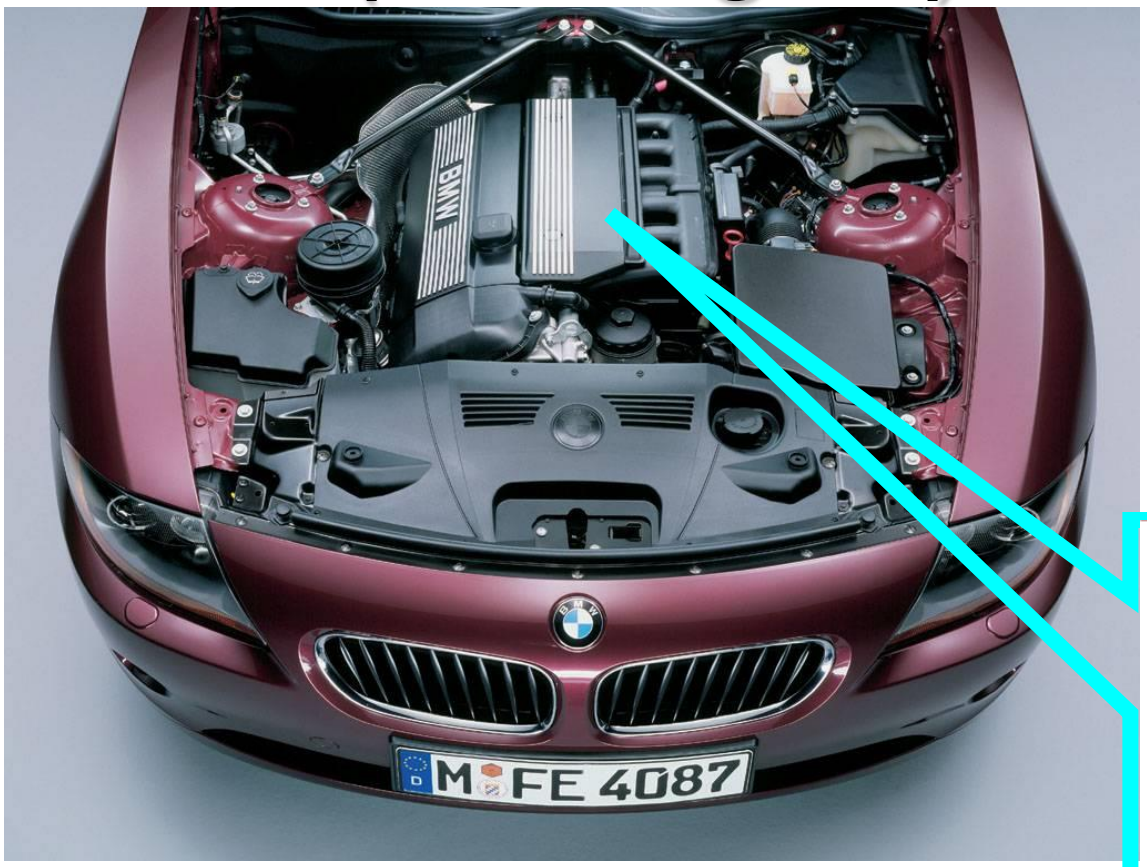
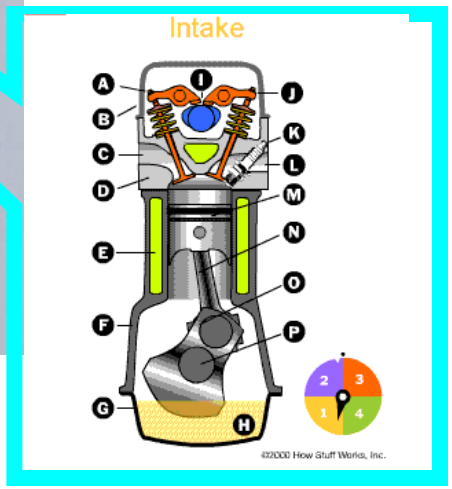
Internal Combustion Engine. (I C Engine)





Heat Engine

A heat engine is a prime mover which derives the heat energy from the combustion of fuels and converts this energy into mechanical work.

1. External Combustion Engines (E.C. Engines)

Combustion of fuel takes place ***outside the engine cylinder***.

Example: Steam Engine,

2. Internal Combustion Engines (I.C. Engines)

Combustion of fuel takes place ***inside the engine cylinder***.

Example: Petrol Engine, Diesel Engine, etc.

Comparison between External combustion engine and internal combustion engine:

	External combustion engine	Internal combustion engine
1	Combustion of air-fuel is outside the engine cylinder (in a boiler)	Combustion of air-fuel is inside the engine cylinder (in a boiler)
2	The engines are running smoothly and silently due to outside combustion	Very noisy operated engine
3	Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome.	It is light and compact due to lower ratio of weight and bulk to output.
4	Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts.	Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used
5	It can use cheaper fuels including solid fuels	High grade fuels are used with proper filtration
6	Lower efficiency about 15-20%	Higher efficiency about 35-40%
7	Higher requirement of water for dissipation of energy through cooling system	Lesser requirement of water
8	High starting torque	IC engines are not self-starting

I. C. Engine

The internal combustion (I.C) engine is a heat engine that converts heat energy derived from the combustion of the fuel into mechanical energy which is available on a rotating output shaft.

Classification of I C Engines

According to:

(i) Nature of Thermodynamic Cycle :

1. Otto cycle engine.
2. Diesel cycle engine.

(ii) Type of the Fuel- used :

1. Petrol engine.
2. Diesel engine.
3. Gas engine.
4. Bi-fuel Engine
5. Dual Fuel Engine

Classification of I C Engines

(iii) Number of Strokes :

1. Two stroke engine
2. Four stroke engine

(iv) Method of Ignition:

1. Spark ignition engine (S.I. Engine).
2. Compression ignition engine (C.I. engine).

(v) Number of Cylinders:

1. Single cylinder engine.
2. Multi cylinder engine.

Classification of I C Engines

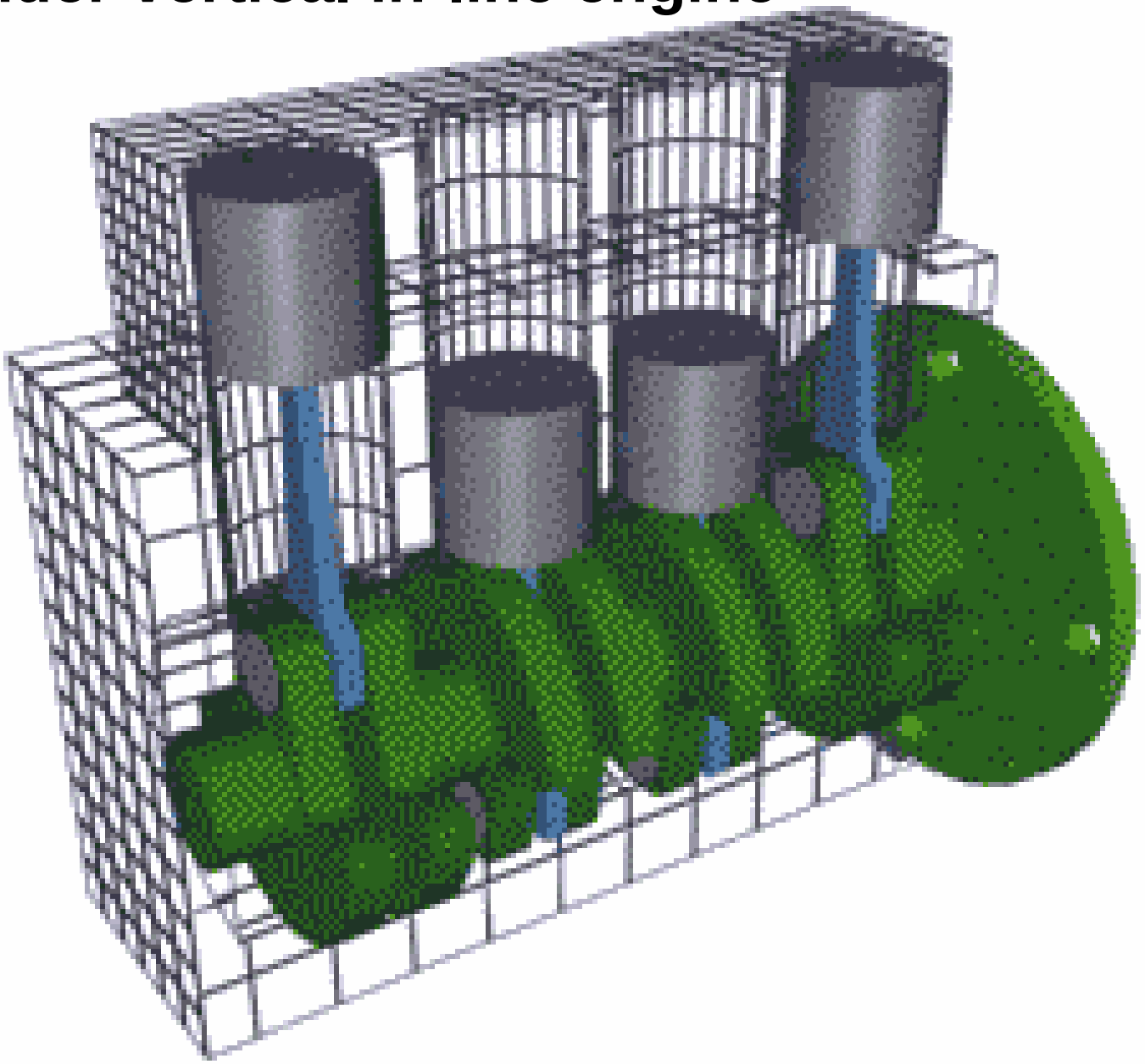
(vi) Position of the Cylinder:

1. Horizontal engine
2. Vertical engine
3. V- engine
4. In-line engine
5. Opposed cylinder engine
6. Radial engine

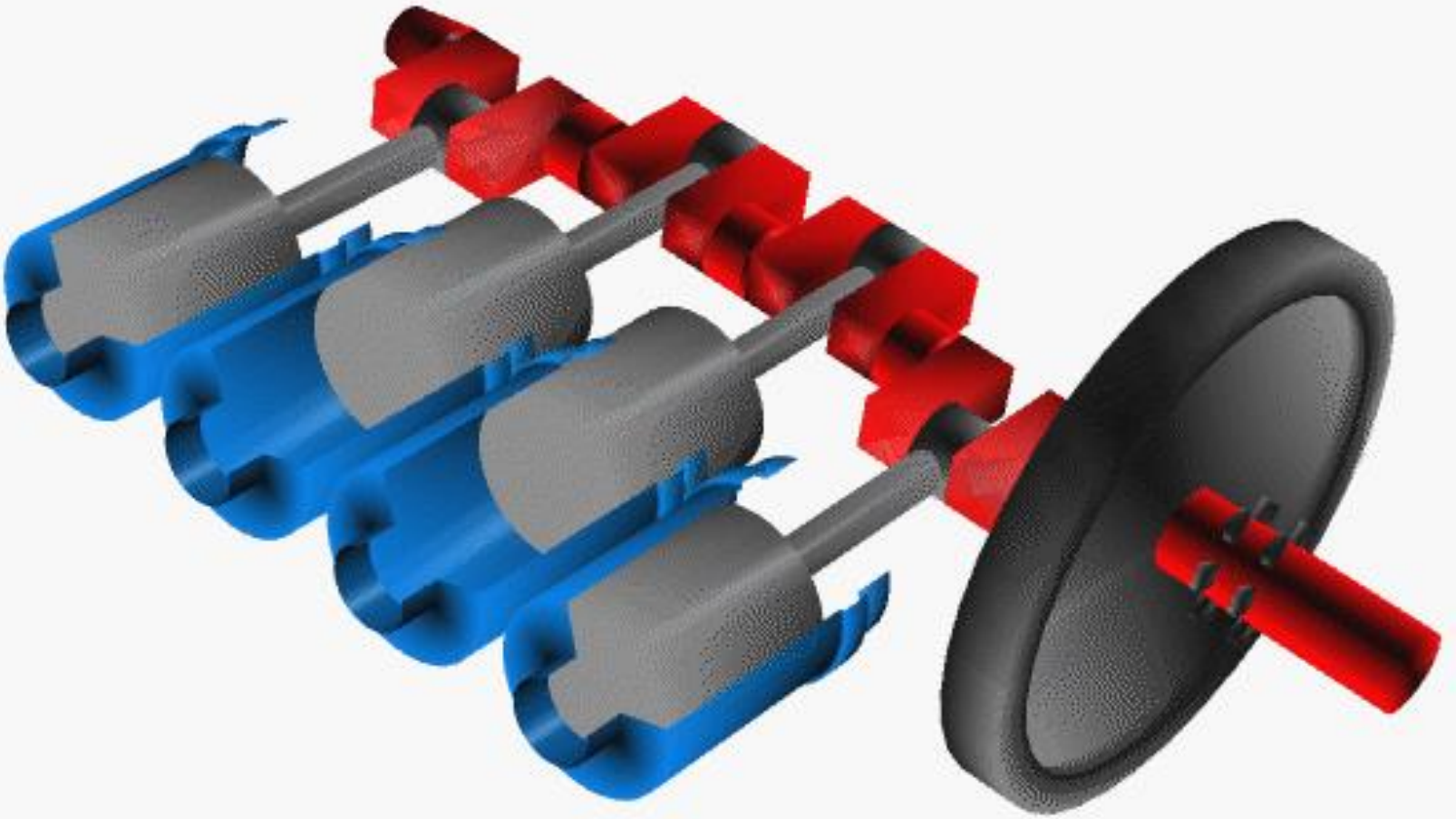
(vii) Method of Cooling:

1. Air cooled engine.
2. Water cooled engine

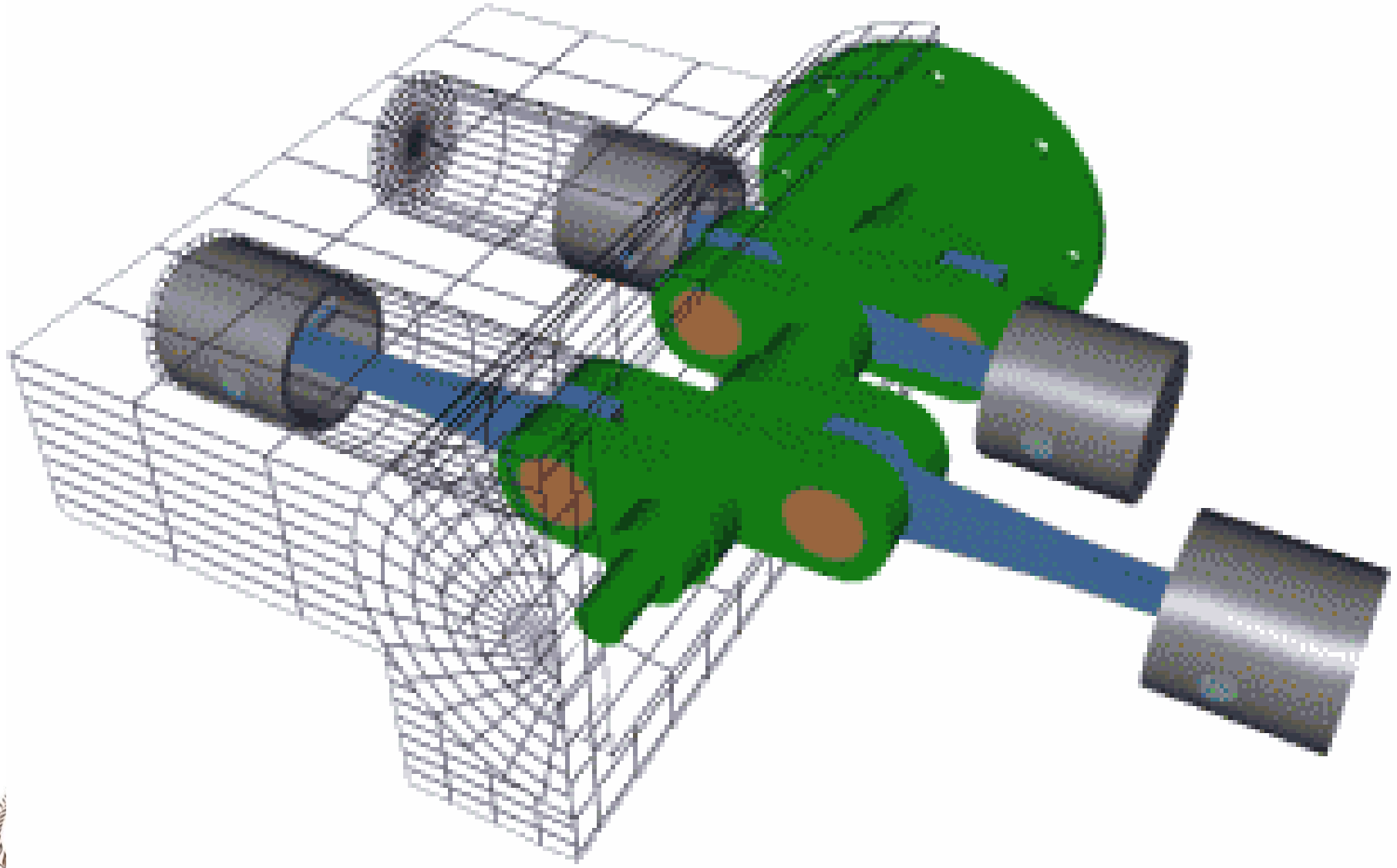
4 cylinder vertical in-line engine



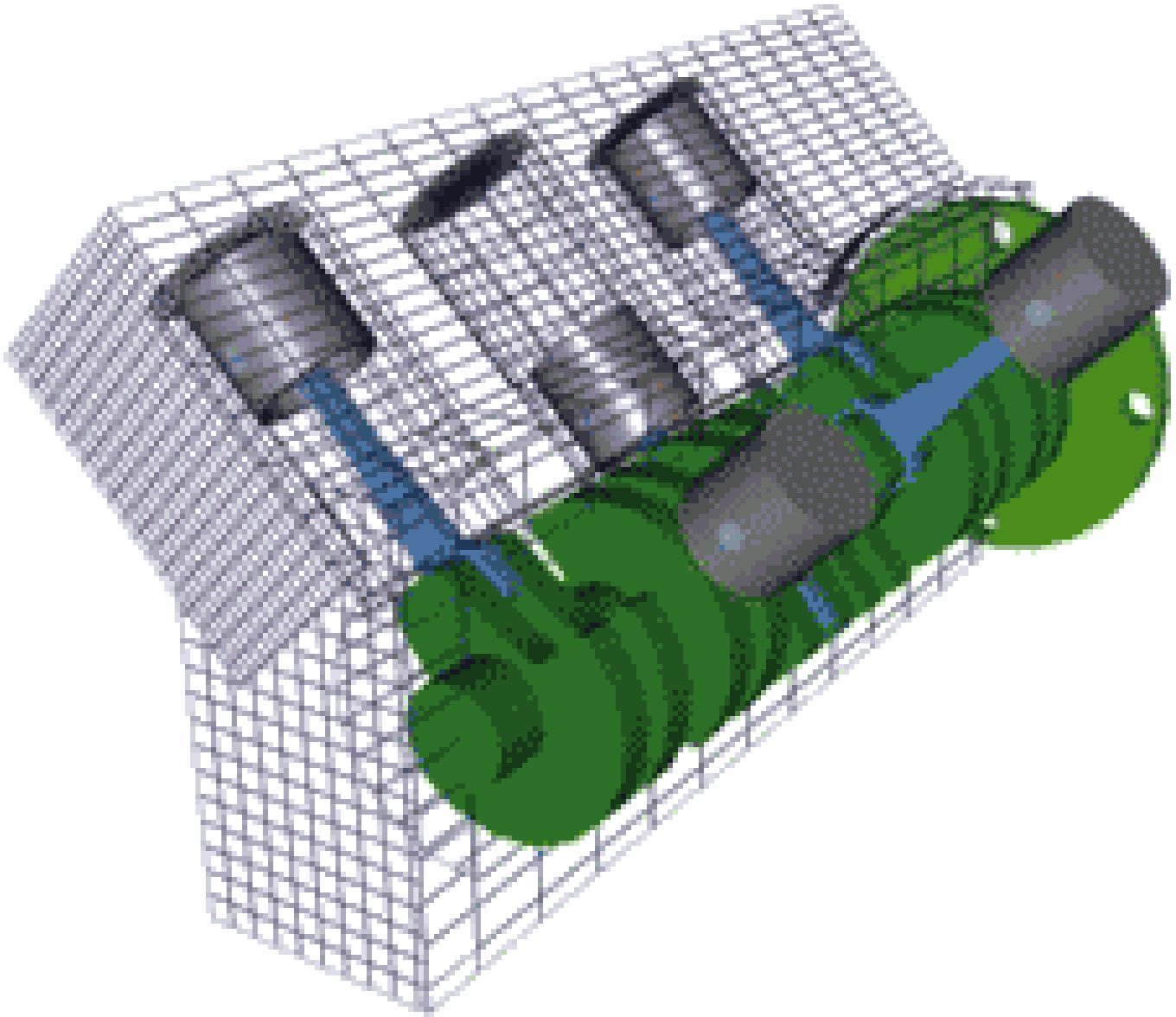
4 cylinder horizontal in-line engine



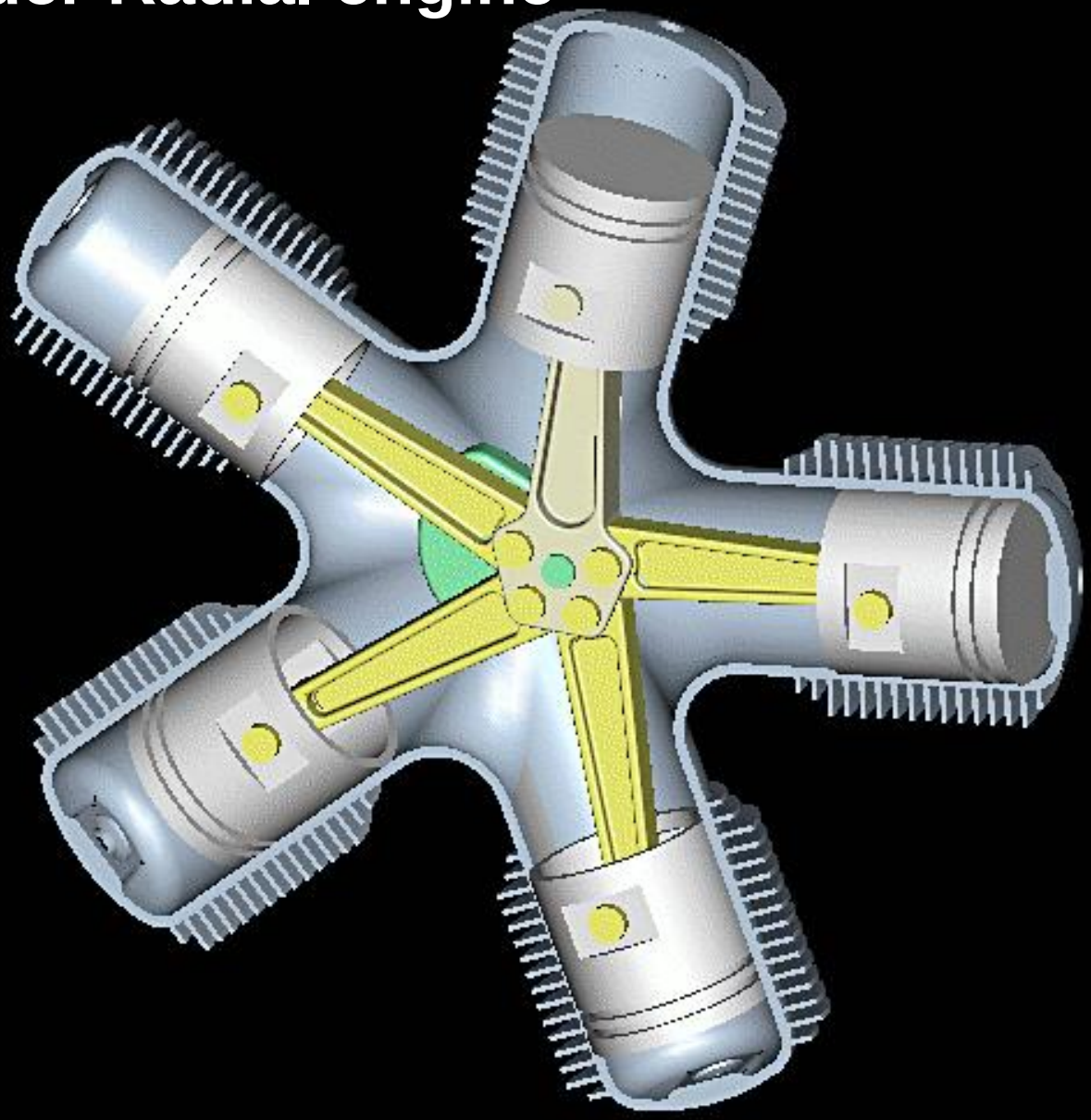
4 cylinder horizontal opposed engine



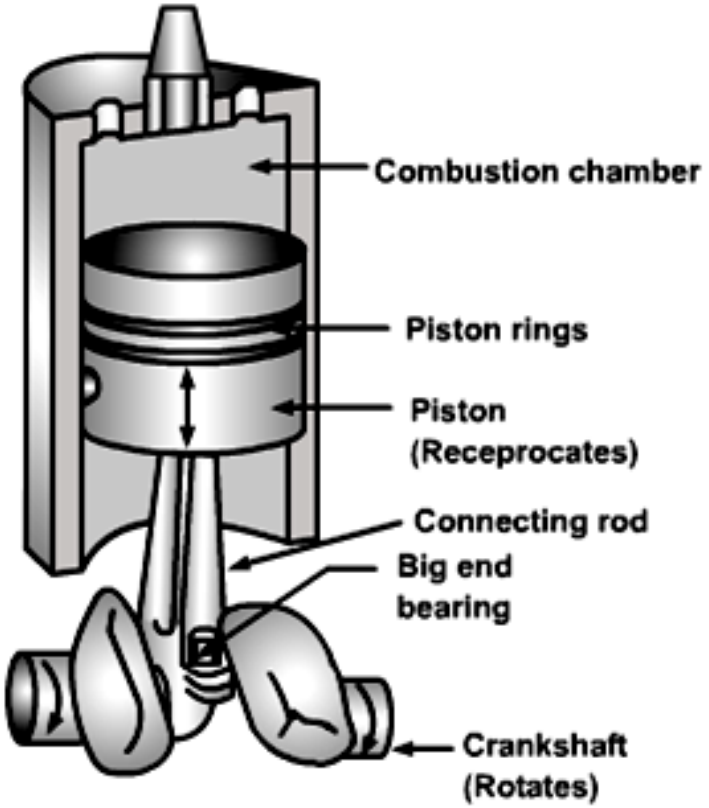
6 cylinder V engine

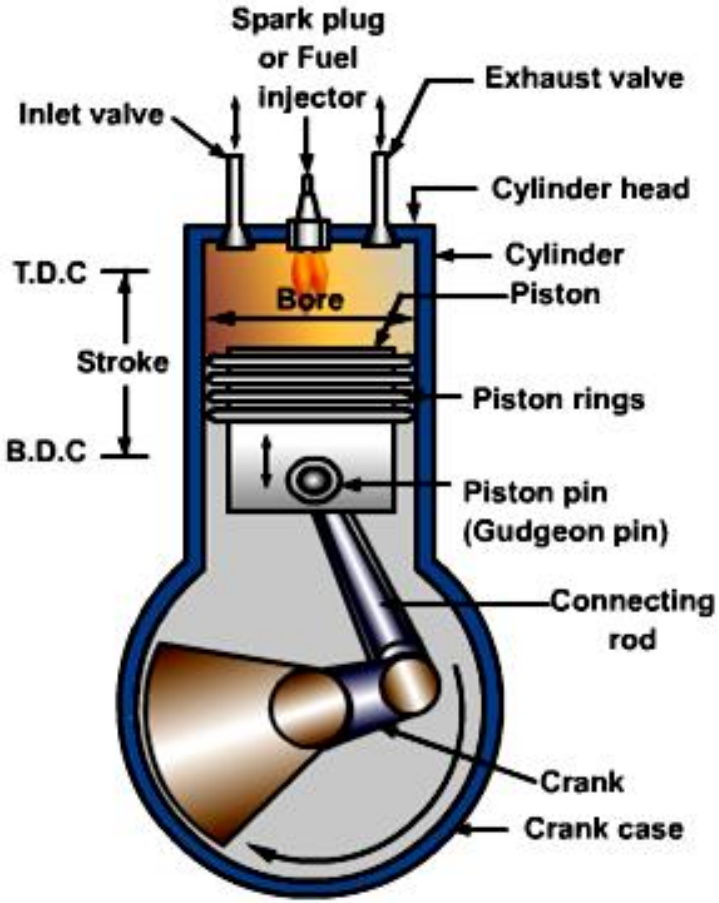


5 cylinder Radial engine

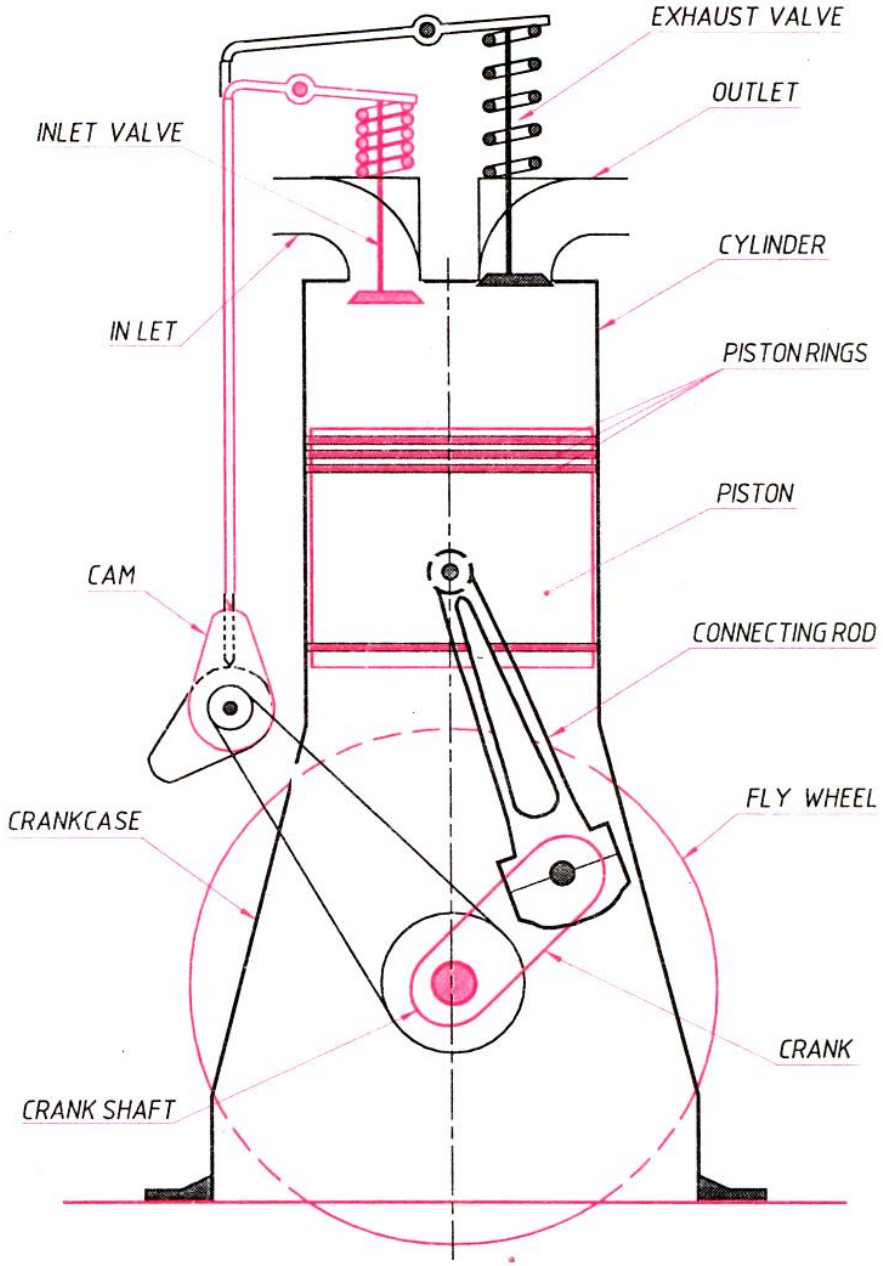


I. C. Engine Parts





T.D.C = TOP DEAD CENTRE
B.D.C = BOTTOM DEAD CENTRE

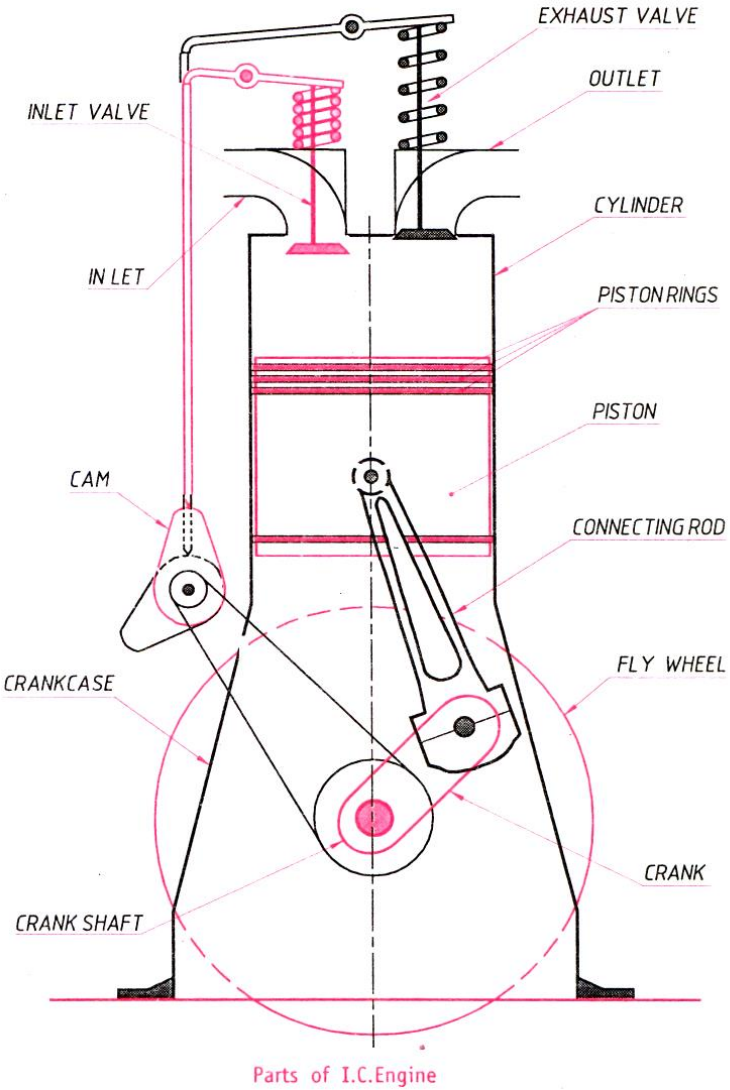


Parts of I.C.Engine

IC Engine Parts

Cylinder block

- Cylinder is a part in which the intake of fuel, compression of fuel and burning of fuel take place.
- The main function of cylinder is to guide the piston.



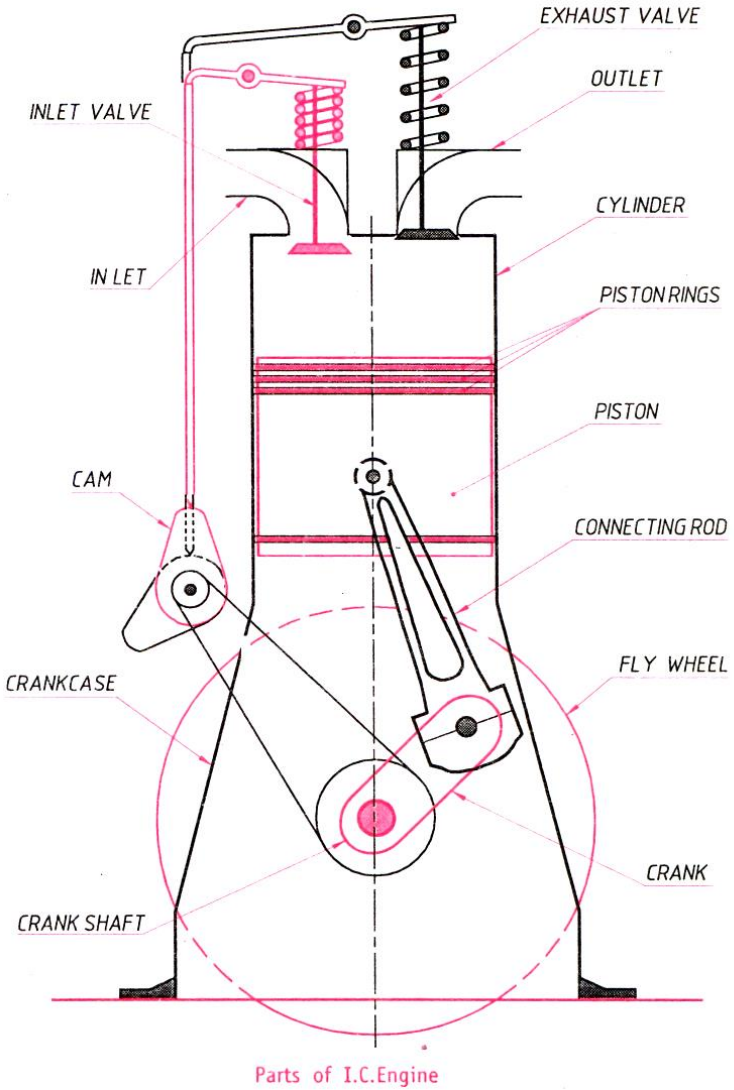
IC Engine Parts

Piston

A piston is fitted to each cylinder as a face to receive gas pressure and transmit the thrust to the connecting rod.

It is a prime mover in the engine.

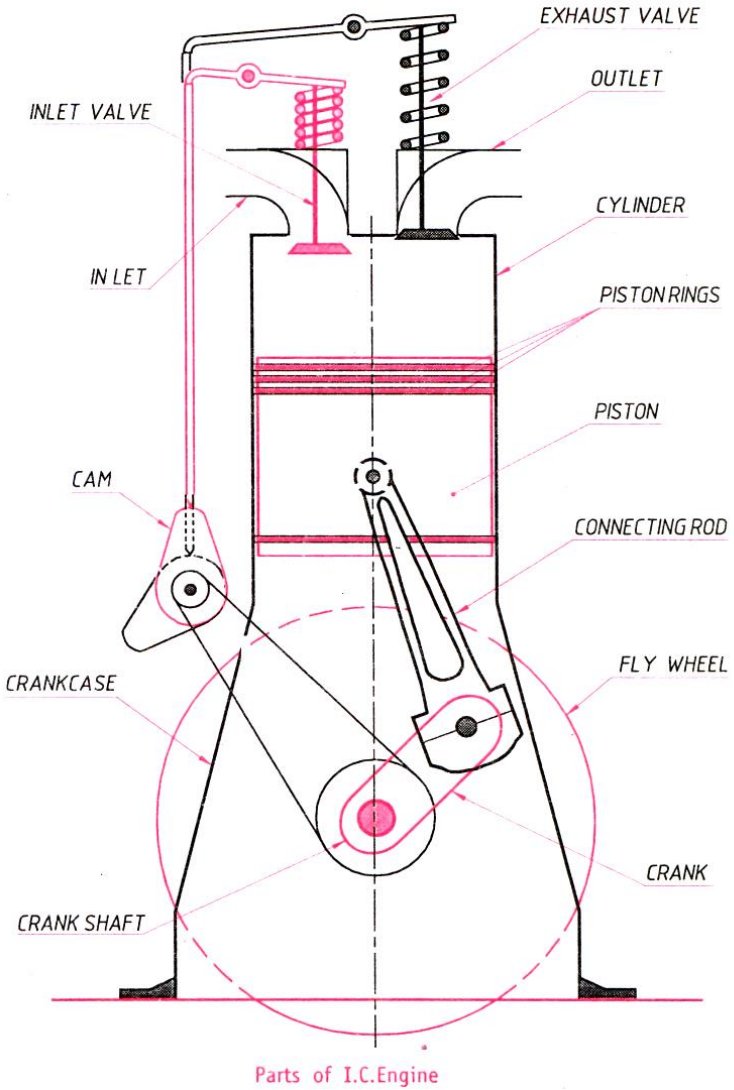
The main function of piston is to give tight seal to the cylinder through bore and slide freely inside the cylinder



IC Engine Parts

Piston rings

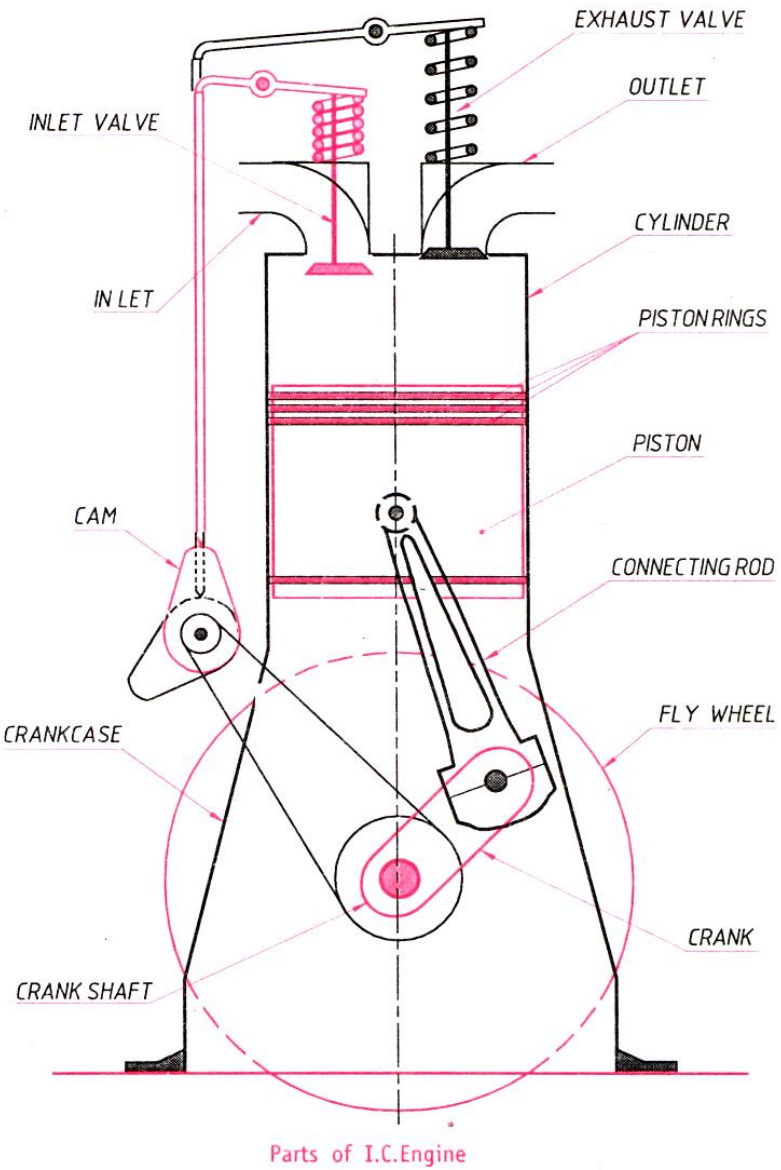
- To provide a good sealing fit and less friction resistance between the piston and cylinder, pistons are equipped with piston rings.
- These rings are fitted in grooves which have been cut in the piston.
- They are split at one end so they can expand or slipped over the end of piston.



IC Engine Parts

Connecting rod

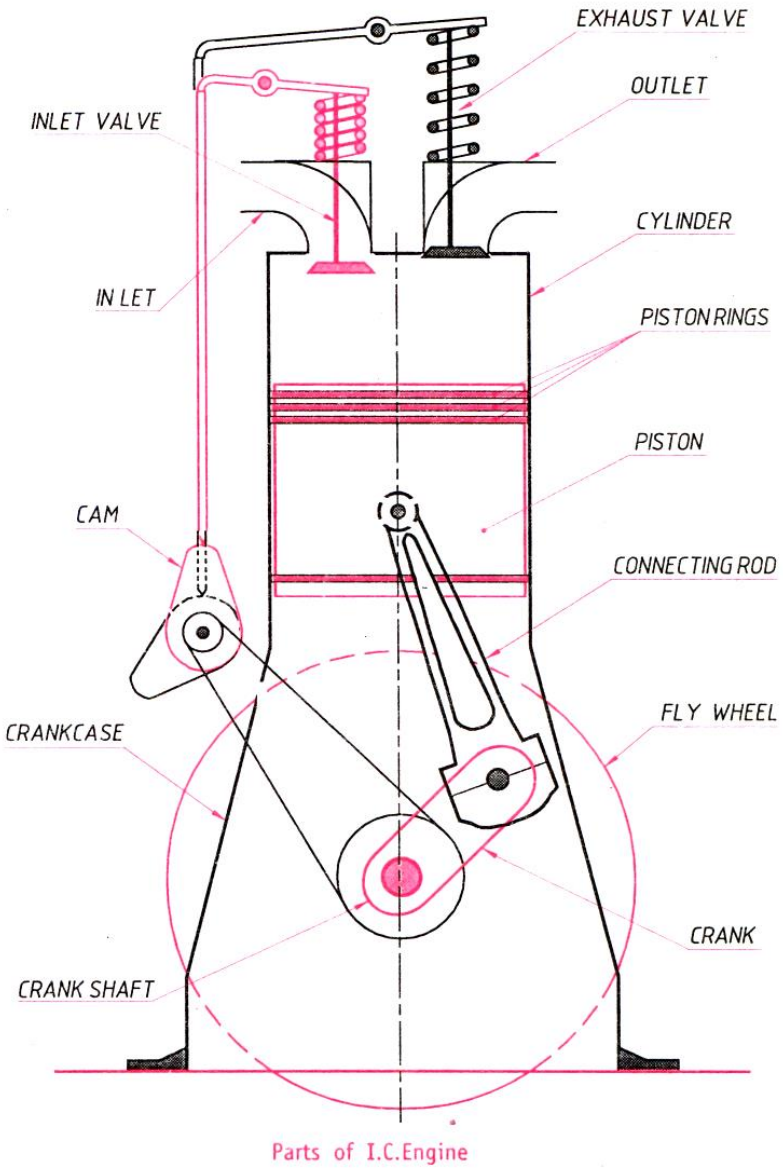
- Connecting rod connects the piston to crankshaft and transmits the motion and thrust of piston to crankshaft.
- It converts the reciprocating motion of the piston into rotary motion of crankshaft.
- There are two end of connecting rod; big end and small end.
- Big end is connected to the crankshaft and the small end is connected to the piston



IC Engine Parts

Crankshaft

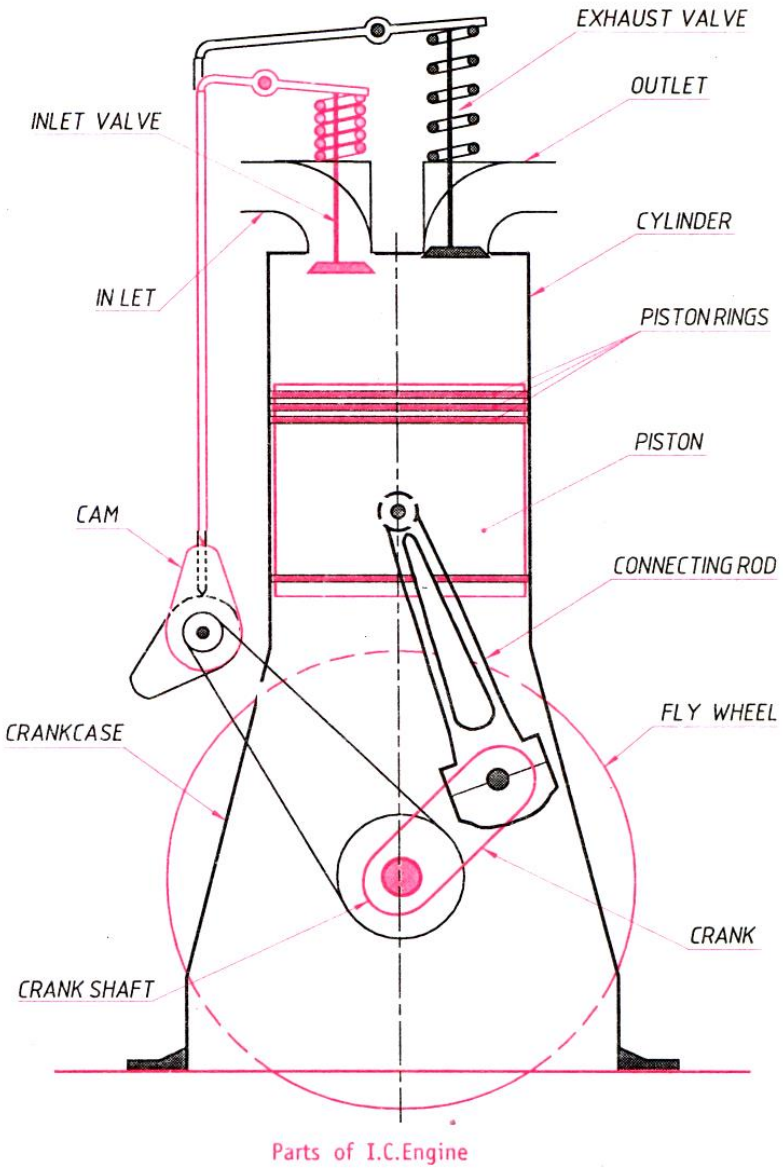
- The crankshaft of receives the efforts or thrust supplied by piston to the connecting rod.
- Converts the reciprocating motion of piston into rotary motion of crankshaft.
- The crankshaft mounts in bearing so it can rotate freely.
- The shape and size of crankshaft depends on the number and arrangement of cylinders.



IC Engine Parts

Crankcase

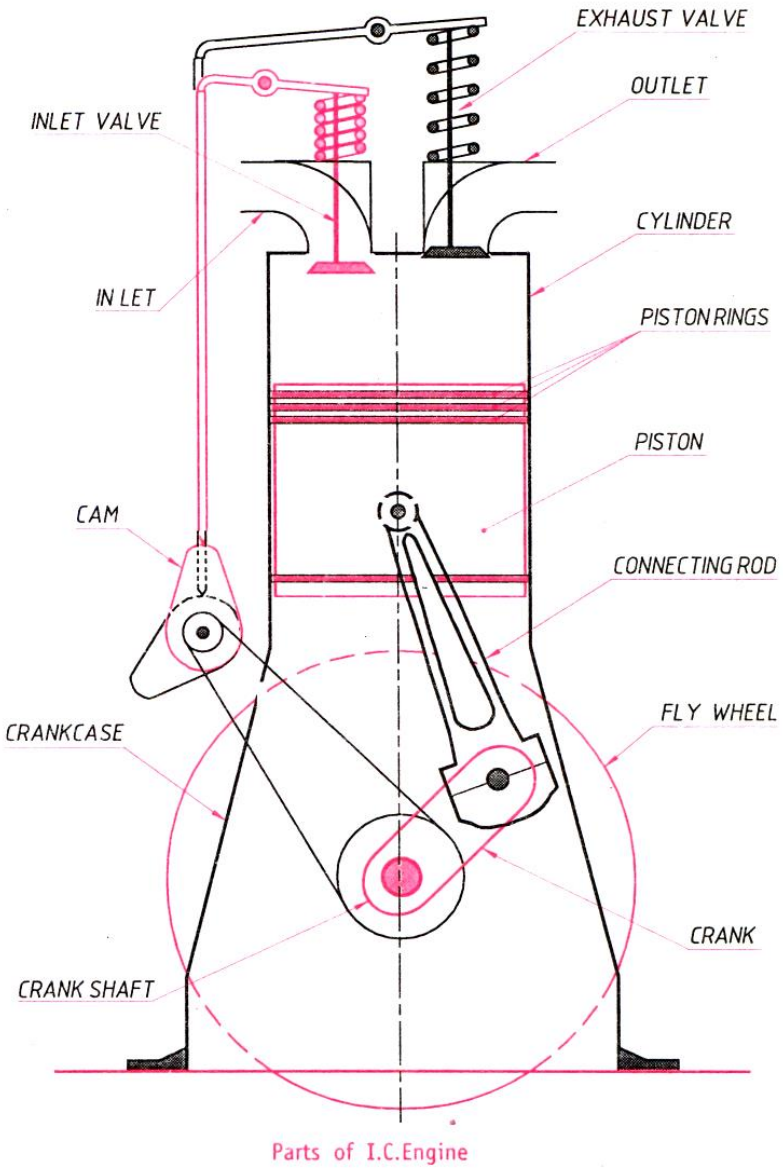
- The main body of the engine at which the cylinder are attached and which contains the crankshaft and crankshaft bearing is called crankcase.
- It serves as the lubricating system too and sometime it is called oil sump.



IC Engine Parts

Valves

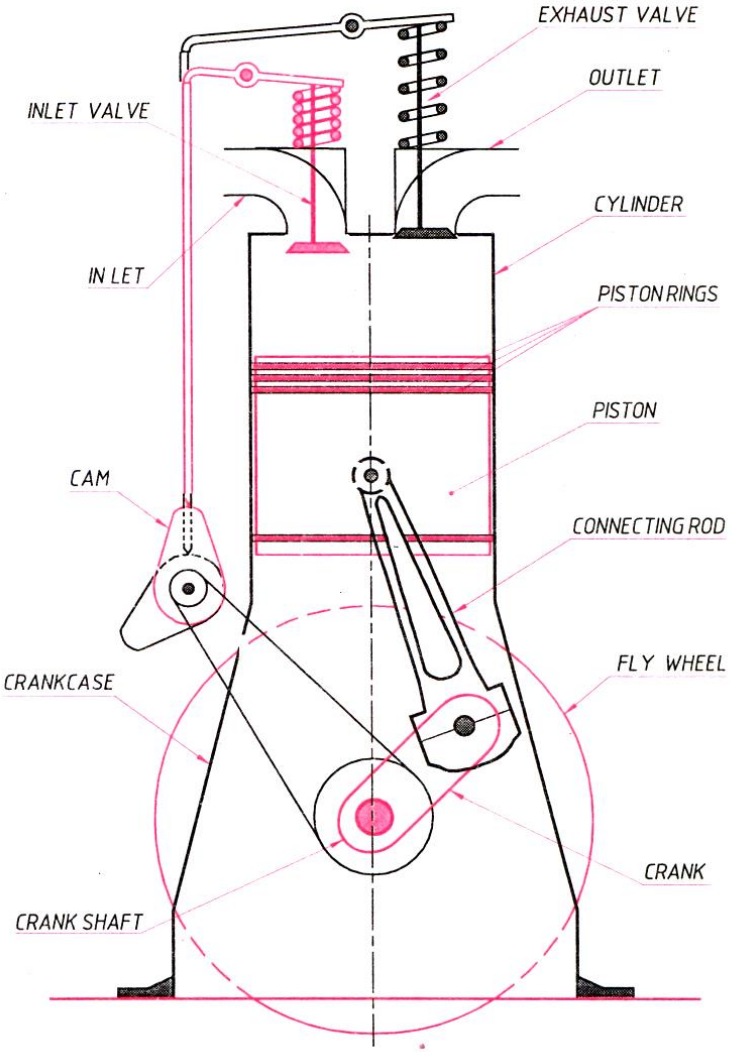
- Are used to control the inlet and exhaust of internal combustion engine.
- The number of valves in an engine depends on the number of cylinders.
- Two valves are used for each cylinder one for inlet of air-fuel mixture inside the cylinder and other for exhaust of combustion gases.
- The valves are fitted at the cylinder head by use of strong spring which keeps them closed.
- Both valves usually open inwards.



IC Engine Parts

- In a 4 stroke engine the valves are made to open and close by the cams fitted on a cam shaft, which inturn is driven by the crank shaft.

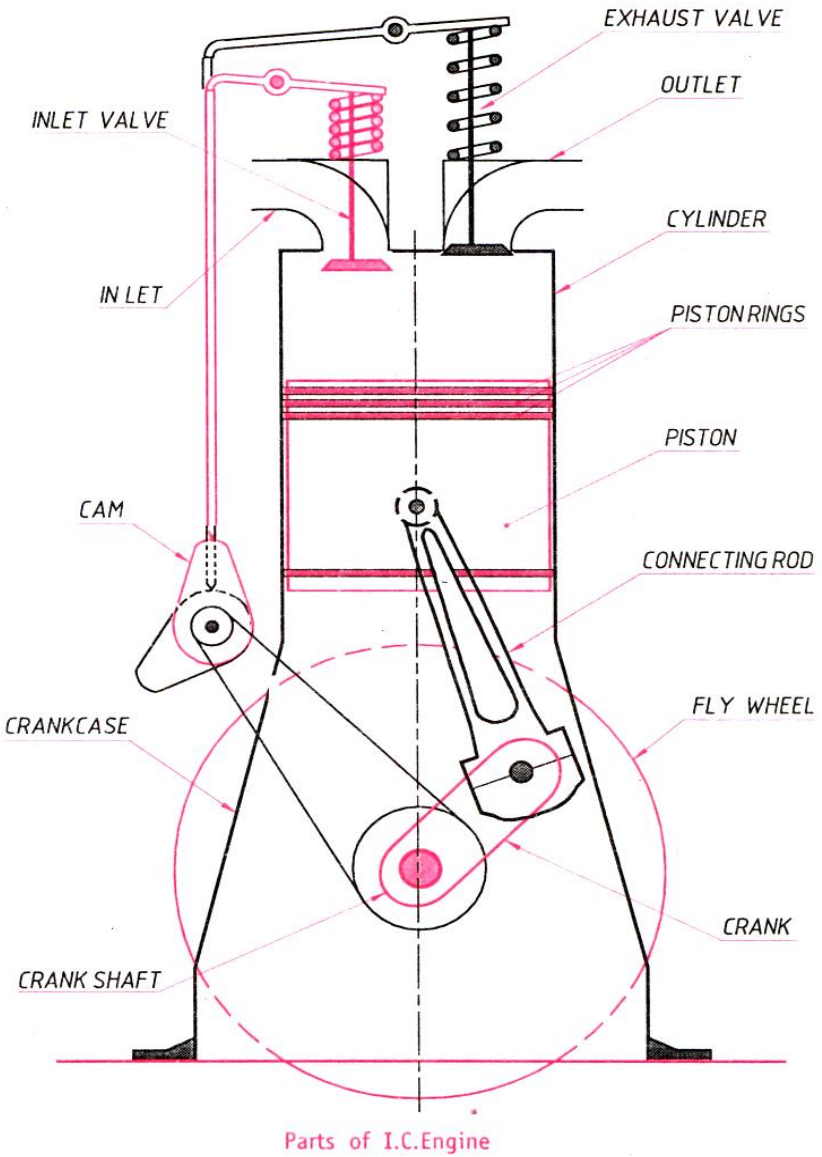
- Since the valves have to open and close once in two revolutions of the crank shaft the speed of the cam shaft is half of that of the crank shaft.



IC Engine Parts

Camshaft

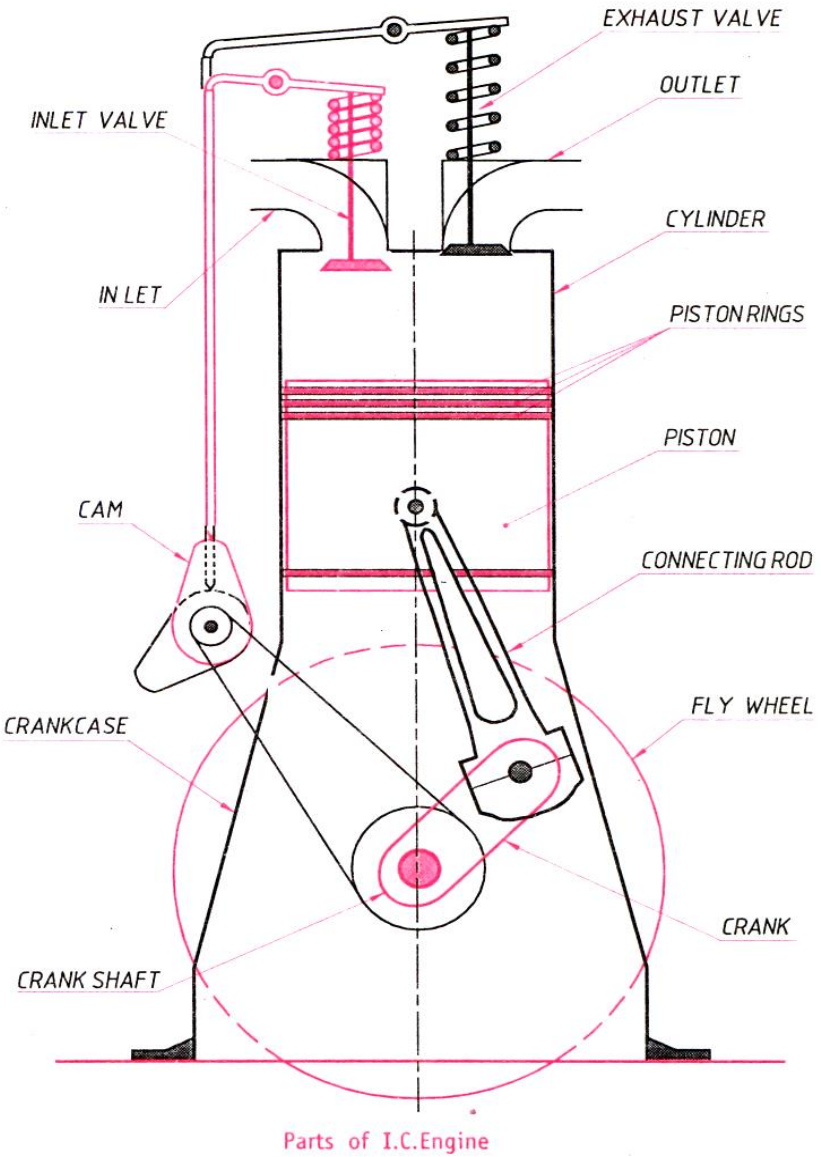
- Camshaft is used in IC engine to control the opening and closing of valves at proper timing.
- To regulate its timing, a cam is use which is oval in shape and it exerts a pressure on the valve to open and release to close.



IC Engine Parts

Flywheel

- A flywheel is secured on the crankshaft.
- The main function of flywheel is to rotate the shaft during preparatory stroke.
- It also makes crankshaft rotation more uniform.



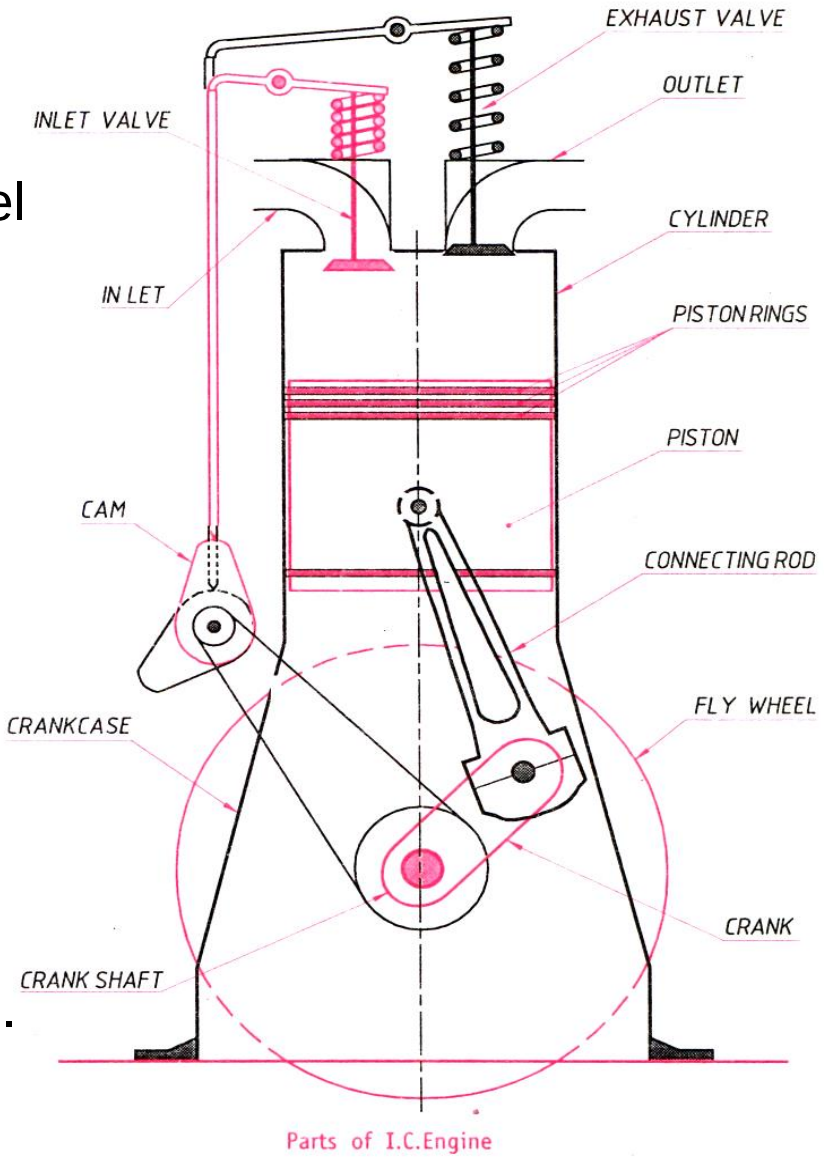
IC Engine Parts

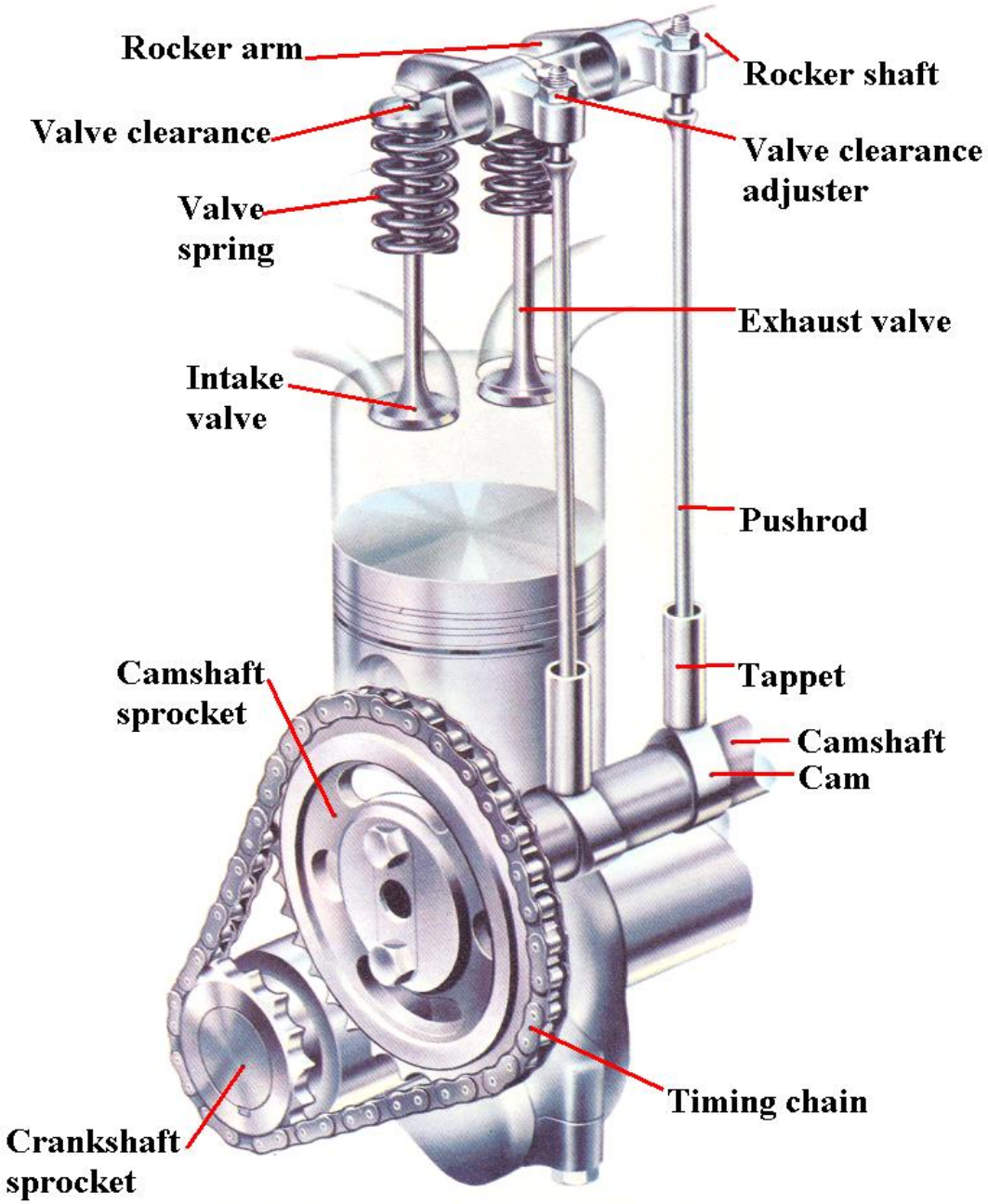
Spark plug

- It is used in Spark Ignition (Petrol) engine.
- Spark plug ignites the compressed air fuel mixture at the end of compression stroke.
- It is fitted on cylinder head.

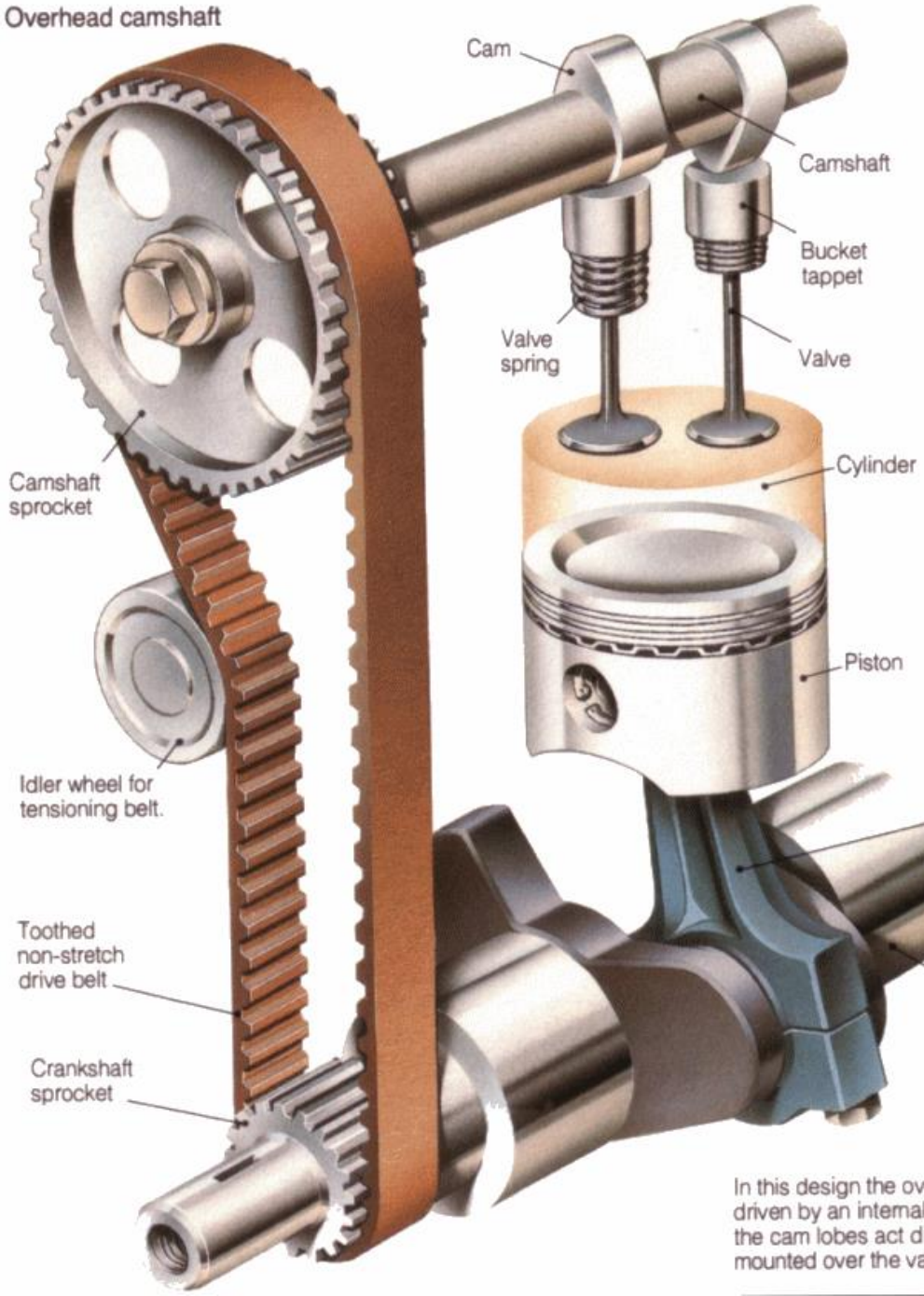
Injector

- It is used in Compression Ignition (Diesel) engine.
- Injector sprays the fuel into combustion chamber at the end of compression stroke.
- It is fitted on cylinder head.



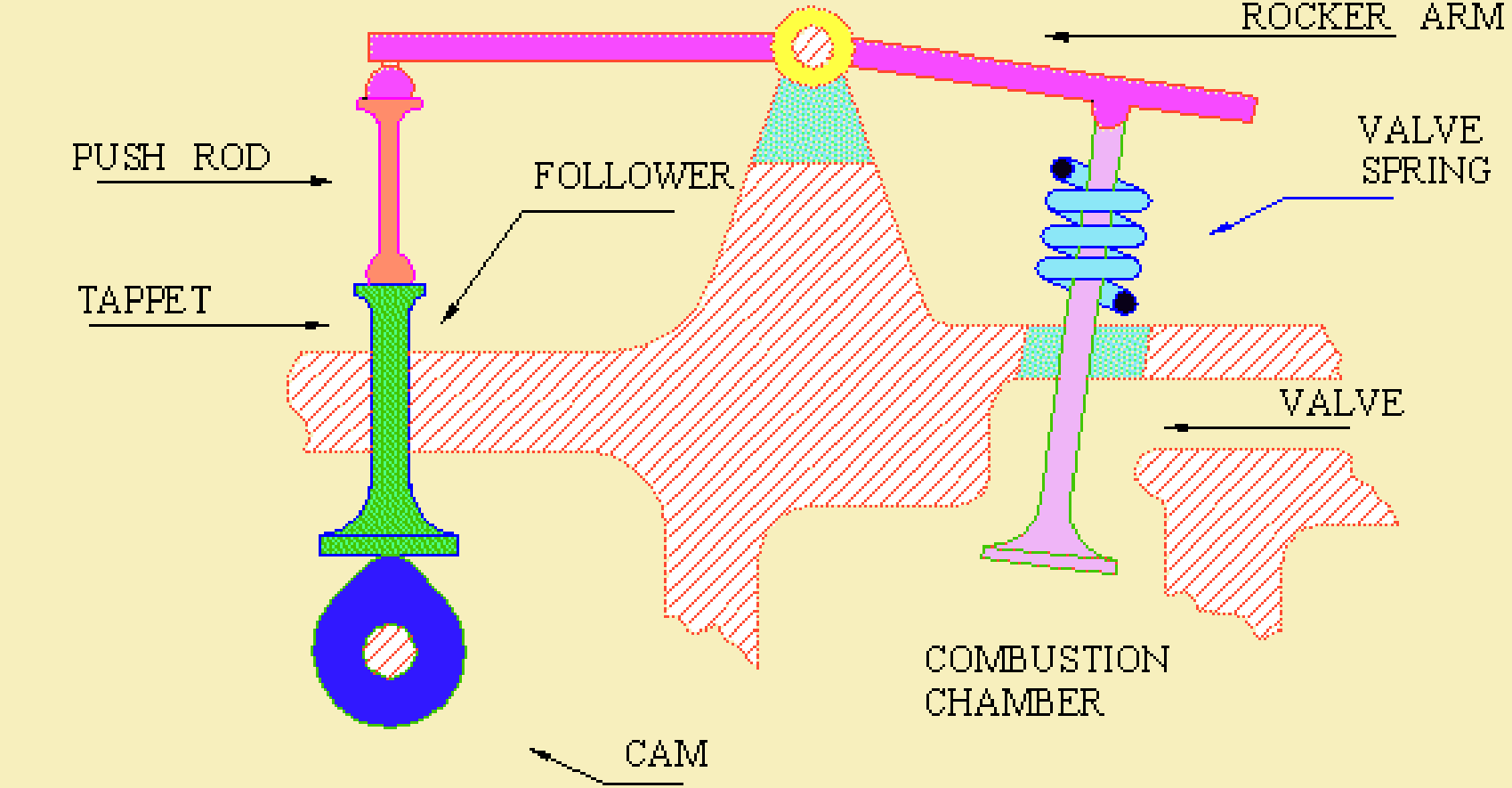

Rocker arm
Rocker shaft
Valve clearance
Valve clearance adjuster
Valve spring
Exhaust valve
Intake valve
Pushrod
Camshaft sprocket
Tappet
Camshaft
Cam
Timing chain
Crankshaft sprocket

Overhead camshaft



In this design the overhead camshaft is driven by an internally toothed belt, and the cam lobes act directly on tappets mounted over the valves.

CAM OPERATED VALVE



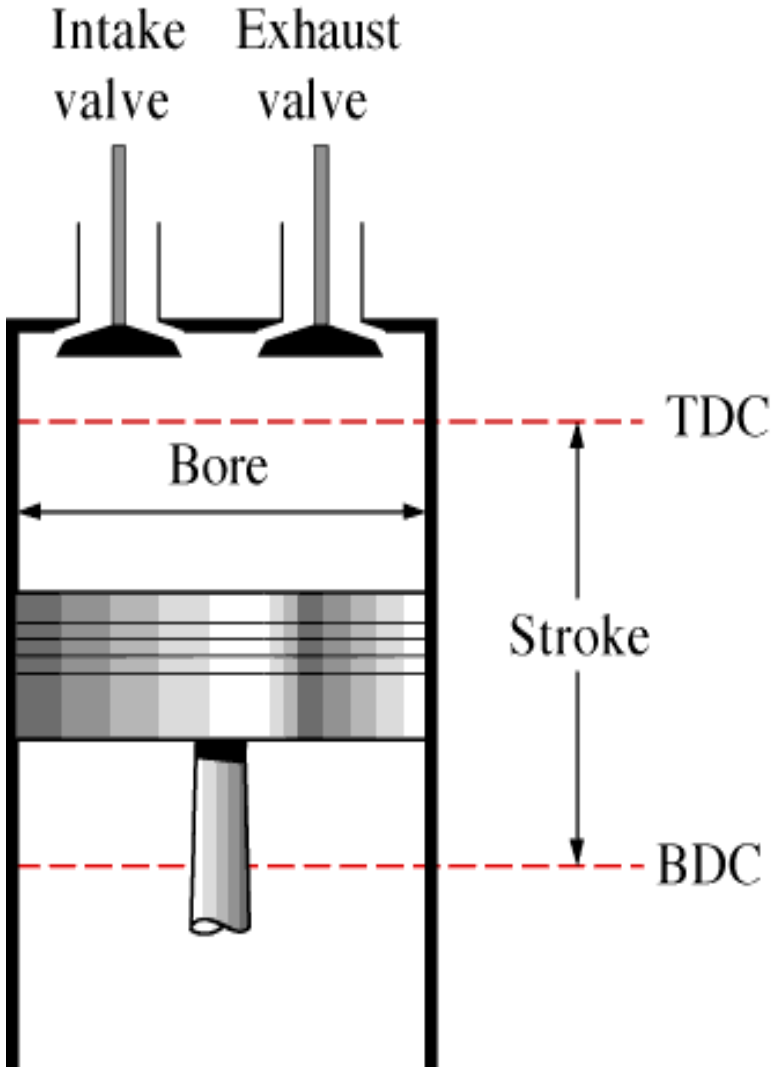
I C Engine terms & Definitions

- **TDC (top dead center):**

  It is the top most position occupied by the piston towards the head side of the cylinder

- **BDC (bottom dead center):**

  It is the lowermost position occupied by the piston towards the crank end side of the cylinder.

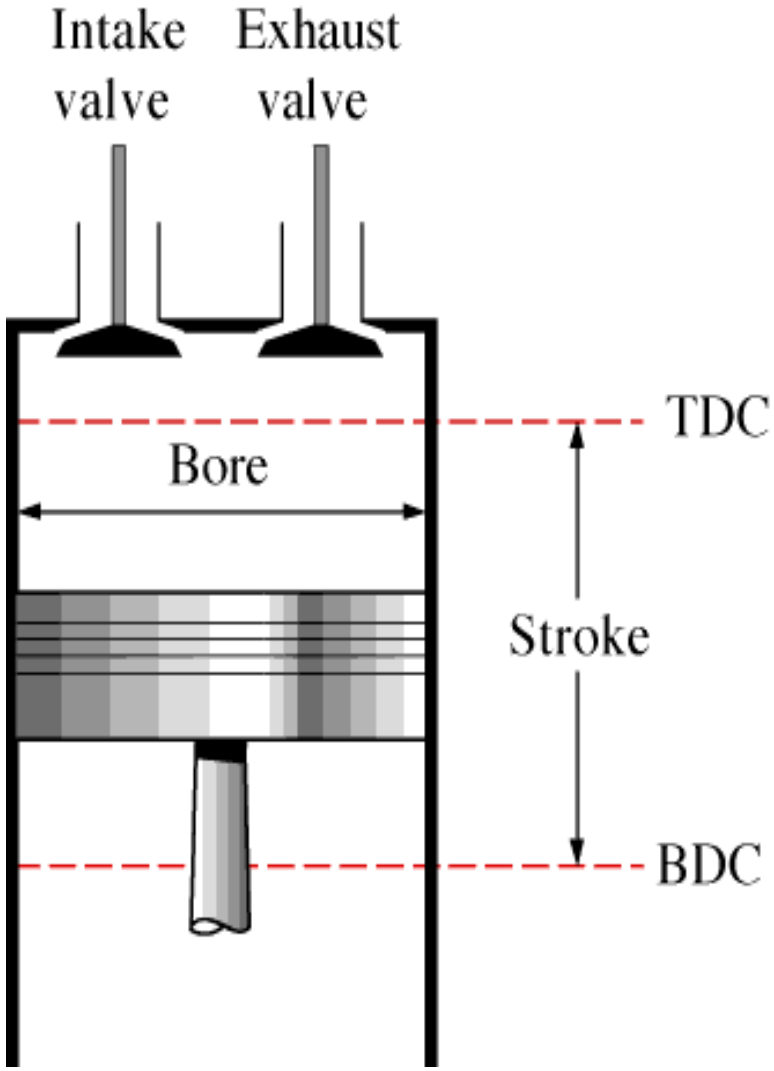


- **Stroke:**

It is the linear distance travelled by the piston when it moves from TDC to BDC

- **Bore:**

It is the inner diameter of the engine cylinder.

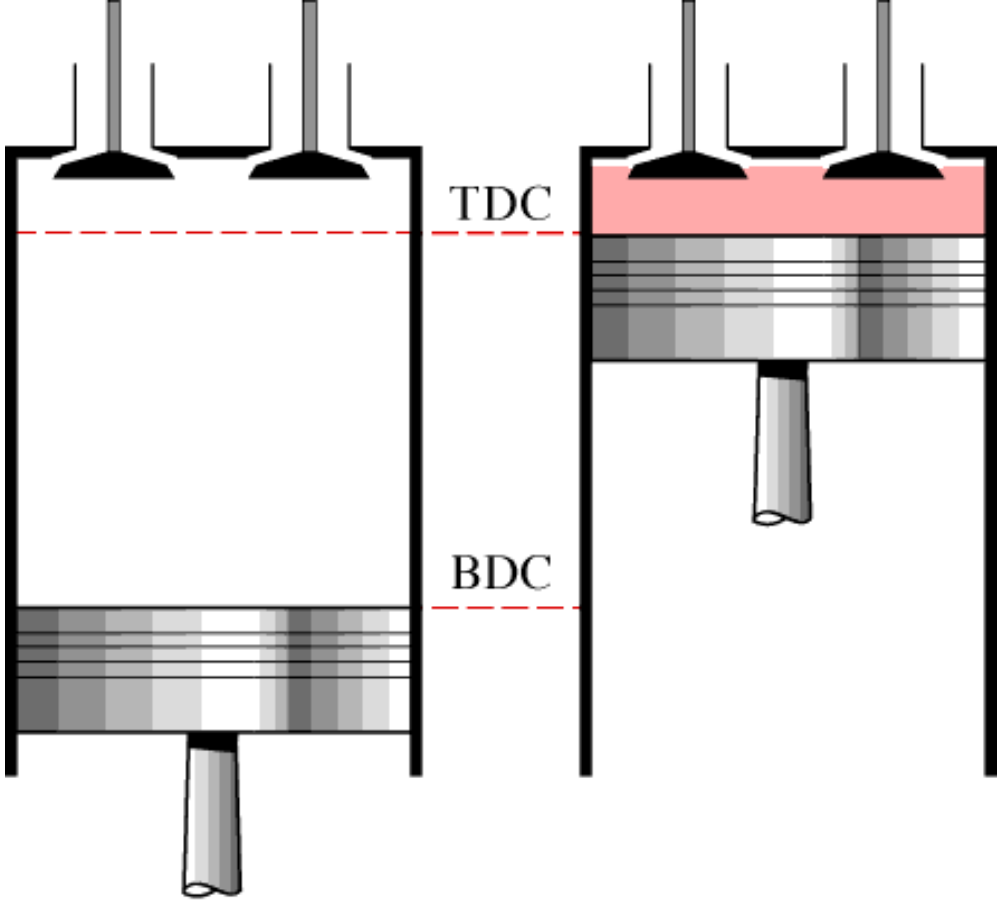


- **Swept volume or (Displacement volume)**

  It is the volume swept by the piston while moving from TDC and BDC

- **Clearance volume:**

  It is the volume contained in the cylinder above the top of the piston, when the piston is at TDC.



(*a*) Displacement volume

(*b*) Clearance volume

- Total volume = Swept volume (V_S) + Clearance volume (V_C)

- Compression ratio: "r"
- It is the ratio of total cylinder volume to clearance volume

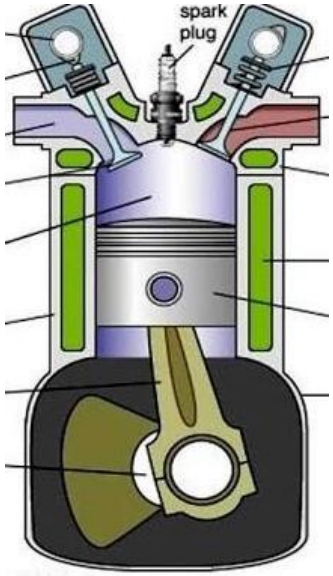
$$r = \frac{\text{Total volume}}{\text{Clearance volume}}$$

$$r = \frac{V_S + V_C}{V_C}$$

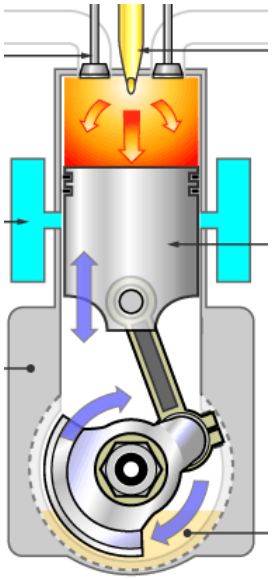
Value of "r" for,
Petrol engine lies between 7 to 12
Diesel engine lies between 16 to 22

I.C. Engines to study

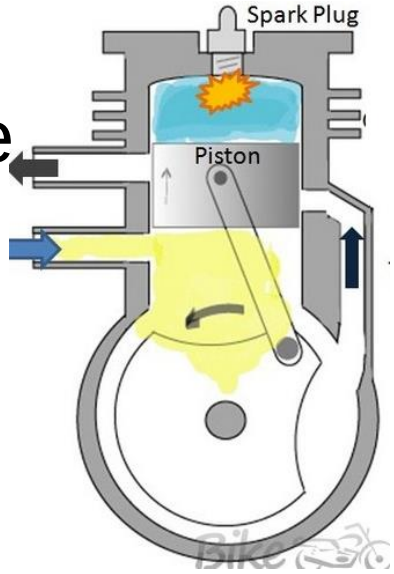
4 stroke
Petrol Engine



4 stroke
Diesel Engine



2 stroke
Petrol Engine



2 stroke
Diesel Engine

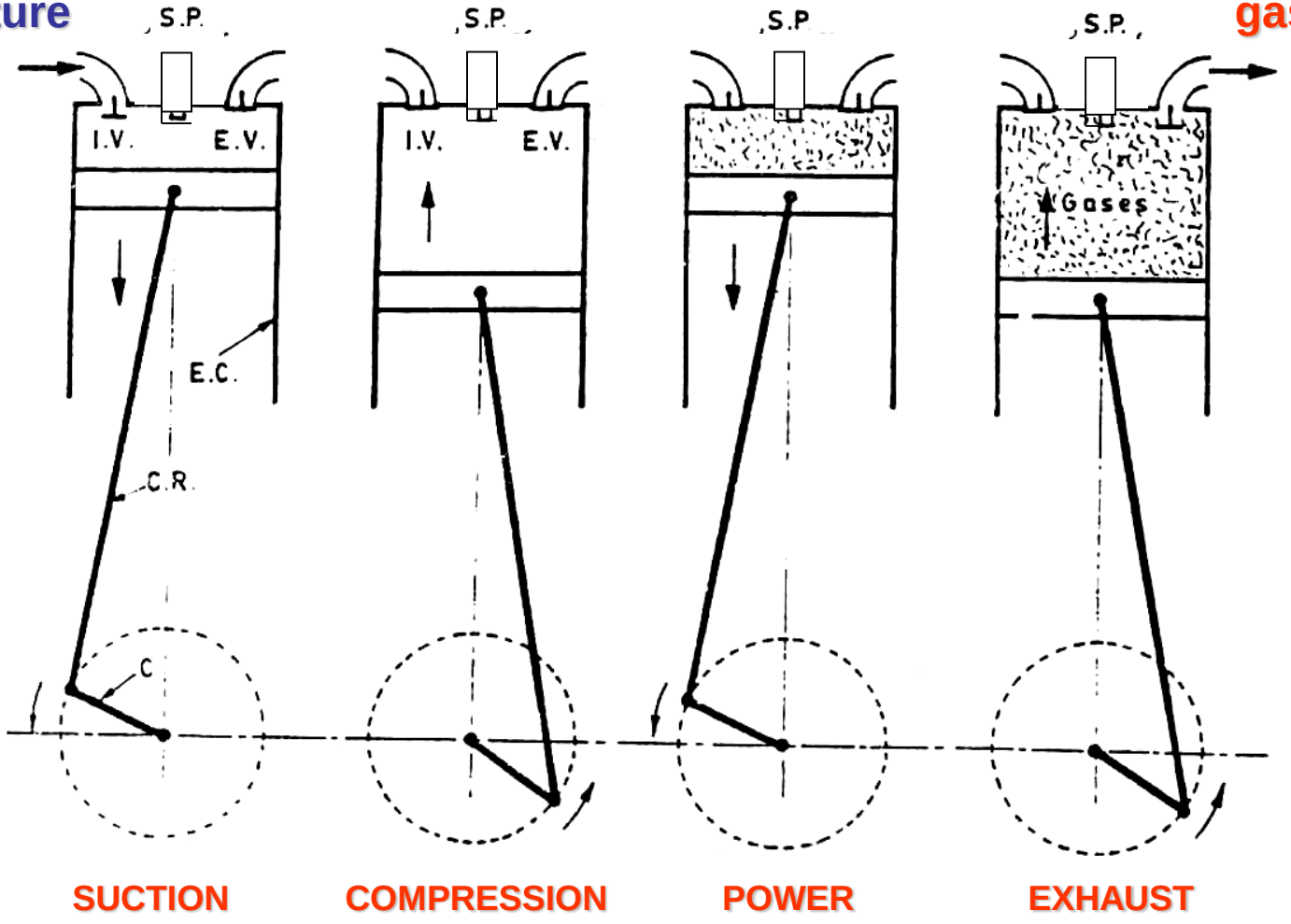
Working of 4-S Petrol Engine

- The 4 stroke petrol engine works on the principle of **" OTTO CYCLE"** also known as ***Constant Volume Cycle.***
- The engines operating on this cycle use either petrol or the gaseous such as LPG / CNG as their fuels.
- The working of the cycle takes place in 4 strokes of the piston or in two revolutions of the crank shaft.
- In a 4-Stroke petrol engine, the charge admitted to the engine cylinder is a homogeneous mixture of petrol and air.
- Depending on the load on the engine, the fuel and air is mixed in proper proportions and sent in to the cylinder by a device known as carburetor. Or through the MPFI system.

- The piston performs ***four strokes*** to complete ***one working cycle.*** They are
  1. Suction stroke
  2. Compression stroke
  3. Working or power or Expansion Stroke, and
  4. Exhaust stroke
- A spark plug is used to produce a spark so as to ignite the charge inside the cylinder.
- Since ignition in these engines is due to a spark, they are also called ***Spark Ignition Engines or S.I. Engines.***

Petrol – Air mixture

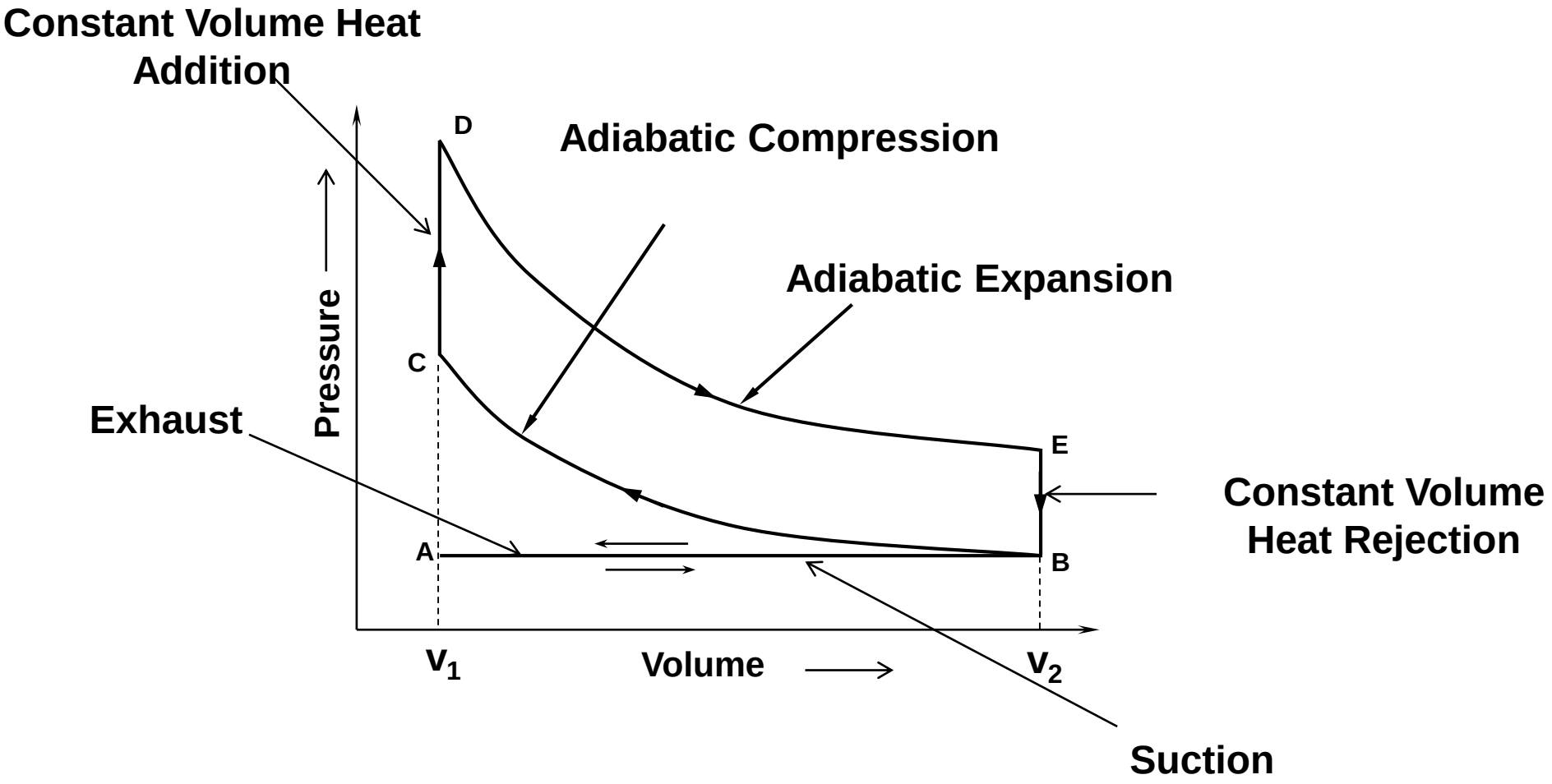
Exhaust gases



I.V = Inlet valve, **E.V** = Exhaust valve, **E.C** = Engine cylinder

C.R = Connecting rod, **C** = Crank, **S.P** = Spark plug

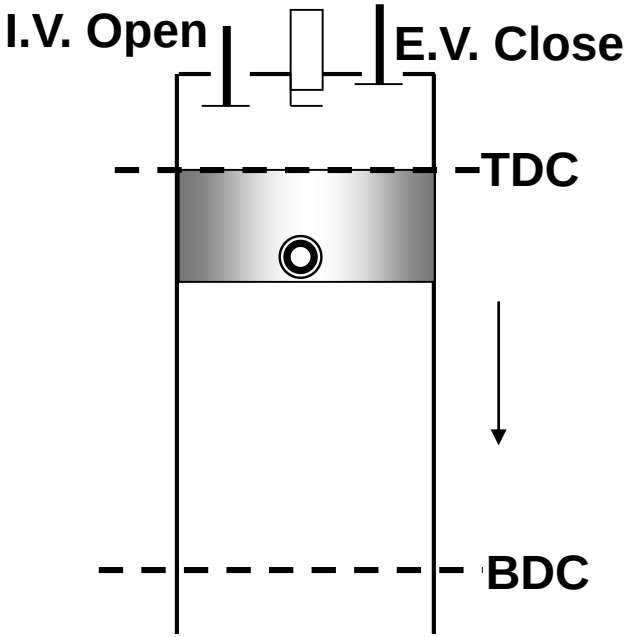
Working of 4-Stroke Petrol Engine

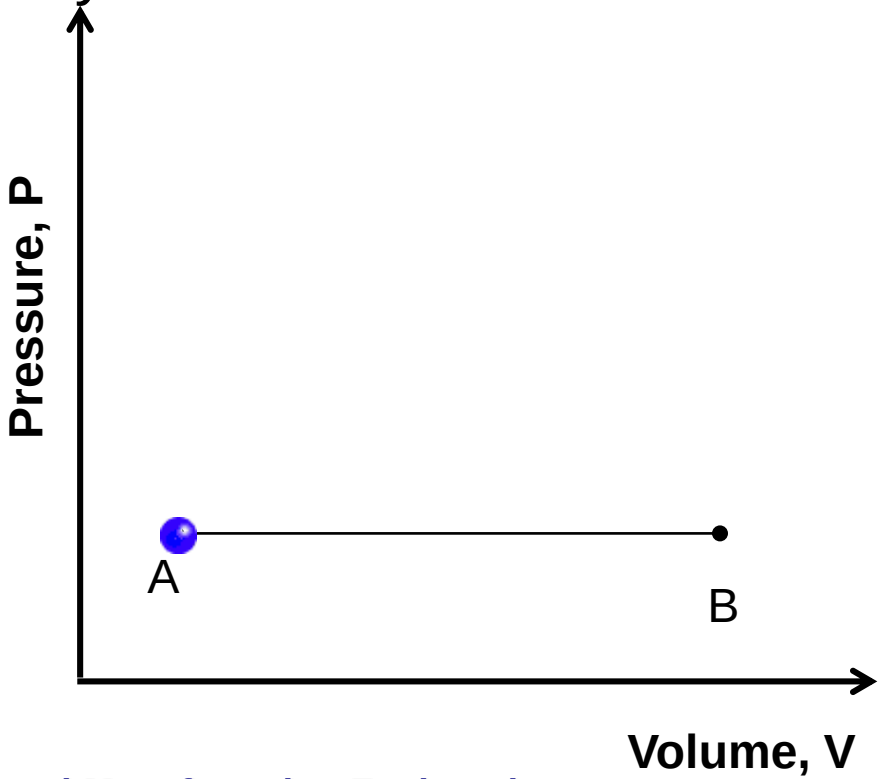


Theoretical Otto cycle

Suction Stroke: During suction stroke the inlet valve is open and the exhaust valve closed.

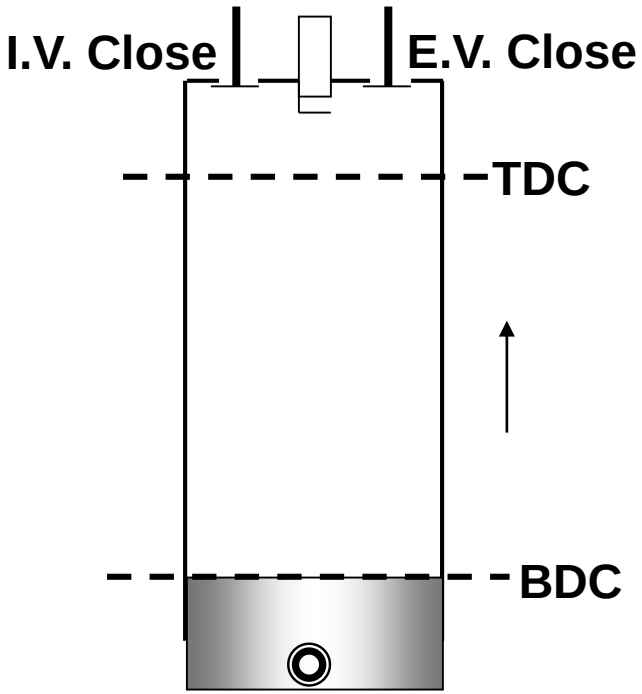
- The piston moves from TDC to BDC, drawing a fresh charge of vaporized fuel-air mixture. Crank shaft rotates by half a rotation.
- This stroke is represented by the line AB on the P-V diagram.

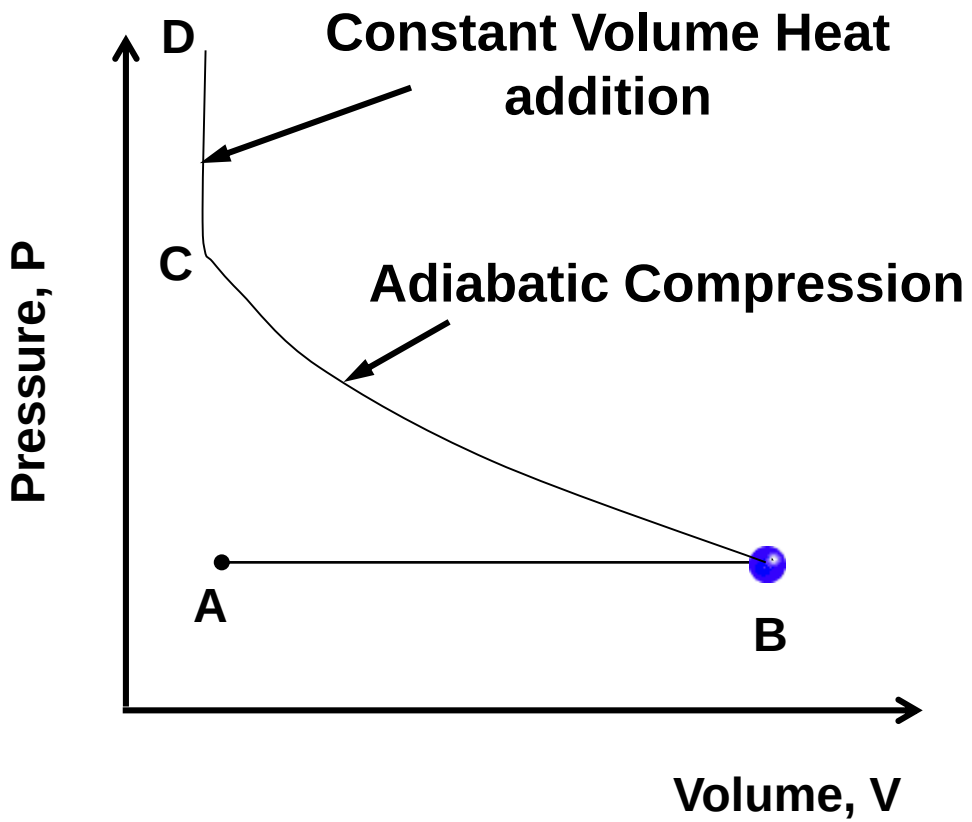




Compression Stroke: During compression stroke, both inlet & exhaust valves are closed.

- The piston moves from BDC to TDC, thus compressing air petrol mixture. Crank shaft rotates by half a rotation.
- Due to compression, the pressure and temperature of the charge are increased. This is shown by the curve BC on the P- V diagram which is an adiabatic compression process.
- Just before the end of this stroke the spark - plug initiates a spark which ignites the compressed charge leading to instantaneous increase in pressure while volume remains constant. This constant volume heat addition process is represented by line CD.


I.V. Close
E.V. Close
TDC
BDC


D
Constant Volume Heat addition
C
Adiabatic Compression
A
B
Pressure, P
Volume, V

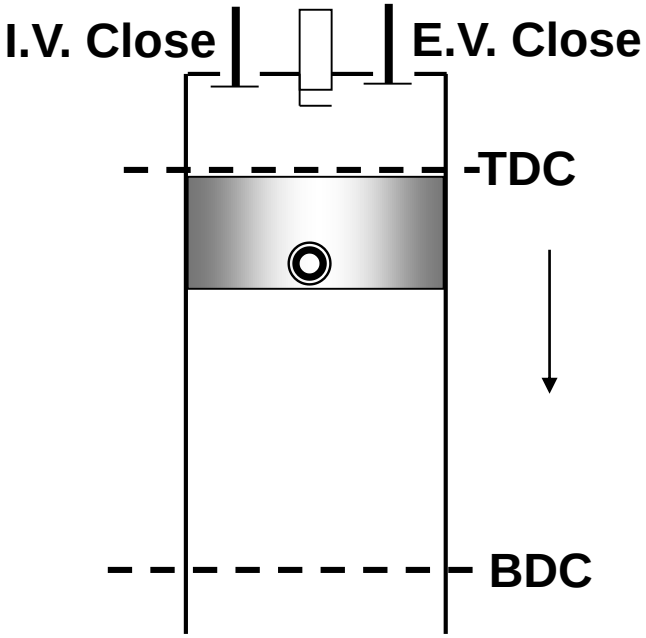
Working Stroke: During working stroke, both inlet & exhaust valves are closed.

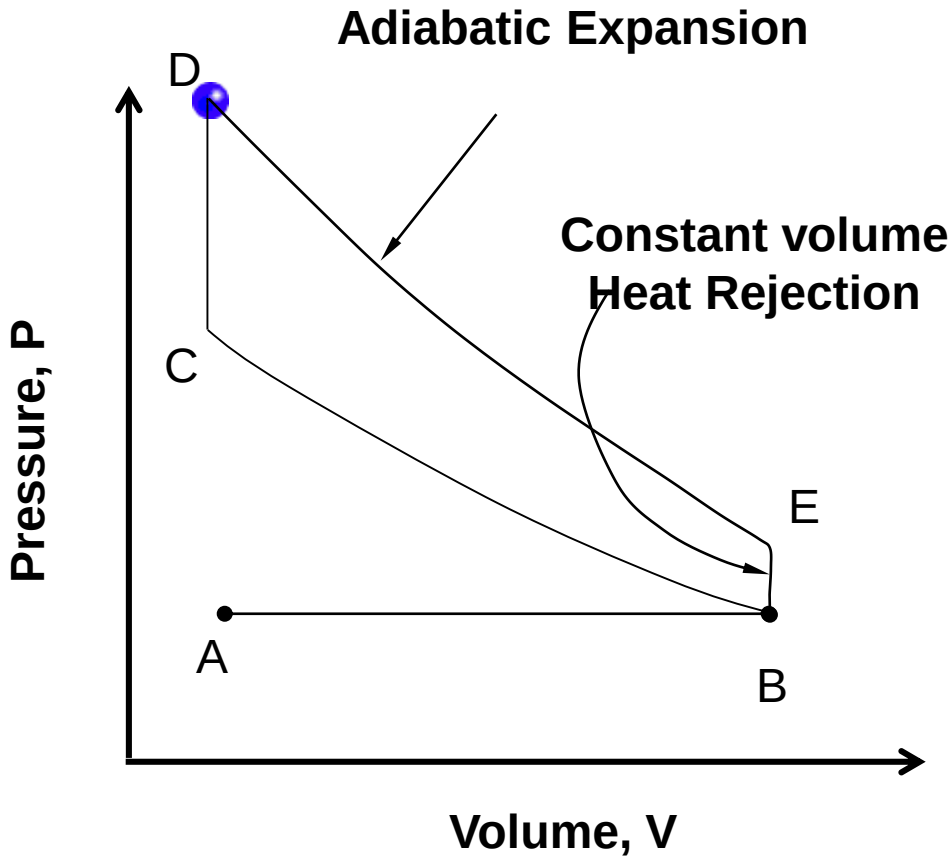
- The high pressure burning gases expand exerting pressure on the piston forcing it to move downwards from TDC to BDC producing linear motion.

- Connecting rod and crank convert this linear motion into rotary motion of the crank shaft. Crank shaft rotates by half a rotation

- The expansion of gases is an adiabatic expansion process which is shown by the line DE on the P-V diagram.

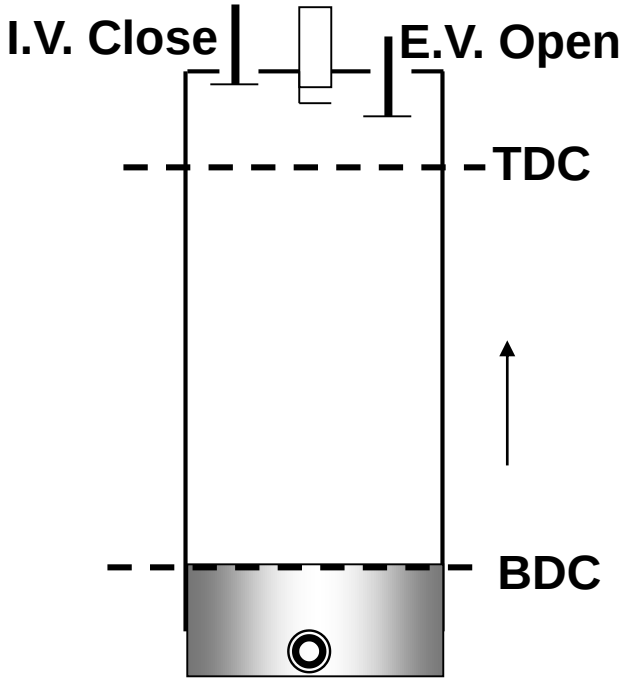
- Just before the piston reaches BDC, the exhaust valve opens causing sudden release of gases to atmosphere resulting in sudden drop in pressure at constant volume inside the cylinder as shown by line EB on the P-V diagram.

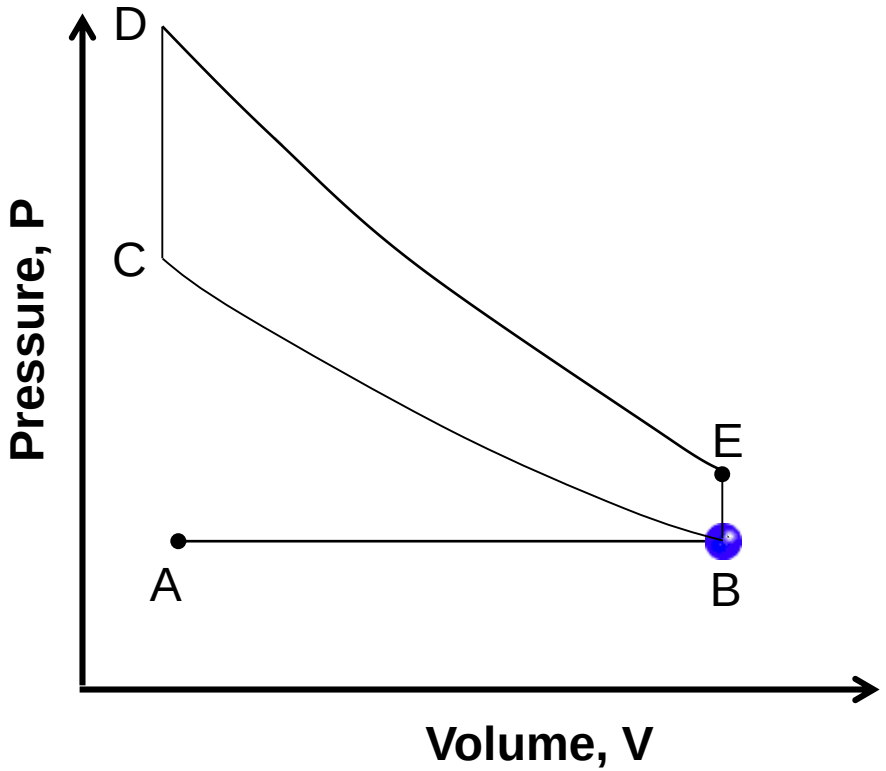

I.V. Close
E.V. Close
TDC
BDC


Adiabatic Expansion
D
Constant volume
Heat Rejection
C
E
A
B
Pressure, P
Volume, V

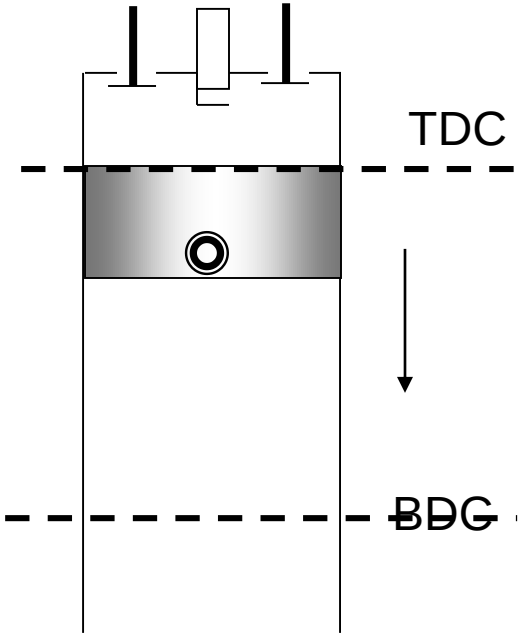
Exhaust Stroke: During the exhaust stroke the exhaust valve is open and inlet valve is closed.

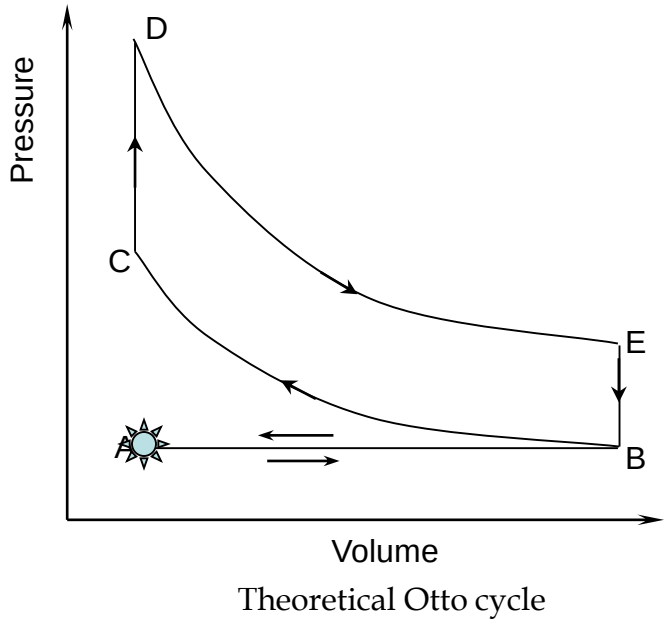
- During this stroke the piston moves from BDC to TDC and drives out the remaining gases to the atmosphere. Crank shaft rotates by half a rotation.
- This stroke is represented the line BA on the P-V diagram.





P V diagram for SI Engine / Otto cycle engine





Theoretical Otto cycle

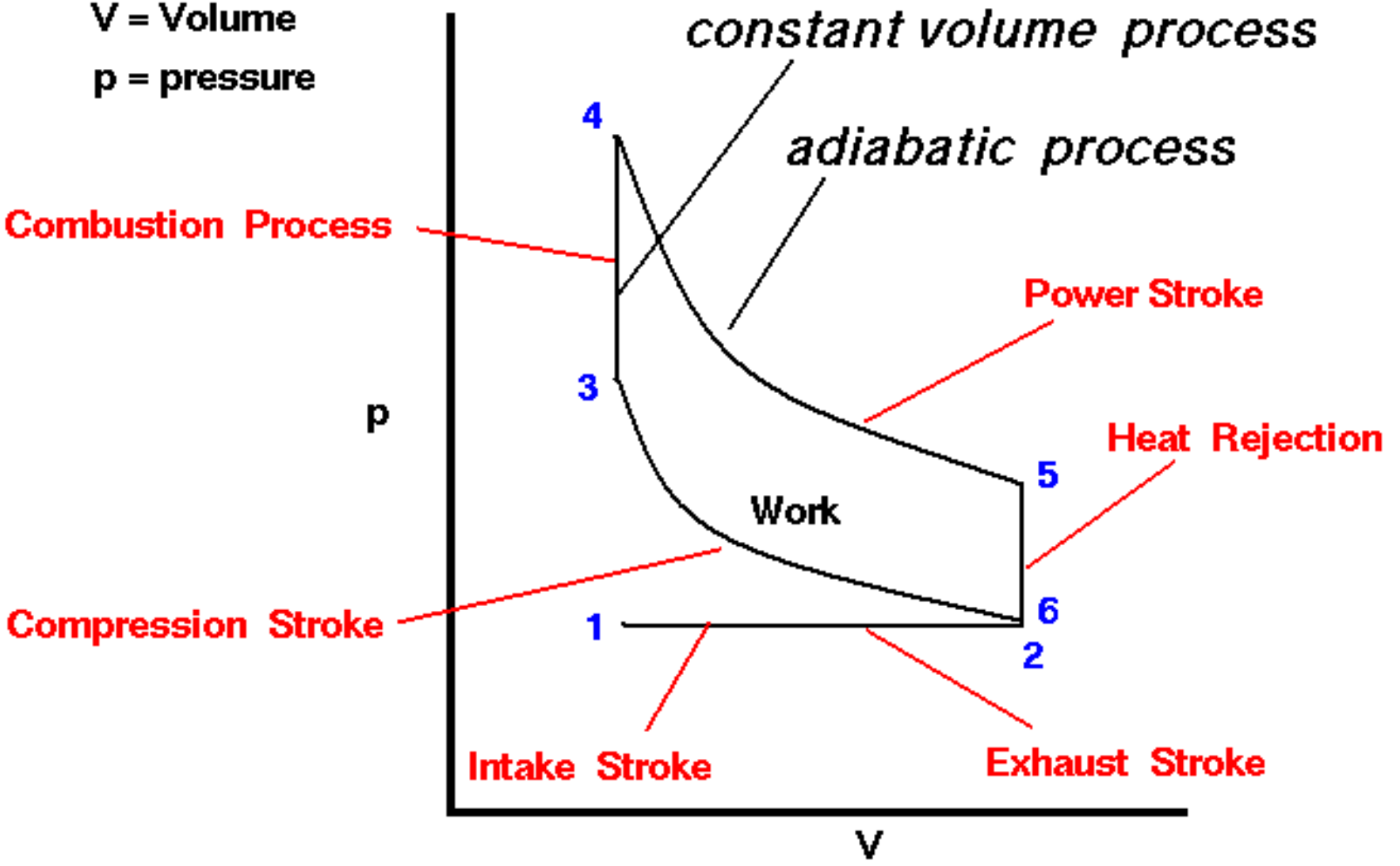
Ideal Otto Cycle

p–V diagram

Glenn Research Center

V = Volume

p = pressure



Concluding Remarks on working of 4S Petrol Engine

- Power is developed in alternate revolutions of the crankshaft.
- Energy developed during power stroke is stored in the ***flywheel.*** Energy required to perform suction, compression and exhaust stroke is provided from the flywheel.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

Flywheel is a heavy disc rigidly keyed to the crank shaft

Working of 4 Stroke Diesel Engine

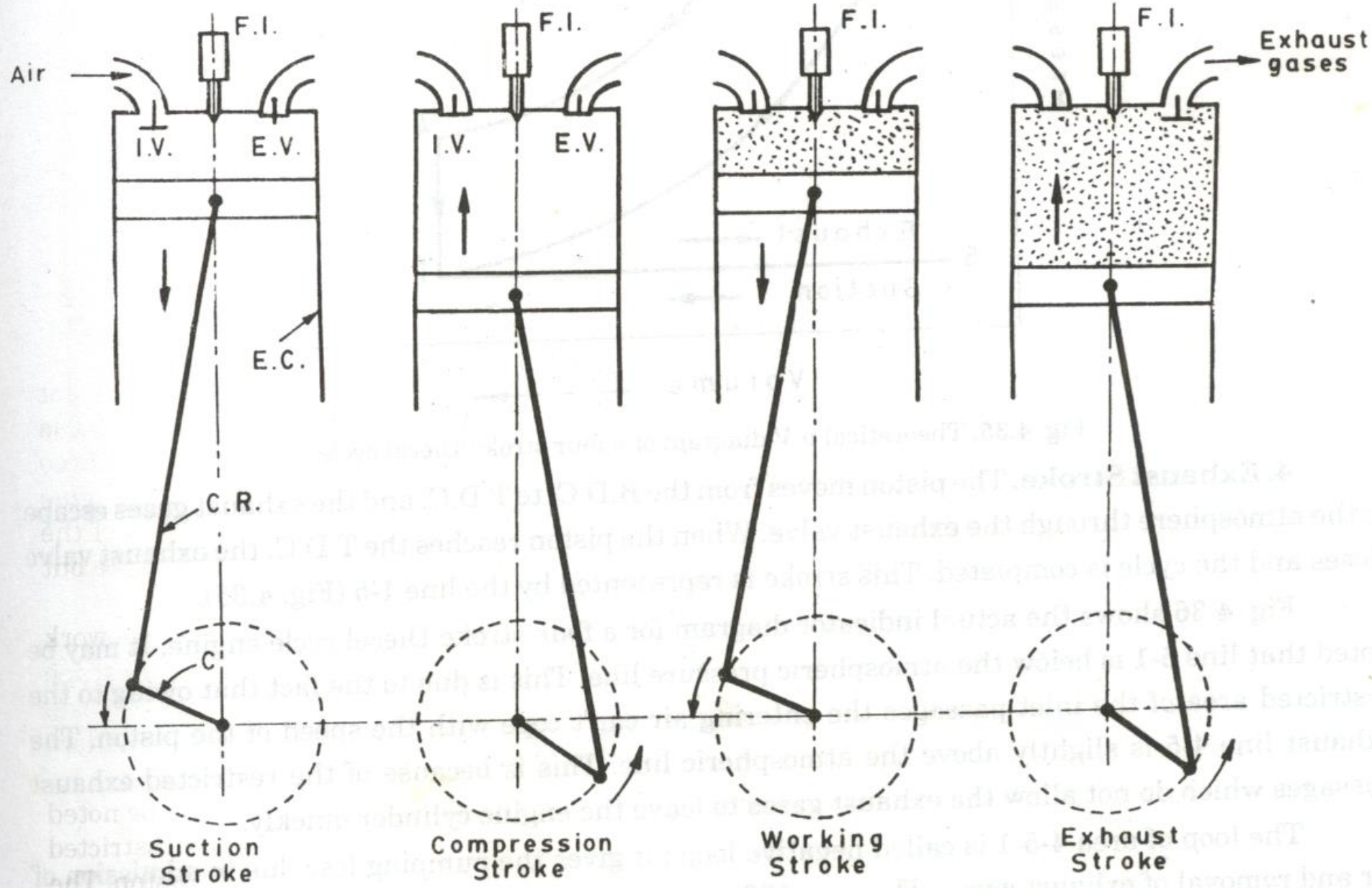
- The basic construction of a four stroke diesel engine is same as that of four stroke petrol engine.
- Instead of a spark plug, a ***Fuel Injector*** is mounted in its place.
- Instead of a carburettor, a ***fuel pump*** or a CRDI system supplies the fuel oil to the fuel injector at higher pressure.
- The fuel injector injects the fuel into the cylinder as a fine spray at very high pressure at the beginning of power stroke.

- In case of diesel engine, only air enters the cylinder during suction stroke, i.e., charge is only air.
- Only air is compressed during the compression stroke.
- At the end of the compression stroke, the fuel injector injects diesel into the cylinder in the form of fine spray.
- When this fine spray of diesel comes in contact with hot compressed air in the cylinder, it auto ignites resulting in the combustion of injected diesel fuel.
- Since ignition in these engines is due to the high temperature of the compressed air, they are called as Compression Ignition Engines (C.I. Engines).

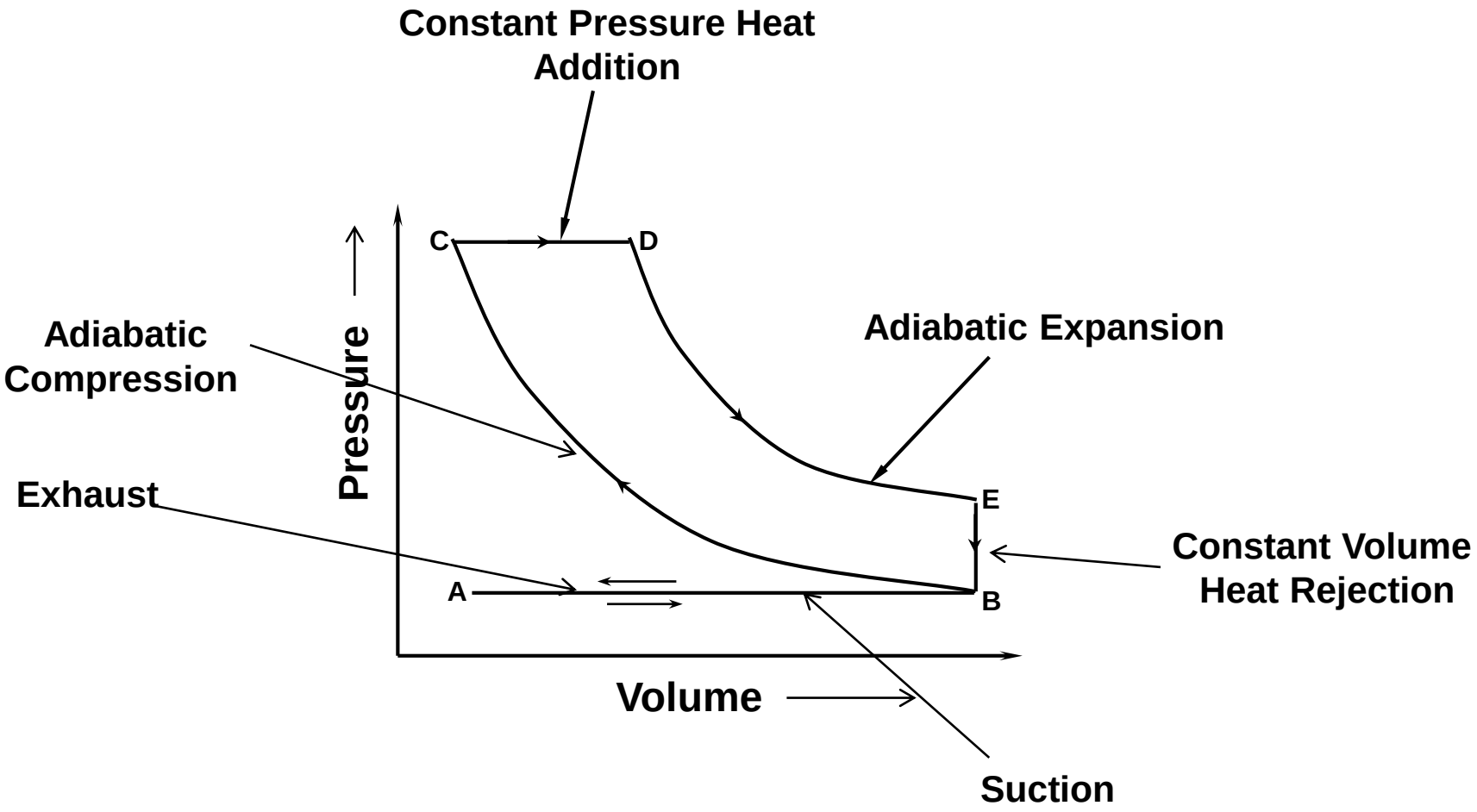
- The diesel engines works on the principle of **“ DIESEL CYCLE”** also known as ***Constant Pressure Cycle.***

- The engines operating on this cycle use either diesel fuel or vegetable oils or bio-fuels as fuel.

- .The working of the cycle takes place in 4 strokes of the piston or in two revolutions of the crank shaft.



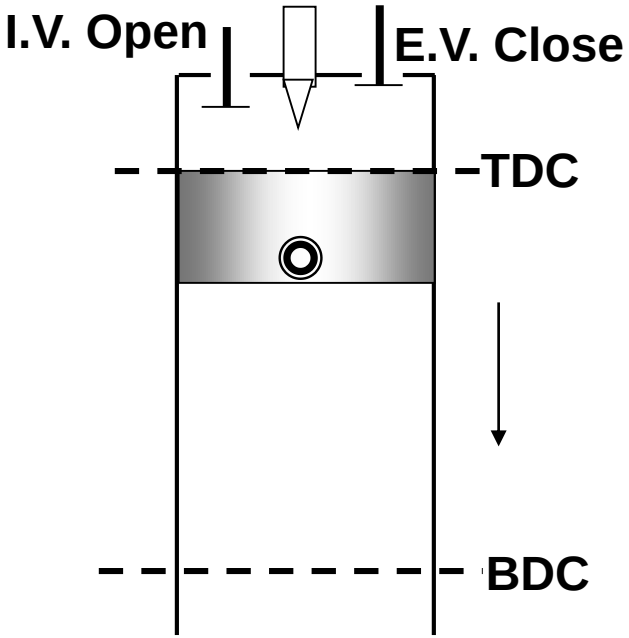
F.I. = Fuel Injector I.V. = Inlet Valve , E.V. = Exhaust Valve

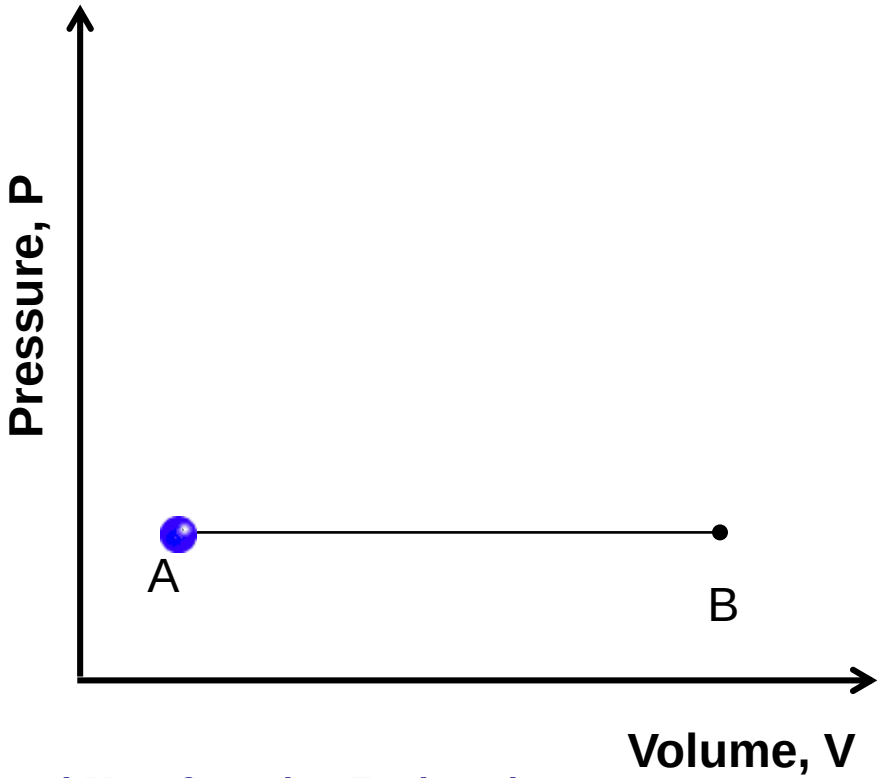


Theoretical Diesel cycle

Suction Stroke: During suction stroke the inlet valve is open and the exhaust valve closed.

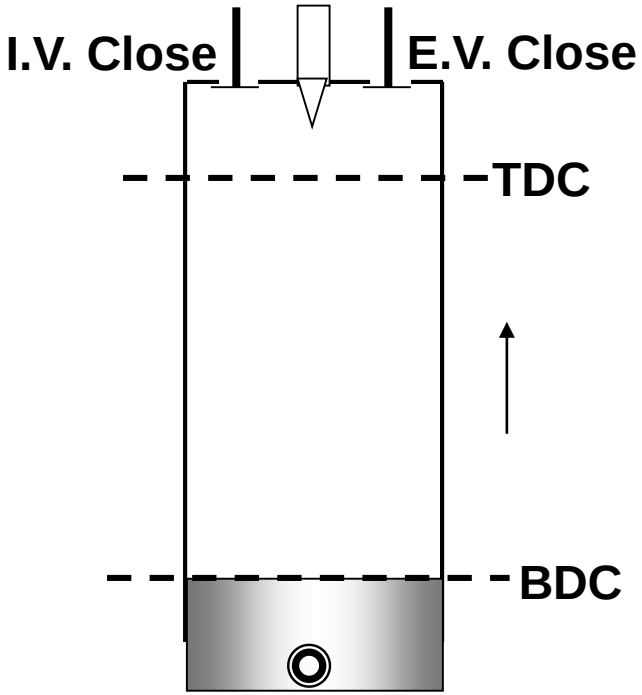
- The piston moves from TDC to BDC, drawing a fresh charge of only air . Crank shaft rotates by half a rotation.
- This stroke is represented by the line AB on the P-V diagram.

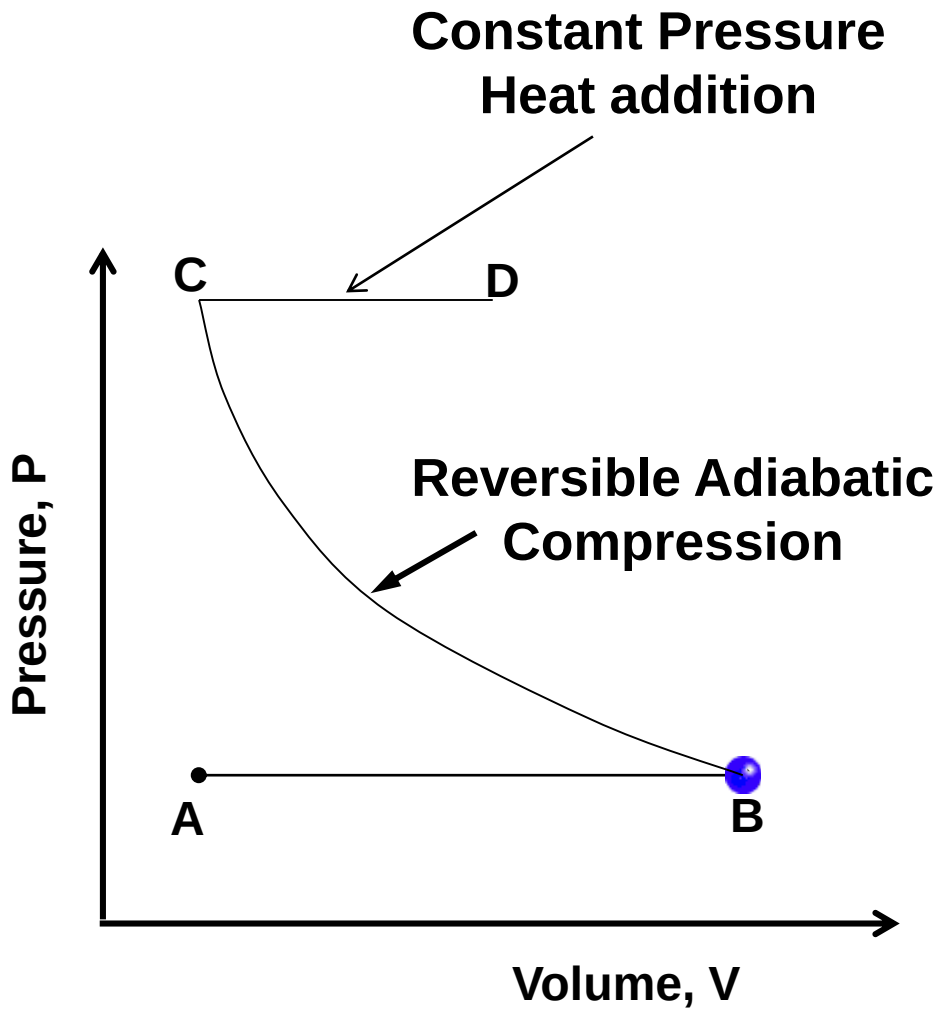




Compression Stroke: During compression stroke, both inlet & exhaust valves are closed.

- The piston moves from BDC to TDC, thus compressing the air. Crank shaft rotates by half a rotation.
- Due to compression, the pressure and temperature of the air are increased. This is shown by the curve BC on the P- V diagram which is an adiabatic compression process.
- Just before the end of this stroke the fuel injector continuously injects a metered quantity of diesel in the form of a fine spray into the hot compressed air.
- The temperature of compressed air is sufficient to ignite the diesel being sprayed. Partial expansion of burning gases at constant pressure causes the initial movement of the piston as shown by the horizontal line CD on the P-V diagram, which is a constant pressure heat addition process.


I.V. Close
E.V. Close
TDC
BDC


Constant Pressure
Heat addition
C
D
Reversible Adiabatic
Compression
Pressure, P
A
B
Volume, V

Working Stroke: During working stroke, both inlet & exhaust valves are closed.

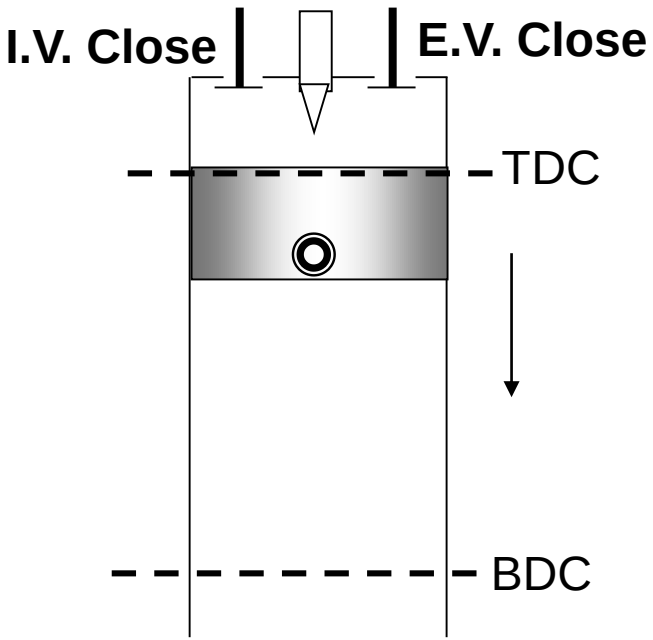
- The high pressure burning gases expand exerting pressure on the piston forcing it to move downwards from TDC to BDC producing linear motion.

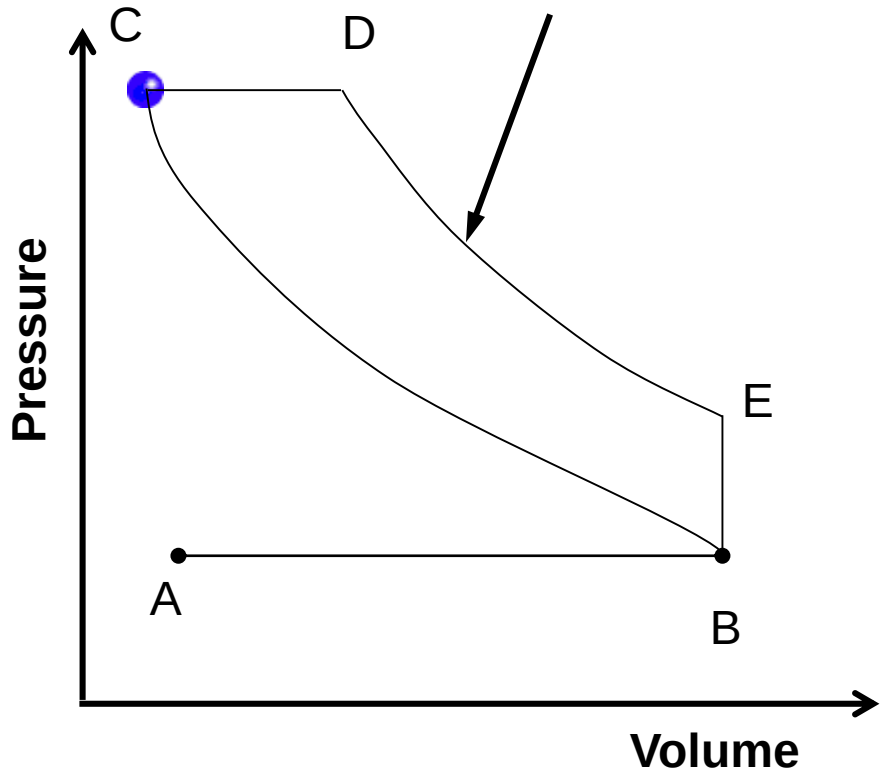
- Connecting rod and crank convert this linear motion into rotary motion of the crank shaft. Crank shaft rotates by half a rotation

- The expansion of gases is an adiabatic expansion process which is shown by the line DE on the P-V diagram.

- Just before the piston reaches BDC, the exhaust valve opens causing sudden release of gases to atmosphere resulting in sudden drop in pressure at constant volume inside the cylinder as shown by line EB on the P-V diagram.

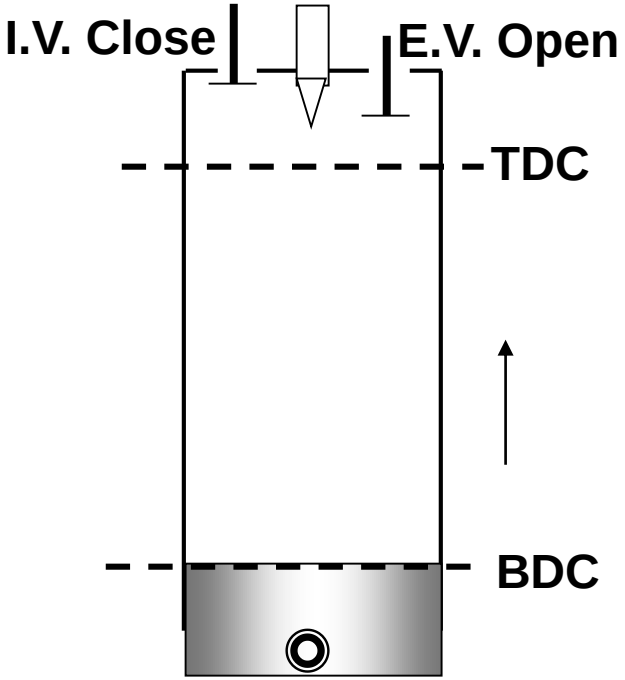
Adiabatic Expansion

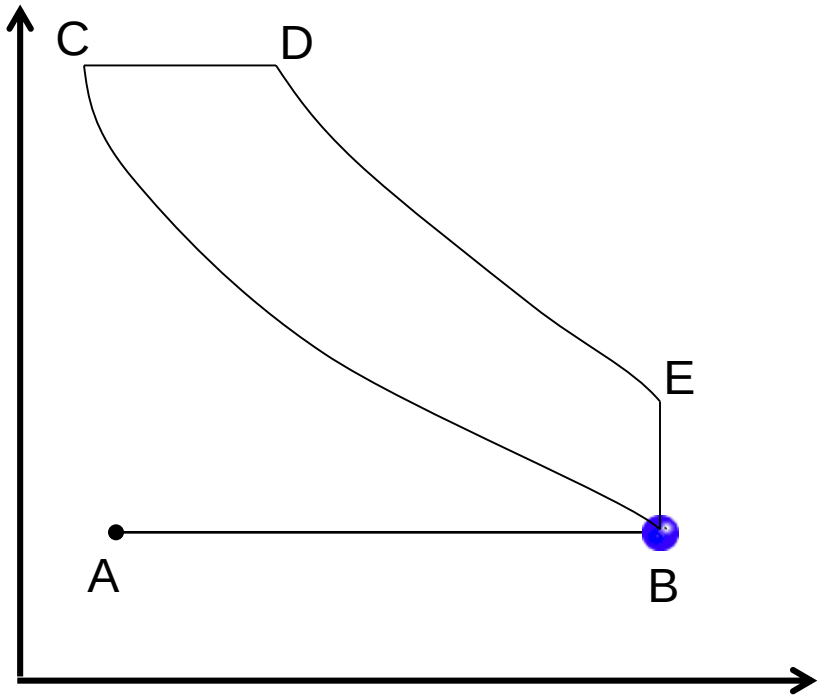




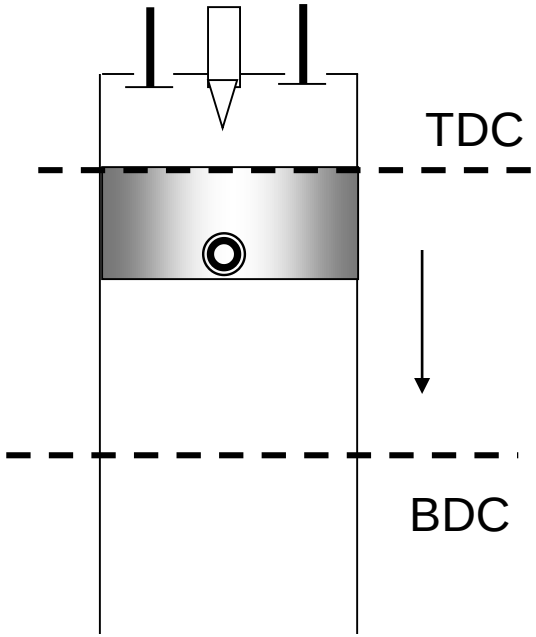
Exhaust Stroke: During the exhaust stroke the exhaust valve is open and inlet valve is closed.

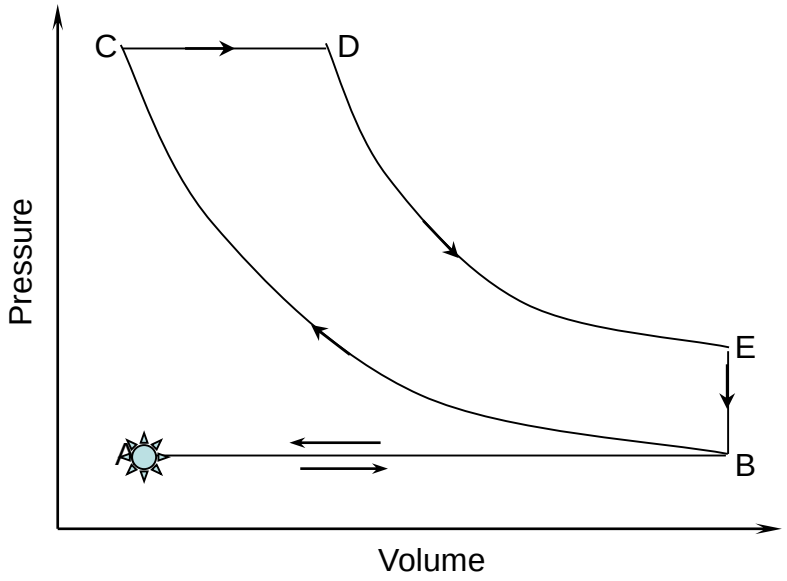
- During this stroke the piston moves from BDC to TDC and drives out the remaining gases to the atmosphere. Crank shaft rotates by half a rotation.
- This stroke is represented the line horizontal BA on the P-V diagram.





P V Diagram for C.I. Engine / Diesel Cycle Engine





Theoretical Diesel cycle

Concluding Remarks on working of 4S Diesel Engine

- Power is developed in alternate revolutions of the crankshaft.
- Energy developed during power stroke is stored in the ***flywheel.*** Energy required to perform suction, compression and exhaust stroke is provided from the flywheel.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

Flywheel is a heavy disc rigidly keyed to the crank shaft

Comparison between

Petrol & Diesel Engine

	Petrol engine	Diesel engine
1	It works on Otto cycle.	It works on diesel cycle.
2	Air and petrol are mixed in the carburetor before they enter into the cylinder.	Diesel is fed into the cylinder by fuel injectior and is mixed with air inside the cylinder.
3	Method of ignition: Spark Ignition	Method of ignition : Compression Ignition

4	Cylinder is fitted with a spark plug.	Cylinder is fitted with a fuel injector.
5	Less thermal efficiency	More thermal efficiency
6	Compression ratio ranges from 7:1 to 12:1	Compression ratio ranges from 16:1 to 22:1
7	Less initial cost and more running cost.	More initial cost and less running cost.
8	Light weight and occupies less space.	Heavy and occupies more space.

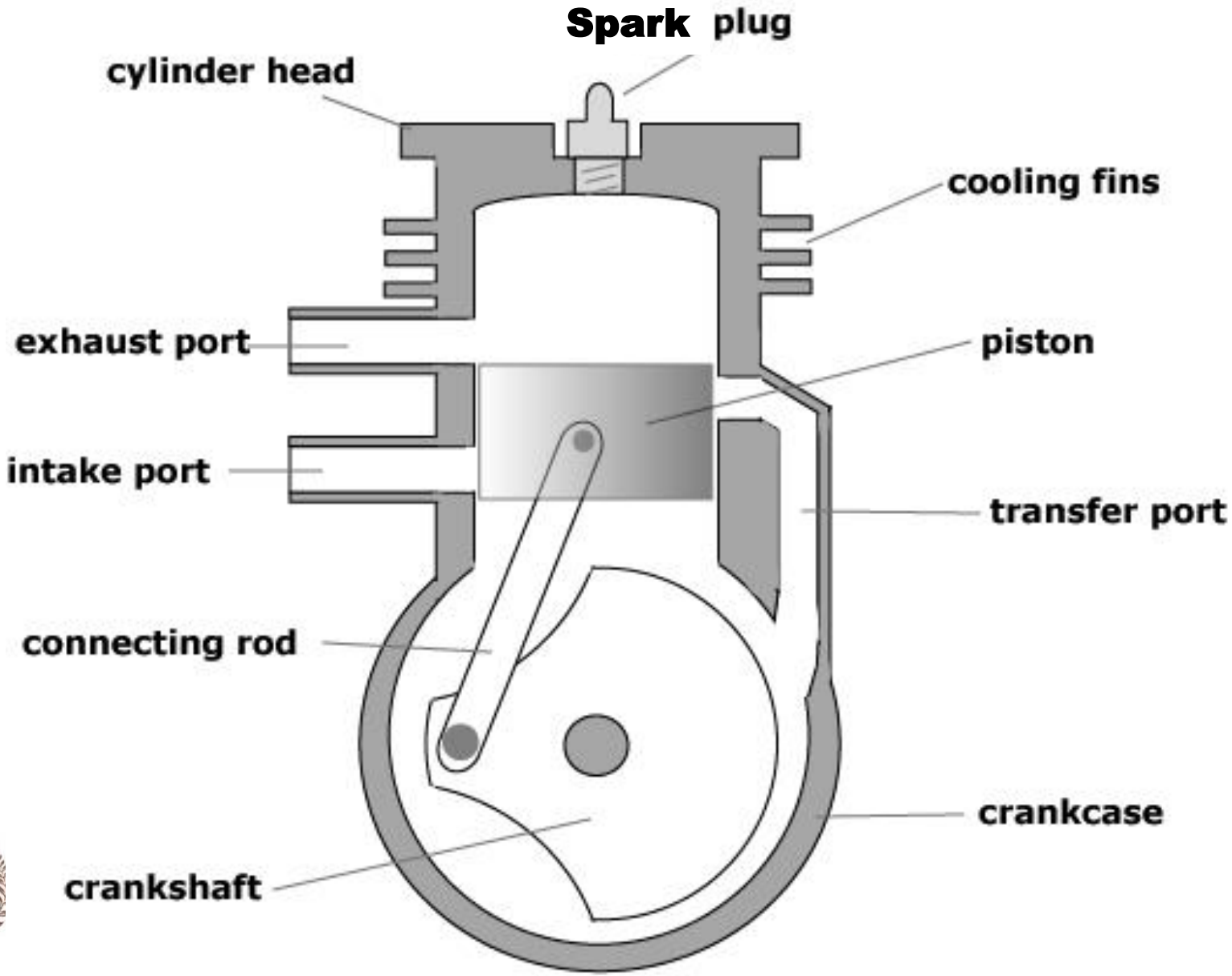
9	Easy to start even in cold weather.	Difficult to start in cold weather and requires heater plugs.
10	Used in light vehicles like cars, motor cycle, scooters, etc.	Used in heavy duty vehicles like trucks, buses, tractors, etc.

Two Stroke Engine

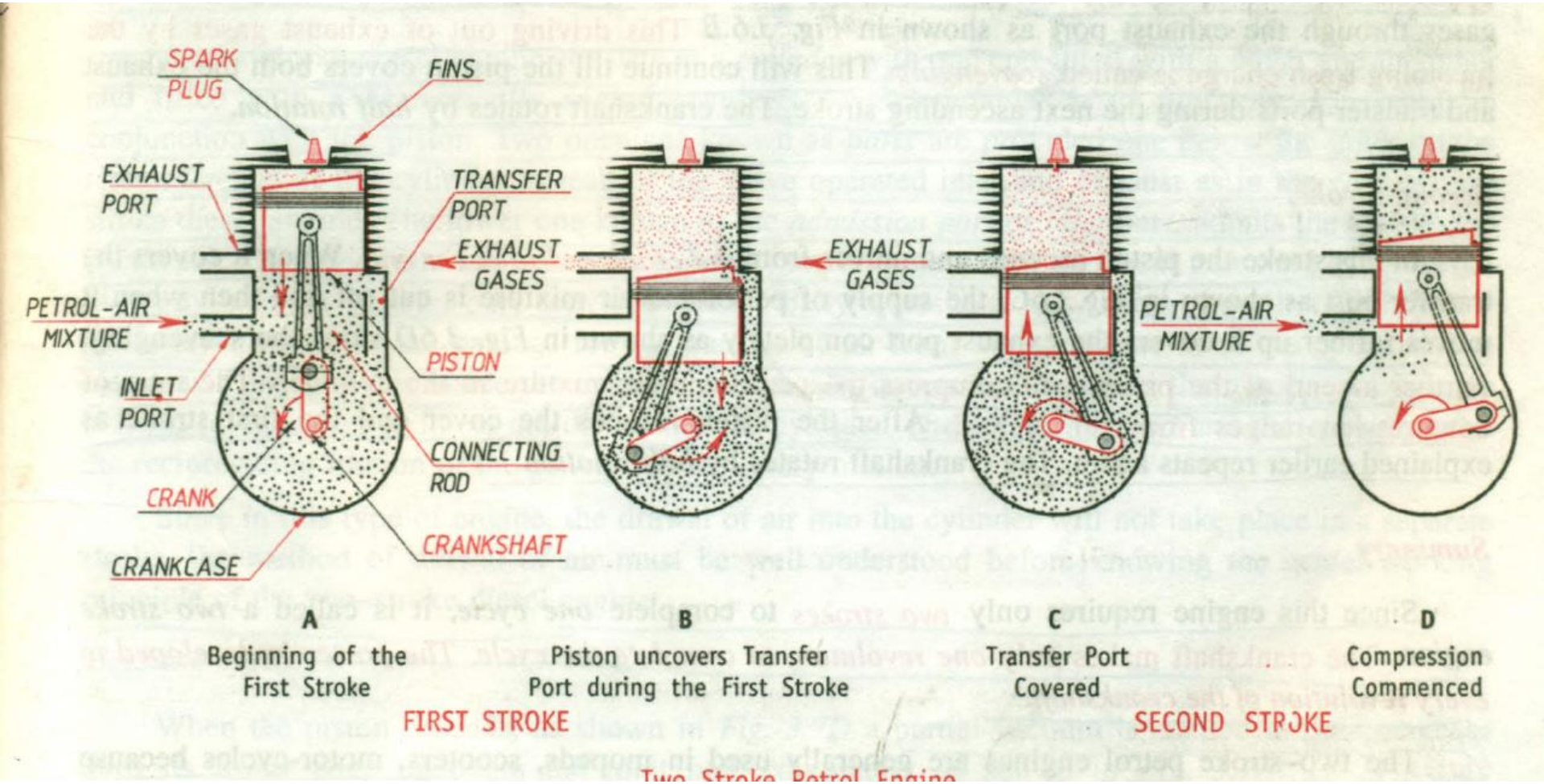
- In a two stroke engine, the working cycle is completed in ***two strokes*** of the piston or in one revolution of the crankshaft.
- Out of the four strokes, two strokes that are eliminated are, ***suction*** and ***exhaust*** strokes.
- In fact the suction and exhaust processes are performed while the power and compression strokes are in progress.
- In case of the two stroke engines instead of valves, ***ports*** are used.
- Ports in the cylinder liner are opened and closed by the piston itself.

- A two stroke engine consists of a cylinder with one end fitted with a cover and the other end fitted with a crankcase.
- Two openings known as ports are provided one below the other on the circumference of the cylinder.
- The lower one is the inlet port which admits the fresh charge into the crankcase and the upper one is the exhaust port which expels the burnt gases into the atmosphere.
- A transfer port is provided diametrically opposite to the exhaust port but slightly at a lower level. It serves as the passage for the transfer of the charge from the crankcase to the cylinder.

2-Stroke engine



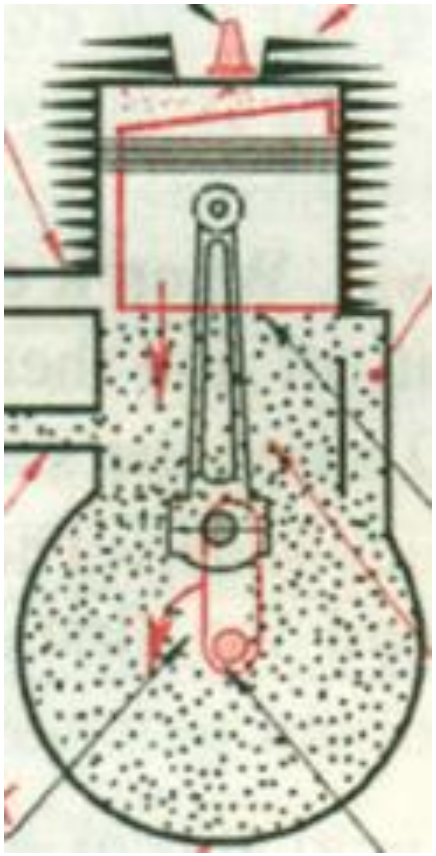
Working of Two Stroke Petrol Engine



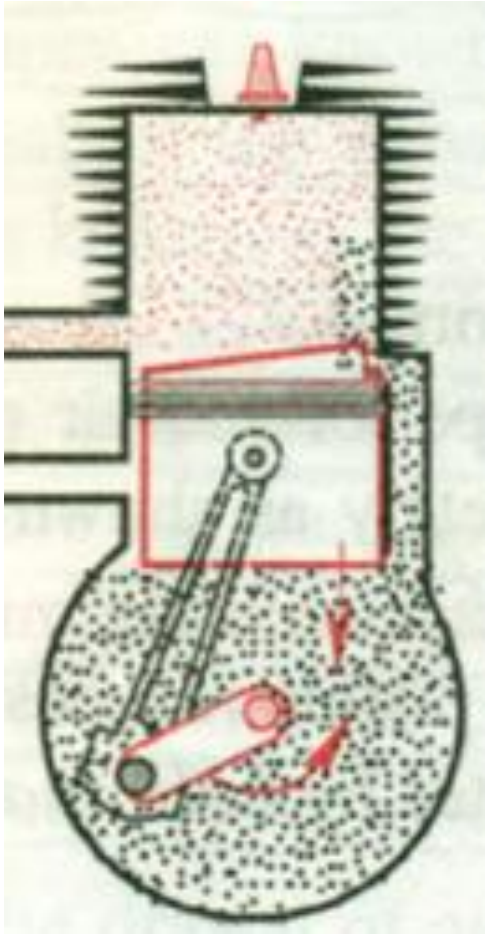
Two Stroke Petrol Engine

First stroke (Downward)

- At the beginning of the first stroke the piston is at the cover end and as soon as the charge(petrol air mixture) is ignited by the spark plug, the hot gases force the piston to move from TDC to BDC or the crank end.
- The downward movement of the piston first uncovers the exhaust port causing the burnt gases to escape to the atmosphere.
- Further downward movement of the piston covers the inlet port thereby stopping the entry of fresh air petrol mixture in to the crankcase and compressing the already drawn fresh charge in the crankcase.

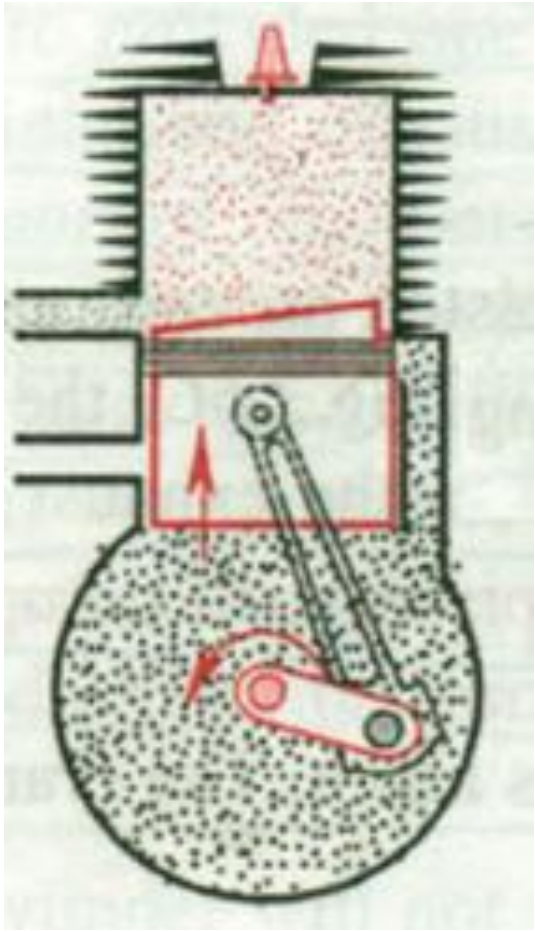


- As soon as the top edge of the piston uncovers the transfer port during its further downward movement the compressed charge from the crankcase flows into the cylinder.
- The compressed charge entering the engine cylinder, pushes the exhaust gases out of the cylinder.
- The process of removal of exhaust gases by the fresh incoming charge is known as scavenging.
- Scavenging continues till the piston covers transfer and exhaust ports during its next upward stroke.
- During this stroke crankshaft rotates by half a revolution.



Second stroke: (upward)

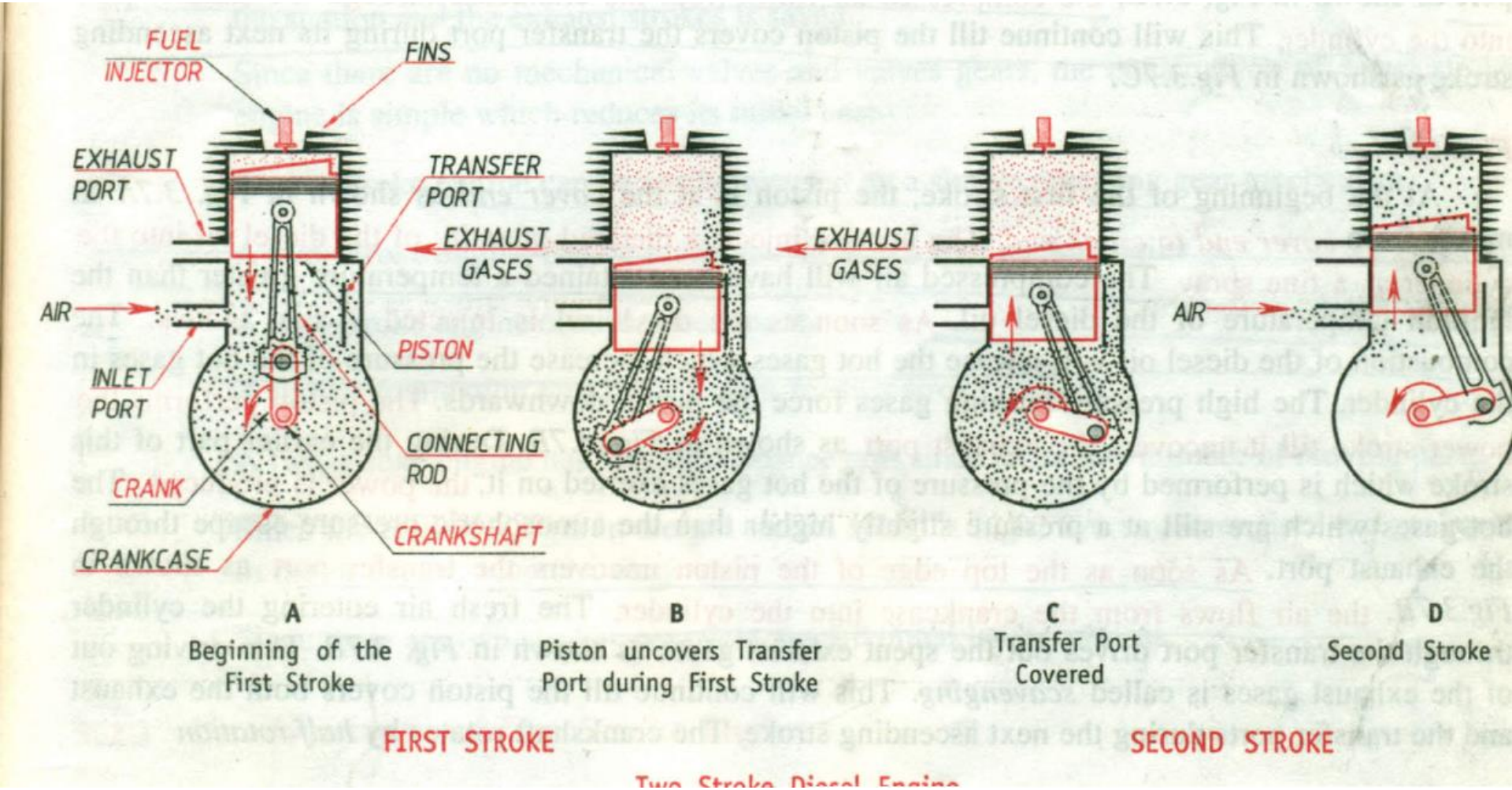
- In this stroke the piston moves from BDC to TDC. First it covers the transfer port thereby stopping the entry of fresh charge into the cylinder from the crankcase.
- Further upward movement of the piston uncovers the inlet port thereby creating a vacuum in the crankcase and fresh charge starts entering the crankcase.
- Further upward movement of the piston covers the exhaust port thereby stopping scavenging and compressing the petrol air mixture in the cylinder.
- The compressed charge is ignited in the combustion chamber by the spark plug and the cycle of events are then repeated. Crankshaft rotates by half a revolution.



Concluding Remarks on working of 2S Petrol Engine

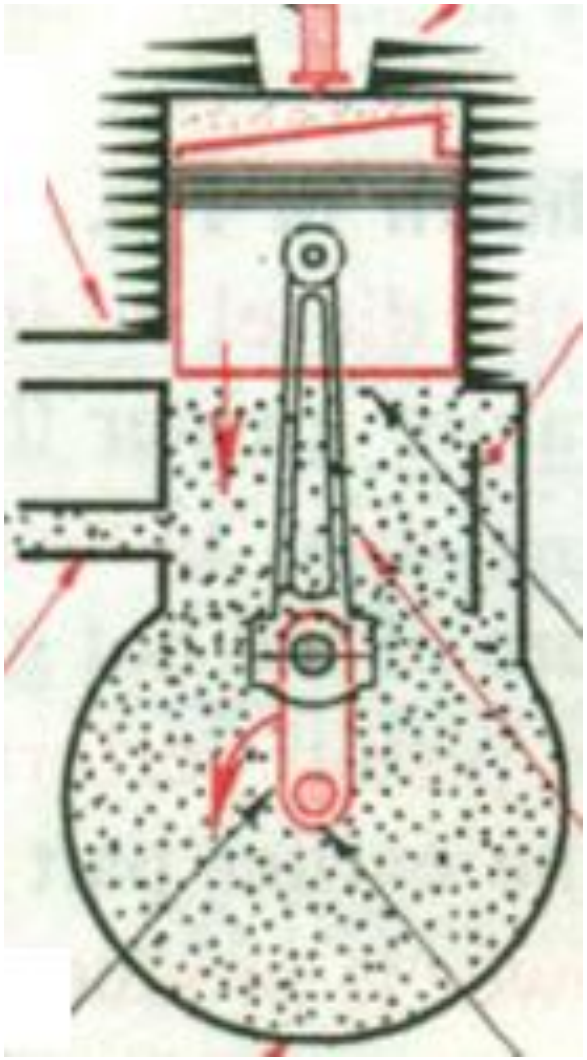
- This engine requires 2 strokes to complete one working cycle.
- The crank shaft makes one revolution to complete one cycle (half revolution per stroke).
- Power is developed in every revolution of the crankshaft.
- Energy developed during the first (power) stroke is stored in the ***flywheel.*** Energy required to perform the second stroke is provided from the flywheel.
- Smaller flywheel is required as power is developed in every revolution of crank shaft.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

Working of Two Stroke Diesel Engine

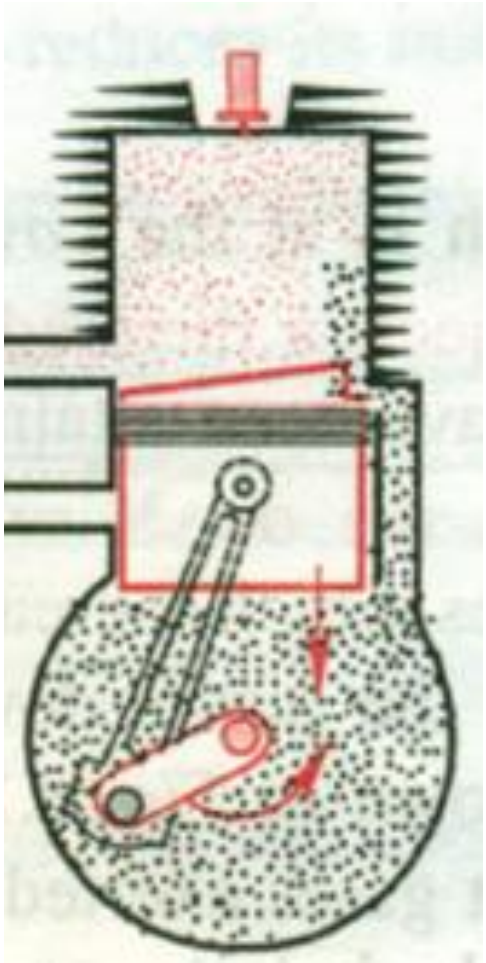


First stroke (Downward)

- At the beginning of the first stroke the piston is at the cover end and as soon as the fuel injector injects diesel into the hot compressed air, combustion starts and the hot gases force the piston to move from TDC to BDC or the crank end.
- The downward movement of the piston first uncovers the exhaust port causing the burnt gases to escape to the atmosphere.
- Further downward movement of the piston covers the inlet port thereby stopping the entry of fresh air in to the crankcase and compressing the already drawn air in the crankcase.

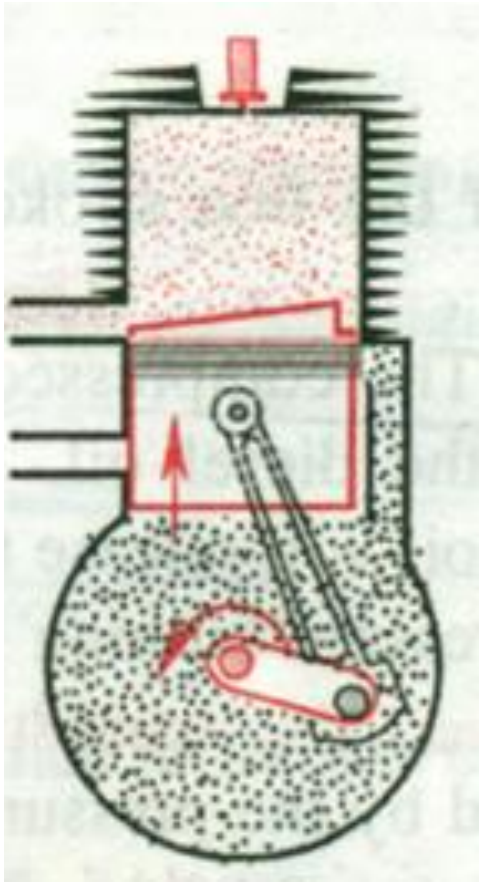


- As soon as the top edge of the piston uncovers the transfer port during its further downward movement the compressed air from the crankcase flows into the cylinder.
- The compressed air entering the engine cylinder, pushes the exhaust gases out of the cylinder.
- The process of removal of exhaust gases by the fresh incoming charge is known as scavenging.
- Scavenging continues till the piston covers transfer and exhaust ports during its next upward stroke.
- During this stroke crankshaft rotates by half a revolution.



Second stroke: (upward)

- In this stroke the piston moves from BDC to TDC. First it covers the transfer port thereby stopping the entry of fresh air into the cylinder from the crankcase.
- Further upward movement of the piston uncovers the inlet port thereby creating a vacuum in the crankcase and fresh air starts entering the crankcase.
- Further upward movement of the piston covers the exhaust port thereby stopping scavenging and compressing the air in the cylinder.
- The compressed air is ignited in the combustion chamber by the injection of diesel from the fuel injector and the cycle of events are then repeated. Crankshaft rotates by half a revolution.



Comparison between

4 - stroke & 2 - stroke Engine

	4 – stroke engine	2 – stroke engine
1	One power stroke for every two revolution of the Crank shaft	One power stroke for every revolution of the crank shaft
2	Cycle is completed in two revolutions of the crank shaft	Cycle is completed in one revolution of the crank shaft
3	Less fuel consumption	More fuel consumption.

4	Higher thermal efficiency	Lower thermal efficiency
5	Engine design is complicated	Engine design is simple.
6	Lesser rate of engine wear and tear.	Higher rate of wear and tear.
7	It has inlet and exhaust valves	It has inlet and exhaust ports

8	Engine is heavy & bulky.	For the same power, the engine is light and compact.
9	It requires lesser cooling and lubrication	It requires greater cooling and lubrication
10	Higher initial cost	Lower initial cost.
11	Lower running noise and vibration	Higher running noise and vibration.
12	Used in cars, trucks, buses, tractors, etc.	Used in mopeds, motor cycles, scooters, etc.

CARBURETOR

Function:

The main function of a carburetor is to atomize & vaporize the fuel & to mix thoroughly with air in appropriate proportion.

Atomization:

Breaking up of the fuel into small particles.

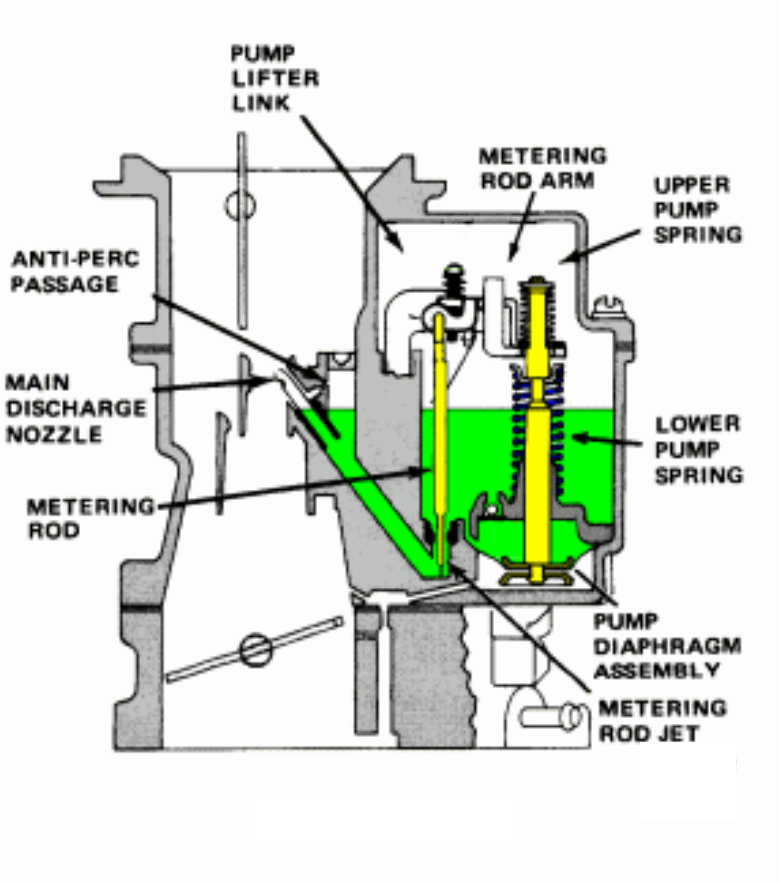
Vaporization:

Change in state of fuel from liquid to vapour.

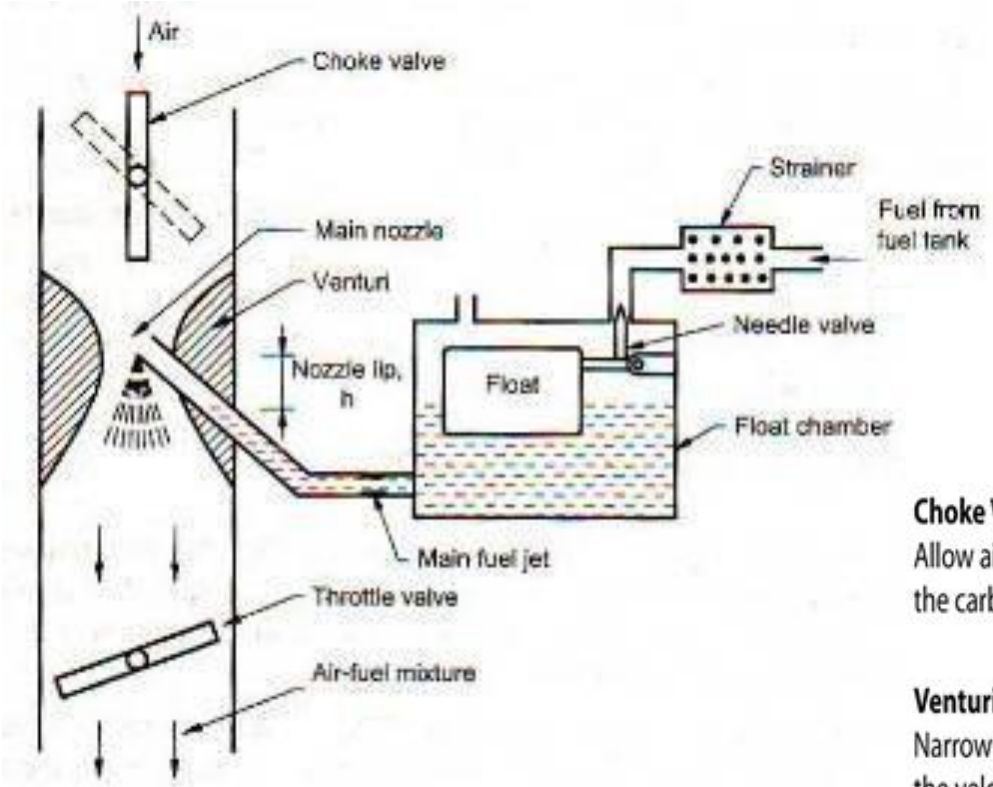
CARBURETOR

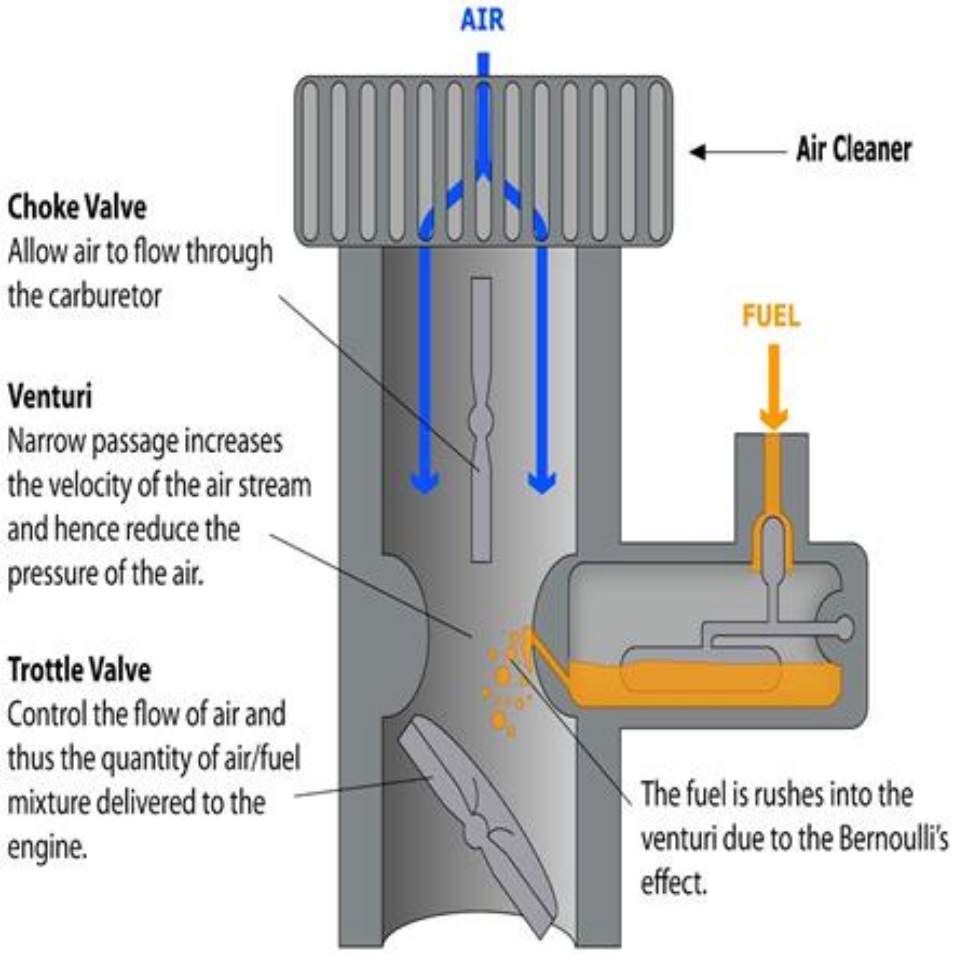
Working Principle:

- The carburetor works on Bernoulli's principle: the faster the air moves, the lower is its static pressure, and higher is the dynamic pressure.
- The throttle linkage does not directly control the flow of liquid fuel. Instead, it actuates carburetor mechanisms, which meter the flow of air being carried into the engine.
- The speed of this air flow, and its (static) pressure, determines the amount of fuel drawn into the airstream.



Working of a Simple Carburetor





- As the fuel level drops, the float comes down thereby opening the needle valve and enabling the petrol to enter into the float chamber.
- Purpose of needle valve is to maintain the constant level of petrol in the float chamber.
- During suction stroke, pressure at the throat reduces and because of the reduced pressure developed in the venturi region petrol comes out of the nozzle as a fine spray & gets vaporized.
- The amount of petrol issuing from the jet is proportional to the velocity of air through the venturi tube which depends upon the position of the throttle valve operated by the accelerator.
- Choke is used for starting the engine when it is in the cold condition.

I.C.ENGINE RELATIONS

- **Indicated Power [I.P.]:** It is the power developed inside the IC engine cylinder

$$Indicated\ power = \frac{i \times P_m \times L \times A \times n}{60000} \quad \text{kW}$$

Where, i = no. of cylinders

n = No. of working cycles/ min.

n = N/2, for 4 stroke engine

= N, for 2 stroke engine

L = Stroke length (m),

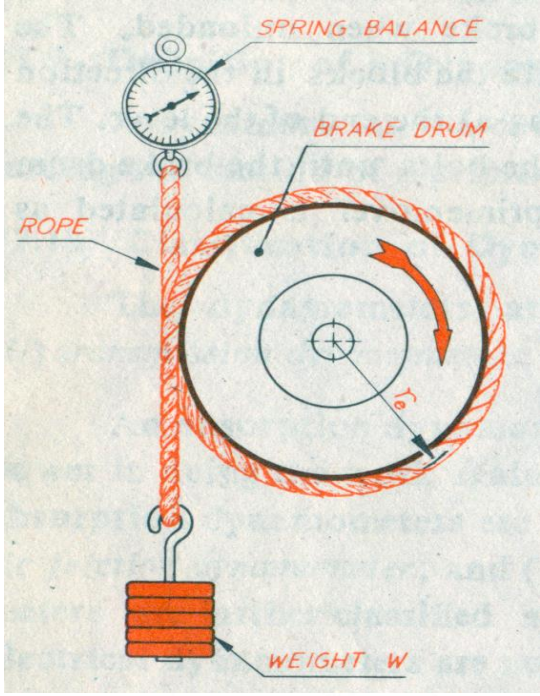
D = Bore diameter (m)

P_m = Indicated mean effective pressure (N/m^2)

A = Area of the cylinder, $A = \frac{\pi}{4} D^2, m^2$

- **Brake Power [B.P]:** It is the power developed by the engine at the output shaft.

$$Brake\ Power = \frac{2\pi NT}{60000} \quad kW$$



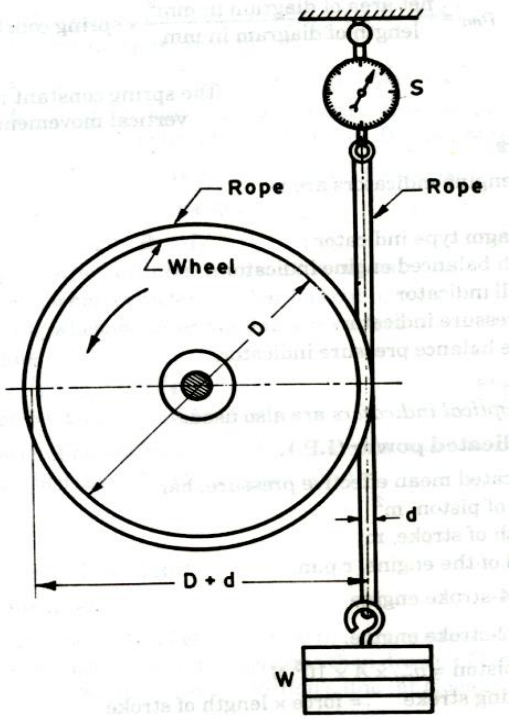
Where, N = Speed of the crank shaft in rpm.

T =Torque applied on the brake drum due to load "W_{net}", (N-m)

$$T = W_{net} R_d \quad N\text{-}m$$

W_{net}= Net load acting on the brake drum (N)

R_d = Radius of the brake drum (m)



- **Frictional Power [F.P]:** It is the difference between the indicated power and the brake power.

$$F.P. = [I.P. – B.P.] \quad kW$$

- **Mechanical Efficiency [η_{mech}]:** It is the ratio of the brake power and the indicated power.

$$Mechanical\ \ efficiency, \eta_{mech} = \frac{B.P.}{I.P.} \times 100\%$$

- **Brake thermal Efficiency [η_{bth}]:** It is the ratio of the brake power to the heat energy supplied by the fuel.

$$\eta_{bth} = \frac{B.P \times 3600}{m_f \times C_v} \text{x}100\%$$

- **Indicated thermal Efficiency [η_{ith}]:**
  It is the ratio of the indicated power to the heat energy supplied by the fuel.

$$\eta_{ith} = \frac{I.P \times 3600}{m_f \times C_v} \text{x}100\%$$

Where, m_f = mass of the fuel supplied (kg/hr)

C_V = Calorific Value of the fuel (kJ/kg)