the heat energy is converted into useful work.

$$W = Q_1 - Q_2$$

## *EFFICIENCY OF HEAT ENGINE*

The thermal efficiency 'η' of a cyclic heat engine is defined as the ratio of the network W by the engine in each cycle to heat absorbed $Q_1$ in each cycle.

$$Efficiency(\eta) = \frac{output}{input}$$

$$Efficiency(\eta) = \frac{W}{Q_1}$$

$$Efficiency(\eta) = \frac{Q_1 - Q_2}{Q_1}$$

$$Efficiency(\eta) = \frac{Q_1}{Q_1} - \frac{Q_2}{Q_1}$$

$$Efficiency(\eta) = \left(1 - \frac{Q_2}{Q_1}\right)$$

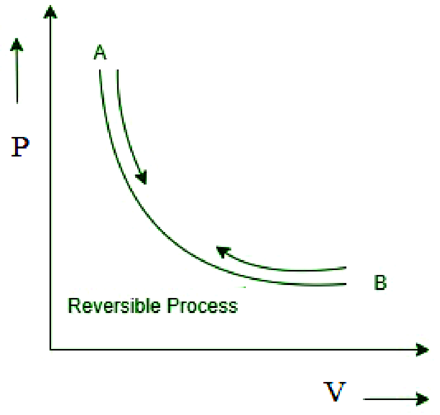
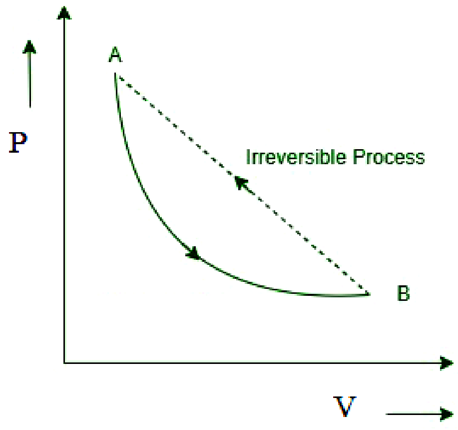
***For 100% efficiency $Q_2$ = 0 i.e. no heat is rejected to a low-temperature reservoir (sink) and the whole heat absorbed is converted into work. However experimental facts show that no cyclic engine can achieve an efficiency of 100%.***

## REVERSIBLE PROCESS

***A reversible process can be retraced in exactly reverse order, without producing any change in the surrounding***

## IRREVERSIBLE PROCESS

***The process cannot be retraced in a backward direction by reversing the controlling factors in known as an irreversible process***

| S.No | REVERSIBLE PROCESS | IRREVERSIBLE PROCESS |
|---|---|---|
| 1 | A reversible process is a change that can be retraced in a reverse (opposite) direction | An irreversible process is a change that cannot be retraced in a reverse (opposite) direction |
| 2 | The path of a reversible process is the same in the forward and reversed direction | The path of an irreversible process is not the same in the forward and reversed direction |
| 3 |   |   |
| 4 | Reversible changes are very low and there is no loss of any energy in the process | There is a permanent loss of energy from the system due to friction or other dissipative forces in an irreversible process |
| 5 | Working substance restored to its original conditions | Working substance does not restore to its original conditions |
| 6 | Reversible processes are ideal processes | Irreversible processes are real processes |

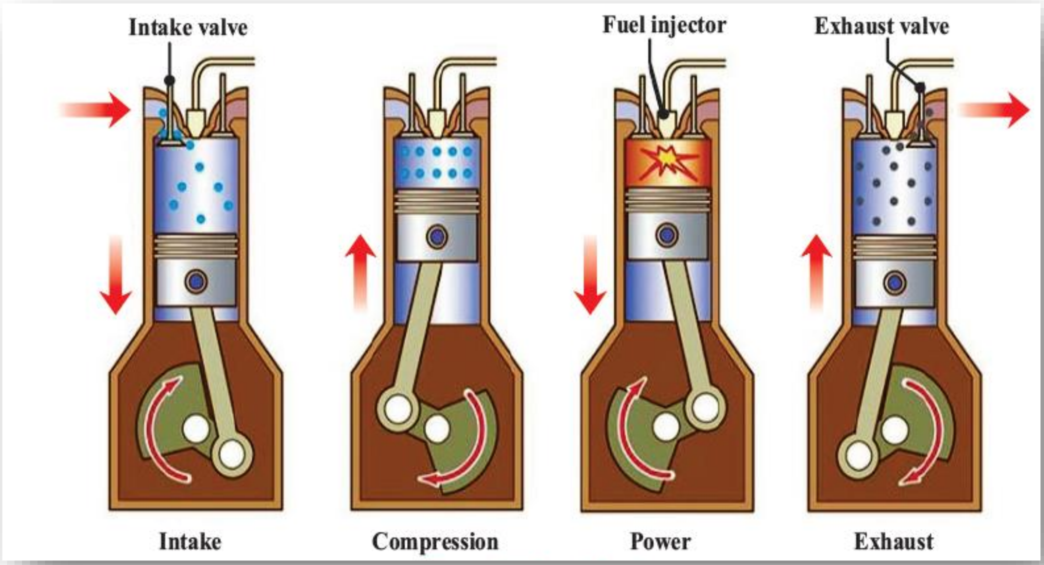
## PETROL ENGINE

A petrol engine is an internal combustion engine designed to run on volatile fuel such as petrol (gasoline), which has sparked imagination. In these engines air and fuel are generally mixed post-compression.

It works on the Otto cycle and the name comes from the German engineer Nicolas Otto, who made the first working prototype. All engines are based on the principle of the Carnot cycle.

A typical four-stroke petrol engine as shown in figure. also undergoes four successive processes in each cycle.

1. *The cycle starts on the intake stroke in which the piston moves outward and the petrol air mixture is drawn through an Intel valve into the cylinder from the carburetor at atmospheric pressure*.
2. *On the compression stroke, the Intel valve is closed and the mixture is compressed adiabatically by inward movement of the piston.*

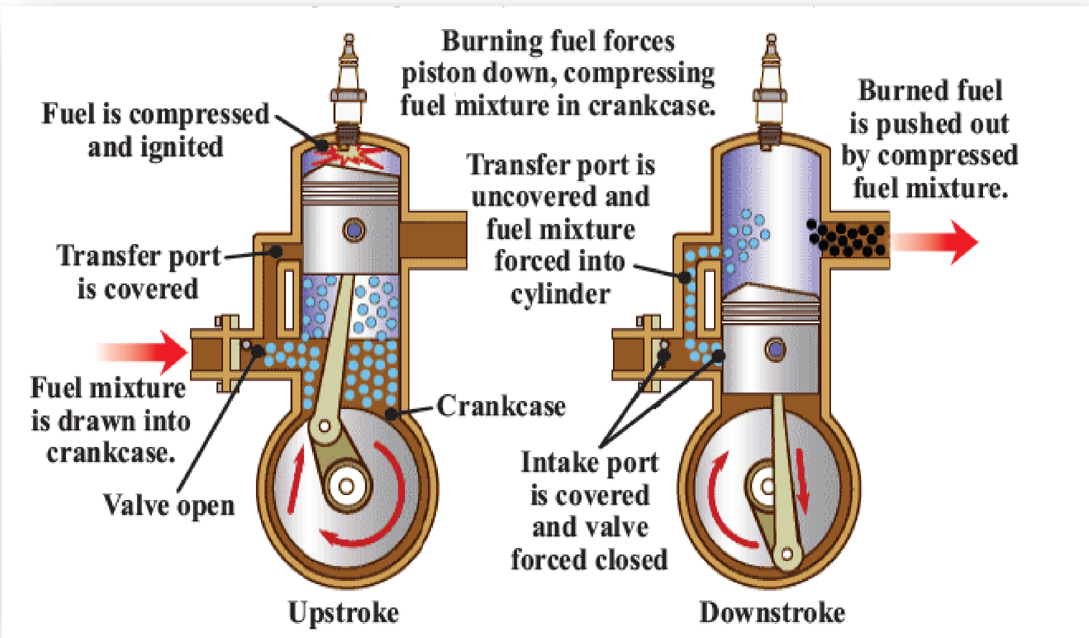



3. On the power stroke, a spark fires the mixture causing a rapid increase in pressure and temperature. The burning mixture expands adiabatically and forces the piston to move outward. This is the stroke which delivers power to the crankshaft to drive the flywheels.

4. On the exhaust stroke, the outlet valves open. The residual gases are expelled and the piston moves inward. The cycle then begins again. The cylinders are timed to fire turn by turn in succession for a smooth running of the car. ***The actual efficiency of the properly tuned engine is usually not more than 25% to 30% because of friction and other heat losses.***

**DIESEL ENGINE**

The diesel engine was named after Rudolf Diesel (German inventor and Mechanical Engineer). When the fuel comes into contact with high temperature, it ignites, creating energy that drives the piston down transferring energy to the crankshaft. There are two classes of diesel engines: two strokes and four strokes. Most diesel engines generally use the four-stroke cycle.



No spark plug is needed in the diesel engine. Diesel is sprayed into the cylinder at maximum compression. Because air is at a very high temperature immediately after compression, the fuel mixture ignites on contact with air in the cylinder and pushes the piston outward. The efficiency of diesel engines is about 35% to 40%.

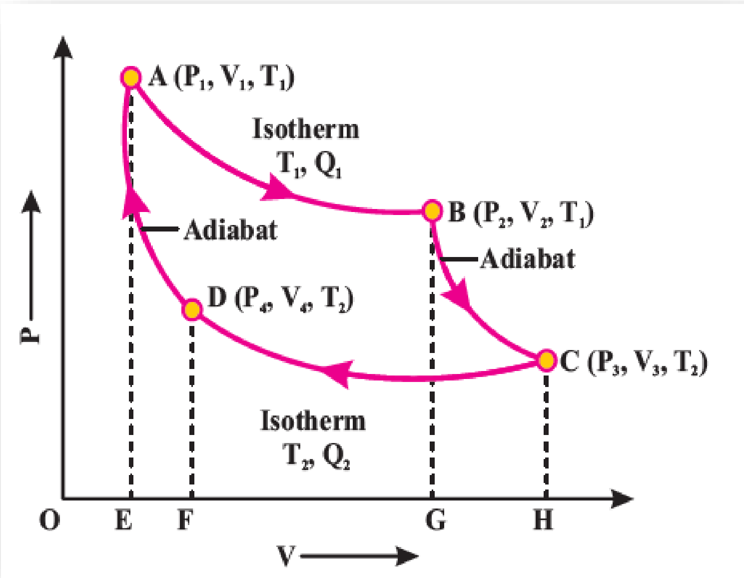
## THE CARNOT'S ENGINE

A French engineer and scientist ***SADI CARNOT*** proposed the concept of an ideal engine in 1824. Carnot's engine has a maximum efficiency and no actual engine can be so efficient. Carnot's theorem can be stated as follows

**No real engine operating two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs**.

## CONSTRUCTION

**The system consists of a cylinder having perfectly non-conducting walls and perfectly conducting base fitted with a non-conducting, frictionless moveable piston. Cylinder contains a perfect gas a working substance. A hot body temperature '$T_H$' and a cold body temperature '$T_c$' both of large heat capacity are used as a source and sink respectively**




## THE CARNOT'S CYCLE

The Carnot engine operating cycle consists of four processes, two isothermal and two adiabatic.

## STEP I *(ISOTHERMAL EXPANSION)*

*In Process A→B (from fig) is an isothermal expansion at temperature $T_1$. The gas cylinder is placed in thermal contact with an energy reservoir at temperature '$T_1$'. During the expansion, we decrease the load on the piston, the gas absorbs energy $Q_1$ from the source through the base of the cylinder and does work $W_{AB}$ in raising the piston.*

## STEP II *(ADIABATIC EXPANSION)*

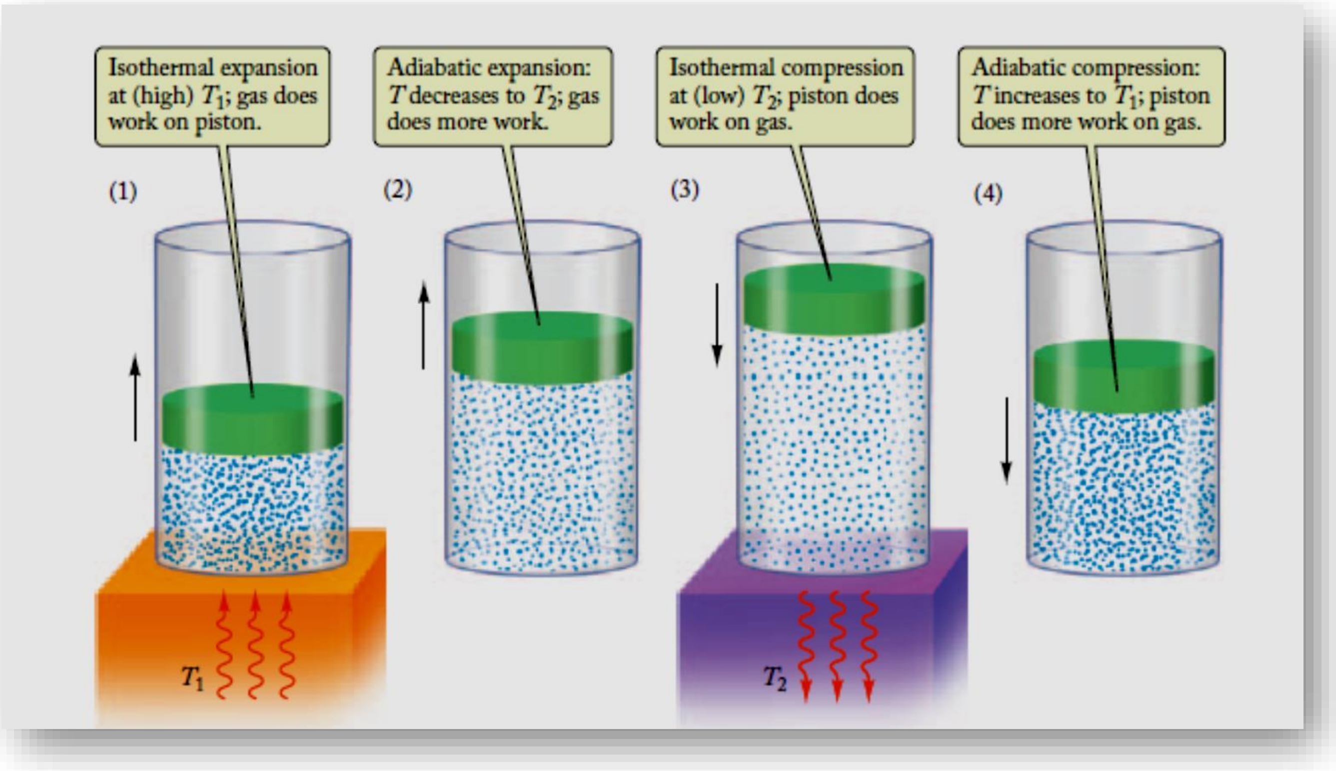
*In process B→C (from fig) base of the cylinder is replaced by thermally no conducting wall, and the gas expands adiabatically due to a decrease in load on the piston, that is, no energy enters or leaves the system. During the expansion, the temperature of the gas decreases from $T_1$ to $T_2$ and the gas does work $W_{BC}$ in raising the piston.*

**STEP III** *(ISOTHERMAL COMPRESSION)*

*In process C→D (from fig), the gas cylinder is placed in thermal contact with an energy reservoir at temperature **$T_2$** and is compressed isothermally at temperature **$T_2$**, By increasing the load on the piston. During this time the gas expels energy **$Q_2$** to the sink, and the work done by the piston on the gas is **$W_{CD}$**.*

**STEP IV** *(ADIABATIC COMPRESSION)*

**In the final process D→A, the base of the cylinder is replaced by a non conducting wall, and the gas is compressed adiabatically, by increasing the load on the piston. The temperature of the gas increases to $T_1$, and the work done by the piston on the gas is $W_{DA}$.**




## EFFICIENCY OF CARNOT ENGINE

**DEFINITION**

**The thermal efficiency of the heat engine is the ratio of its output to the input i.e.,**

$$Efficiency = \frac{output}{input}$$

**FORMULA**

The total work W is done in one complete cycle equal to the net energy transferred into the system, $Q_1 - Q_2$ the thermal efficiency of the engine is given by the above equation.

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

Now, $$W = Q_1 - Q_2$$

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

$$\eta = \left(\frac{Q_1}{Q_1} - \frac{Q_2}{Q_2}\right)$$

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right)$$

The above equation shows that the efficiency of the engine increases as the ratio $\frac{Q_2}{Q_1}$ decreases. It can also be proved that the heat transferred to or from a Carnot engine is directly proportional to the temperature of the hot or cold body

i.e.,

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

$$\eta = \left(1 - \frac{T_2}{T_1}\right)$$

The efficiency is usually taken in percentage, in that case

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

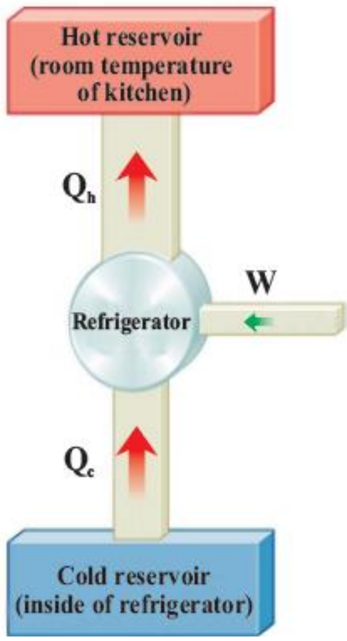
Thus, the efficiency of the Carnot engine depends on the temperature of the hot and cold reservoir at absolute zero temperature ($T_2$= 0 k).

Such reservoirs are not available and hence the maximum efficiency is always less than one.

No Practical heat engine can be perfectly reversible and also energy dissipation is inevitable. This fact is stated Carnot's theorem.

***"No heat engine can be more efficient than a Carnot engine operating between the same two temperatures".***

Carnot's theorem can be extended to state that "all Carnot's engines operating between the same two temperatures have the same efficiency, irrespective of the nature of working substance". All real engines are less efficient than Carnot engines due to friction and other heat losses.



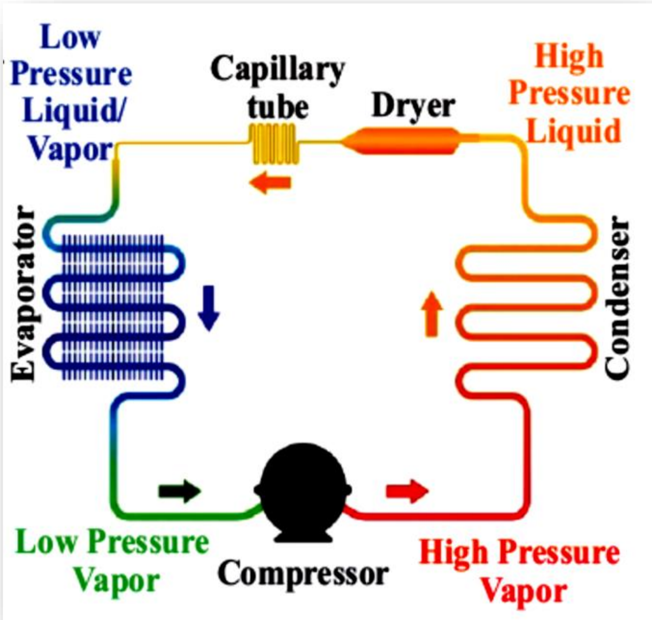

## REFRIGERATOR

In a refrigerator or heat pump, the engine takes in energy $|Q_C|$ from the cold reservoir and expels energy $|Q_1|$ to a hot reservoir as shown in Fig:, which can be accomplished only if work is done on the engine. From the first law of thermodynamics, we know that the energy given up to the hot reservoir must equal to sum of the work done and the energy taken in the form of the work done and the energy taken in the form of the cold reservoir.

$$Q_1 = W + Q_C$$

*Therefore, the refrigerator transfers energy from a colder body to a hotter body.*

In Practice, a refrigerator includes a circulating fluid that gases through two sets of metal coils that can exchange energy with the surroundings. The fluid is cold and at low pressure when it is in the coils located in a cool environment, where it absorbs energy by heat. The resulting warm fluid is then compressed and enters the other coils as a hot, high-pressure fluid. There it releases its stored energy to the warm surroundings. In a refrigerator, the external coils are behind or underneath the unit as shown in figure, the internal coils are in the walls of the refrigerator and absorb energy from the food.




## EFFICIENCY OF A REFRIGERATOR

The effectiveness of a refrigerator is described in terms of a number called the coefficient of performance (COP).

The Coefficient of performance of a refrigerator is defined as

***The heat removed from the cold reservoir $Q_C$ (i.e. inside the refrigerator) is divided by the work done w to remove the heat( i.e. the work done by the compressor).***

$$\text{coefficient of performance of refrigerator} = \frac{\text{heat extracted}}{\text{work}}$$

$$\text{coefficient of performance of refrigerator} = \frac{Q_C}{W}$$

$$\text{coefficient of performance } (K_R) = \frac{Q_C}{W}$$

$$\text{coefficient of performance } (K_R) = \frac{Q_C}{Q_h - Q_C}$$

We know that for Carnot cycle $Q_1 \ \alpha \ T_1 \ \ and \ \ Q_2 \ \alpha \ T_2$

**coefficient of performance ($K_R$)** $= \dfrac{T_C}{T_h - T_C}$

*$T_C$ is the cryogenic temperature at which the heat is removed*
*$T_h$ is the cryogenic temperature at which the heat is rejected*

*It can also be seen from above relations that the coefficient of performance of refrigerator can be larger than 100% unlike the efficiency of heat engine which is always less than 100%. A good refrigerator should have a high COP, typically 5 or 6.*

## ENTROPY

**Entropy is a macroscopic state variable which describes the unavailability of the energy or disorder ness in a system.**

## DEFINITION

**In a thermal process the change in entropy (ΔS) of a system is the ratio of heat added to or removed from the system to its absolute temperature T.**

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

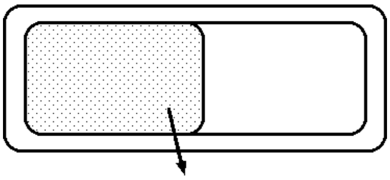
## UNIT

**SI unit of entropy is $JK^{-1}$**

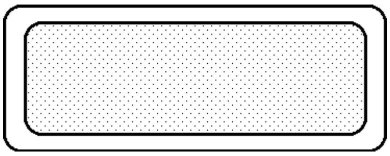
## SIGN CONVENTION

*When heat is added to a system(Q>0) the entropy of system increases*
*When heat is removed from a system( Q<0 ), its entropy decreases*

### *ENTROPY AND DISORDERS*




Consider the large number of gas molecules in an insulated container with a removable partition. Let $V_1 = V$.



When partition is removed the molecule will occupy $V_2 = 2V$. Now the molecules are less localized i.e., the disorder has increased.

## EXPLANATION

Entropy change ΔS during a reversible isothermal process as

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

Change in entropy is positive when heat is added and negative when heat is removed from the system. Suppose an amount of heat $Q$ flows from a reservoir at temperature $T_2$ when $T_1 > T_2$. The change in entropy of the reservoir at temperature $T_1$, which loses heat, decreases by $\frac{Q}{T_1}$, and of the reservoir at temperature $T_2$ which gains heat increases by $\frac{Q}{T_2}$. As

$T_1 > T_2$ so $\frac{Q}{T_2}$ will be greater than $\frac{Q}{T_1}$. i.e. $\frac{Q}{T_2} > \frac{Q}{T_1}$. Hence, net change in entropy = $\Delta S = \frac{Q}{T_2} - \frac{Q}{T_1}$ is positive. It follows that in all natural processes where heat flows from one system to another, there is always a net increase in entropy.

**ENTROPY AND THE SECOND LAW OF THERMODYNAMICS**

**In terms of disorder, the second law can be stated as:**
**The entropy of the universe during any change, the disorder of a system either remains constant or increases.**

**Since the disorder is related to entropy therefore second law will be:**
**When an isolated system changes the entropy of the system either remains constant or increases.**

## INCREASE IN ENTROPY MEANS DEGRADATION OF ENERGY

Suppose a quantity of heat Q in a reservoir at temperature $T_1$. Let the temperature of the coldest available reservoir be $T_0$. A Carnot engine working between the temperatures $T_1$ and $T_o$ can absorb heat Q at temperature $T_1$ and do useful work $W_1$ given by:

$$W_1 = Q - Q_0$$

**The efficiency of Carnot engine is:**

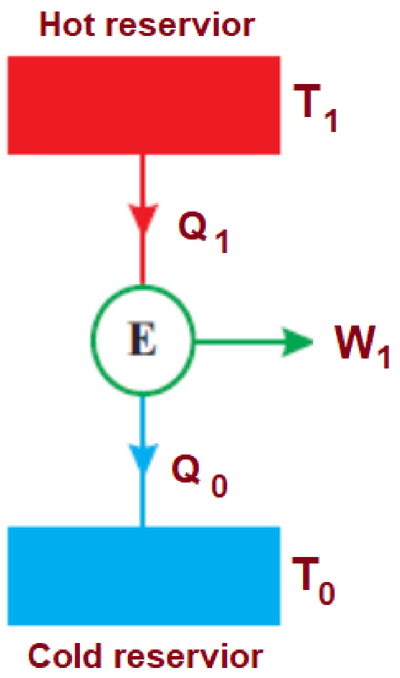
$$\eta = \frac{W_1}{Q}$$

$$\left(1 - \frac{T_0}{T_1}\right) = \frac{W_1}{Q}$$

$$\left(1 - \frac{T_0}{T_1}\right) Q = W_1$$

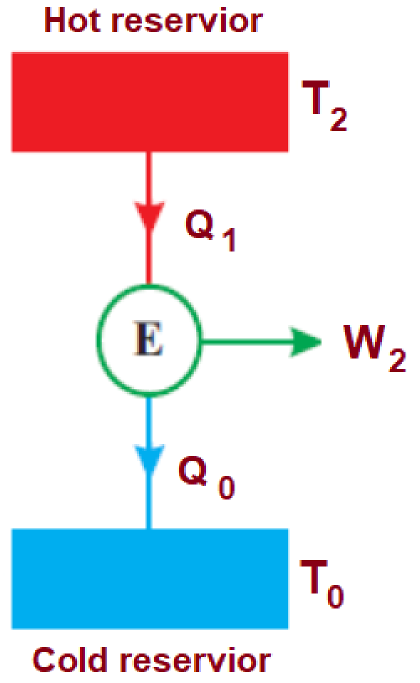
$$W_1 = Q\left(1 - \frac{T_0}{T_1}\right) \ldots\ldots\ldots (i)$$

Equation (i) gives the maximum available energy which can be converted into useful work.




Consider an irreversible process, in which heat Q in a reservoir at temperature $T_2$ $(T_2 < T_1)$. Let the temperature of the coldest available reservoir be $T_0$. A Carnot engine working between the temperatures $T_2$ and $T_o$ can absorb heat Q at temperature $T_2$ and do useful work $W_2$ given by:

**The efficiency of Carnot engine is:**




$$\eta = \frac{W_2}{Q}$$

$$\left(1 - \frac{T_0}{T_2}\right) = \frac{W_2}{Q}$$

$$\left(1 - \frac{T_0}{T_2}\right) Q = W_2$$

$$W_2 = Q\left(1 - \frac{T_0}{T_2}\right) \ldots\ldots\ldots..(ii)$$

Equation (ii) gives the maximum available energy which can be converted into useful work. When heat Q is stored in the reservoir at a lower temperature $T_2$.

All natural processes are irreversible, we conclude that the energy of the universe is continuously becoming unavailable for useful work. This is called the degradation of energy. From the equation (i) and (ii), we get

$$W_1 - W_2 = Q\left(1 - \frac{T_0}{T_1}\right) - Q\left(1 - \frac{T_0}{T_2}\right)$$

$$W_1 - W_2 = Q\left(1 - \frac{T_0}{T_1} - 1 + \frac{T_0}{T_2}\right)$$

$$W_1 - W_2 = Q\left(\frac{T_0}{T_2} - \frac{T_0}{T_1}\right)$$

$$W_1 - W_2 = \left(\frac{Q}{T_2} - \frac{Q}{T_1}\right) T_0$$

Thus $\left(\frac{Q}{T_2} - \frac{Q}{T_1}\right)$ is an increase in the entropy of the universe. Also **($W_1 - W_2$)** is the amount of energy degraded or made available for useful work.

## ENERGY IS DEGRADED DURING ALL-NATURAL PROCESS

It is believed that the temperature of the universe is increasing gradually and its entropy is also increasing. The mode of increase of entropy indicates that after a very long time, the entropy of the universe will be maximum and all the objects will be at the same temperature. At that time, no useful energy will be available and life will cease to exist, which is known as the "**Heat Death**" of the universe, which may not occur in near future.

It seems to be a law of nature that all natural processes always take place in such a direction to cause an increase in the entropy of a system and its surroundings.

Thus the 2nd law of thermodynamics is also expressed as the "Law of increase of entropy".

It states that "**when all the systems taking part in a process are included", the entropy either remains constant or increases**".

Symbolically, $\Delta S \geq 0$

## IDENTIFICATION OF A SYSTEM TENDS TO BECOME LESS ORDERLY OVER TIME

The disorder of the system increases during any natural process.

The time arrow concept of entropy tells us in which direction the time is going. It is the change in entropy that ultimately provides us with the answer to why systems will naturally evolve in one direction with time and not the other. Systems always evolve in time in such a way that the total entropy of the system plus the environment increases. If you observe a system in which the entropy appears to decrease, you can be sure that somewhere there is a change in the entropy of the environment large enough to make the total entropy change positive. Entropy has been called a "**time arrow**: i.e. events occur in the direction of increasing disorder with time.

In all the processes going on in practical life, the entropy always increases with time, and disorder is produced more and more. Hence this increase in entropy is identification for the time passage.

# SHORT REASONING QUESTIONS

### 1. What are some factors that affect the efficiency of automobile engines?

Ans The efficiency of an automobile engine can be influenced by several factors, including:

1. **Engine Design**:
   **Type of Engine**: Different engine types (e.g., gasoline, diesel, hybrid, electric) have varying efficiencies.
   **Engine Size**: Smaller engines typically have better thermal efficiency but may lack power compared to larger engines.
2. **Fuel Type**:
   Different fuels have different energy contents and combustion properties. For instance, diesel fuel generally provides more energy per liter than gasoline.
3. **Air-Fuel Ratio**:
   The optimal mixture of air and fuel is crucial for efficient combustion. A lean mixture (more air) can improve efficiency, while a rich mixture (more fuel) can lead to wasted fuel.
4. **Combustion Process**:
   the combustion process, specifically the air-fuel mixture. Achieving the optimal air-fuel ratio is crucial for efficient combustion.
   - **Ignition Timing**: Proper timing of the ignition can maximize the power produced from the fuel.
5. **Engine Temperature**:
   Operating at the right temperature can enhance efficiency. Engines that run

too cold may not combust fuel completely, while those that run too hot can suffer from pre-ignition.

6. **Mechanical Losses**:
 Friction between moving parts, such as pistons and crankshafts, can reduce efficiency. Using advanced materials and lubricants can help minimize these losses.
7. **Aerodynamics**:
 The vehicle's design affects air resistance. A more aerodynamic shape reduces drag, allowing the engine to operate more efficiently at higher speeds.
8. **Weight of the Vehicle**:
 Heavier vehicles require more energy to move. Reducing weight through the use of lighter materials can improve overall efficiency.
9. **Maintenance**:
 Regular maintenance, including oil changes, air filter replacements, and spark plug checks, can keep the engine running efficiently.
10. **Driving Conditions**:
 Stop-and-go traffic, highway driving, and terrain (hills vs. flat) can all affect engine performance and efficiency.

**2 What happens to the room temperature in which an air conditioner is left running on the table in the middle of the room?**

Ans When an air conditioner is placed on a table in the middle of the room is left running in a room, it will actively cool the air in that space as well as reject heat to the room. Thus, no change in room temperature will take place.

When the air conditioner is kept running for longer period, then some heat produced due to compressor, so the temperature of the room may increased slightly.

**3 Describe the concept of a reversible and irreversible process**

Ans A thermodynamic process is reversible if the process can return back in such a that both the system and the surroundings return to their original states, with no other change anywhere else in the universe. It means both system and surroundings are returned to their initial states at the end of the reverse process. In contrast, an irreversible process cannot return both the system and its environment to their initial states, reflecting the natural processes commonly found in nature. Reversible processes are theoretical constructs that typically do not occur in real-life scenarios, while irreversible processes reflect real-world behavior.

4 What is the Carnot engine? Give the operation of the Carnot cycle and show that the efficiency of even this engine is less than 100%.

Ans A Carnot heat engine is a theoretical engine that operates on a reversible Carnot cycle. A Carnot engine operating between two given temperatures has the greatest possible efficiency of any heat engine operating between these two temperatures.

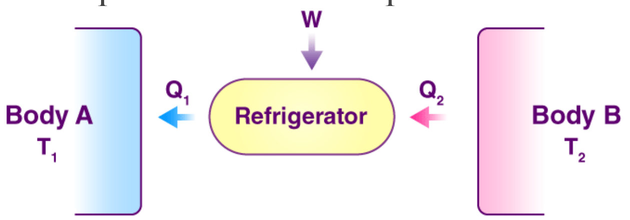
the efficiency of Carnot engines. It consists of four reversible processes: two isothermal (constant temperature) processes and two adiabatic (no heat transfer). For a process to be adiabatic, it should occur so fast that the molecules don't get a chance to transfer heat, similarly for the process to be isothermal, it should be undergoing so slowly that the temperature is uniform throughout and no variations occur, whatsoever. Since both the mentioned cases are physically impossible, the efficiency of Carnot cycles cannot be 1.

In cyclic processes friction is the major contributor to the reduction of efficiency and some amount of heat should always be rejected, it is not possible to get a 100 % efficiency.

5 **Describe that refrigerator is a heat engine operating in reverse as that of an ideal heat engine and find its efficiency**.

Ans A refrigerator functions by transferring heat from a cold reservoir (inside the fridge) to a hot reservoir (the environment). This process is the reverse of an ideal heat engine, which converts heat from a hot reservoir into work and expels some heat to a cold reservoir.

A refrigerator takes out heat from a lower temperature $\mathbf{T_2}$ and releases it to a higher temperature $\mathbf{T_1}$. For this process to occur, work must be done on the system. Below is the schematic representation of the process:




## EFFICIENCY OF A REFRIGERATOR

The effectiveness of a refrigerator is described in terms of a number called the coefficient of performance (COP).

The Coefficient of performance of a refrigerator is defined as

The heat removed from the cold reservoir $Q_C$ (i.e. inside the refrigerator) is divided by the work done w to remove the heat ( i.e. the work done by the compressor).

$$\text{coefficient of performance of refrigerator} = \frac{\text{heat extracted}}{\text{work}}$$

$$\text{coefficient of performance of refrigerator} = \frac{Q_C}{W}$$

$$\text{coefficient of performance } (K_R) = \frac{Q_C}{W}$$

$$\text{coefficient of performance } (K_R) = \frac{Q_C}{Q_h - Q_C}$$

We know that for Carnot cycle $Q_1 \ \alpha \ T_1$ *and* $Q_2 \ \alpha \ T_2$

$$\text{coefficient of performance } (K_R) = \frac{T_C}{T_h - T_C}$$

***$T_C$ is the cryogenic temperature at which the heat is removed***

***$T_h$ is the cryogenic temperature at which the heat is rejected***

*It can also be seen from the above relations that the coefficient of performance of a refrigerator can be larger than 100%, unlike the efficiency of a heat engine which is always less than 100%. A good refrigerator should have a high COP, typically 5 or 6.*

6 Explain that change in entropy is positive when heat is added and negative when heat is removed from the system.

Ans Entropy is a measure of the disorder or randomness of a system, and it is a fundamental concept in thermodynamics.

**Change in Entropy When Heat is Added**

When heat is added to a system from a heat reservoir, the energy of the system increases. This influx of heat increases the motion of the molecules, causing them to move more vigorously and resulting in a higher degree of disorder (or randomness) within the system.

Mathematically, the change in entropy can be expressed as:

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

Since ΔQ is positive when heat is added, and assuming the temperature T is also positive, the change in entropy ΔSΔS will also be positive.

### Change in Entropy When Heat is Removed

When heat is removed from the system, the energy content of the system decreases. This results in a reduction in molecular motion and a correspondence decrease in the system's randomness or disorder.

In this case, the change in entropy can again be expressed by the same formula:

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

However, because heat is being removed from the system, ΔQ is negative.

Thus, the change in entropy ΔS will be negative. The removal of heat from the system decreases its entropy, indicating a decrease in disorder

### 7 Explain that an increase in entropy means degradation of energy

Ans Entropy is a measure of the energy of a system that is unavailable for doing useful work. An increase in entropy of a system leads to an increase in randomness and degradation of energy.

When energy is converted from one form to another (e.g., from thermal energy to mechanical work in a heat engine), some of it becomes dispersed or "lost" due to irreversibility in the process. This is often associated with an increase in entropy.

For example, when a hot object cools down to its surroundings, the thermal energy that was once highly concentrated in the hot object becomes distributed throughout the cooler surroundings, increasing the overall entropy of the system. The once usable energy (the thermal energy of the hot object) has degraded in quality.

As entropy increases, the energy becomes less available to do work. The process of energy transformation is often inefficient due to friction, heat loss, and other dissipative factors that contribute to entropy increase and energy degradation.