

# INTRODUCTION TO AUTOMOBILE ENGINEERING



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# Curriculum

## **A. MODULE - I (16 hours)**

- **Automobile Architecture:**

Definition of automobile, Automobile layout, Chassis, Automobile body, Automobile types: Front, Rear and Four-wheel drive, Safety parameters, Regulatory bodies.

- **Various Units of an Automobile:**

Engine and its different systems (Fuel system, Cooling system, Lubrication system), Air intake and exhaust system, Transmission system, Steering system, Suspension system, Brake system, Battery and ignition system, Electrical system.

- **Engine:**

Classification of engine, Engine nomenclature, Components of engine, Engine performance parameters, Valve timing diagram of SI & CI Engines, Modern development of engines: CRDI, GDI, HCCI, Dual fuel engine, Stratified charge engine.

## **B. MODULE – II (15 hours)**

- **Thermodynamic analysis of Cycles:**

Air Standard Cycles- Otto, Diesel and Dual Cycle, Actual cycles.

- **Carburetion:**

Factors affecting carburetion, Principle of carburetion, Modern Carburettor, Additional systems in carburettor, Vacuum type carburettor.

- **Fuel Injection:**

Classification of injection systems, Fuel feed pump, Injection pump, Injection pump governor, Mechanical governor, Fuel injector, Nozzle, Electronic injection Systems, Multi-Point Fuel Injection (MPFI) system, Injection timing.

### **C. Module- III (14 hours)**

- **Transmission System:**

Layout of power flow from engine to wheels, Basics regarding Clutch, Gearbox, Propeller shaft and Differential, Automatic transmission system, Torque convertor, Overdrive.

- **Cooling and Lubrication System:**

Air cooling & water cooling systems, Effect of cooling on power output and efficiency, Properties of lubricants and different types of lubricating system.

- **Supercharging and Turbocharging:**

Effect of super charging, Methods of super charging, Basic principle and method of turbo charging.









# MODULE-

# I



# AUTOMOBILE ARCHITECTURE

## DEFINITION OF AUTOMOBILE

Automobile: Auto + Mobile = Self + Mobile

This French original word means all “Vehicles that are Self-powered”.

To put it simply, *anything that has its own power source and moves on the road is an automobile*. It can be a car, bike, auto rickshaw, truck, bus, tractor powered by an internal combustion engine. It can also be a vehicle powered by alternative means like an electric battery, fuel cell etc. *This definition excludes aircrafts, trains and ships from the definition of automobile.*

## CLASSIFICATION OF AUTOMOBILE

Automobiles can be classified into several types based on many criteria. A brief classification of automobiles is listed below: -

### Based on Purpose:

- **Passenger vehicles:** These vehicles carry passengers e.g. Buses, Cars, 2/3 wheelers etc.
- **Goods vehicles:** These vehicles carry goods from one place to another place. e.g. Goods lorry, Goods carrier.
- **Special Purpose:** These vehicles include Ambulance, Fire engines, Army Vehicles, Concrete mixers, Dump trucks, Garbage compactors, aerial platform trucks, mobile / high reach cranes, material handling forklifts, agricultural tractors etc.

### Based on Load Capacity:

- **Light Motor Vehicle (LMV):** Small motor vehicles. e.g. Car, Jeep, Scooter, motorcycle etc.
- **Medium Duty Vehicle:** Relatively medium sized vehicles e.g. small trucks, mini buses etc.
- **Heavy Motor Vehicle (HMV):** Large and bulky motor vehicles. e.g. Bus, Truck, Tractor etc.

### Based on fuel used:

- **Petrol engine vehicles:** Automobiles powered by a petrol engine. e.g.: scooters, cars, motorcycles.
- **Diesel engine vehicles:** Automobiles powered by diesel engine. e.g.: Trucks, Buses, Tractors.
- **Gas powered vehicles:** Vehicles that use LPG, CNG, Propane etc. or Gas turbine as a power source.

- **Electric vehicles:** Automobiles that use electricity as a power source. e.g. Electric cars, electric buses.
- **Solar vehicles:** Automobiles using solar energy e.g. solar powered cars.
- **Hydrogen vehicles:** Automobiles using hydrogen as power source. e.g. Honda FCX Clarity.
- **Hybrid vehicles:** Vehicles that use two or more distinct power sources e.g. Hybrid buses, hybrid cars like Toyota Prius, Honda Insight etc. These use an electric motor and an internal combustion engine, or an electric motor with a battery and fuel cells for energy storage.

#### Based on Drive of the vehicles:

- **Left-Hand drive (LHD):** Steering wheel fitted on the left-hand side.
- **Right-Hand drive (RHD):** Steering wheel fitted on the right-hand side.
- **Fluid power drive:** Vehicles employing torque converter, fluid coupling or hydramatic transmission.

#### Based on number of wheels and axles:

- **Two-wheelers:** Motorcycles, Scooters.
- **Three-wheelers:** Tempo, Auto-rickshaws.
- **Four-wheeler:** Car, Jeep, Bus, Truck.
- **Multi axle vehicle:** Vehicles that have more than two-axles e.g. Tata 3118 Trucks, Ashok Leyland U3718 Trucks, Volvo B9400 Buses.

#### Based on type of transmission:

- **Automatic transmission vehicles:** Automobiles that are capable of changing gear ratios automatically as they move. e.g. Automatic Transmission Cars.
- **Manual transmission vehicles:** Automobiles whose gear ratios have to be changed manually.
- **Semi-automatic transmission vehicles:** Vehicles that facilitate manual gear changing without a clutch pedal. This is also known as automated manual transmission (AMT).

#### Based on Suspension system used:

- **Dependent Suspension–** Vehicle using Leaf Spring suspension e.g. Trucks.
- **Independent Suspension–** Vehicle using Coil spring, Torsion bar, Pneumatic suspension e.g. cars.



### Based on Body style:

- **Closed Cars**– Vehicles e.g. Sedans, SUV Coupe, Saloon cars etc.
- **Open Cars**– Vehicles e.g. Sports cars, Convertibles etc.
- **Special Style Vehicles**- Estate cars, Station wagons etc.

### Based on Number of Drive wheels of the Vehicle:

- **Single-wheel drive vehicle**
- **Two-wheel drive vehicles**
- **Four-wheel drive vehicles**
- **Six-wheel drive vehicles**

### Based on Side of Drive axles of the Vehicle:

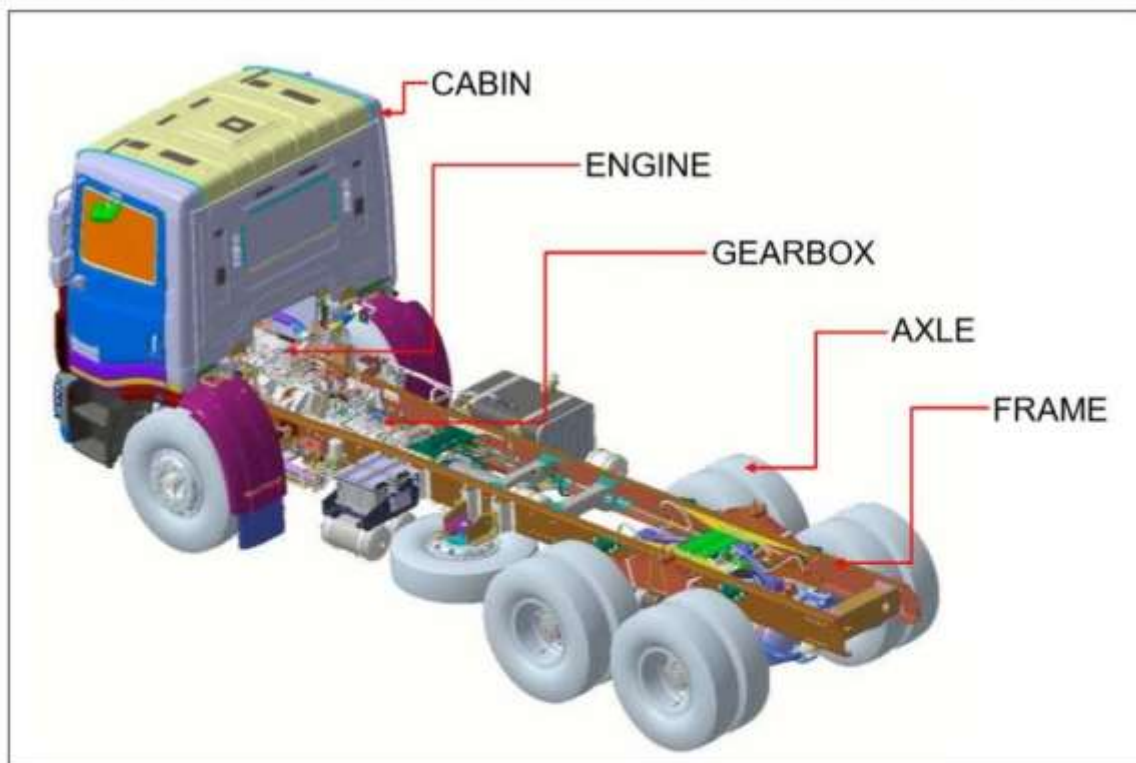
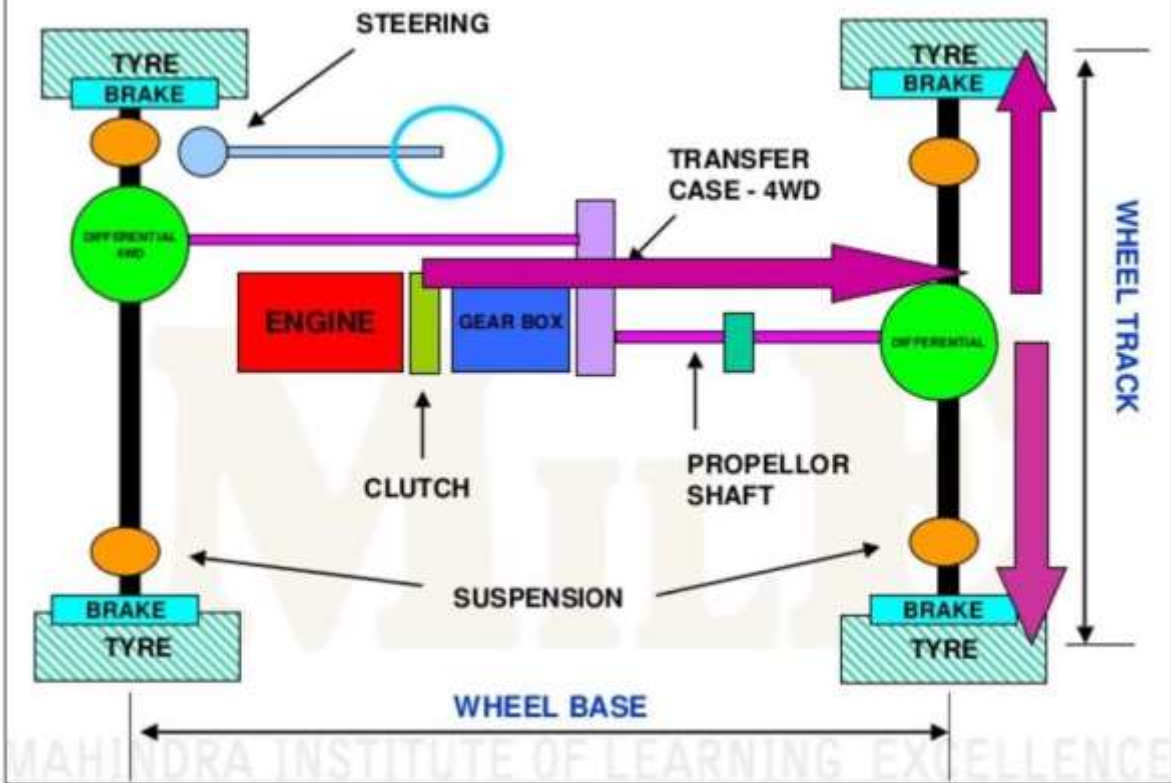
- **Front wheel drive vehicles**- Most of the light weight passenger cars.
- **Rear wheel drive vehicles**- Trucks and Buses
- **Four-wheel / All-wheel drive vehicles** – Jeep, Military trucks, Off-road vehicles

## **MAJOR UNITS OF AUTOMOBILE**

- An engine or *Power plant* that produces power to move the vehicle.
- A *Power train* to carry power from engine to the drive wheels. This has several sub-units.
- A *Suspension system* that absorbs the shock of the tyres and wheels meeting bumps and holes in the road.
- A *Steering system* so that the driver can control the direction of the vehicle travel.
- A *Braking system* so that the driver can slow or stop the movement of the vehicle.
- An *Electrical system* to provide electricity for cranking of the engine, charging the battery and powering of the lights and other electrical equipment.
- A *Body* that provides enclosures or compartments for the engine, passengers and luggage or cargo.
- A *Frame* to hold and provide support to above units to enable turning the entire system into a power operated vehicle.

Detailed explanation of these major units is provided in next chapter.

## ANATOMY OF AN AUTOMOBILE - DRIVELINE





Pictures of major units /aggregates of an automobile are shown below: -



Engin



Power Train (Sub-units shown)





Clutch



Transmission



Transfer Case



Dead Front



Propeller



Live Front



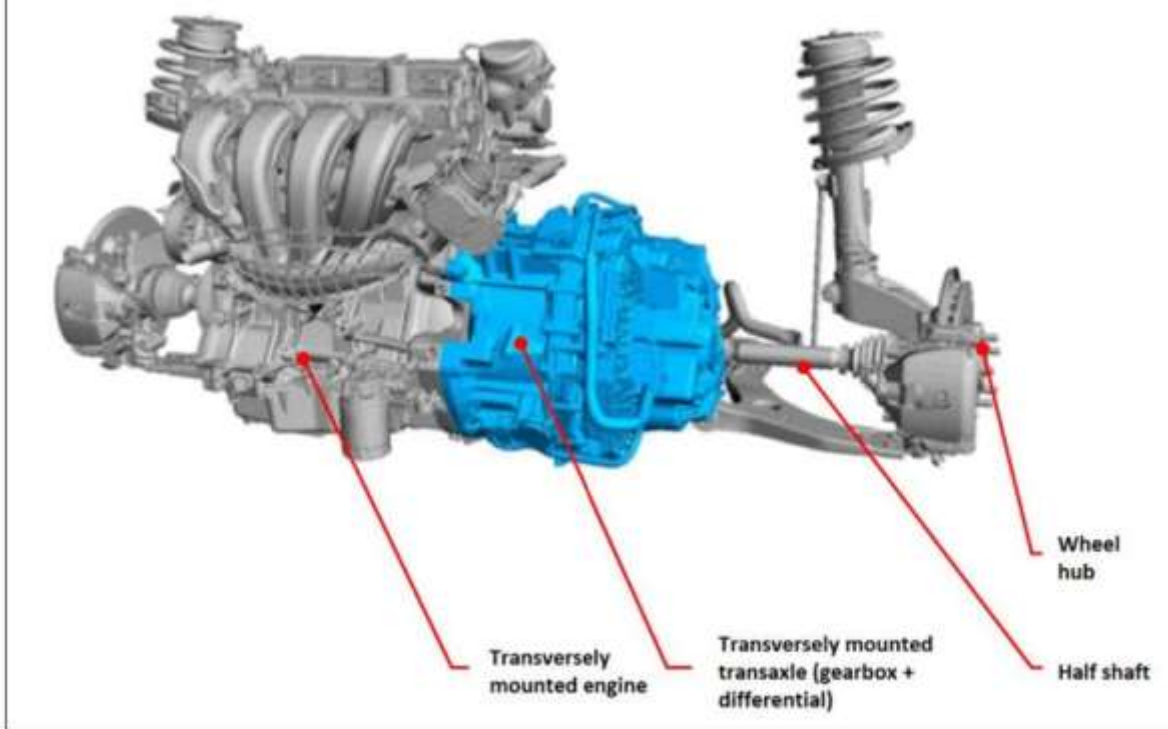
Live Rear Axle



Multiple Live Rear



## Transaxle Location



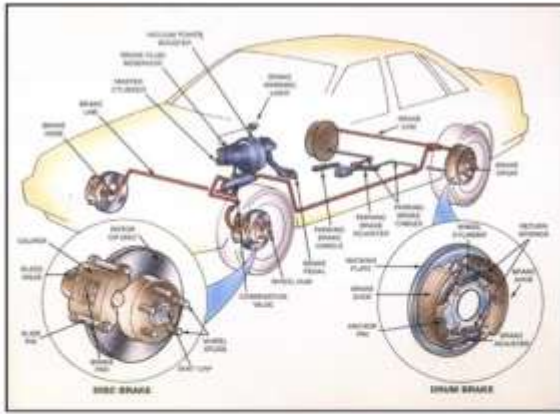
Transaxle (Transmission +



Suspensi



Steering



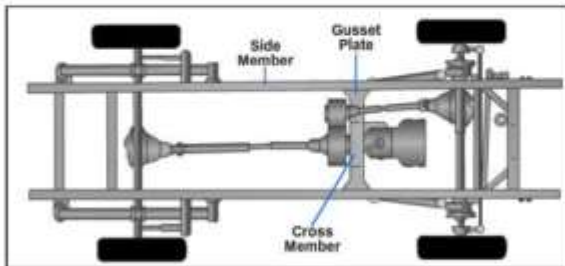
Braking



Electrical



Automobile Body



Ladder Type



Monocoque Type or Frameless

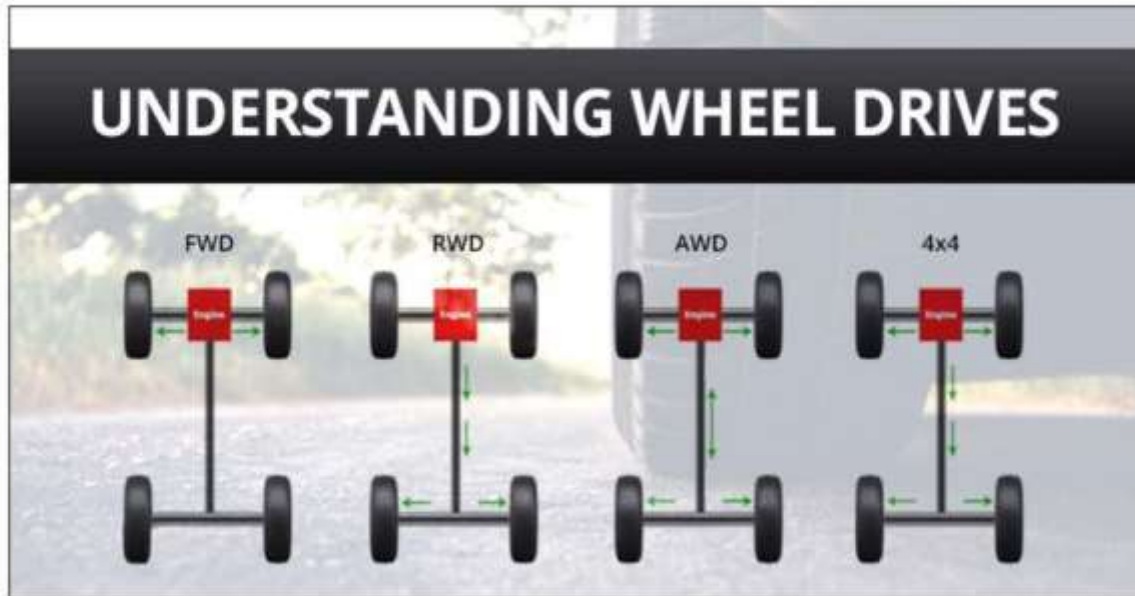
## **AUTOMOBILE LAYOUTS**

*The automobile layout describes the location of "Engine" and "Drive wheels" with reference to each other and where they are placed in the vehicle.* Many different combinations of engine location and driven wheels are found in practice, and the location of each is dependent on the application for which the vehicle will be used. Factors influencing the design choice include cost, complexity, reliability, packaging (location and size of the passenger compartment and boot), weight distribution, and the vehicle's intended handling characteristics.

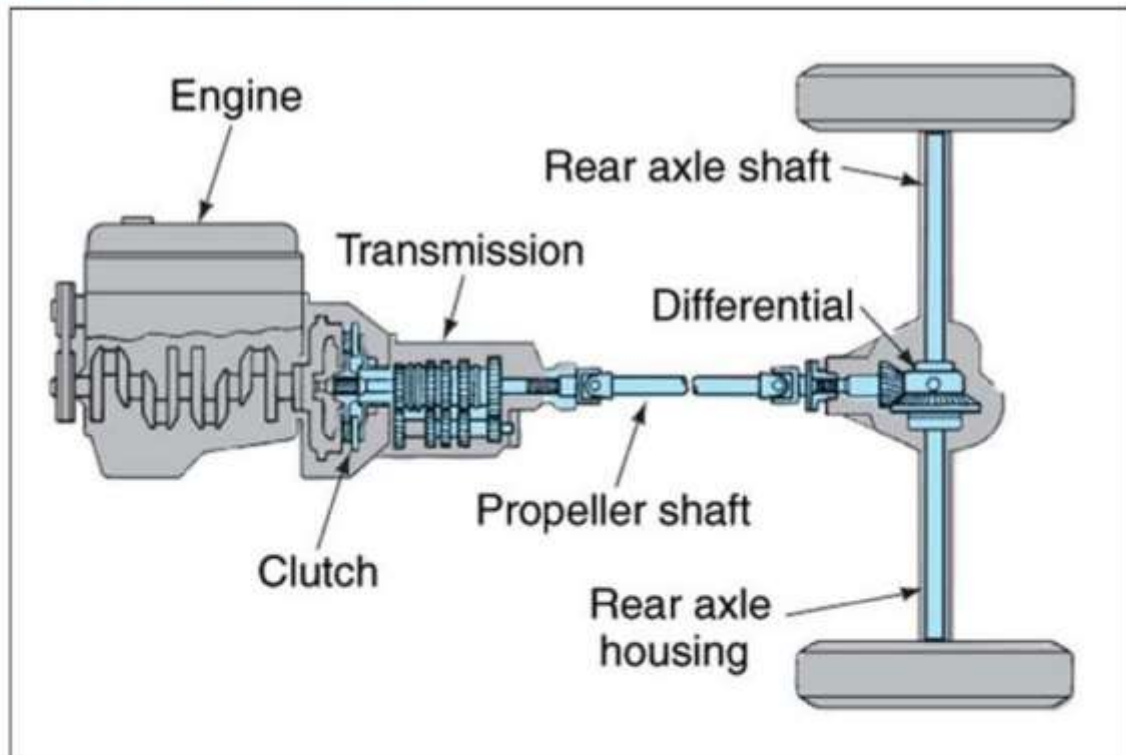
*Different types of Automobile Layouts are: -*

- Front Engine, Rear wheel drive
- Front Engine, Front Wheel Drive

- Front Engine, Four Wheel / All-Wheel Drive
- Rear Engine, Rear Wheel Drive
- Mid-engine, Rear Wheel Drive



Front Engine, Rear wheel drive (FR)







*In this layout, a front mounted engine-clutch-gear box unit drives a beam type rear axle suspended on leaf springs through a propeller shaft with two universal joints. With the help of coil springs, the front wheels are independently sprung. The vast majority of rear-wheel-drive vehicles use a longitudinally mounted engine in the front of the vehicle, driving the rear wheels through a driveshaft linked via a differential between the rear axles. This layout is one of the oldest layouts that has remained unchanged for many years.*

### Advantages

- **Even weight distribution** — The layout offers reasonably balanced weight distribution between both front wheels and rear wheels thereby providing good handling characteristics.
- **Weight transfer** during acceleration — During heavy acceleration, weight is placed on the rear, or driving wheels, which improves traction.
- **No Torque steer**- Torque steer means unintended influence of engine torque on steering wheels causing a tugging sensation at the steering wheel. This is not felt in this type of layout.
- **Steering radius** — As no complicated drive shaft joints are required at the front wheels, it is possible to turn them further than would be possible using front-wheel drive, resulting in a smaller steering radius for a given wheelbase. Also, since the engine is located longitudinally, movement of steered wheels are easier.
- **More Luggage space** — Behind the rear seats, large luggage space is available by providing increasing carrying capacity as well as space for easy body movement.
- **Better Braking** — the more even weight distribution helps prevent lockup from the rear wheels becoming unloaded under heavy braking.
- **Towing** — Rear-wheel drive puts the wheels which are pulling the load closer to the point where a trailer articulates, helping steering, especially for large loads.
- **Serviceability** — Accessibility of various parts like engine, transmission, rear axles are better compared to other layouts.

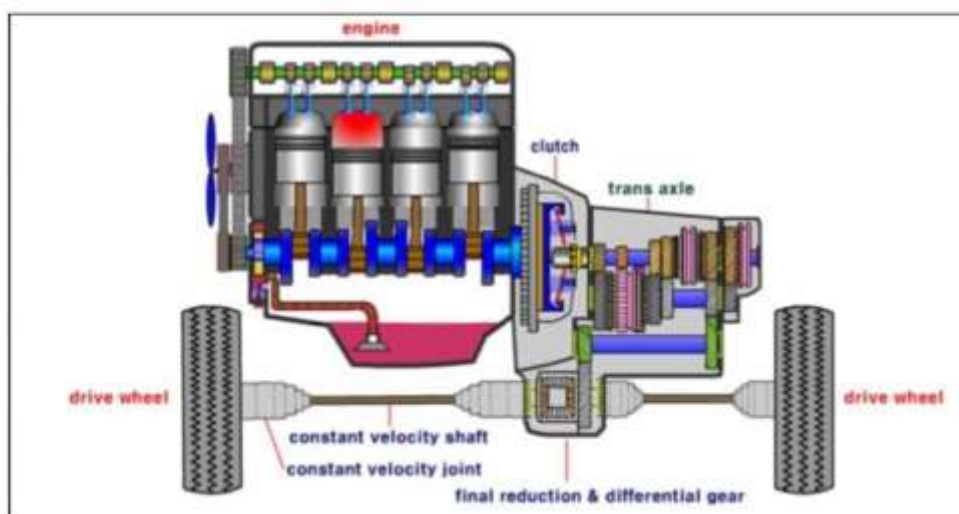


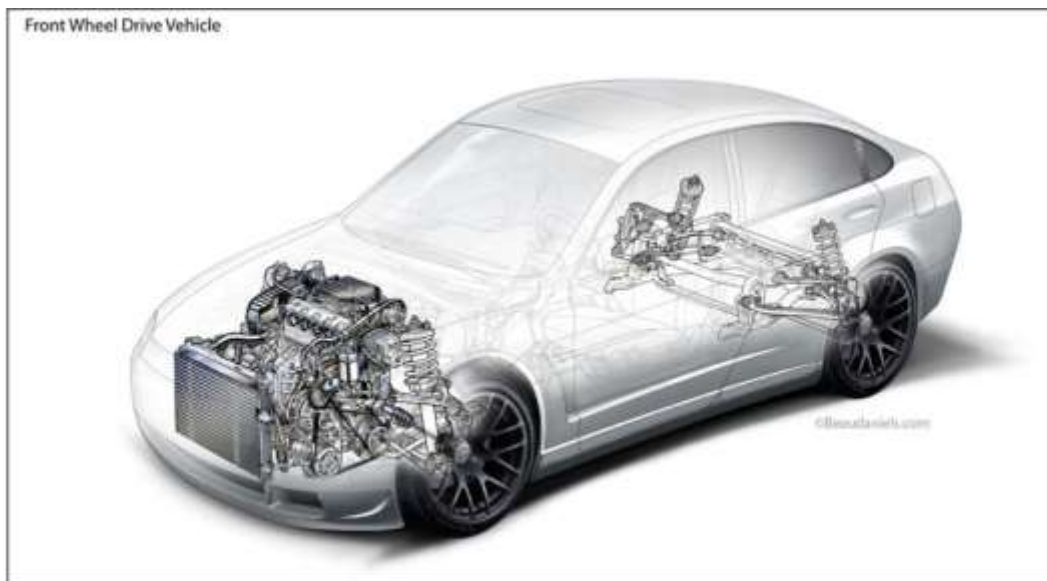
- **Simple and small Control linkages**— Control linkages like accelerator, clutch, gear shift etc. are short and simple.
- **Can accommodate more powerful engines-** This is due to the longitudinal of the drivetrain. Engines such as Inline-6, 90° big-bore V8, V10 and V12 used in luxury and sports cars can easily be accommodated.
- **Better Engine cooling** – The natural air flow created by forward vehicle movement greatly assists cooling in front placed radiator. This results in superior engine cooling and also does not require a powerful cooling fan consuming more power from the engine.

### Disadvantages

- **Vibration due to Split Propeller shaft-** A single or split propeller shaft with universal joints and supporting bearings between front mounted gearbox and rear axle may generate vibration, drumming, howl and other noises under certain operating conditions.
- **Propeller Shaft floor tunnel-** The floor tunnel is necessary to provide a clearance for the operation of a propeller shaft system and it may interfere with passenger leg-room.
- **Loss of Rear wheel drive Traction on Snow, ice and sand -** During braking, loss of traction on drive wheels are noticed particularly in pickup trucks, as the weight of the engine and cab significantly shift the weight from the rear to the front wheels. A rear-wheel-drive vehicle when stuck in mud also tends to plough further into the ground when attempts are made to drive away.
- **Increased weight** — This is due to need for propeller shaft and its tunnel on the vehicle floor, longer rear axle half shafts etc. A rear-wheel-drive car will weigh slightly more than a comparable front-wheel-drive car (but less than four-wheel drive).
- **Higher initial purchase price** — Modern rear-wheel-drive vehicles are typically more expensive to purchase than comparable front-wheel-drive vehicles.

### Front Engine, Front wheel drive (FF)





*In this layout the front wheels of the vehicle are driven with the engine placed at the front of the vehicle.* In this arrangement the engine and transmission unit are placed in transverse manner with respect to the longitudinal axis of the vehicle. No propeller shaft is used in the front engine front wheel drive and differentials are included in the same assembly. This layout provides an optimum body-luggage space and a flat front line resulting due to the transverse longitudinal engine position. A good road adhesion is provided by the large proportion of vehicle's weight acting on driven wheels. *This is the most popular layout used in modern cars today due to its compact packaging.*

### Advantages

- **Larger Interior space:** Since the powertrain is a single unit contained in the engine compartment of the vehicle, there is no need to devote interior space for a driveshaft tunnel or rear differential. This increases the volume available for passengers and cargo. Instead, the tunnel may be used to route the exhaust system pipes.
- **Reduced Weight:** Fewer components means lower weight.
- **Improved fuel efficiency:** This is due to less weight.
- **Assembly efficiency:** The powertrain can often be assembled and installed as a sub-assembly, which allows more efficient production. This also brings down the manufacturing cost.
- **Good road adhesion:** Good road adhesion is obtained as large part of vehicle weight is carried by the front driving wheels under normal conditions. This also provides improved directional stability on wet, snowy, or icy surfaces compared to a FR-layout.
- **Lower flat floor line:** This is possible due to dispensing of propeller shaft which eliminates need for propeller shaft tunnel and also lowers the centre of gravity of the vehicle.

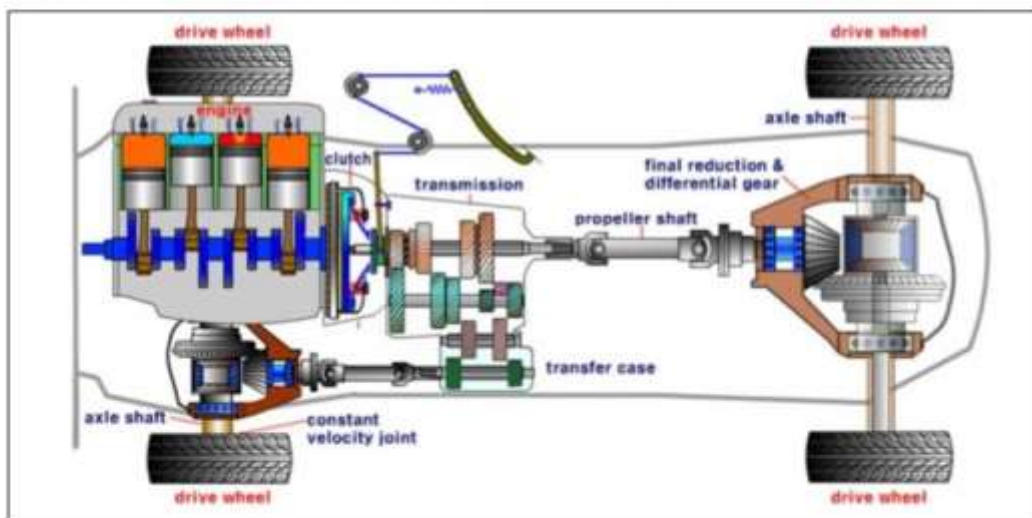


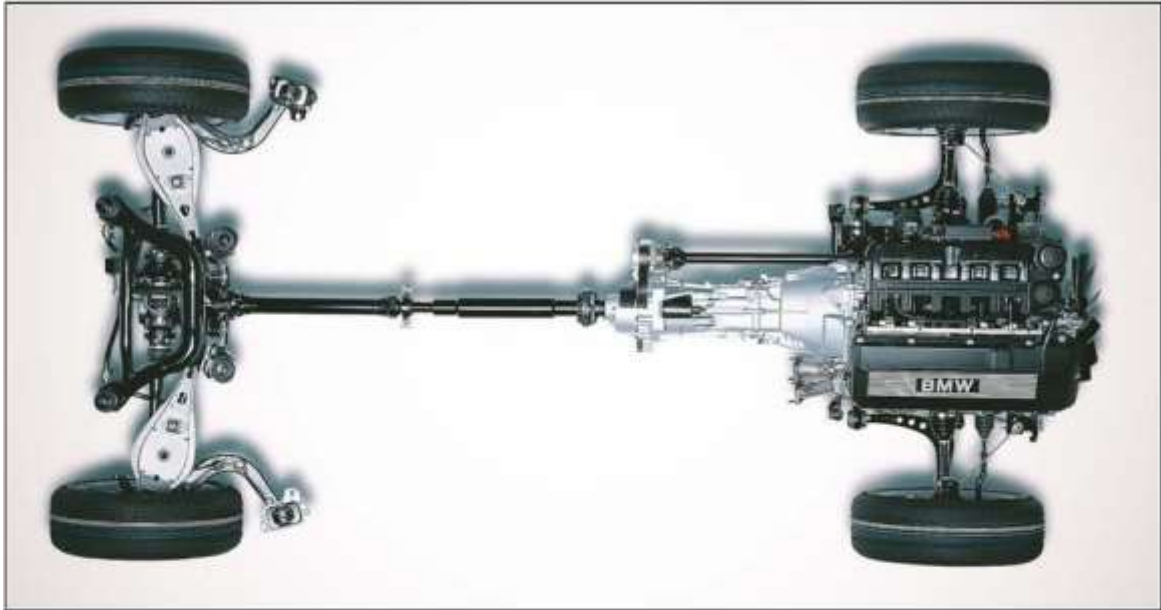
## Disadvantages

- **Nose heavy:** Front-engine front-wheel-drive layouts are "nose heavy" with more weight distribution forward, which makes them prone to understeer, especially in high horsepower applications.
- **Torque steer prone:** This layout is prone to torque steer where there is a tendency for some front-wheel-drive cars to pull to the left or right under hard acceleration.
- **Weight shift during braking:** In this layout, the weight shifts back during acceleration which results in load on the front drive axle thereby affecting the acceleration of the vehicle. This also reduces the tractive effort required during climbing of steep gradients and also during acceleration.
- **Larger Turning circle** — FF layouts almost always use a Transverse engine ("east-west") installation, which limits the amount by which the front wheels can turn, thus increasing the turning circle of a front-wheel-drive car compared to a rear-wheel-drive one with the same wheelbase.
- **Limitation of size of Engine:** The transverse engine layout restricts the size of the engine that can be placed in modern engine compartments. Therefore, this layout is rarely adopted in powerful luxury and sports cars. FF configurations can usually only accommodate In-line-4 and V6 engines, while longer engines such as In-line-6 and 90° big-bore V8 will rarely fit.
- **Need for using Complicated CV Joints:** Because the front wheels are powered as well as steered, therefore complicated "Constant Velocity Joints (CV Joints)" are required.

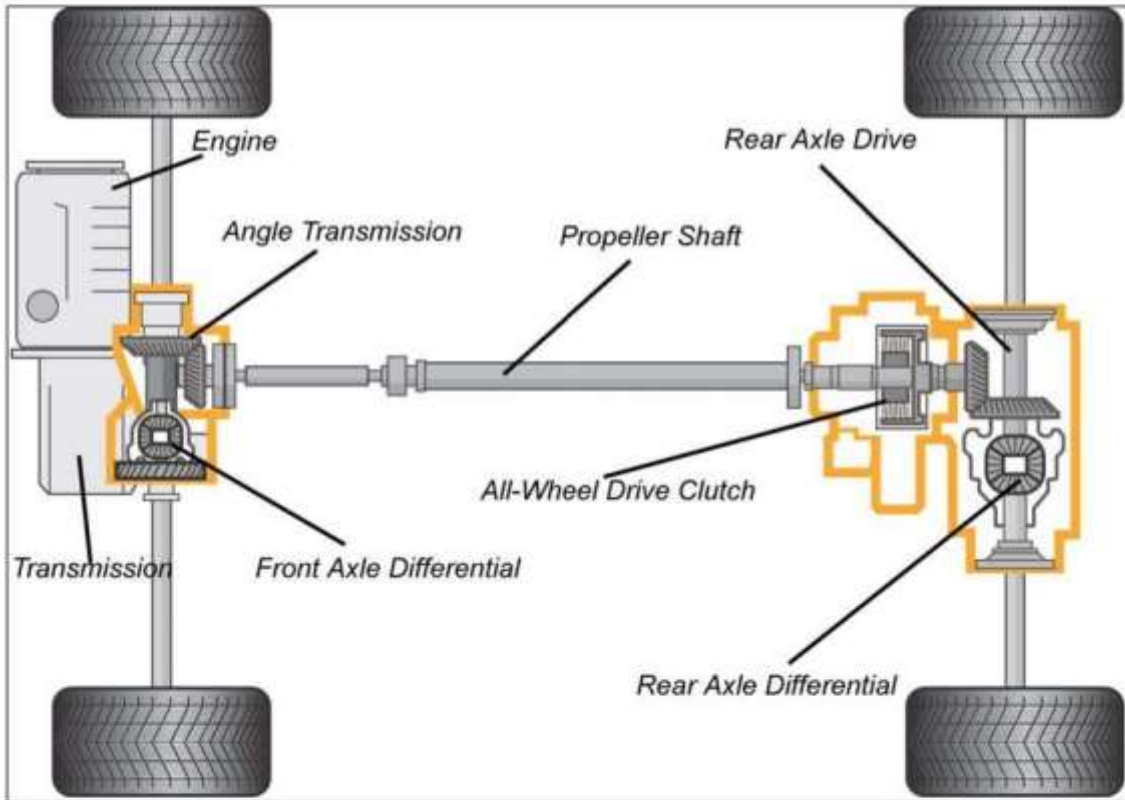
## Front Engine, Four Wheel / All wheel drive (4WD / AWD)

*In this layout, all the four wheels are driven with engine placed on the front of the vehicle.* Due to all four wheels getting driven, the whole weight of the vehicle is available for traction. The system is provided in jeeps which are known as 4x4 wheel drive or all-wheel drive vehicles. These vehicles are also called "Off-road vehicles" as they are constructed mainly for the purpose of unformed or off-road driving conditions. Examples are Mahindra Scorpio, Maruti Suzuki Gypsy, Tata Safari, Toyota Fortuner, Mitsubishi Pajero, Mahindra Bolero etc.

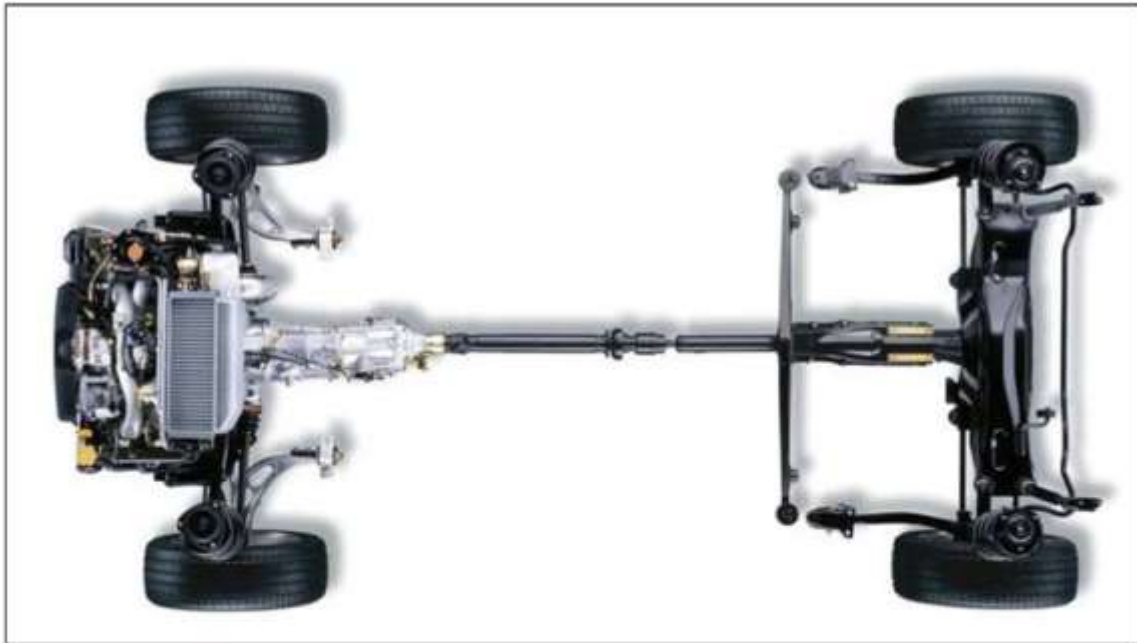




Four-Wheel Drive







All-Wheel

**Difference between Four-wheel Drive (4WD) and All-wheel Drive (AWD)**

The difference between the two driving systems is based on the usage of all the four wheels of a car. *In 4WD system*, the driver has the option to power and use all the four wheels or only the two wheels in a system, whereas *in AWD system*, all the driving wheels are permanently engaged and the driver has no option to disengage the system.

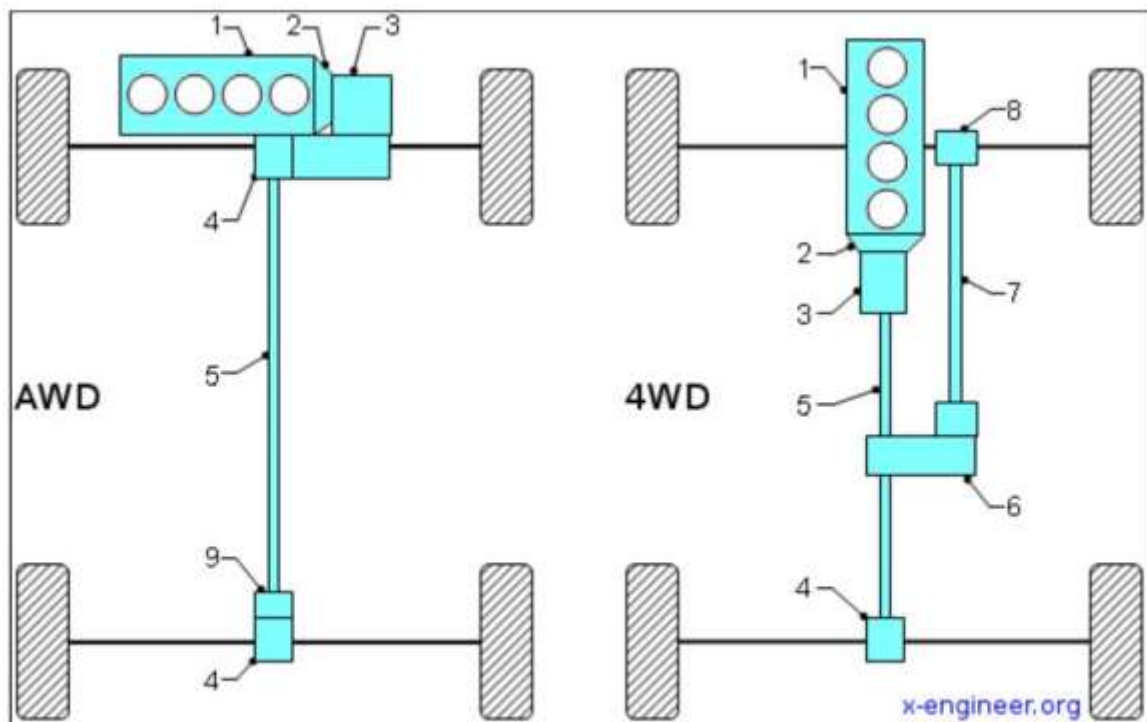


Table below indicates the difference between 4WD and AWD vehicles: -

	<b>AWD</b>	<b>4WD</b>
<b>Acronym</b>	It stands for 'All Wheel Drive'.	It stands for '4 Wheel Drive'.
<b>Definition</b>	It has a central differential system and thus is designed to power all four wheels at the same time.	Depending on the type of the system and on the road conditions, it is designed to automatically adjust the power in the front and back wheels.
<b>Gear</b>	Only high range gearing.	Low range and high range gearing.
<b>Weather</b>	It does not help in running the car smoothly in snow and rains.	It helps to run the car smoothly in snow and rains.
<b>Cost</b>	It is expensive.	It is cheap.
<b>Weight</b>	It is light in weight and consumes less space.	It is heavy in weight and consumes space.
<b>Types</b>	It can be automatic or selectable.	It is part time or full time.
<b>Engine power</b>	The vehicles deliver 90% of its engine power to the front wheels. More engine power is diverted to rear wheels via viscous coupling, only when the front wheels start to slip.	It transmits all of its engine power to the rear wheels. The second speed option allows splitting the engine power equally between front and rear wheels.
<b>Differential device</b>	The option of central differential is available.	The option of central differential is inbuilt and is not available.
<b>Advantages</b>	<ul style="list-style-type: none"> <li>• Provides increased grip and control under all road conditions.</li> <li>• Gives sportier handling and traction to a broader range of cars.</li> <li>• Works all the time</li> </ul>	<ul style="list-style-type: none"> <li>• Best traction in off-road conditions.</li> <li>• Can be turned off to improve fuel economy.</li> <li>• Proven, rugged technology.</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>• Reduces Fuel Economy.</li> <li>• Increases the weight and complexity of vehicles.</li> </ul>	<ul style="list-style-type: none"> <li>• Adds weight and complexity to cars.</li> <li>• Can't be used in all conditions.</li> <li>• More expensive than two-wheel drive models.</li> </ul>

	<ul style="list-style-type: none"> <li>• Not as good in extreme off-road conditions.</li> </ul>	
<b>Examples</b>	Dodge Ram 1500, Jeep Wrangler, Jeep Grand Cherokee	Nissan Rogue, Honda CR-V, Lexus RX 350

### Advantages

In terms of handling, traction and performance, 4WD systems generally have most of the advantages of both front-wheel drive and rear-wheel drive. Some unique benefits are:

- **Increased Traction:** Traction is nearly doubled compared to a two-wheel-drive layout. Given sufficient power, this results in unparalleled acceleration and driveability on surfaces with less than ideal grip, and superior engine braking on soft or slippery roads. *The development of 4WD systems for high performance cars was stimulated primarily by rallying.*
- **Ease of vehicle driving with wheel(s) in ditch:** If front wheel falls into a ditch, the vehicle can be climbed out by rear wheels and vice versa.
- **Uniform tyre wear and other driveline components:** Wear of tyres and other driveline components are uniformly shared.

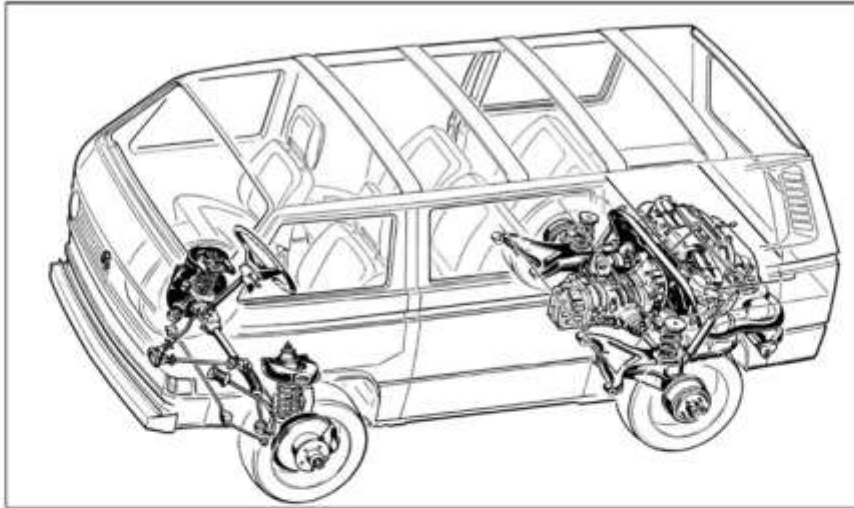
### Disadvantages

- **Higher Weight and Complexity:** Due to addition of more number of parts, the weight of the vehicle increases. This pushes up the manufacturing cost of the vehicle. The complexity of the power train also makes the maintenance procedures complex and increases the cost of repairs compared to 2WD designs.
- **Higher Fuel consumption: Higher weight, increased inertia of rotating masses,** more number of parts results in higher fuel consumption and as such increases the operating cost.

### Rear Engine, Rear wheel drive (RR)

*In this layout, the engine is mounted in the rear of the vehicle and drives the rear wheels. If the engine is mounted longitudinally, then a short propeller shaft connects with the final drive. If engine is mounted transversely between the drive wheels, then engine, clutch, gear box and final drive forms a single unit with both the rear wheels driven by two half shafts. Examples are Tata Nano, Rear engine buses of Volvo, Tata Motors, Ashok Leyland, Volkswagen Transporter, Porsche 911 Car etc.*





### Advantages

- **Short and compact driveline:** A short drive line is possible as the engine, gear box and final drive can be combined into a single unit.
- **Improved drive wheel traction:** Majority of the weight at the rear of the vehicle provides improved traction during hill climbing and during acceleration.
- **Excellent braking ability:** This layout provides excellent braking ability because of greater amount of weight from the engine and power train concentrated over the rear tires during braking.
- **Flat floor construction:** Due to absence of propeller shaft tunnel, flat floor construction is possible. **This feature makes this layout exceptionally suitable for low floor buses, aircraft tarmac coaches and other passenger buses.**
- **Ease in steering:** Less weight on the steering tires makes steering easier and possibly more precise.

- **Improved driver visibility:** Absence of engine at front allows for a shorter hood and improves driver visibility. It also allows for more foot space.
- **Superior cabin comfort:** The exhaust gases, fumes, engine heat and noises are carried away from passengers resulting in superior passenger cabin comfort.
- **Lower driveline losses:** A RR can have **lower driveline losses and lighter weight** because it has no need to use a driveshaft to connect the transmission or gearbox to the rear axle.
- **Short exhaust system:** Rear-engine configuration shortens the exhaust system to reduce backflow and generally simplifies the design of the vehicle.

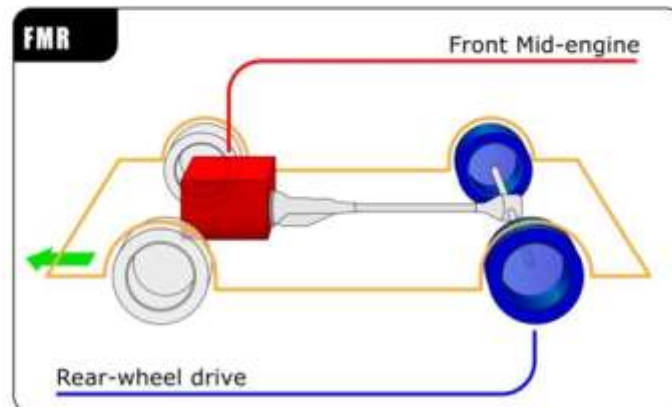
### Disadvantages

- **Less room for rear passengers:** The cabin has less room for rear passengers than does a front-engine vehicle.
- **Reduced luggage space:** Luggage space has to be located on the front of the vehicle. However due to narrow front and also presence of fuel tank, restricted luggage compartment is possible.
- **Difficult steering in slippery conditions:** Rearward concentration of weight causes the vehicle to be affected by side winds at high speeds. It also makes the vehicle oversteer on slippery roads and also while taking narrow turns.
- **Difficult engine cooling:** In air cooled engines, natural air cooling is not possible hence requires a large fan consuming more engine power. For liquid-cooled vehicles, this layout requires either increased coolant piping from a front-mounted radiator (meaning more weight and complexity) or relocating the radiator to the sides or rear and adding air ducting to compensate for the lower airflow at the rear of the car.
- **Difficulty in locating fuel tank in safe zone:** Fuel tank is difficult to be located in safe zone in this layout.
- **Long control linkages:** Mechanical lever type control linkages (for accelerator and clutch) becomes long and complicated. However, this problem has greatly been resolved by using cable type linkages.

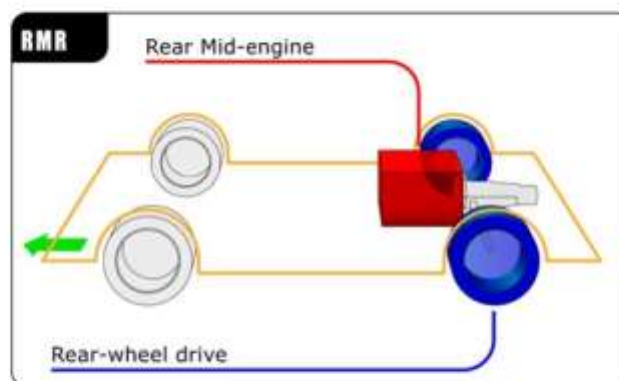
### Mid-Engine, Rear wheel drive

*In the Mid-engine layout, an engine sits in the middle of a vehicle but it is generally between the front and rear axles.* In the vehicle with this type of layout, the rear tires carry more weight. So, they get more traction and provide more assistance to the front tires while braking. Thus, it reduces the chance of rear-wheel locking and skidding or spinning. The mid-engine design also provides added empty space at the front of the vehicle between the bumper and the windshield. Some of the mid-engine layouts are: -

- ❖ **Front mid-engine, rear wheel drive (FMR)** - Engine placed between driver and front axle.



- ❖ **Rear mid-engine, rear wheel drive (RMR)** - Engine placed between driver and rear drive axle.



- ❖ **Front mid-engine, four-wheel drive (FM4)** – In this layout, similar to FMR layout, the engine is placed between driver and behind front axle. Front wheel drive is added to make this a four-wheel drive. *This layout poses an engineering challenge i.e. getting power to the front wheels past the engine* - this would normally involve raising the engine to allow a propeller shaft to pass under the engine, or in the case of the Ferrari FF taking power from both ends of the crankshaft with two separate gearboxes.
- ❖ **Rear mid-engine, four-wheel drive (M4)** – In this layout, engine is placed between the axles with four-wheel drive.





### Advantages

- **Better traction and braking assistance:** Placement of heavy engine in the middle puts more weight on the rear tires, thereby improving traction. Also, this provides more assistance to the front tires during braking. This results in less chance of rear-wheel lockup and less chance of a skid or spin out.
- **Ideal Car handling and stability:** Mid-engine placement helps in ideal car handling. If we talk about ideal car handling especially in sports car, we require balanced traction between the front and rear wheels whenever cornering. This helps in increasing the speed around curves without sliding out. Without mid-engine placement this balance is harder to achieve.
- **Additional frontal crash safety:** Mid-engine design also provide additional empty crush space in the front of the automobile between the bumper and the windshield, which can then be used in a frontal collision to absorb more of the impact force to minimize penetration into the passenger compartment of the vehicle.
- **Smooth ride:** The heavy mass of the engine is located close to the back of the seats. This makes it easier for the suspension to absorb the force of bumps so the riders feel a smoother ride.

### Disadvantages

- **Restricted passenger space:** This is the main drawback of this type of layout. Since engine is behind driver, the passenger compartment is pushed forward towards

the front axle. Hence this layout is suitable mostly for 2-seater cars like sports car, racing car etc.

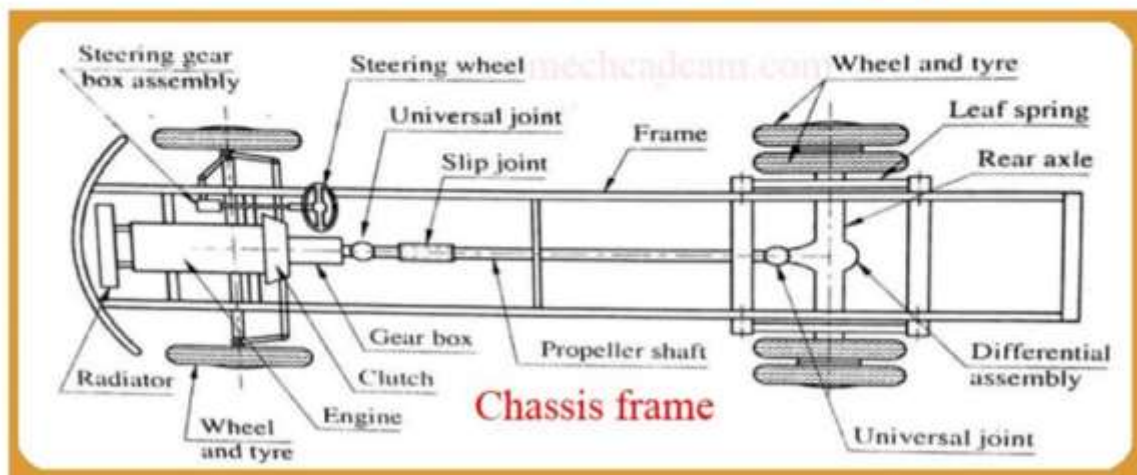
## VIDEO OF DIFFERENT AUTOMOBILE LAYOUTS

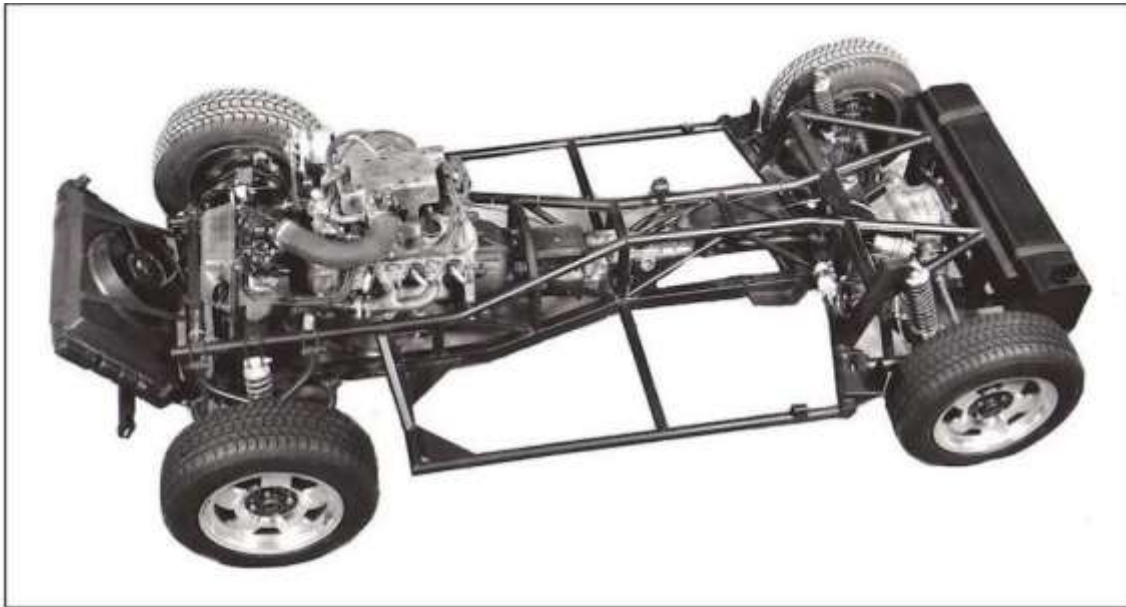
- [E-Note Videos\01Automobile layout-I \[720p\].mp4](#)
- [E-Note Videos\02Automobile Layout -II.mp4](#)

## AUTOMOBILE CHASSIS

To construct any automobile, chassis is the basic requirement. Chassis is a French term which was initially used to denote the frame or main structure of a vehicle. It is extensively used in complex vehicles except the body. *A vehicle without body is called chassis.*

*Chassis is the back bone of the vehicle.* The components of the vehicle such as power plant, transmission system, axles, wheels and tyres, suspension, controlling systems such as braking, steering etc. and also electrical system parts are mounted on the chassis frame. It is the main mounting of all components including the body. *So, it is also called carrying unit.*





*The main components of the chassis are: -*

- ❖ Frame
- ❖ Front suspension
- ❖ Steering mechanism
- ❖ Engine, clutch and gear box
- ❖ Radiator
- ❖ Propeller shaft



- ❖ Wheels
- ❖ Rear and front suspension
- ❖ Differential unit
- ❖ Universal joint
- ❖ Brakes and braking system
- ❖ Storage type battery
- ❖ Fuel tank
- ❖ Electrical systems
- ❖ Exhaust piping and silencer
- ❖ Piping for engine coolant, fuels, brake fluids, clutch fluid etc.

### Classification of Chassis:

The chassis can be classified into following types on the following basis:

#### ❖ According to the fitment of engine:

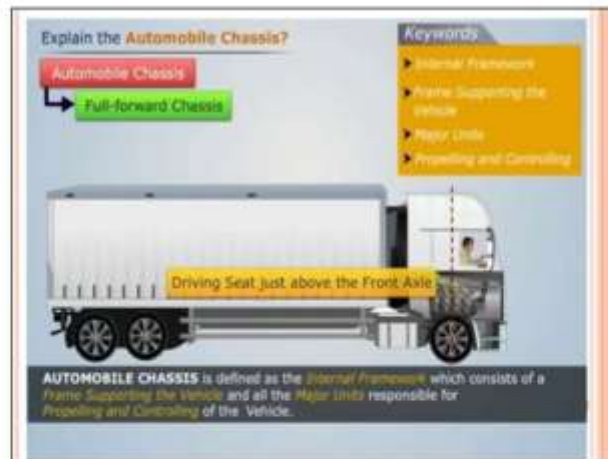
- (a) Conventional chassis – Engine is fitted ahead of driver’s cabin



- (b) Semi-forward chassis – Half of engine is ahead of driver’s cabin and rest in driver’s cabin



(c) Full-forward chassis – In this design, entire engine is placed inside driver's cabin.



(d) Engine at rear

(e) Engine at centre

❖ *According to the number of wheels fitted in the vehicles and the number of driving wheels:*

- ❖ 4 x 2 drive chassis - It has four wheels out of which 2 are driving wheels.
- ❖ 4 x 4 drive chassis - It has four wheels and all of them are driving wheels.
- ❖ 6 x 2 drive chassis - It has six wheels out of which 2 are driving wheels.
- ❖ 6 x 4 drive chassis - It has six wheels out of which 4 are driving wheels.
- ❖ 6 x 6 drive chassis – It has six wheels out of which all of them are driving wheels.

#### Characteristics of a Good Chassis:

- ❖ Fast pickup
- ❖ Strength
- ❖ Safety
- ❖ Durability
- ❖ Dependability
- ❖ Ease of control
- ❖ Quietness
- ❖ Speed
- ❖ Power accessibility
- ❖ Economy of operation
- ❖ Low centre of gravity
- ❖ Stability
- ❖ Braking ability
- ❖ Adequate ground clearance
- ❖ Good springing
- ❖ Simplicity of lubrication

### VIDEO OF TYPES OF AUTOMOBILE CHASSIS

## **AUTOMOBILE BODY**

Body is the super-structure for all vehicles. It may either be constructed separately and bolted to the chassis or manufactured integral with the chassis (i.e. Frameless construction). The chassis and the body make the complete vehicle. A body consists of windows and doors, engine cover, roof, luggage cover etc. The electrical system in the body is connected to the chassis electrical units so that the battery and the generator/alternator can furnish the required electrical energy to the system.

### **Some terminology pertaining to Automobile Body:**

- ❖ **Cab:** It is the driver's cabin which may be a closed region separated from the rest of the body (as in a truck) or open region (as in a car).
- ❖ **Fascia:** It is the frontage of the vehicle visible to the driver. It includes dash board, Infotainment system, glove box compartments etc.
- ❖ **Dash board:** It houses various indicators and controls like engine speed, engine temperature, oil pressure, speedometer, odo meter, fuel gage, voltmeter, ammeter, ABS sensor, Airbag sensor, light switches, side indicators, air-conditioning, controls, Infotainment system controls etc.
- ❖ **Leg room:** It is the space provided for movement of legs of driver and passengers. Sufficient leg room is needed for comfortable driving, riding and travelling.
- ❖ **Head room:** It is the vertical distance between inside of vehicle floor and bottom of vehicle ceiling. This dimension is dependent on the stability considerations of the vehicle.
- ❖ **Shoulder room:** This is the clear horizontal distance available inside the body.
- ❖ **Boot space:** This is the storage space available below the rear hood.
- ❖ **Body work:** This means design, styling and construction of entire body.

### **Main parts of body work:**

The body work includes following main parts: -

- ❖ Body safety members
- ❖ Bonnet
- ❖ Side pillars
- ❖ Rear hood
- ❖ Front side panel
- ❖ Rear side panel
- ❖ Door pillars
- ❖ Windshield pillars
- ❖ Rear quarter pillar
- ❖ Body sill
- ❖ Roof



- ❖ Door panels
- ❖ Front bumper
- ❖ Rear bumper

Some of these parts are shown in the pictures below: -

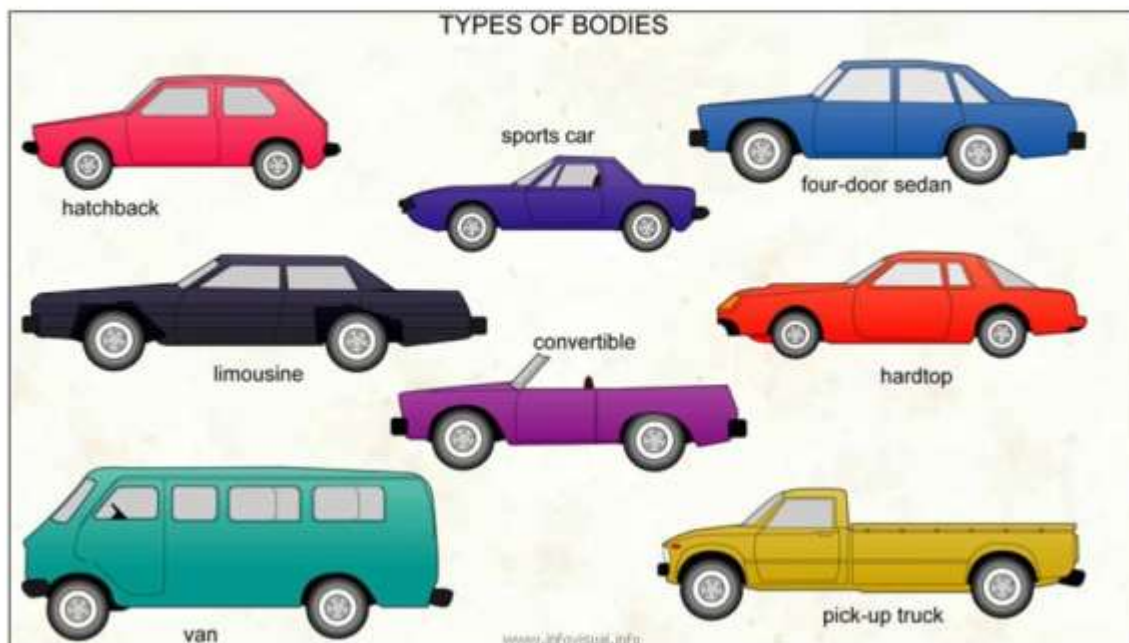


Requirements of Automobile Body:

The vehicle body should fulfil following requirement: -

- ❖ It should be strong enough to withstand all types of forces acting on the body viz. weight of the vehicle, luggage, inertia, braking and cornering forces, wind load etc.
- ❖ Stresses induced in the body should be distributed evenly to all portions.
- ❖ Weight of the body should be as minimum as possible.
- ❖ Body should be able to cope with impact loads of reasonable magnitude.
- ❖ It should have reasonable fatigue life.
- ❖ It must provide adequate space for both passengers and the luggage.
- ❖ It should have minimum number of components.
- ❖ It must have sufficient torsional stiffness i.e. ability to resist the twisting stresses produced by irregular road surface.
- ❖ It should have good access to the engine and suspension elements.
- ❖ It must ensure a quiet ride, easy entry and exit.
- ❖ It should create minimum vibration during running.
- ❖ The shape of the body should offer minimum drag.
- ❖ It should be easy to manufacture as well as low in cost.
- ❖ It should be designed in such a way that passengers and luggage are protected from bad weather.
- ❖ It should give good aesthetic appeal in shape and colour.

Types of Automobile Body:





## Vehicle Configuration

<p><b>Bus (9-15 Seats, Including Driver)</b></p>	<p><b>Truck/Trailer (Single-Unit Truck Pulling a Trailer)</b></p>
<p><b>Bus (16 or More Seats, Including Driver)</b></p>	<p><b>Truck Tractor (Bobtail)</b></p>
<p><b>Single-Unit (2 Axles, 6 Tires)</b></p>	<p><b>Tractor/Semi Trailer (One Trailer)</b></p>
<p><b>Single-Unit (3 or More Axles)</b></p>	<p><b>Truck Tractor/Double (Two Trailers)</b></p>
	<p><b>Truck Tractor/Triple (Three Trailers)</b></p>

Revised 06/06

Federal Motor Carrier Safety Administration

U.S. Department of Transportation  
[www.fmcsa.dot.gov](http://www.fmcsa.dot.gov)





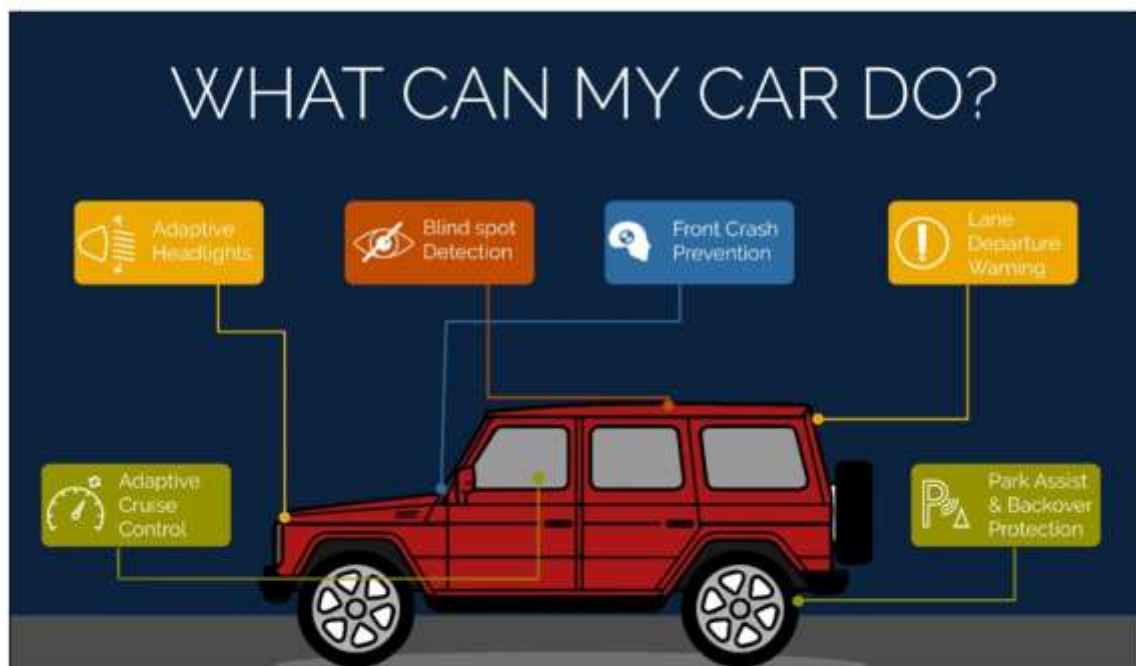
Based on application, size, design and styling various types of vehicle bodies are used. Some of these are: -

- ❖ Passenger car
- ❖ Straight truck
- ❖ Half-body type truck
- ❖ Platform type truck
- ❖ Tractor
- ❖ Tractor with articulated trailer
- ❖ Tanker
- ❖ Dumper truck
- ❖ Delivery van
- ❖ Station wagon
- ❖ Pickup truck
- ❖ Jeep
- ❖ Buses
- ❖ Mini-buses
- ❖ Three-wheelers

## **AUTOMOBILE SAFETY PARAMETERS**

“Automobile safety” is the study and practice of design, construction, equipment and regulation to minimize the occurrence and consequences of traffic collisions.

Passenger safety occupies a prime spot in the automobile sector today. Stakeholders across the automobile value chain acknowledge the importance of passenger/occupant safety and are constantly upgrading their offerings to provide fail safe safety technologies that will protect passengers and pedestrians. Proactive policy implementation and consumer awareness has played a key role in making automotive safety systems popular.



### **Active and Passive Safety**

The terms "active" and "passive" are simple but important terms in the world of automotive safety.

"Active safety" systems as the term suggests play a preventive role in mitigating crashes and accidents by providing advance warning or by providing the driver with additional assistance in steering/controlling the vehicle.

"Passive safety" systems play a role in limiting/containing the damage/injuries caused to driver, passengers and pedestrians in the event of a crash/accident.

Examples of technology used for both active and passive safety parameters are provided in the tables below: -

## Active Safety

Technology	Acronym	Definition
Anti-lock Braking System	ABS	ABS allows the wheels on a motor vehicle to maintain tractive contact with the road surface based on driver inputs while braking. This prevents the wheels from locking up (ceasing rotation) and avoids uncontrolled skidding. This automated system works on the principles of threshold braking and cadence braking.
Electronic Stability Control	ESC	ESC system improves vehicle's stability by detecting and reducing loss of traction (skidding). This system prevents crashes by reducing the danger of vehicle skidding or driver losing control as a result of oversteering. This system becomes active when a driver loses control of his or her car.
Adaptive Cruise Control	ACC	ACC is an intelligent form of cruise control that slows down and speeds up automatically to maintain a safe distance from the vehicles ahead. The control is based on sensor information from on-board sensors.
Tyre-Pressure Monitoring System	TPMS	TPMS is an electronic system designed to monitor air pressure inside pneumatic tires on various types of vehicles. TPMS report real-time tyre-pressure information to the driver of the vehicle, either via a gauge, a pictogram display, or a simple low-pressure warning light.
Lane Departure Warning	LDW	LDW system is a mechanism designed to warn a driver when the vehicle begins to move out of its lane on freeways and arterial roads. These systems are designed to minimize accidents by addressing causes of collisions such as driver error, distractions, and drowsiness.
Night Vision System	NVS	NVS extend the perception of the driver beyond the limited reach of headlights through the use of <u>thermo</u> graphic cameras, infrared lights, heads up displays, and other technologies to prevent accidents.
Blind Spot Detection	BSD	Blind spots are areas outside of a vehicle that the driver is unable to see. These can be caused by window pillars, headrests, back seat passengers, and other objects. A BSD system is a vehicle-based sensor device that detects other vehicles located to the driver's side and rear.
Driver Monitoring	DM	This safety system uses infrared sensors to monitor driver attentiveness. Specifically, a driver monitoring system includes a Closed-Circuit Camera (CCD) camera placed on the steering column that is capable of eye tracking via infrared Light-Emitting Diode (LED) detectors. If the driver is not paying attention to the road ahead and a collision is eminent, the system flashes lights and warning sounds for the driver.
Road Sign Recognition	RSR	Road sign recognition notifies and warns the driver of enforced restrictions on the road.
Automatic Emergency Braking	AEB	This system slows the vehicle and potentially reduces collision severity in an unavoidable situation. If the driver's braking is not enough to avoid a collision, autonomous emergency braking applies maximum brake pressure to reduce speed and impact of collision.



## Passive Safety

Technology	Acronym	Definition
Airbag	AB	Automotive airbags consist of flexible fabric bag or a cushion designed to inflate rapidly during a collision. Its function is to cushion its occupants during a crash when they hit objects inside such as the steering wheel or a window. Modern vehicles comprise of multiple airbag modules in different side and frontal locations of the passenger seating positions which offer maximum protection during collision.
Seat belt	SB	Seat belts are safety belts installed on the passenger seat of a vehicle to secure the occupant against harmful movements that may result due to collision, jerk, or sudden braking.
Occupant Sensing Systems	OSS	It is a system of sensors that detect who is sitting in the passenger seat. Occupant sensing systems eliminate the need for an on/off switch for airbags in most cases, because they use sophisticated technology to identify whether an adult or a child is in the seat. The sensor assembly is installed in the bottom cushion of the passenger seat and is used to suppress or enable the passenger's airbag, based on the classification of the occupant.
Whiplash Protection	WLP	In a WHIPS equipped seat, the entire backrest is designed to protect the front occupant's neck in case of rear impact. WHIPS utilizes a specially designed hinge-mount that attaches the back rest to the seat bottom, which has a pre-determined rate of rearward movement in the event of certain types of rear impacts. The seatback also has a series of springs that allows the cushion to move slightly backward on impact, thereby cradling the body within the seat. This, combined with high-mounted head restraints, to limit the "whipping" motion of the head that often occurs during a rear-end impact.
Child Safety Systems	CSS	Child safety systems are specifically designed seats that protect children from injury or death during collisions. Generally, these seats are installed based on end-user requirements.
Pedestrian Safety System	PSS	This system prevents vehicles from colliding with pedestrians by sensing the situation and provides guidance to make decision. In most of the advanced vehicle, this system automatically decreases vehicle speed to avoid collision with pedestrians.

## Audi A6

Driver assistance systems

04/16

### Front camera:

- Audi active lane assist
- ACC with Stop&Go function
- Speed limit display
- Audi pre-sense / front / plus
- Audi adaptive light

### Ultrasonic sensors at side:

- Parking assist with display of surroundings

### 360° Cameras:

- Rear camera
- 360° Cameras



### Ultrasonic sensor at rear:

- Parking system plus
- Parking assist with display of surroundings

30 Plus

### Ultrasonic sensors at front:

- ACC with Stop&Go function
- Parking system plus
- Parking assist with display of surroundings

### Infrared camera:

- Night vision assistant with highlighting of detected pedestrians and wild animals



### Front radar sensors:

- ACC with Stop&Go function
- Audi pre-sense / front / plus

### Rear radar sensors:

- Audi side assist
- Audi pre-sense rear / plus

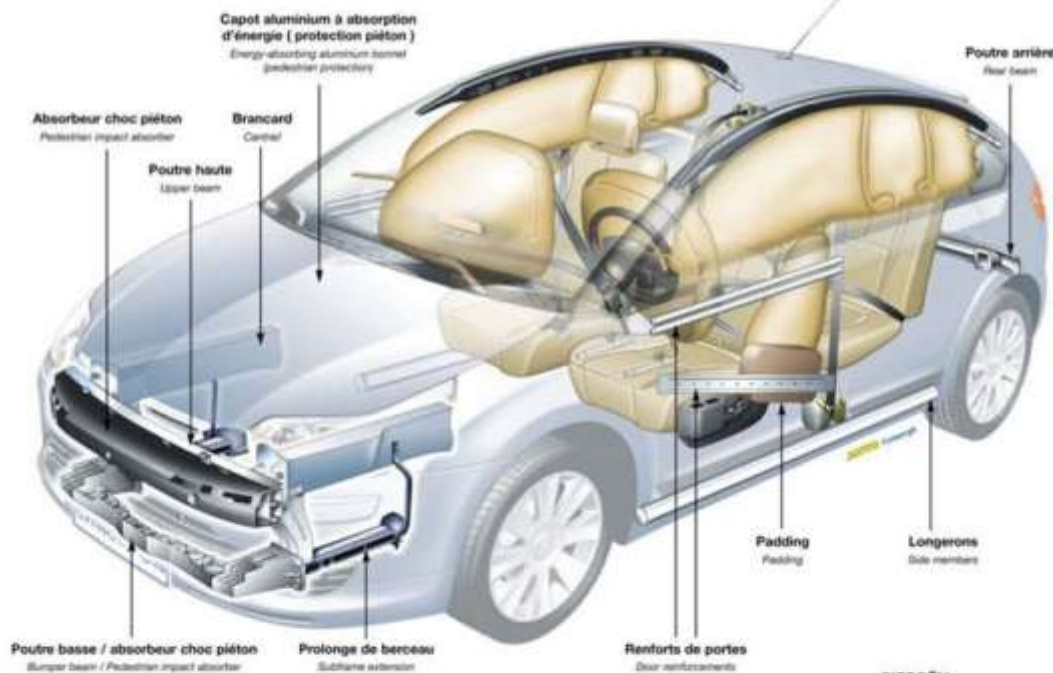
### Crash sensors:

- Front protection adaptivity
- Side protection
- Rear impact protection

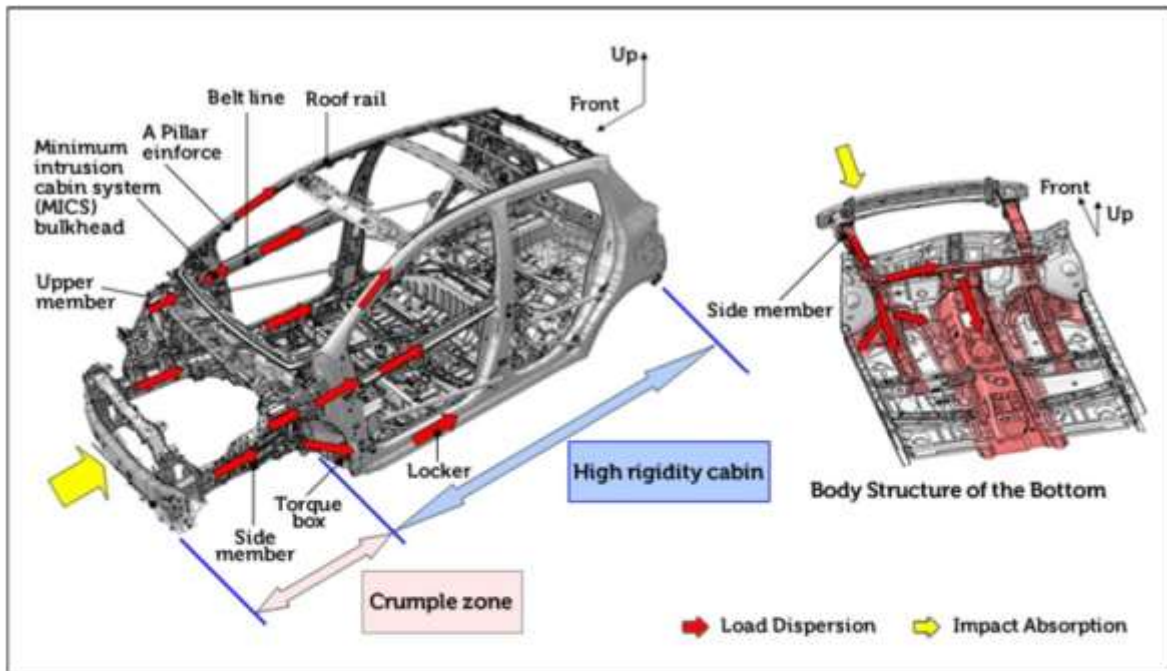
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## Sécurité passive et protection piéton / Passive security and pedestrian protection



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## **AUTOMOBILE REGULATORY BODIES IN INDIA**

The automotive regulations in India are governed by the [“Ministry of Road Transport and Highways \(MoRT&H\)”](#) which is the nodal ministry for regulation of the automotive sector in India.

In order to involve all stake holders in regulation formulation, MoRT&H has constituted three [Committees](#) to deliberate and advise the Ministry on issues related to Safety and Emission Regulations. These are: -

- ❖ **CMVR – Technical Standing Committee (CMVR-TSC):** It advises the Ministry on various Technical aspects related to CMVR. Its members are represented by: -
  - Ministry of Heavy Industries & Public Enterprises (MoHI&PE)
  - MoRT&H
  - Bureau of Indian Standards (BIS)
  - Testing Agencies such as Automotive Research Association of India (ARAI)\*
  - Vehicle Research and Development Establishment (VRDE)
  - Central Institute of Road Transport (CIRT)
  - Industry representatives from Society of Indian Automobile Manufacturers (SIAM)
  - Automotive Component Manufacturers Association (ACMA)
  - Tractor Manufacturers Association (TMA)
  - Representatives from State Transport Departments.
  
- ❖ **Automotive Industry Standards Committee (AISC):** CMVR-TSC is assisted by another committee called the AISC having members from various stake holders in drafting the technical standards related to safety.



- ❖ **Standing Committee on Implementation of Emission Legislation (SCOE):** This Committee deliberates the issues related to implementation of emission regulation.

Under Rule 126 of the CMVR, various test agencies are established to test and certify the vehicles based on the safety standards and emission norms prescribed by the Ministry.

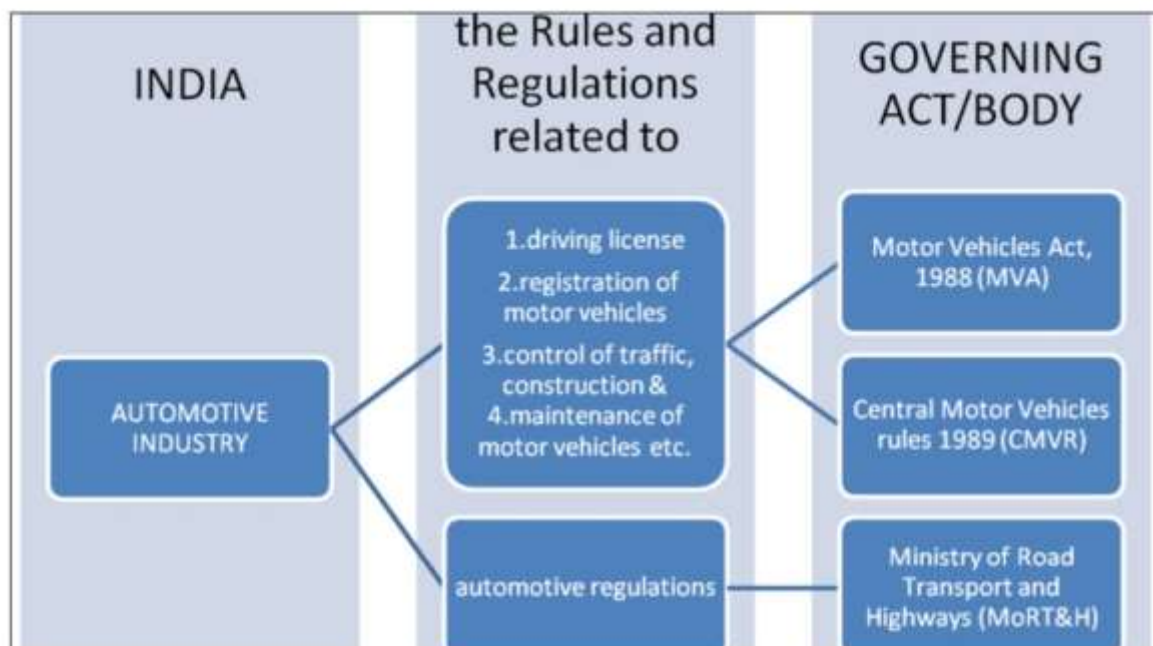
Every manufacturer of motor vehicle has to submit a prototype of the vehicle to be manufactured to any of the test agencies mentioned hereafter. After testing the vehicle for compliance of all standards and norms, the test agency shall grant a certificate to the manufacturer.

The various test agencies are: -

- Automotive Research Association of India, Pune (ARAI),
- Vehicle Research & Development Establishment, Ahmed Nagar (VRDE)
- Central Farm Machinery Testing and Training Institute, Budhni
- Indian Institute of Petroleum, Dehradun
- Central Institute of Road Transport, Pune
- International Centre for Automotive Technology, Manesar.

Functions of Regulating Bodies

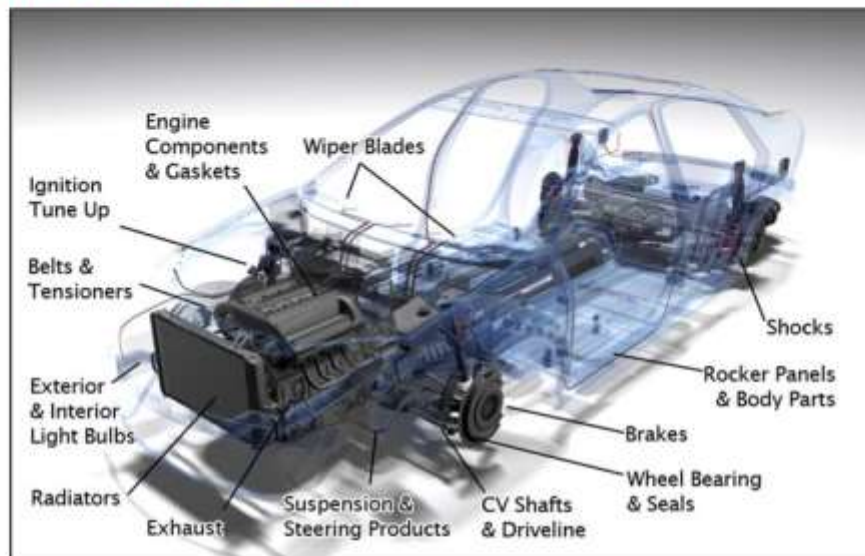
The various functions of regulating bodies are summarised in the picture and table below: -



FUNCTIONS OF CMVR-TSC	FUNCTIONS OF AISC	FUNCTIONS OF SCOE
<b>Central Motor Vehicle Rules – Technical Standing Committee</b>	<b>Automobile Industries Standing Committee</b>	<b>Standing Committee on Implementation of Emission Legislation (SCOE)</b>
To provide technical clarification and interpretation of the Central Motor Vehicles Rules having technical bearing, to MoRT&H, as and when so desired	Preparation of new standards for automotive items related to safety.	To discuss the future emission & Noise norms
To recommend to the Government the International standards which can be used in lieu of standard notified under the CMVR. Permit use of components/parts/assemblies complying with such standards	To review and recommend amendments to the existing standards	To recommend norms for in-use vehicles to MoRT&H
To make recommendations on any other technical issues which have direct relevance in implementation of the Central Motor Vehicles Rules	Recommend adoption of such standards to CMVR Technical Standing Committee	To finalise the test procedures and the implementation strategy for emission norm
To make recommendations on the new safety standards of various components for notification and implementation under Central Motor Vehicles Rules	· Recommend commissioning of testing facilities at appropriate stages	Advise MoRT&H on any issue relating to implementation of emission & Noise regulations.
To make recommendations on lead time for implementation of such safety standards	· Recommend the necessary funding of such facilities to the CMVR Technical Standing Committee	
To recommend amendment of Central Motor Vehicles Rules having technical bearing keeping in view of Changes in automobile technologies	Advise CMVR Technical Standing Committee on any other issues referred to it	

# VARIOUS UNITS OF AUTOMOBILE

## VARIOUS UNITS OF AUTOMOBILE



The various units of an automobile have briefly been discussed in earlier chapter. Their detailed explanations are provided below.

### Frame

Frame is the foundation for carrying the engine and body of the vehicle. It also carries steering, power train etc. by means of springs, axles, rubber pads etc. The frames are made of box, tubular, channel or U-shaped section which are welded or riveted together. In order to make them rigid to withstand shocks, blows, twists and vibration - mats, cross-bracing or cross members are used. When the engine, wheels, power trains, brackets and steering systems are fitted on the frame, the assembly is known as chassis. Frame bends upward in a shape at the rear to provide space for rear springs. It is tapered at the front to provide space for turning front wheels when steered.

Frames are of three types as below: -

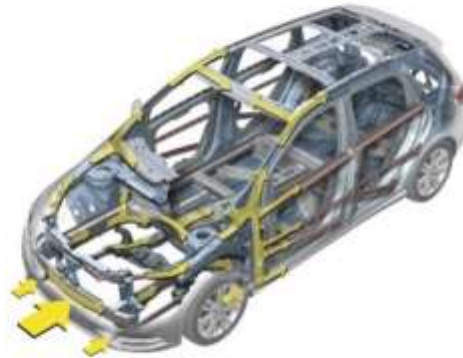
#### ❖ Conventional or Ladder Type Frame:





This type of frame is widely used in Light, Medium and Heavy Trucks, Pickups as well as in SUVs. It has two long side members and 5 to 6 cross members joined together with the help of rivets and bolts. The frame sections that are used generally either of channel section or tubular section or box section. The choice of section is dependent on the magnitude and types of loads expected to be carried by the frame.

❖ **Integral or Monocoque Type Frame:**



This frame is used these days in most of the cars. There is no frame and all the assembly units are attached to the body. All the functions of the frame carried out by the body itself. Due to elimination of long frame it is cheaper and due to less weight most economical also. Only disadvantage is repairing is difficult.

❖ **Semi-integral Type Frame:**



In this design, half frame is fixed in the front end on which engine gear box and front suspension are mounted. It has the advantage when the vehicle is met with accident the front frame can be taken easily to replace the damaged chassis frame. This type of frame is used in some of the European and American cars.

**Suspension System**

Suspension systems are used in vehicles for: -

- ❖ To insulate the wheel and axles from the frame

- ❖ To avoid the transmission of road effects to passengers while travelling on uneven road
- ❖ To provide a comfortable ride to passengers
- ❖ to avoid additional stresses in the vehicle frame

### Steering System

The function of steering system is to enable the driver to accurately control the directions taken by the vehicle under all operating conditions. The system must be quick to respond to driver's effort, light, accurate, fatigue free, easy to operate, shock and vibration free. The steering system converts rotary motion of the steering wheel to angular motion of the vehicle wheels. It multiplies the driver's effort by a system of gearing, levers and linkages by providing mechanical advantage. Modern automobiles use "Power assisted steering" systems to reduce the driver's fatigue and more precise and responsive steering which can be operated hydraulically or electrically or electronically.

### Braking System

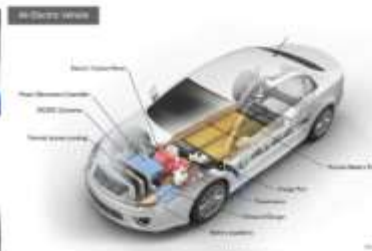
This is a very crucial and vital system in controlling the movement of the vehicle. Braking system helps in bringing the moving vehicle to complete stop or to slow down as per actual operating conditions. Braking systems use principle of friction to absorb the kinetic energy of the moving vehicle and convert it into heat energy which is then radiated to atmosphere.

### Engine or Power plant

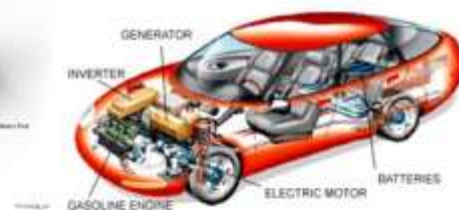
The engine or power plant provides the energy to propel the vehicle as per requirement. It also provides energy required for other operating systems such as electric systems, vehicle control systems, HVAC systems, lighting, horn etc. The engine can be an internal combustion engine (IC engine) which converts chemical energy in liquid or gaseous fuel to mechanical energy through combustion. It also can be provided by electric vehicles (EV) which use an electric motor for traction, and chemical batteries, fuel cells, solar cells, ultracapacitors, and/or flywheels for their corresponding energy sources. Some times an electric vehicle with two energy sources are used comprising of a liquid fuel IC engine and a battery-electric machine. These types of vehicles are known as Hybrid vehicles.



Internal Combustion



All Electric



Hybrid Vehicle



## Clutch

“Clutch” is a friction type device whose main function is to engage or disengage the drive smoothly from the engine to the transmission and rest of the power train as per requirement. The disengagement of clutch is required while changing the gear or bringing the vehicle to rest. It consists of a single steel disc faced with suitable friction material. It is clamped between two surfaces directly driven by the engine. For disengaging the clutch, the two surfaces are positively separated by pressing the clutch pedal.

## Transmission or Gear box

The main function of the gear-box is to multiply the torque supplied by the engine to the road wheel according to the operating conditions. It also provides a mechanism for reversing the direction of the vehicle without changing the direction of rotation of the IC engine. The torque multiplication takes place by gear trains with different gear ratios. The gear changing action takes place either manually by disengaging the clutch and using the gear shift lever or automatically by selecting the driving mode (Park, Neutral, Drive, Reverse) and using the accelerator pedal. Transmission also can be of “Continuously Variable (CVT)” which uses a system of variable diameter pulleys to provide stepless transmission ratios.



Manual Transmission



Fully Automatic Transmission



Automated Manual Transmission

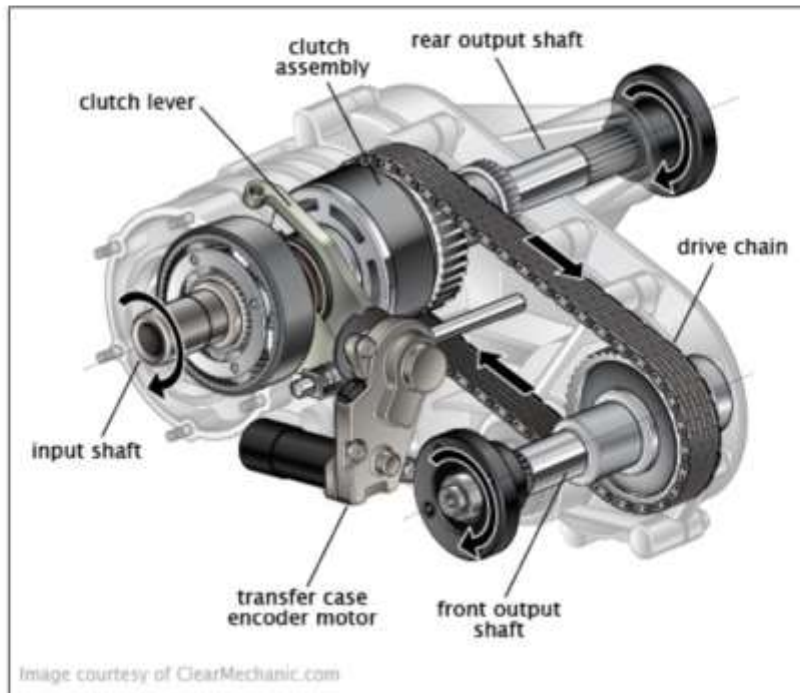


Continuously Variable



## Transfer Case

A "Transfer case" is a part of the drivetrain of four-wheel-drive, all-wheel-drive, and other multiple powered axle vehicles. The transfer case transfers power from the transmission to the front and rear axles by means of drive shafts. It also synchronizes the difference between the rotation of the front and rear wheels and may contain one or more sets of low range gears for off-road use.



## Propeller Shaft and Universal Joints

The function of propeller shaft is to transmit power from rear end of the gear box (main shaft) to final reduction gear in the drive axle. The propeller shaft is made of hollow tubular section. It uses pairs of universal joints (known as Hooke's joint) as power is to be transmitted at angle and also this angle constantly changes due to up and down movement of the rear axles because of flexible spring mounting. It also incorporates a "Slip joint" to enable change in its length to accommodate relative movement of the drive axle with respect to the frame during vehicle movement.



### Constant Velocity (CV) Joints

**Constant-velocity joints** (also known as **homokinetic** or **CV joints**) allow a drive shaft to transmit power through a variable angle at constant rotational speed. They are mainly used in front wheel drive vehicles for facilitating steering action on the drive axle. Many modern rear wheel drive cars with independent rear suspension typically use CV joints at the ends of the rear axle half shafts and increasingly use them on the drive shafts.



### Differential Mechanism

The differential mechanism enables transmission of power from propeller shaft to the rear axle wheels. It helps the two rear wheels (left and right) to rotate at different speeds while negotiating a curve (hence the name "differential"). The outer wheel must travel a longer distance (hence higher rotational speed) compared to inner wheel (hence lower rotational speed) during the same time when the vehicle takes a turn on a curve. The differential gear also ensures that the torque is equally distributed between two wheels without any consideration of their rotational speed.



### Springs

Springs are fitted between frame and wheel to prevent the upward movement of the frame along with up and down movement of the wheel. A spring is a reservoir of energy which is stored in steel springs by bending them or by extending or compressing them. When the spring resumes to its normal state, this energy is released. Leaf springs, coil springs, air springs are widely used in automobile along with shock absorbers.



Leaf Spring



Coil



Air

### Front Axle

Front axle is used for steering of front wheels carried on stub axles which swivel around the axis of the kingpin between axle extremities. Steering arms and track rod link, two stub axles are together used for swivelling them by a steering wheel about kingpins. The steering wheel is linked to one of the stub axles by a shaft, a steering gear box and suitable linkages. An axle in which one-piece beam is used to support the vehicle through springs (axle and spring arrangement) is used in heavy vehicles. An arrangement known as independent front suspension is used in cars which replaces the axle and spring arrangement. Under the control of springs, wheels are free to rise and fall independently in the vertical direction to each other.

### Rear Axle

Rear axle or driving axle is a tube which encloses two drive shafts one each for left and right wheel to drive these wheels. It provides support to the rear driving wheels besides transmitting engine power to them. The rear axle is enlarged in the centre to house the final drive which comprises of a gear train for providing final speed reduction between the engine and the drive wheels. The rear axle also changes the direction of power transmission from propeller shaft by  $90^\circ$ .

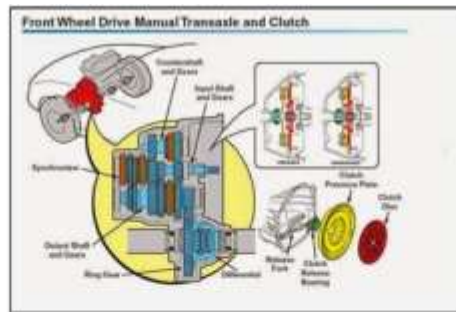
The rear axle includes the final drive gears, differential mechanism, rear axle shafts, rear wheel hubs, braking system, rear wheels etc.



### Transaxle

A transaxle is a clutch, transmission and differential combination in a single assembly. Transaxles are used in front-wheel drive vehicles. A transaxle allows the wheels next to the engine to propel the vehicle. Short drive axles are used to connect the transaxle output to the hubs and drive wheels. Transaxles are also widely used in rear engine, rear drive axle vehicles.



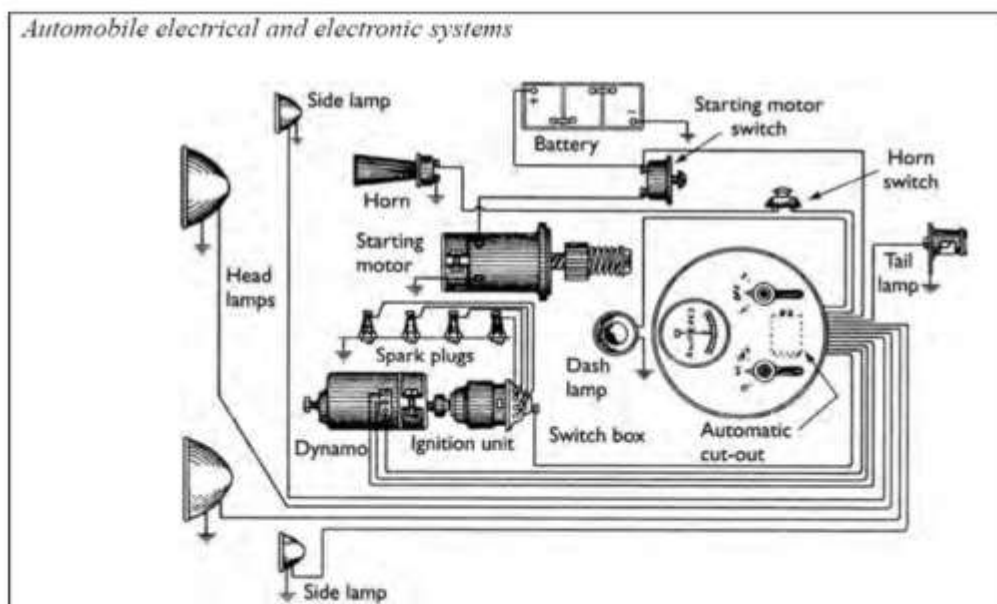


## Battery

In reality, the battery is the heart of the electrical system of a motor vehicle. It supplies current to the starter motor and ignition system. **The function of the battery is to store electrical energy which can be used whenever required.** Battery may be called nerve - centre of the whole installation because it supplies electrical energy for operating all electrical devices and other units except the charging device. It also supplies the electricity for operating the various electrical devices when the vehicle is not operating or running slowly and generator speed is insufficient to meet the full load requirements.

## Electrical System

The automotive electrical system does several jobs. It produces electric energy in the alternator. It stores electric energy in the form of chemical energy in the battery. It delivers electrical energy from these sources on demand to any other electrical component in the vehicle. The electrical system supplies electrical energy to crank the starter motor, supplies energy to spark plugs in a SI engine and keeps the batteries charged. Other electric and electronic devices include electronic engine / transmission / traction / braking control system, horn, lights, instrument panel indicators and other driver information systems, various motors such as windshield wiper, power window, windshield washer, door locks, trunk lid etc.

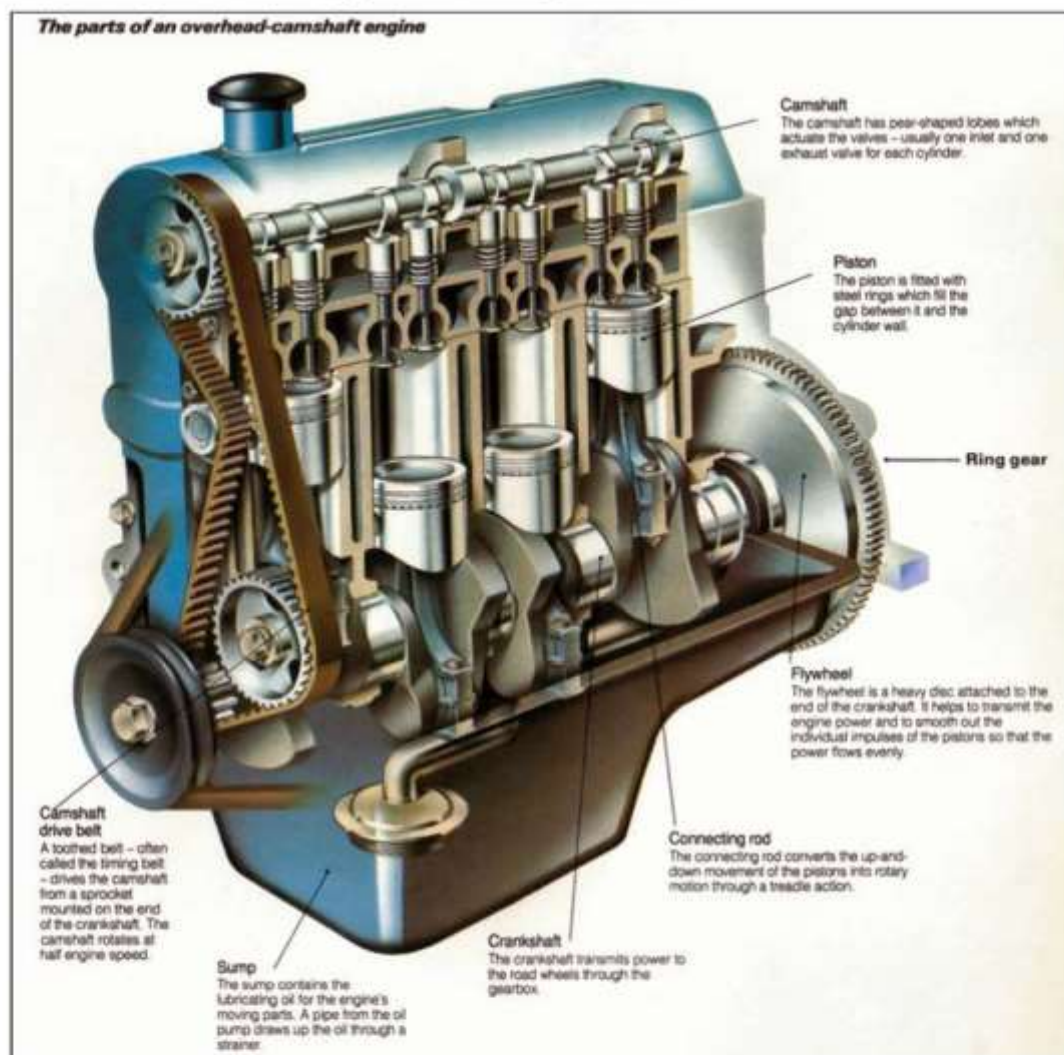


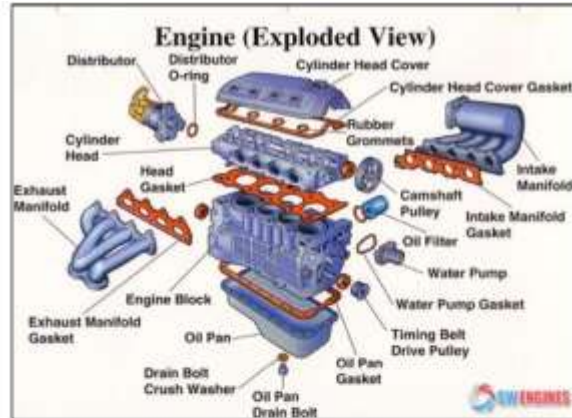
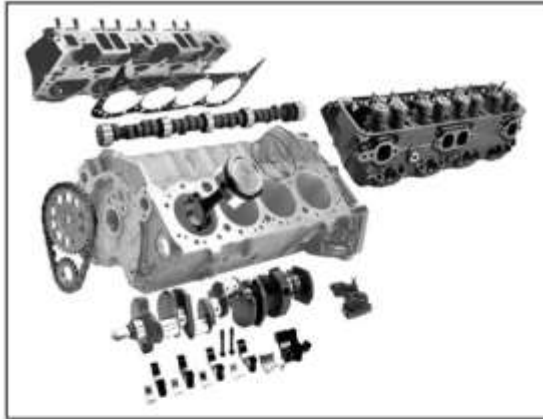
## Wheels

The wheels are fitted below the chassis to support the load of the vehicle and passengers. They are fitted with hollow rubber tyres filled with air in rubber tubes under sufficient pressure necessary for carrying the load. The shocks caused by road irregularities are absorbed by them. By fitting springs between wheels and vehicle to allow the vertical movement of the wheels in relation to vehicle, a greater part of unevenness of road surfaces is taken care of.

## **ENGINE AND ITS DIFFERENT SYSTEMS**

For familiarisation with design and construction of an automobile IC engine, few pictures are shown below. More detailed explanations are given later.





Engine Systems comprise of the following systems: -

- ❖ Starting system
- ❖ Fuel supply system
- ❖ Ignition system
- ❖ Cooling system
- ❖ Lubrication system
- ❖ Air Intake or air Induction system
- ❖ Exhaust system
- ❖ Charging system
- ❖ Engine Management System or Engine Electronic Control System

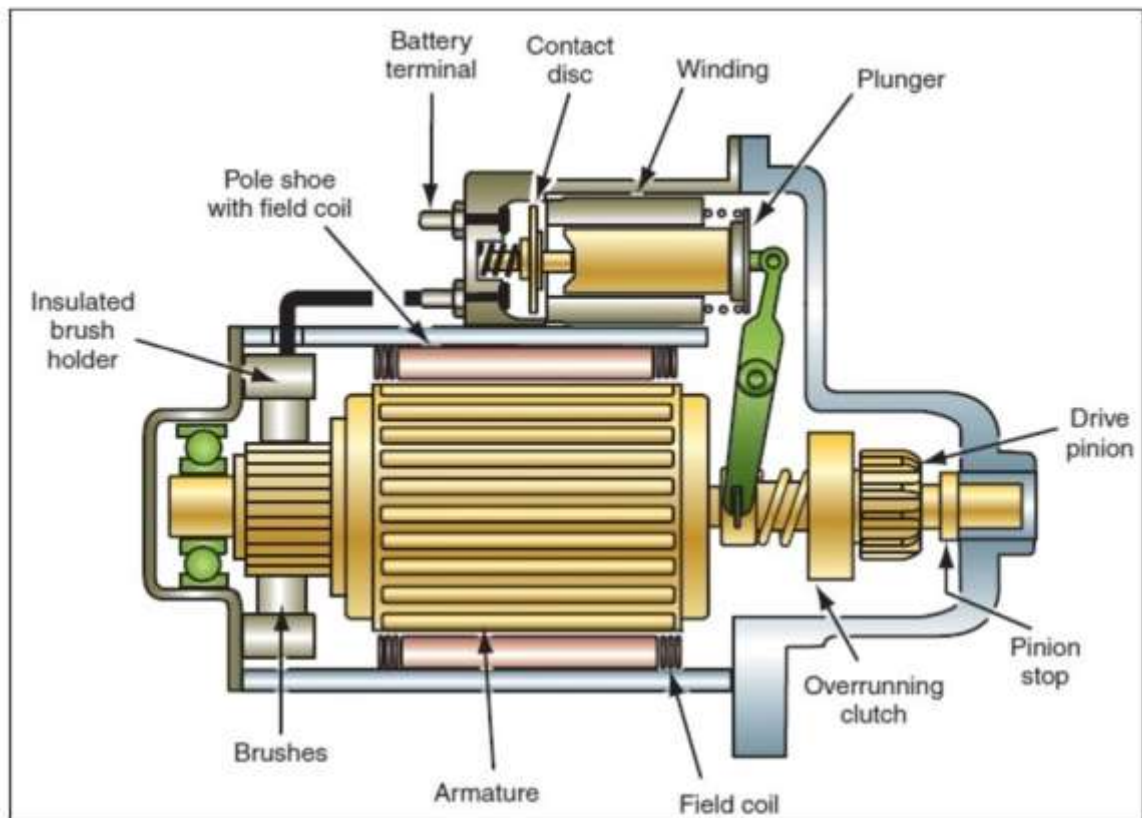
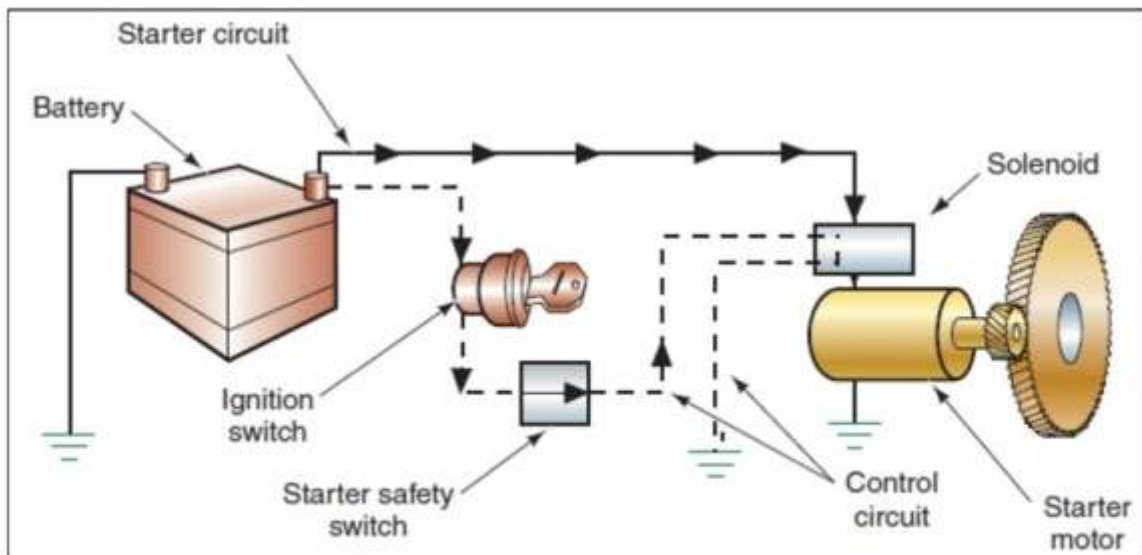
*These are the systems for petrol engines. Diesel Engines have similar systems except for fuel supply and ignition System.* Some parts of the system are built into the engine, some parts are attached to the engine and other parts are located on the body panels in the engine compartment. *Brief description of each of the above systems are provided below.*

### Starting System

To start the automobile engine, the crankshaft must turn fast enough for the air or air-fuel mixture to enter into the cylinders. An electric starter or starter motor does this job. It converts electrical energy from the battery to mechanical energy which rotates the crank shaft.

The starting system has two separate but related circuits. One is the “*Low-current control circuit*”. The other is the “*High-current motor circuit*”. Both the systems operate on battery voltage.

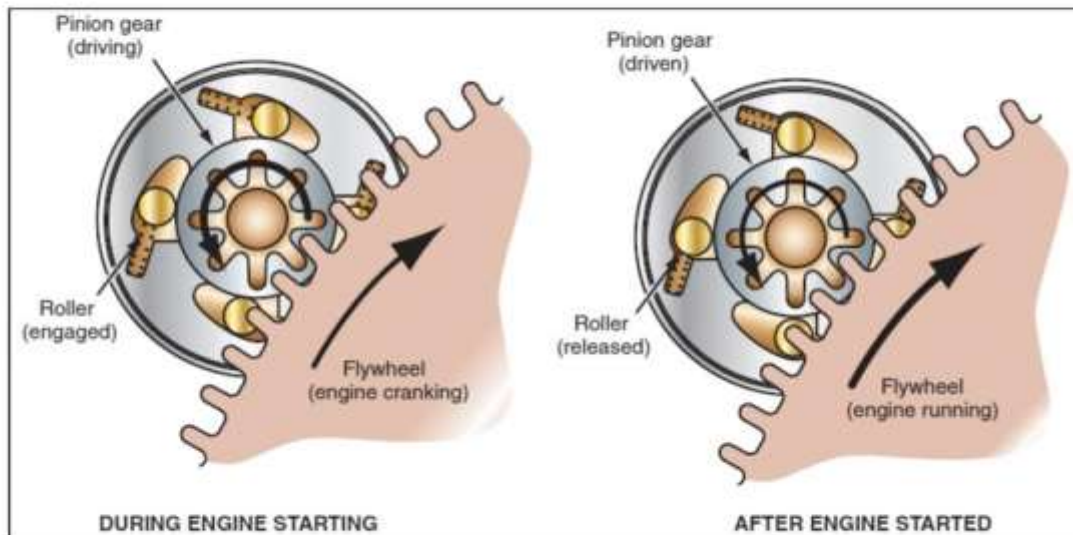




When the driver turns or presses the ignition key to "START", the control circuit causes heavy contacts to close in a **starter relay or solenoid switch**. High current then flows from the battery insulated cable through these contacts to the starter motor. A gear on the starter motor shaft moves into mesh with the ring gear around the engine flywheel. As the starter motor shaft turns, it spins the crankshaft fast enough to start the engine.

Normally the gear ratio between flywheel ring gear and starter motor pinion is about 15:1. When the starter motor turns at 3000 RPM, the ring gear turns at 200 RPM or higher which is fast enough to start the engine. As soon as engine starts, the crank shaft speed may rise up to 3000 RPM. If the pinion remains in mesh with the ring gear, the power of the engine being

many times higher than the starter motor, the ring gear will attempt to drive the pinion. With 15:1 gear ratio, the speed of the pinion will reach about 45,000 RPM or more which will severely damage the starter motor. To prevent this, an **overrunning clutch** is used which is a device that can transmit torque in only one direction. The overrunning clutch transmit starter motor torque only during cranking. After engine starts, the clutch is unlocked thereby disengaging the pinion from the flywheel ring gear.



Overrunning Clutch Used in Starter

## VIDEO OF AUTOMOBILE STARTER

[E-Note Videos\04 Automotive Starter operation.mp4](#)

### Fuel System

The purpose of the fuel system is to supply the engine with a combustible mixture of air and fuel which is known as **air-fuel mixture**. This mixture is burnt in the combustion chamber to produce energy and power.

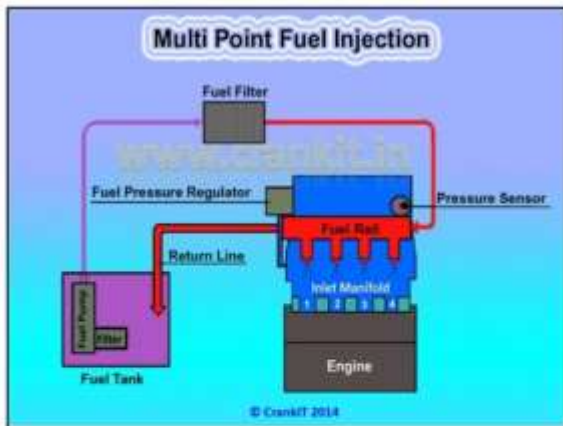
The fuel system is made of two smaller systems or subsystems. These are: -

- ❖ **Fuel Supply system**
- ❖ **Fuel Metering System**

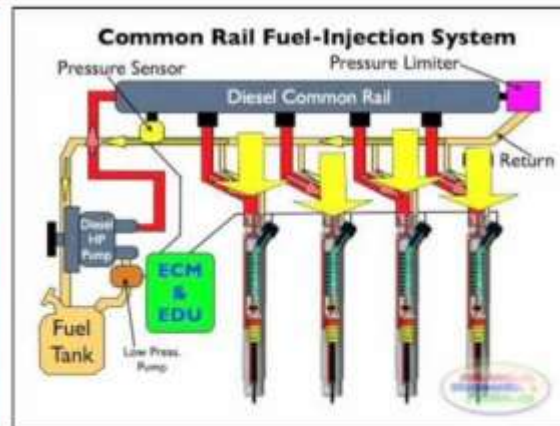
The fuel supply system delivers fuel from the fuel tank to the fuel metering system. The fuel metering system uses either a **carburettor** or a **fuel injection system** whose function is to measure out or meter-out the amount of fuel needed by the engine. This is the fuel that mixes with the air entering the engine to form the air-fuel mixture of appropriate proportion.

*The systems differ from each other in construction and working principle for SI and CI engines.*





Multi-point Fuel Injection (SI)



Common Rail Fuel Injection (CI)

### Ignition System

The purpose of the ignition system is to ignite the compressed air-fuel mixture in the engine combustion chamber. This must occur at the proper time for combustion to begin. To start combustion, the ignition system delivers an electric spark that jumps across an air gap inside the combustion chamber ends of the spark plugs. The heat from this arc ignites the compressed air-fuel mixture which then creates pressure which pushes the pistons down the cylinders so that the engine runs. The spark voltage is around 20KV and in modern high speed engines can go as high as 45KV. This system is used in "Spark Ignition (SI) engines".

"Compression Ignition (CI) Diesel engines" ignite the air-fuel mixture by the heat of compression and do not need a spark. They usually have glow plugs that preheat the combustion chamber to allow starting in cold weather.

Following types of ignition systems are used in automobiles: -

- ❖ Coil ignition system or Battery ignition system
- ❖ Magneto ignition system
- ❖ Electronic ignition system

*Both Battery Ignition system and Magneto Ignition System fall under category called "Conventional Ignition Systems".* These systems work on the principle of mutual magnetic induction.

Electronic ignition system used solid state devices like transistors and capacitors. Brief operating principles of all the above types of ignition systems are explained below: -

### Battery Ignition System

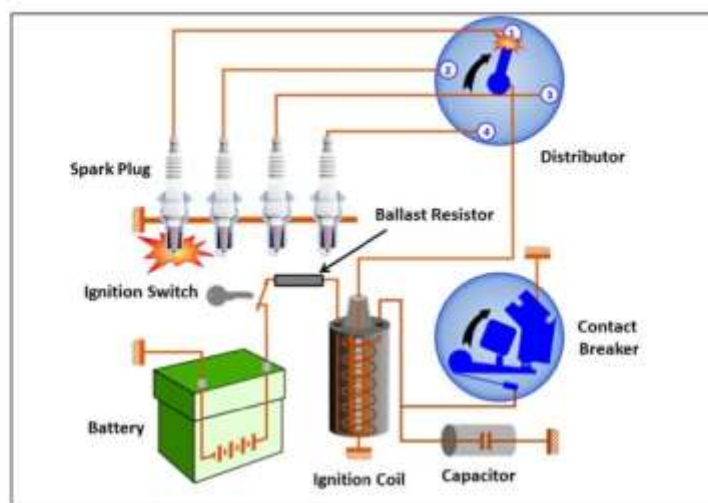
This is based on the principle of "Mutual Induction" and "Transformer Action". When ignition switch and contact breakers are closed, current of about 3A passes through primary windings which creates a strong magnetic field around it. This cuts across the secondary coil. Sudden operation of the contact breaker causes the magnetic field to collapse and creates an induced high voltage EMF in the secondary coil. This EMF is led through a distributor to the respective



spark plug in sequence (as per firing order) which causes a spark to jump across the spark plug tips igniting the air-fuel charge in the cylinder.

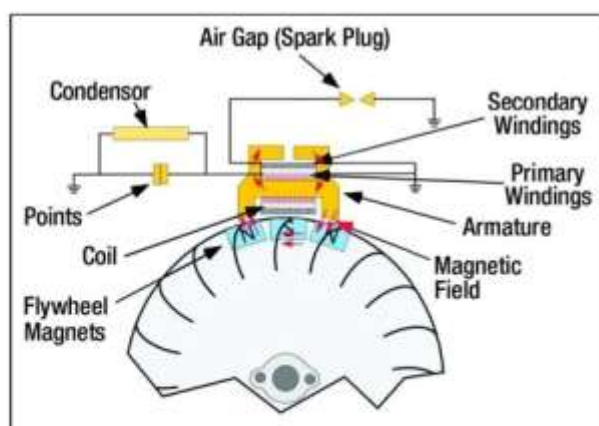
The various parts of a battery ignition system are: -

- Battery
- Ignition switch
- Induction coil
- Circuit / Contact breaker
- Capacitor
- Distributor
- Spark plug
- Connecting high tension cable



### Magneto Ignition System

The magneto-ignition system is similar in principle to battery system except that the magnetic field in the core of the primary and secondary windings is produced by a rotating permanent magnet. The magnet is rotated by the engine flywheel. As the magnet turns, an alternating field is produced from a positive maximum to a negative maximum and back again. The engine also operates a contact breaker interrupting the current and causing the voltage to be increased sufficiently to jump a small gap.



## VIDEO ON IGNITION SYSTEM

### E-Note Videos\05 Ignition System.mp4

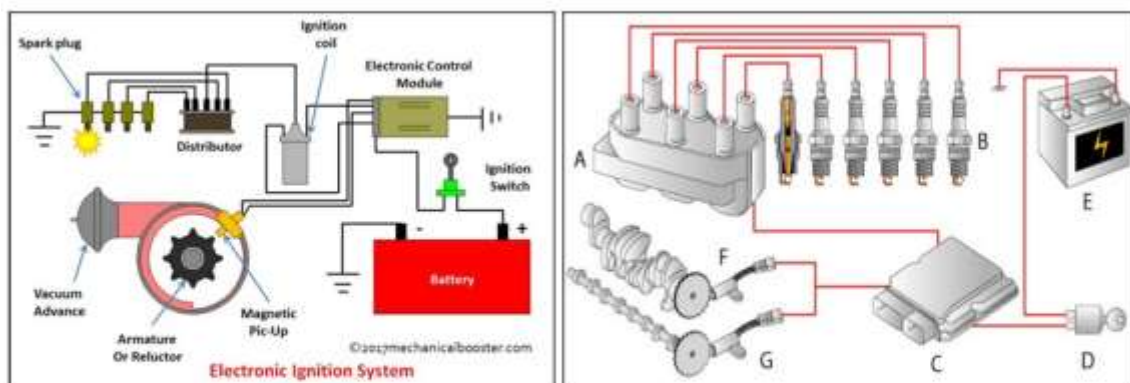
#### Electronic Ignition System

An electronic ignition is a modification on the conventional system. *In a distributor type system*, the contact breaker points have been replaced with a **magnetic pickup coil** and there's an **electronic ignition control module**. When the driver switches ON the ignition switch, the current starts flowing from the battery through the ignition switch to the ignition coil primary winding, which in turn starts the armature pickup coil to receive and send the voltage signals from the armature to the electronic ignition control module. When the tooth of the **rotating reluctor** comes in front of the pickup coil, the voltage signal from pickup coil is sent to the electronic module which in turn senses the signal and stops the current flow to primary coil. When the tooth of the rotating reluctor goes away from the pickup coil, the change in voltage signal is sent by pickup coil to the ignition module and a timing circuit inside ignition module turns ON the current flow. This ON and OFF action in the primary coil induces a very high voltage to the tune of 50KV in the secondary ignition coil which then passes through the distributor to the appropriate spark plug as per firing-order sequence of the engine.

Major components of a *distributor less electronic ignition system* include the ignition coils, ignition wires, ignition control module, camshaft sensor, crankshaft position sensor and the spark plugs. In this system, there are individual ignition coils for each of the spark plugs. The crankshaft position sensor informs the engine computer how fast the engine is running. Likewise, the camshaft sensor tells the computer when to activate the fuel injectors and deliver fuel. The computer accepts both the information and informs the ignition control module what to do based on the information it has received.

In turn, the ignition control module collapses a magnetic field built up inside each one of its ignition coils. The coils produce a high voltage because of this magnetic field collapse, which travels through the ignition wires and to the spark plugs. In general, an electronic ignition system can send around 50,000 volts to the spark plugs to ignite the fuel and air mixture.

Schematic diagrams of both the type of systems are shown below: -



Distributor Type System

Distributor less System

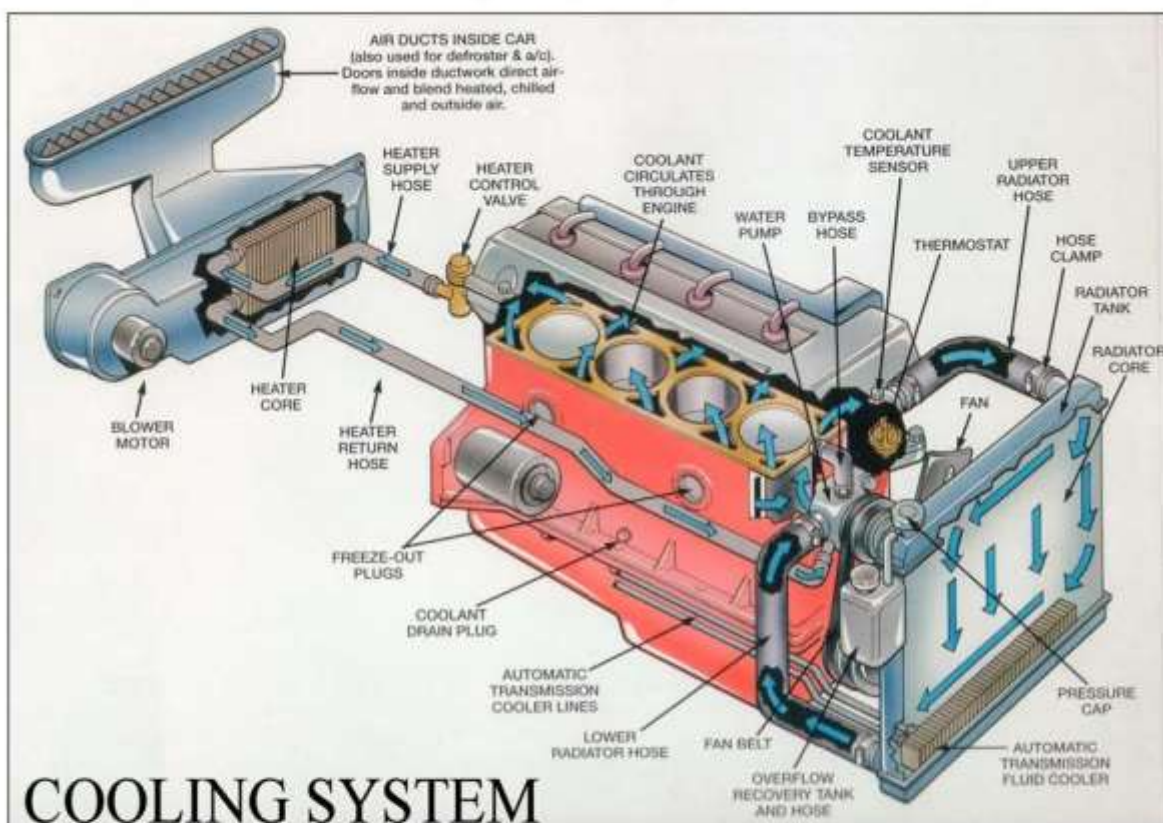


## Cooling System

The burning air-fuel mixture in the engine cylinders may reach a temperature of 2200°C or higher. This means the engine parts become very hot. However, to maintain lubrication, the maximum temperature of engine parts can not be allowed to exceed 260°C or else the lubricating oil will break down and lose its lubricating ability resulting in severe damage to the engine parts. *Therefore, to prevent overheating, a cooling system is absolutely must to remove the excess heat which is about 33% of the total heat energy produced in the combustion chamber.*

The purpose of the engine cooling system is three-fold viz: -

- ❖ To remove excess heat produced during combustion and limit maximum temperature of engine parts around 260°C.
- ❖ To bring the engine operating temperature to normal operating temperature of about 80°C as quick as possible.
- ❖ To provide a source of heat in passenger compartment in the HVAC system.



The various parts of a cooling system are: -

- ❖ **Water Jackets:** These are internal passages in cylinder head and cylinder blocks that surround the cylinder and combustion chamber.



- ❖ **Water Pump:** This is driven by engine and maintains circulation of the coolant in entire cooling water circuit.
- ❖ **Radiator:** This is heat coolant-to-air heat exchanger with two sets of passages one for hot coolant and other for ambient air. In the radiator, the hot water gives off the heat to the ambient air to become cool and goes back to the water jackets via the water pump. Thus, there is a continuous recirculation of water between the radiator and water jackets.
- ❖ **Fan:** The fan pulls or pushes ambient air over the radiator to improve the heat transfer and thereby better engine cooling. It is driven by the engine.
- ❖ **Thermostat:** This is a valve which controls the coolant flow. When the engine is cold, the valve stops flow of hot water from engine to radiator and return back the water back to water jackets. This quickly warms up the coolant to normal operating temperature of the engine after which the valve opens up to allow the hot water to flow to radiator for cooling.

### Lubrication System

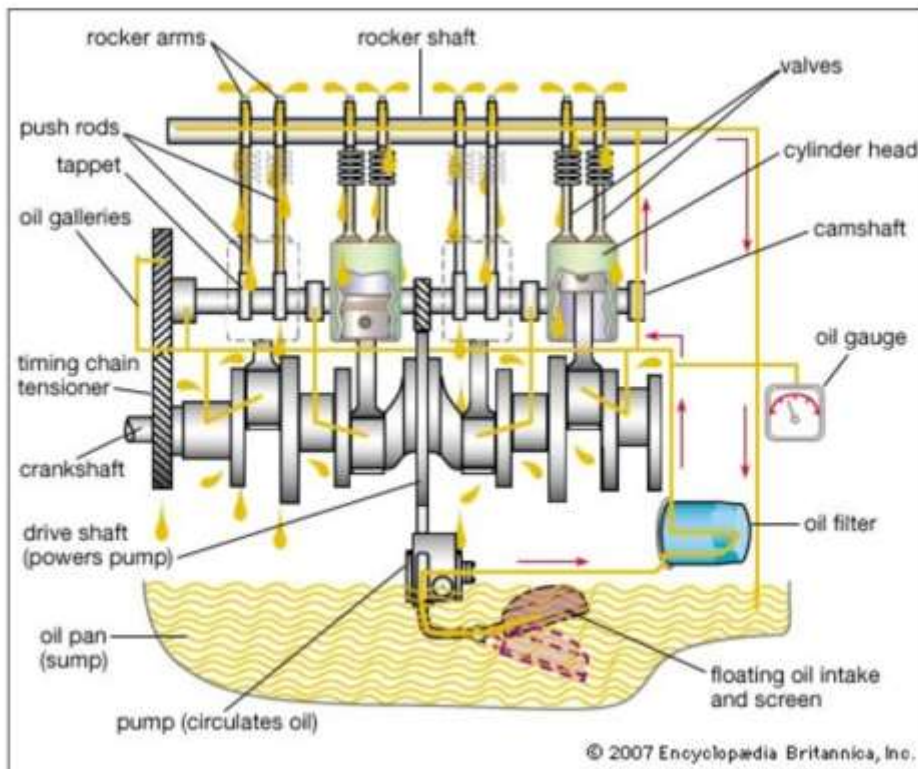
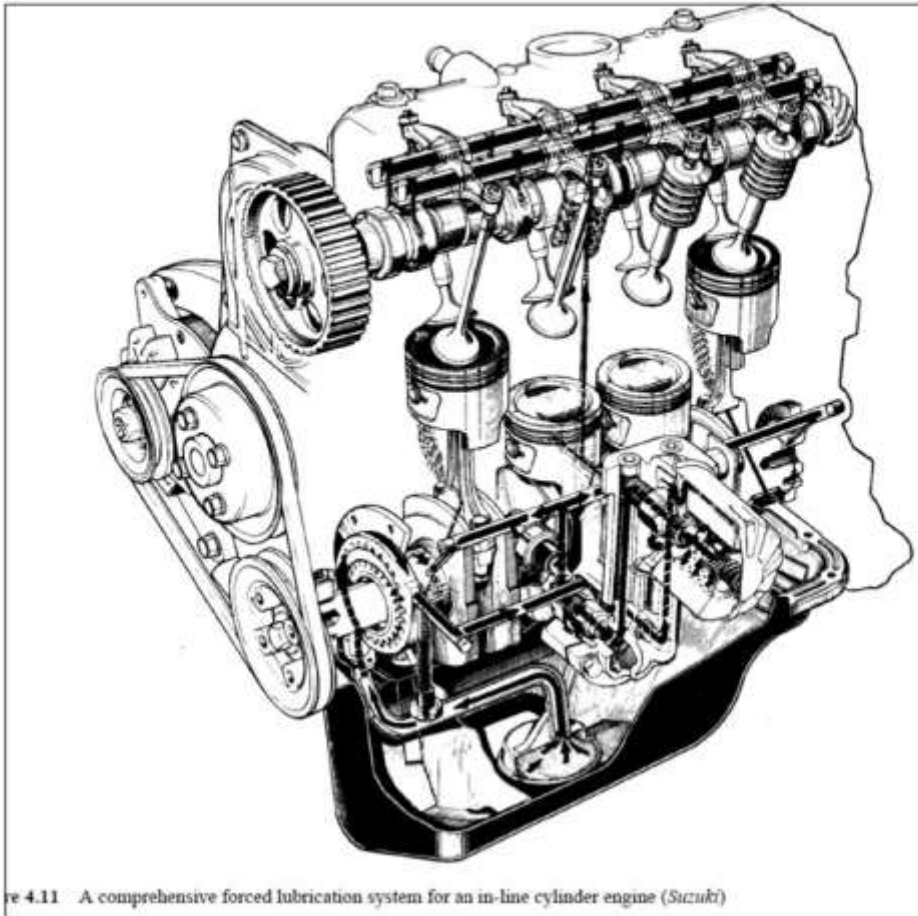
The lubricating system supplies lubricating oil to all moving parts of the engine. The **oil pump** picks up oil from the **oil sump or oil pan**. The pump then sends the oil through the **oil filter** to the **oil galleries (passages)** to main bearing journals that support the crankshaft. Some oil flows from the main bearings through oil holes drilled in the crankshaft to the connecting rod bearings. Oil then passes through an oil line to the **cylinder head** where it flows through an oil gallery to **camshaft bearings** (in overhead cam shaft engine) to lubricate the cam shaft bearing and **valve-train components**. The **pistons, piston rings and piston pins** receive oil thrown off the connecting rod bearings. This oil falls on the **cylinder walls** thereby reaches the pistons, piston rings and piston pins. After the oil circulates to the engine parts, it drops down to the oil sump.

Many engines have small matching grooves or an oil spurt hole in each connecting rod. The opening provides additional piston and cylinder wall lubrication. A spurt of oil sprays out when the hole in connecting rod aligns with the hole in the crankpin journal.

The lubrication system serves several purposes as below: -

- ❖ It lubricates the moving parts to reduce wear and tear by enabling the parts to move on layers of oil. This action reduces friction and thereby reduces power loss in engine.
- ❖ The oil picks up heat as it flows through various parts of the engine. The hot oil drops back to the cool oil pan where it gives off heat. Heavy engines are provided with a water-cooled oil cooler on cylinder block through which the hot oil passes before returning back to the oil sump.
- ❖ Oil fills the clearance between the bearings and rotating journals and creates a film. When heavy loads are suddenly imposed on the bearings, the oil film cushions the shock.

- ❖ Oil works as a cleansing agent by picking up dirt, metal wear dusts etc. and returns back to the oil sump. This helps to keep the engine clean and enhances its life.





### Air Intake or Air Induction System

Combustion air enters the engine through the “Air intake” or “Air induction” system. As much as about 2832 m<sup>3</sup> of air passes through the engine in every 1609 km. The grit and dust in the engine must be removed before the air is allowed to enter the engine. If not, engine wear and damage can result.

The intake air passes through the air filter which has a ring or panel of filter paper or other material that traps the grit and dust as the air passes through. The air cleaner also muffles the induction noise caused due to opening and closing of the inlet valves in the engine.

Major parts for air intake system are given below: -

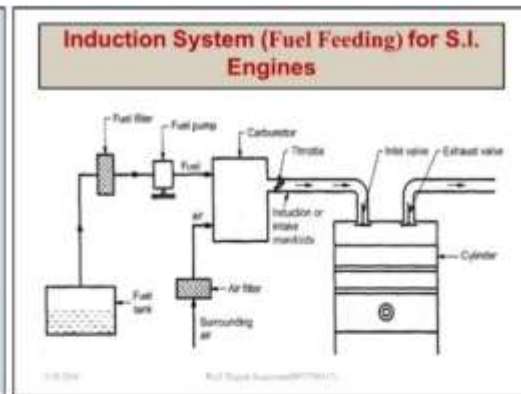
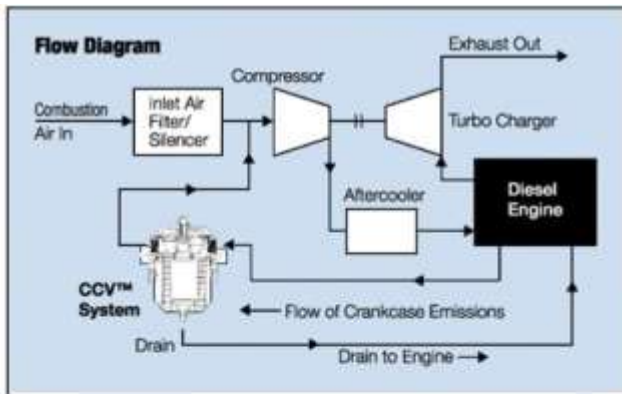
- ❖ Air filter or air cleaner
- ❖ Throttle valve (only in SI engine)
- ❖ Intake manifold which connects with intake ports in the cylinder head.
- ❖ Exhaust gas turbine and air compressor (for turbo-charged engines)
- ❖ Super charger (for super-charged engines)
- ❖ Inter cooler (to cool turbo-charged or super-charged air)
- ❖ Connecting hoses and pipe lines



The air intake systems differ principally between compression ignition and spark ignition engines. In CI engines, only atmospheric air is handled whereas in SI engines, mixture of atmospheric air and fuel vapour is handled.

Also, an engine does not produce same power when operating at different locations and altitudes which is due to variations in ambient conditions. “*Engine driven Supercharger*” or “*Exhaust gas driven Turbocharger*” help in resolving this problem.





### Exhaust System

The exhaust system collects, quiets and cleans the exhaust gases from the engine. The system carries the gases to the rear of the vehicle, treats the pollutants (if **after-treatment system is provided**) and discharges them into the atmosphere. Exhaust system may also include “**Exhaust gas recirculation system (EGR)**” if provided which is a method of exhaust gas pre-treatment for NO<sub>x</sub> emission.

Major parts of exhaust system are given below: -

- ❖ Exhaust manifold
- ❖ Exhaust gas recirculation system (EGR), if provided
- ❖ Exhaust pipe
- ❖ Catalytic Converter, if provided
- ❖ Muffler or Silencer
- ❖ Resonator, if provided
- ❖ Tail pipe

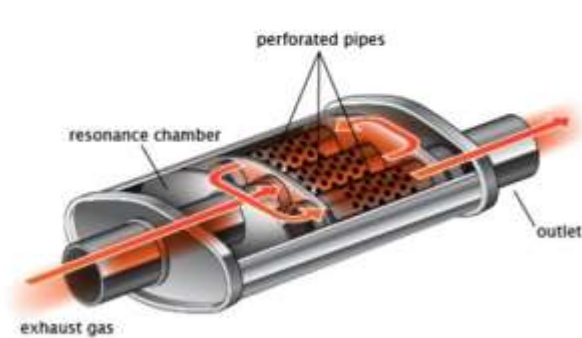
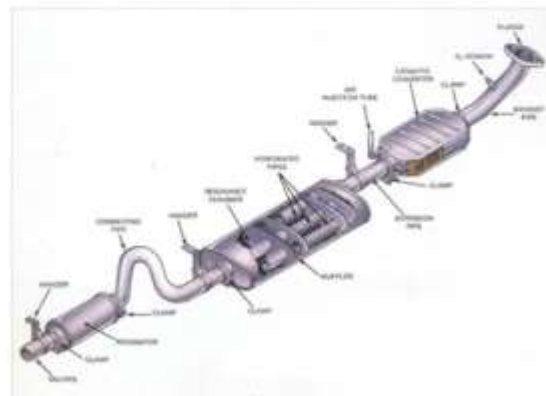
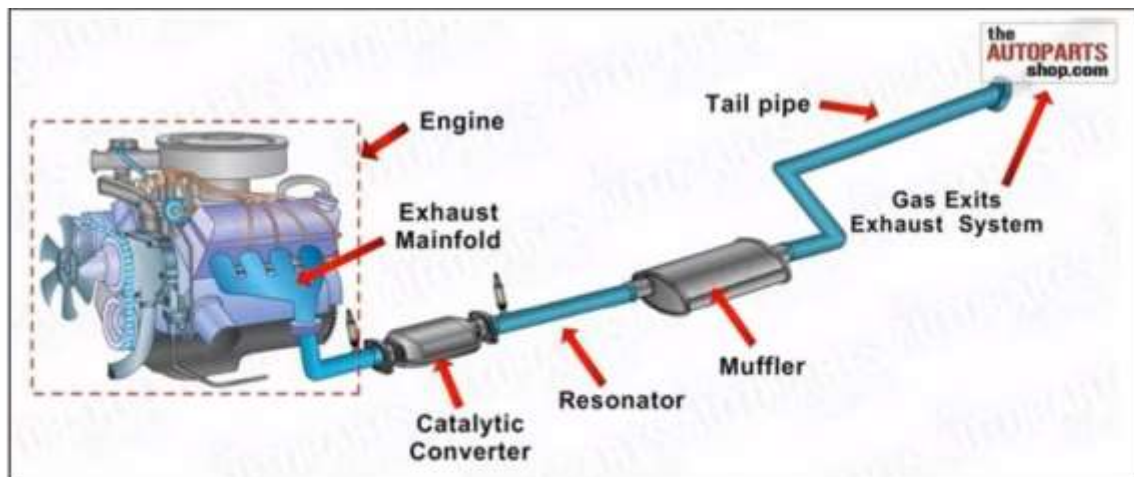


Image courtesy of ClearMechanic.com





### Charging System

The charging system serves following purposes: -

- ❖ Restores to the battery the charge removed from it for cranking the engine.
- ❖ Handles the electrical load of ignition, lights, radio and other electrical and electronic equipment while the engine is running.

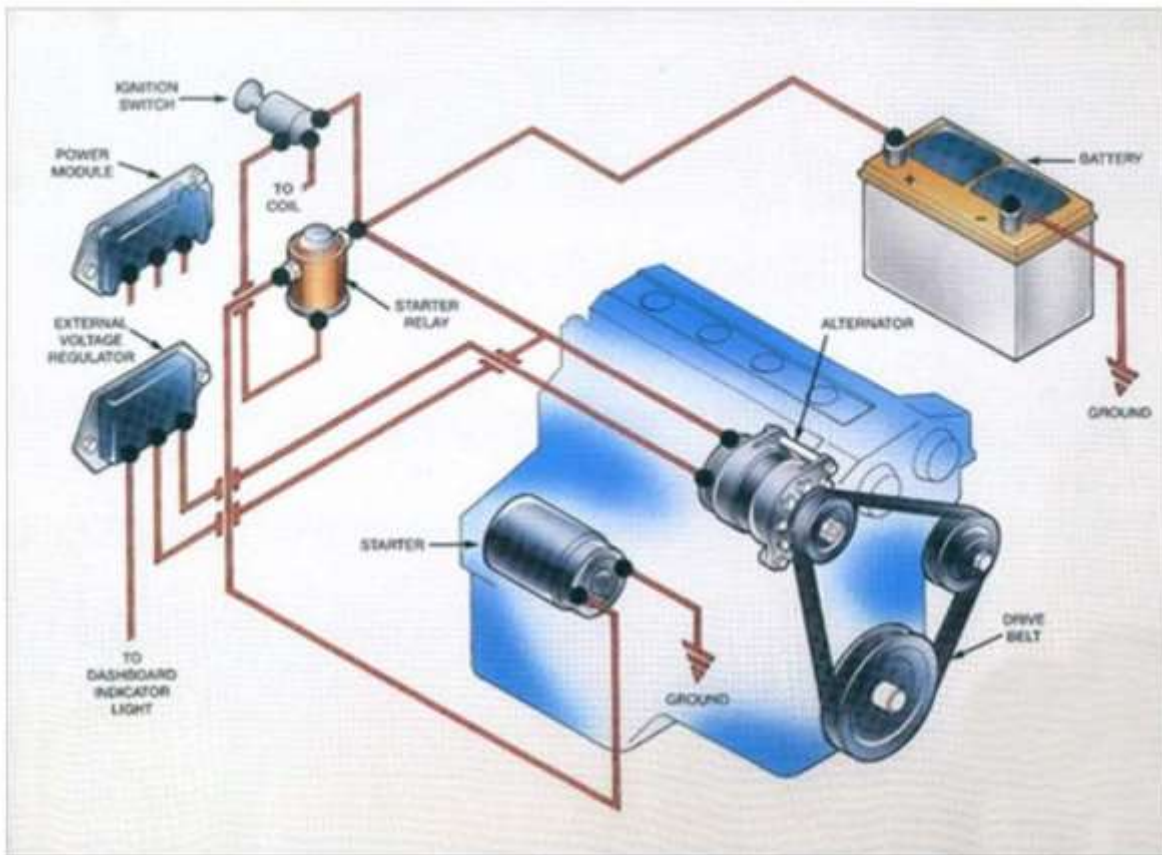
If the charging system stops working, the battery's charge would soon be depleted, leaving the car with a "dead battery." If the battery is weak and the alternator is not working, the engine may not have enough electrical current to fire the spark plugs, so the engine will stop running.

If the battery is "dead", it does not necessarily mean that there is anything wrong with it. It is just depleted off its charge. It can be brought back to life by recharging it with a battery charger or by running the engine so that the alternator can charge it.

The charging system on late model vehicles has demands far in excess of those required by older vehicles. Increased electrical demand through use of electrically operated components, decreased battery size and close voltage regulation have all impacted the charging system. Such close control falls to the computer system. It is accomplished by monitoring operating conditions and electrical demands. INPUTS (corresponding changes) are then made by the computer to the charging system's voltage and amperage outputs through signals sent to the voltage regulation circuits and/or engine idle speed control OUTPUTS.

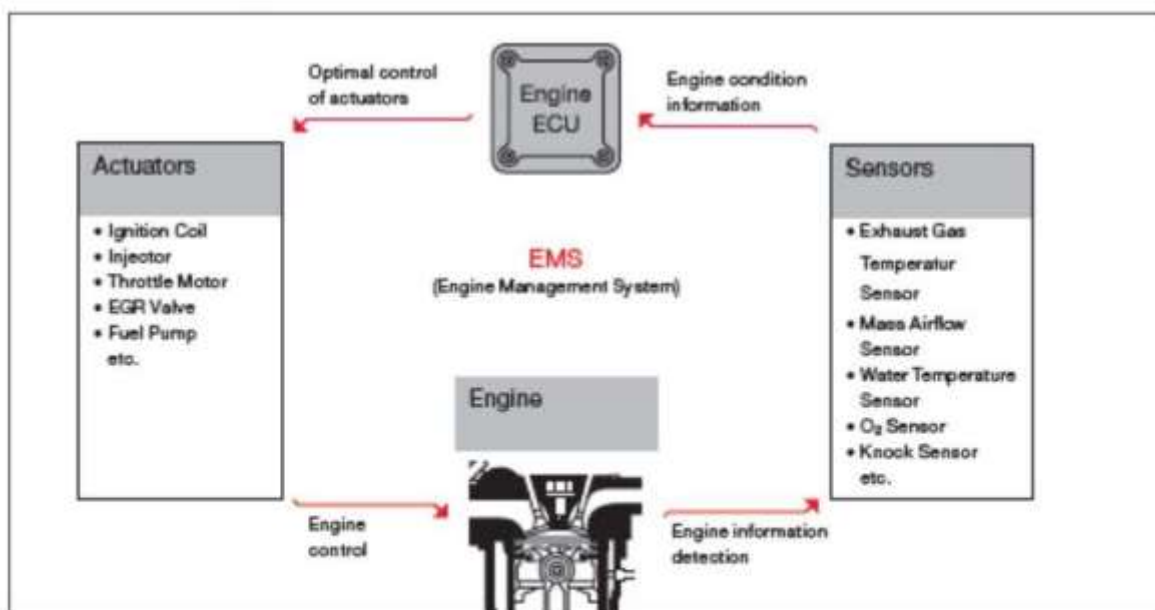
The major parts of engine charging system are: -

- ❖ Alternator with regulator
- ❖ Battery
- ❖ Connecting wires



### Engine Management System (EMS)

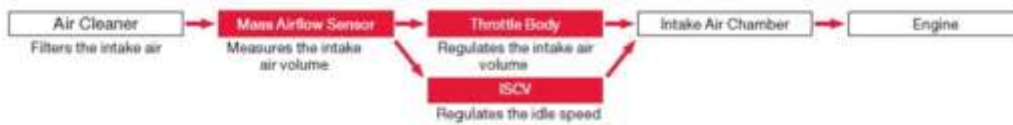
An EMS is a self-contained custom-built computer which controls the running of an engine by monitoring the engine speed, load and temperature and providing the ignition spark at the right time for the prevailing conditions and metering the fuel to the engine in the exact quantity required. The performance and emissions that today's engines deliver would be impossible without the EMS that manage everything from ignition and fuel delivery to every aspect of emissions control. Snapshot of an EMS is shown below: -





## Basic EMS Configuration

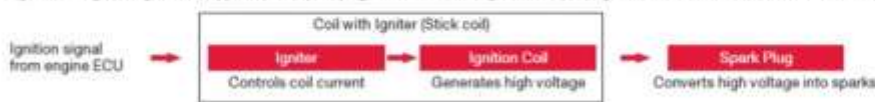
**Intake System:** The intake system adjusts the air volume required for combustion and detects the intake air volume. A mass airflow sensor is used to directly measure the volume of intake air which is filtered by the air cleaner. Air volume adjustment is performed at the throttle body and Idle Speed Control Valve (ISCV), and air is then drawn into the cylinder. Idle speed control in vehicles equipped with Electronic Throttle Control (ETC) is performed only by ETC without the use of an ISCV.



**Fuel System:** The fuel system controls the fuel supply required for combustion. After the fuel pump draws and discharges fuel, the pressure regulator maintains the fuel pressure at a constant level, and the surplus fuel is returned to the fuel tank. The fuel then travels through the fuel filter where dust and moisture are removed, passes through the delivery pipe, and is fed to the injectors. When the fuel is injected by the injector, it causes a small fluctuation in pressure. The pulsation damper absorbs the pulsation of the fuel pressure that occurs at that time.



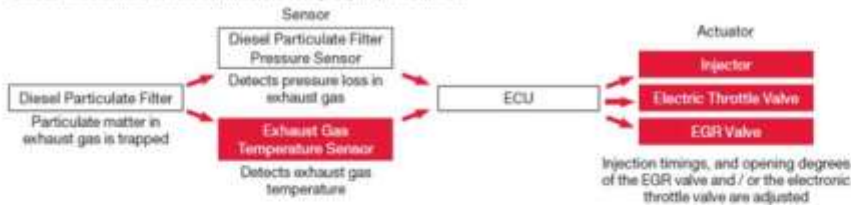
**Ignition System:** The ignition system generates sparks that are necessary for igniting the air-fuel mixture. The optimal ignition timing is calculated by the engine ECU according to each driving condition. An ignition signal is then output to the coil with igniter (stick coil). The coil with igniter generates high voltage based on the ignition signal. The high voltage is then applied to the spark plug electrodes, which generates sparking and causes combustion of the air-fuel mixture within the cylinders.



**Air Fuel Ratio Feedback System:** The air fuel ratio feedback system controls the engine at an optimal condition by monitoring the conditions of the exhaust gas. In this system, Lambda Sensor detects the concentration of oxygen in the exhaust gas, and the engine ECU analyzes the combustion conditions of the engine, in order to control various actuators such as Exhaust Gas Recirculation (EGR) Valve both for diesel or gasoline engines to suit the driving conditions.



**Exhaust Gas Treatment System (Diesel Engines):** The exhaust gas treatment system includes a Diesel Particulate Filter (DPF) to trap particulate matter in exhaust gas, an Exhaust Gas Temperature Sensor to detect exhaust gas temperature and a DPF Pressure Sensor to detect pressure loss in the exhaust gas. The system controls the exhaust gas temperature and fuel injections to burn the particulate matter trapped by the DPF (DPF regeneration control). Thus, exhaust emissions are reduced without reducing engine performance.



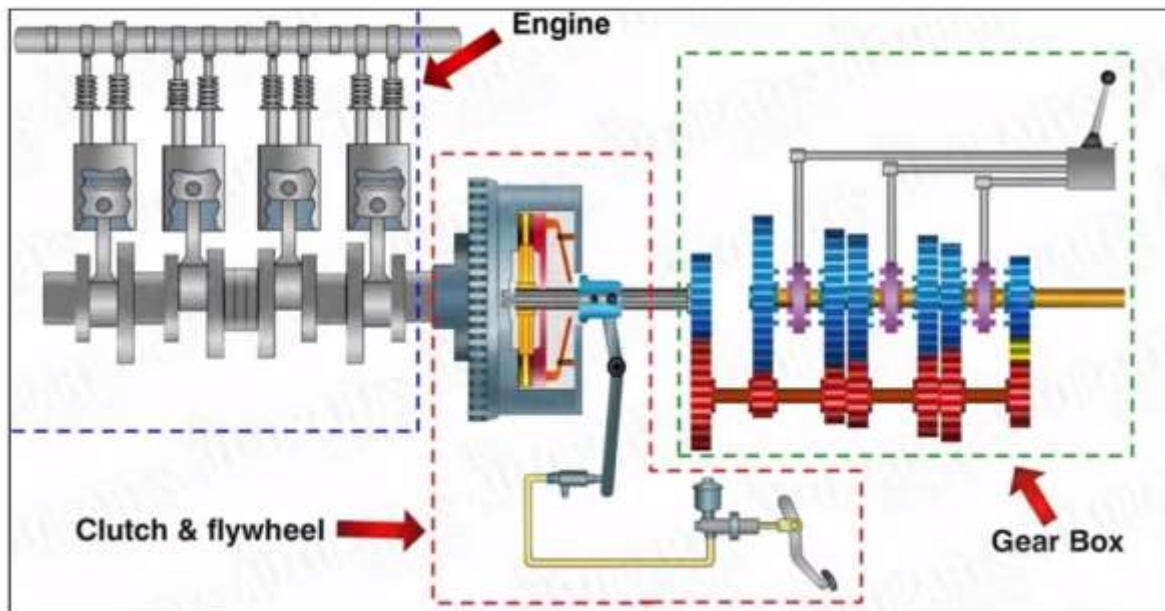
**Control System:** Uses an engine ECU to determine the optimal fuel consumption rate, injection timing, ignition timing, optimum control of exhaust gas, output, etc. in accordance with the operating conditions of the engine detected by various sensors, in order to control various actuators.



## TRANSMISSION SYSTEM

The transmission system refers to the mechanism that transmits the power developed by the engine to the wheels of an automobile in the form of kinetic energy. A basic transmission system comprises of various transmission components such as gears, shafts and other parts, which function together to enable the movement of an automobile.

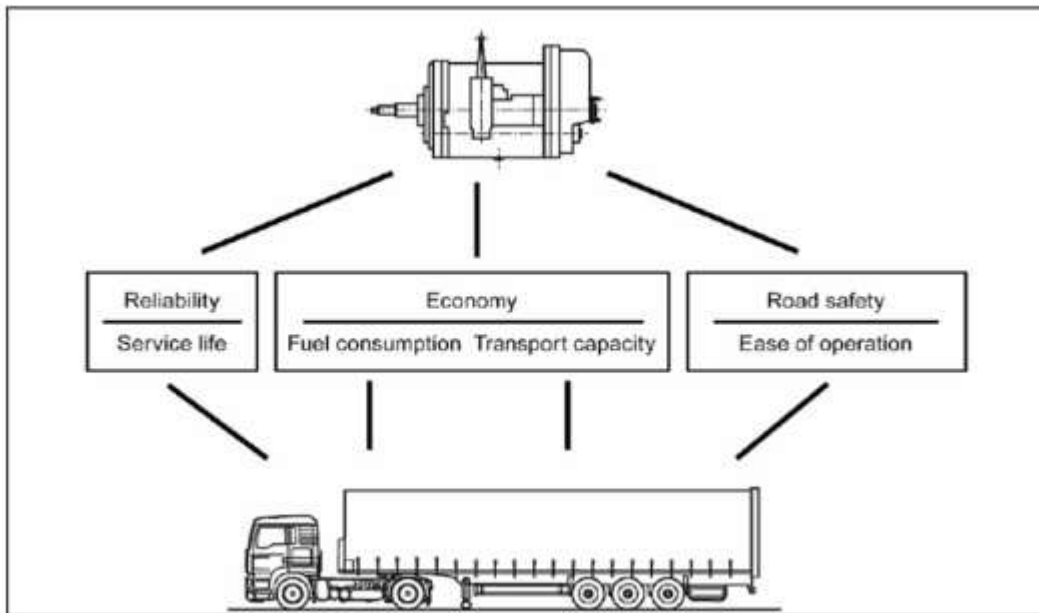
To start a motor vehicle from rest, the inertia of the vehicle must be overcome. A high percentage of all the power of the engine must do this. *If the automobile engine could develop full power in turning the crank shaft slowly like a steam engine, then it would have been possible to transmit the full power to the driving wheels even in starting.* However, the automobile engine does not develop full power when it is running slowly. *It has to be working fairly fast before it develops anything like maximum power, maximum torque etc. Even the maximum power and torque do not occur at same engine speed.*



*There are three reasons for having a transmission or transaxle (Transmission + Axle) in the automotive power train or drive train. The transmission or transaxle can:-*

- ❖ Provide the torque needed to move the vehicle under a variety of road and load conditions. It does this by changing the gear ratio between the engine crank shaft and the drive wheels of the vehicle i.e. a gear box acts as a torque multiplier.
- ❖ Provide a "Reversing mechanism" to enable the vehicle to move back ward without changing engine crank shaft rotation whenever required.
- ❖ Provide a "Neutral gear shifting mode" for starting the engine and running it without turning the drive wheels.

The *effect of automotive transmission on basic attributes* of a vehicle is shown pictorially below: -



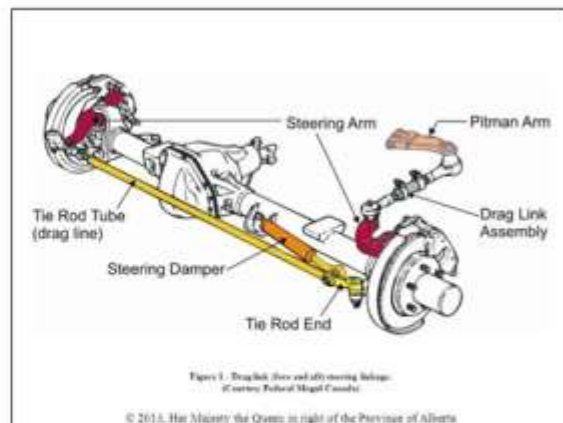
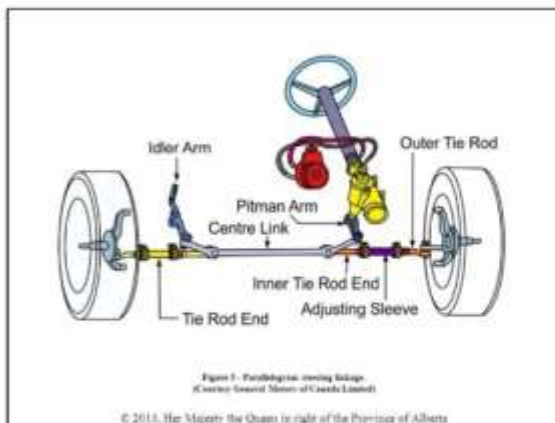
Details of various types of transmissions are explained later in Module-III.

## STEERING SYSTEM

The steering system allows the driver to control the direction of vehicle travel. This is made possible by linkages that connects the *steering wheel* to the steerable wheels and tires. To increase the mechanical advantage of the rotary motion of the steering wheel to linear motion, a *steering gear box* is provided between the steering wheel and the linkages as shown below.

The steering system may be *“Manual”* or *“Power assisted”*. When the only energy system for the steering wheel is the force applied by the driver in turning the steering wheel, the vehicle has *manual steering*. If the steering effort of the driver is further assisted by hydraulic pump or electric motor, the system is called as *power steering*. Most vehicles have power steering for enhanced driving safety and make the parking easier.

### Components of Steering System



The various components of steering system are: -



- ❖ Steering wheel, steering shaft and column
- ❖ Steering gear box
- ❖ Universal joint between steering shaft and steering gear box
- ❖ *Pitman arm or drop arm* at the output shaft of steering gear box
- ❖ *Steering knuckle or drag link* arm mounted on one of the stub axles
- ❖ Drag link connecting the end of pitman arm with drag link arm
- ❖ *"Tie rod arms" or "Track rod arms"* mounted on both stub axles of the steerable axles.
- ❖ *"Tie rod" or "Track rod"* connecting both the tie rod arms or track rod arms.
- ❖ Hydraulic pump and valves if system is provided with *hydraulic power steering (HPS)*.
- ❖ Electrical drives with controls if system is provided with *electrical power steering (EPS)*.

### Working Principle of Steering System

The basic operation is same for both manual and power steering. As the driver turns the steering wheel, the movement is carried to the steering gear box. The *steering gear box* changes the rotary motion of the steering wheel into straight line or linear motion. The linear motion acts through a *drop arm or pitman arm* mounted on the output shaft of the steering gear box. The movement of the pitman arm is transmitted by *drag link* to the *drag link arm or steering knuckle* mounted on the stub axle nearest to the steering wheel (in right hand drive, this is the right wheel stub axle and in left hand drive this is the left wheel stub axle).

This causes movement of the connected *steering knuckle* and the wheel in right or left direction corresponding to the rotation of the steering wheel. This movement of the wheel is further transmitted to other wheel via *tie rod or track rod* which causes the other wheel to move in same direction i.e. right or left. The ends of the various joints are of ball and socket design to provide smooth movement in different angle and planes during actual operation of the steering mechanism.

### Types of Steering System

Two types of steering gears are widely used for automotive application viz. *"Manual"* and *"Power"* steering. Both use a variety of designs. However, out of these, *"Recirculating ball type steering gear box"* and *"Rack and Pinion type steering gear box"* are most widely used. Both of these are available in both manual as well as power steering options.

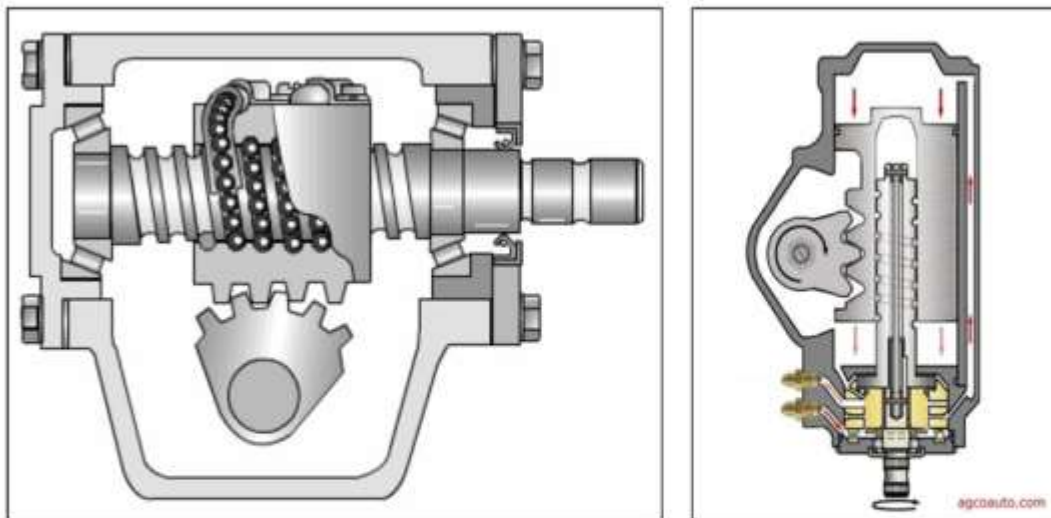
Some vehicles also use a *"Worm-and-roller type steering gear box"* which is quite similar to a recirculating ball type design.

Working principle of both recirculating ball type steering gear box and rack and pinion type steering gear box are explained below: -

### Recirculating ball type Steering

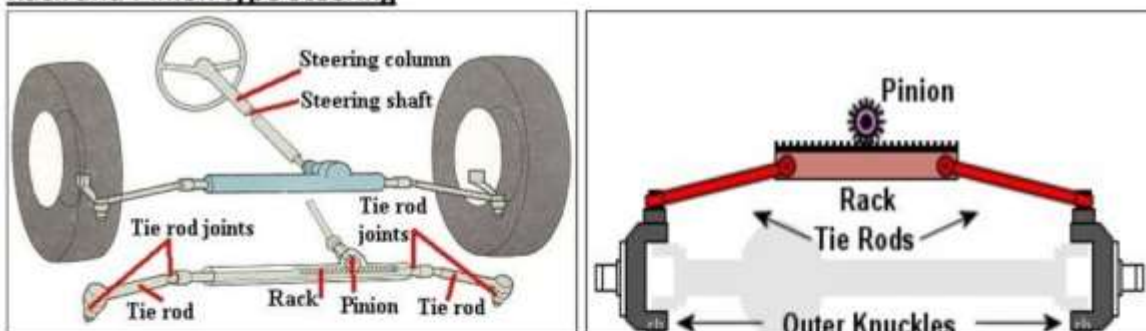
*Trucks and large cars often use this type of steering gear box.* It has a *sector gear* (a section of gear teeth from a gear wheel) on the inner end of the output shaft. The output shaft is called the *sector shaft or pitman arm shaft*. The teeth on the sector gear mesh with teeth cut

on a ball nut. The ball nut rides on the worm shaft which is connected to the steering wheel shaft. Hardened steel balls roll in the grooves inside the ball nut and the worm.



As the steering wheel rotates, the worm forces the balls to roll in the grooves. This action of the balls forces the ball nut to move up or down on the worm. Movement of the ball nut forces the sector shaft to turn. This swings the pitman arm which then operates the steering linkages for turning of the vehicle wheels.

### **Rack and Pinion type Steering**



This type of steering is widely used by modern passenger cars and other down-sized vehicles. It has a pinion gear on the end of the steering shaft that meshes with a flat rack of gear teeth. Tie rods connect the ends of the rack to the steering arms. As the steering wheel turns, the pinion gear moves the rack to the right or left. This moves the tie rods and steering arms which then turn the steering knuckles and the wheels to either right or left.

## **SUSPENSION SYSTEM**

The "Suspension system" is located between the wheel axles and the vehicle body or frame. It consists of a system of tires, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two.

The purpose of the suspension system is to: -

- ❖ Support the weight of the vehicle.



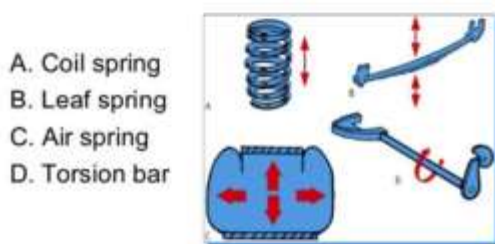
- ❖ Cushions shocks due to movement of the vehicle over bumps and holes on the road.
- ❖ Maintain traction between the tires and road.
- ❖ Hold the wheels in alignment.

The suspension system allows the vehicle to travel over rough surfaces with a minimum of up-and-down body movement. It also allows the vehicle to corner with minimum roll or tendency to lose traction between the tires and the road surface. This provides a cushioning effect so that road shocks have a minimal effect on the occupants and load in the vehicle.

### Components of Suspension System

The suspension system components include *springs* and related parts that support the weight of the vehicle body on the axles and wheels. The springs and *shock absorbers* are the two main parts. While the springs support the weight of the vehicle and absorb the shocks, the *shock absorbers help control or dampen the spring action*. Without this action, spring oscillation occurs. The springs keep the wheel bouncing up and down after they pass bumps or holes. *Shock absorbers allow the basic spring movement, but quickly dampens out the unwanted bouncing that follows*.

### Types of Springs



### Types of Suspension System

Suspension systems can be generally classified into two subgroups viz *“Dependent”* and *“Independent”*. These terms denote to the ability of opposite wheels to move independently of each other.

A *“Dependent suspension”* usually has a beam or live axle that holds wheels parallel to each other and perpendicular to the axle. When the camber of one wheel differs the camber of the opposite wheel changes in the same way (by convention on one side this is a positive change in camber and on the other side this a negative change).

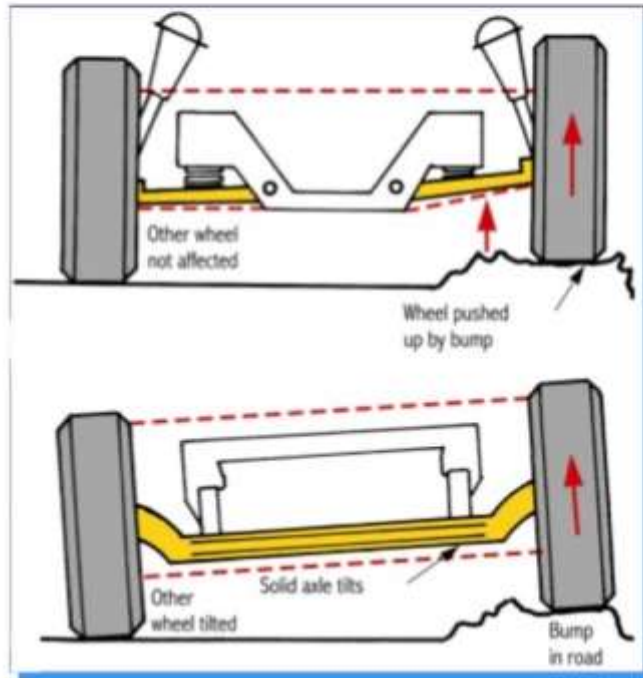
An *“Independent suspension”* permits wheels to rise and fall on their own without disturbing the opposite wheel. Suspensions with other devices like sway bars that link the wheels in some way are still classed as independent.



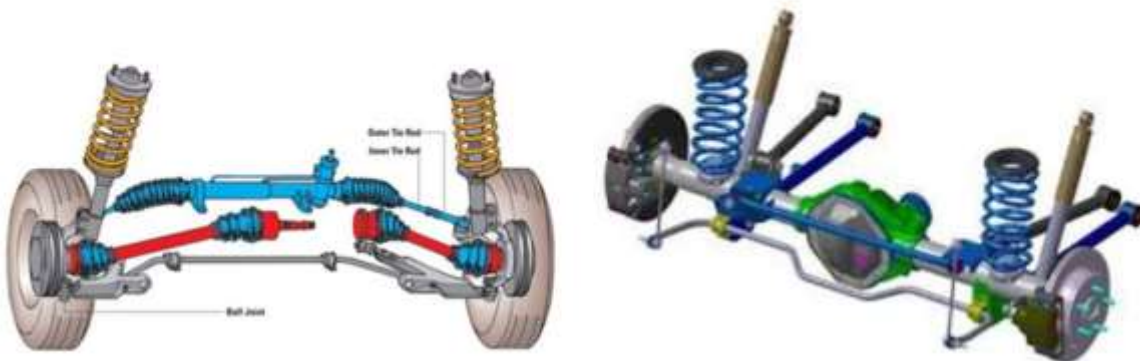
A third type is a *"Semi-dependent suspension"*. In this type, the motion of one wheel does disturb the position of the other but they are not firmly attached to each other. A twist beam rear suspension is such a kind of system.

## Suspensions

**Independent**



**Nonindependent**

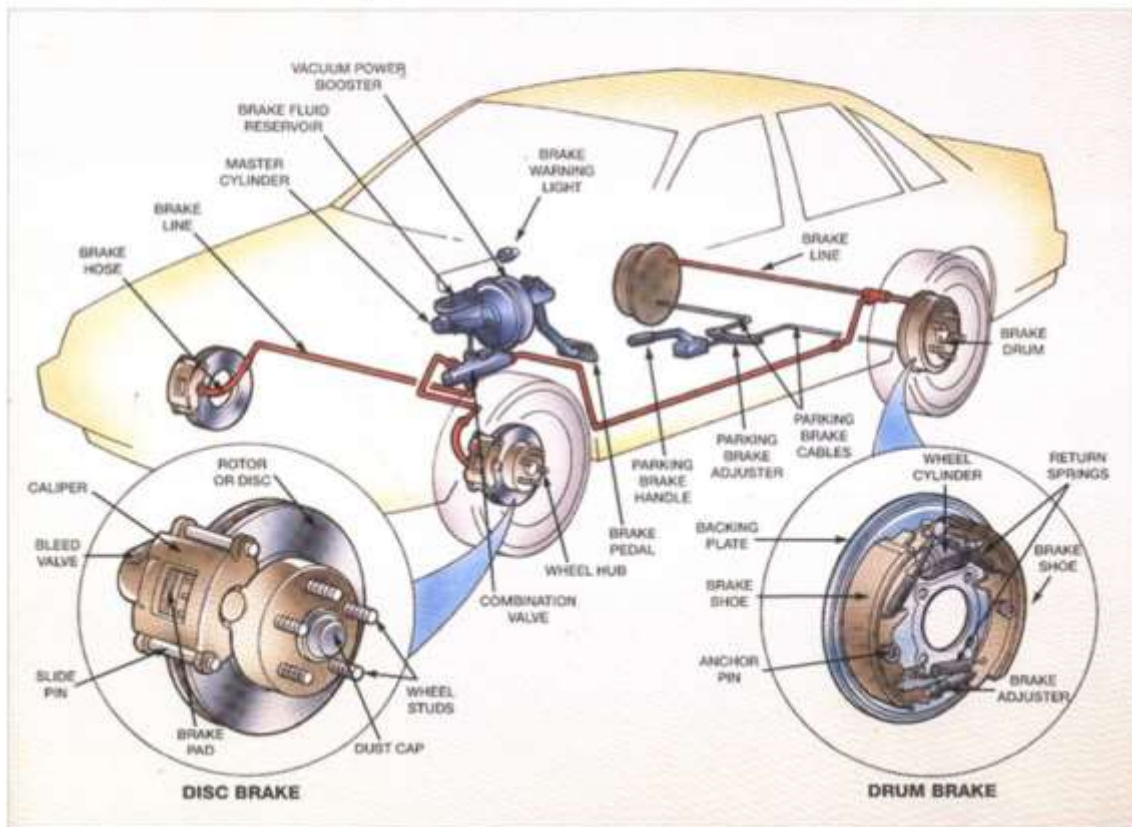


### **BRAKE SYSTEM**

The braking system in an automobile is required to retard the speed of the moving vehicle or bring it to rest in the shortest possible distance whenever required. The vehicle can be held on an inclined surface against the pull of gravity by the application of brake. *Most often this is accomplished by friction.*

Brakes are mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheels. *It absorbs either kinetic energy or potential energy or both*

while remaining in action and this absorbed energy appears in the form of heat. While moving down a steep gradient the vehicle is controlled by the application of the brakes. In this case the brakes remain in action for a longer period making it imperative to dissipate the braking heat to atmosphere as fast as possible.



### Types of Braking System

Braking system of an automobile is classified as per: -

- ❖ Purpose
- ❖ Location
- ❖ Construction
- ❖ Method of actuation

Depending on the "Purpose", there are two types of brakes viz: -

- ❖ "Service brake" which is operated by a foot pedal and used for slowing or stopping the vehicle.
- ❖ "Parking brake" which is operated by a hand lever or foot pedal and used for holding the vehicle stationary when applied. These brakes are also called "Emergency brake" because they are applied when service brake fails.

Depending on the "Location", brakes may either be located at wheels or at transmission or both.

Depending on the "Construction", brakes can be: -



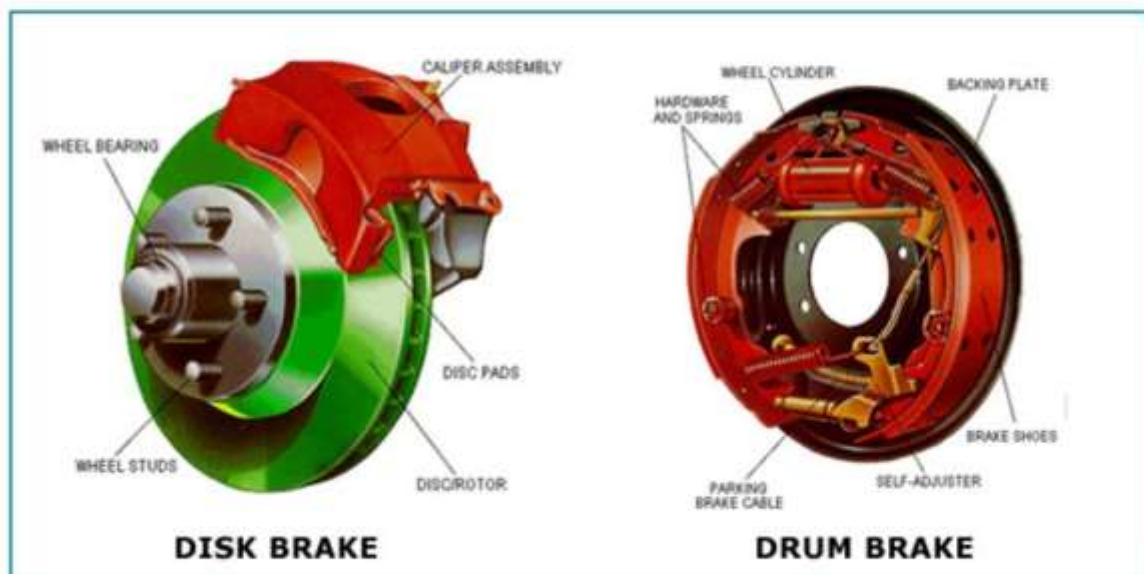
- ❖ Drum type brakes
- ❖ Disc type brakes

Depending on the “Method of actuation”, brakes can be: -

- ❖ Mechanical brakes
- ❖ Hydraulic brakes
- ❖ Electric brakes
- ❖ Vacuum brakes
- ❖ Air brakes
- ❖ By-wire brakes (Used in hybrid, electrical vehicles. Operates by electronic control using electronic sensors and actuators).

Most automotive service brakes are **hydraulic brakes**. They operate hydraulically by pressure applied through a liquid. The service brakes on many medium and heavy-duty trucks are operated by air pressure. These brakes are known as **air brakes**. All these brakes depend on friction between rotating parts and stationary parts for their stopping action.

Brief construction and working principles of “Drum type brakes” and “Disc type brakes” as well as “Hydraulic brakes” and “Air brakes” are explained below: -



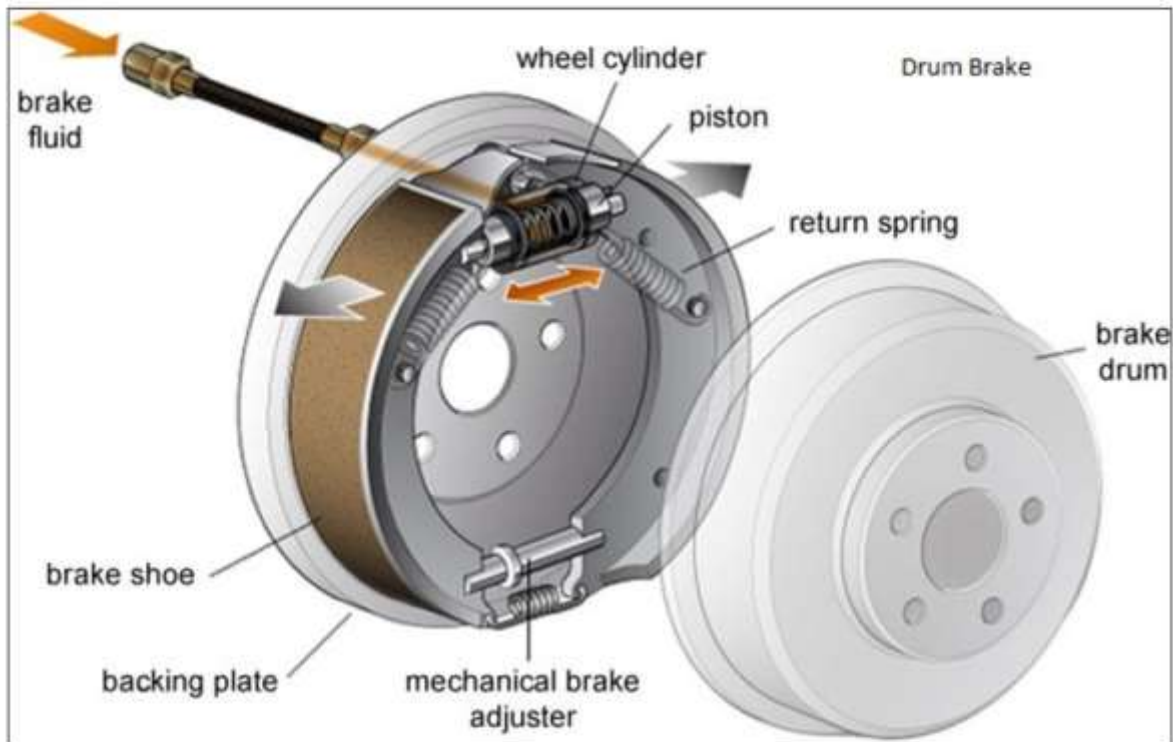
### Drum Type Brakes

A **“Drum brake”** is a brake that uses friction caused by a set of shoes or pads that press outward against a rotating cylinder-shaped part called a brake drum. The shoes are stationary while the brake drum carries the wheels and rotates along with the wheel hub (front and rear). The brake shoes are pivoted on pins and held back by restraining springs to prevent their rubbing against the brake drum when brakes are not applied. **In between the brake shoes, a double acting hydraulic cylinder known as “Wheel cylinder (in hydraulic brakes)” or a “S-shaped cam (in air brakes)” is provided.** The brake shoes therefore can be actuated hydraulically or pneumatically. When the driver presses the brake pedal, the wheel cylinder or S-cam moves the brake shoes outwards against the inner surface of the brake drum and



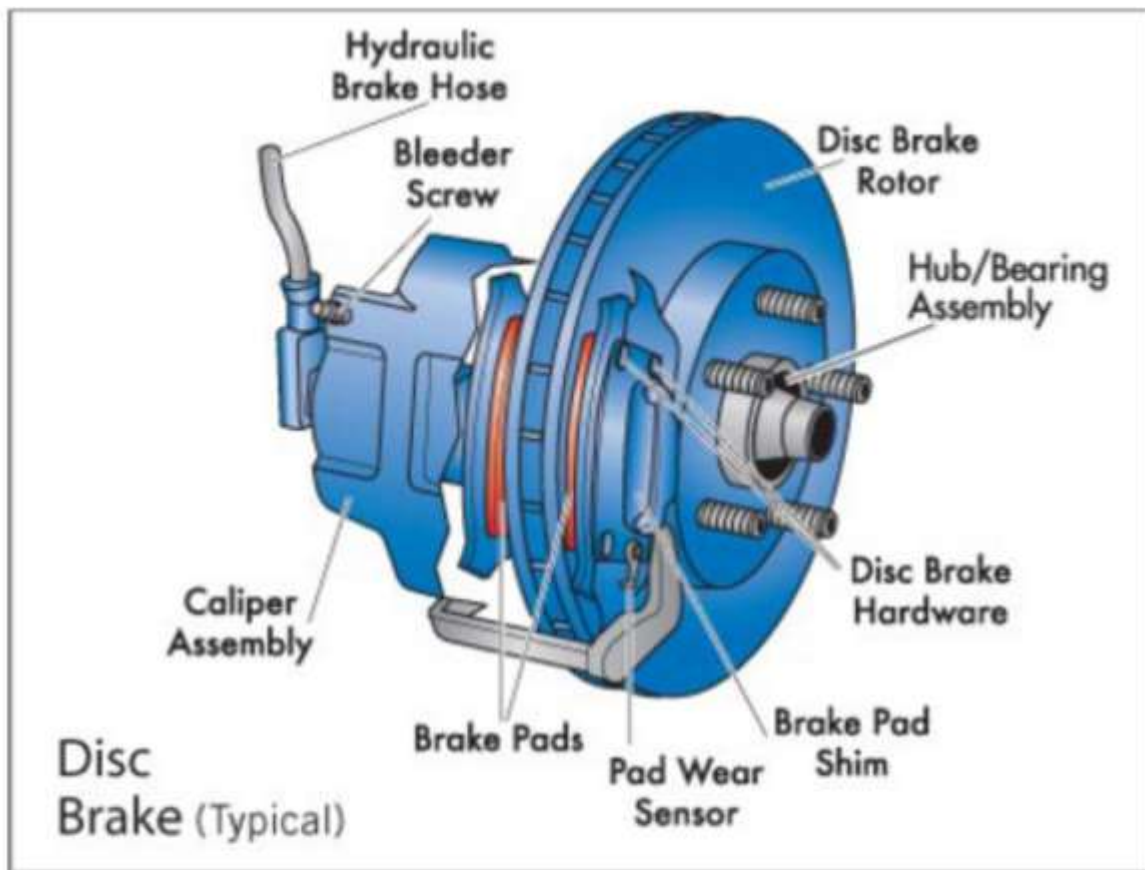
performs the braking action by friction. When the driver lifts off the foot from brake pedal, the restraining springs returns back the brake shoes to their original position.

Drum brakes are used in most heavy-duty trucks, some medium and light duty trucks, few cars, dirt bikes and ATVs (All-terrain vehicles). Drum brakes are often applied to the rear wheels since most of the stopping force is generated by the front brakes of the vehicle and therefore the heat generated in the rear is significantly less. Drum brakes are also used as parking brakes.



### Disc Type Brakes

The disc brake consists of a cast iron disc or in some cases made of composites such as reinforced carbon-carbon or ceramic matrix composites. The disc is connected to the wheel hub flange and rotates along with it. Two friction pads are pressed to this disc to provide braking action. The pads are actuated by hydraulic pistons placed in cylinders formed in a housing known as "Caliper". The caliper is attached to the stationary part of the axle.

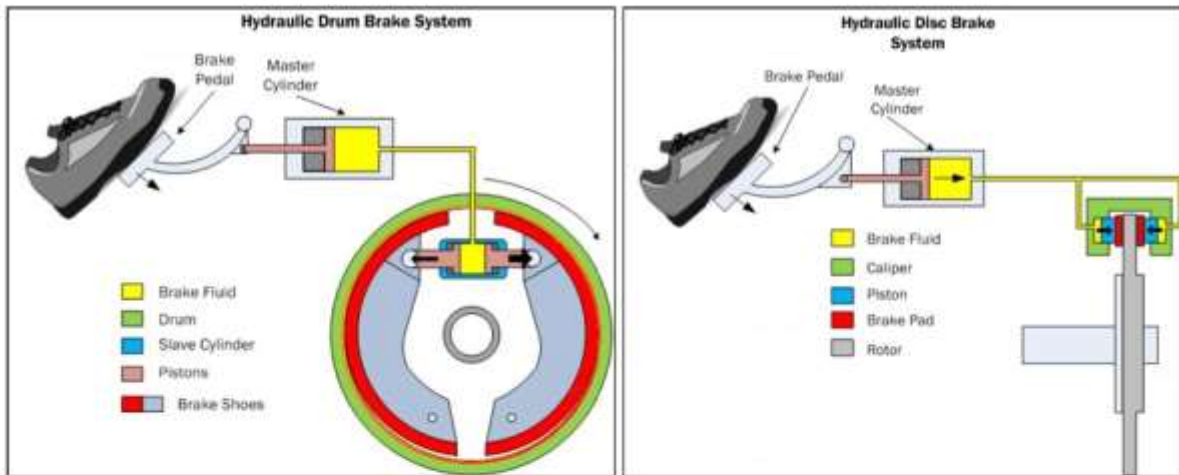


### Hydraulically Actuated Brakes

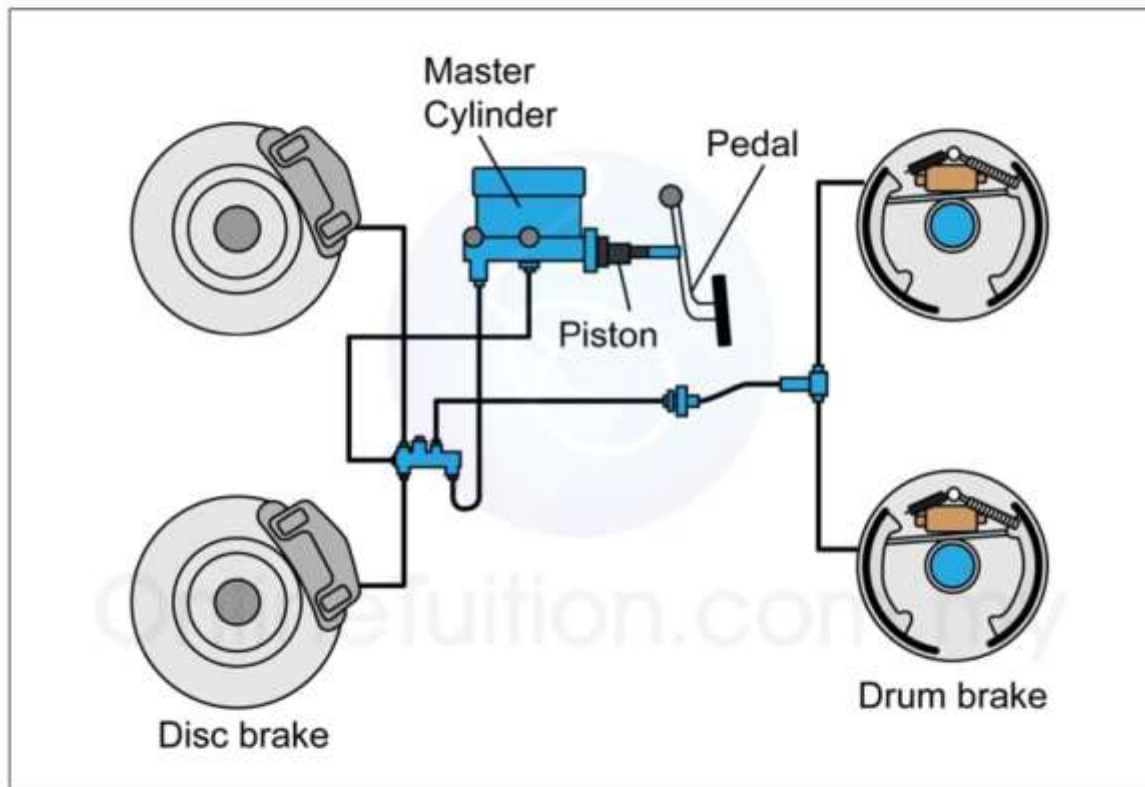
A hydraulic braking system transmits **brake-pedal force** to the **wheel brakes** through **pressurized fluid**, converting the **fluid pressure** into **useful work of braking** at the wheels.

The various components of a hydraulic braking system are: -

- ❖ **Master Cylinder:** This converts foot-pedal force to hydraulic pressure within the fluid system by means of the cylinder and piston.
- ❖ **Wheel cylinders:** The hydraulic line pressure generated in the master cylinder is conveyed to wheel cylinders located in the brakes at each wheel. The pressurized fluid acts on the pistons inside wheel cylinders by which the hydraulic pressure is converted into braking effort. This braking effort either presses the friction pads against the side faces of the disc or forces the shoe friction linings against the inside of the drum.
- ❖ **Brake pipes:** These are steel or nylon pipes which transfer the fluid along the body structure and rigid axle members. Flexible hoses connect the sprung body pipes to the un-sprung axle wheel-brake units, to allow for movement.
- ❖ **Brake fluid reservoir:** This contains brake fluid which supplies to the master cylinder and wheel cylinders during operation.



Layout of a hydraulic braking system having disc brakes in front wheels and drum brakes in rear wheels is shown below: -



### Pneumatically Actuated Brakes

An **"Air brake"** or more formally, a compressed air brake system is a type of friction brake for vehicles in which compressed air pressing on a piston is used to apply the pressure to the brake pad needed to stop the vehicle. This type of braking is similar to the hydraulic brakes except that these brakes use compressed air to apply brakes instead of hydraulic pressure.

Now a day both low and high-pressure air brake systems are used in vehicles. Low pressure brake systems are mostly used in light vehicles to boost the effort applied by the driver. A **"Full Compressed Air brake system"** is normally used in large heavy vehicles, particularly those having multiple trailers which must be linked into the brake system, such as trucks,

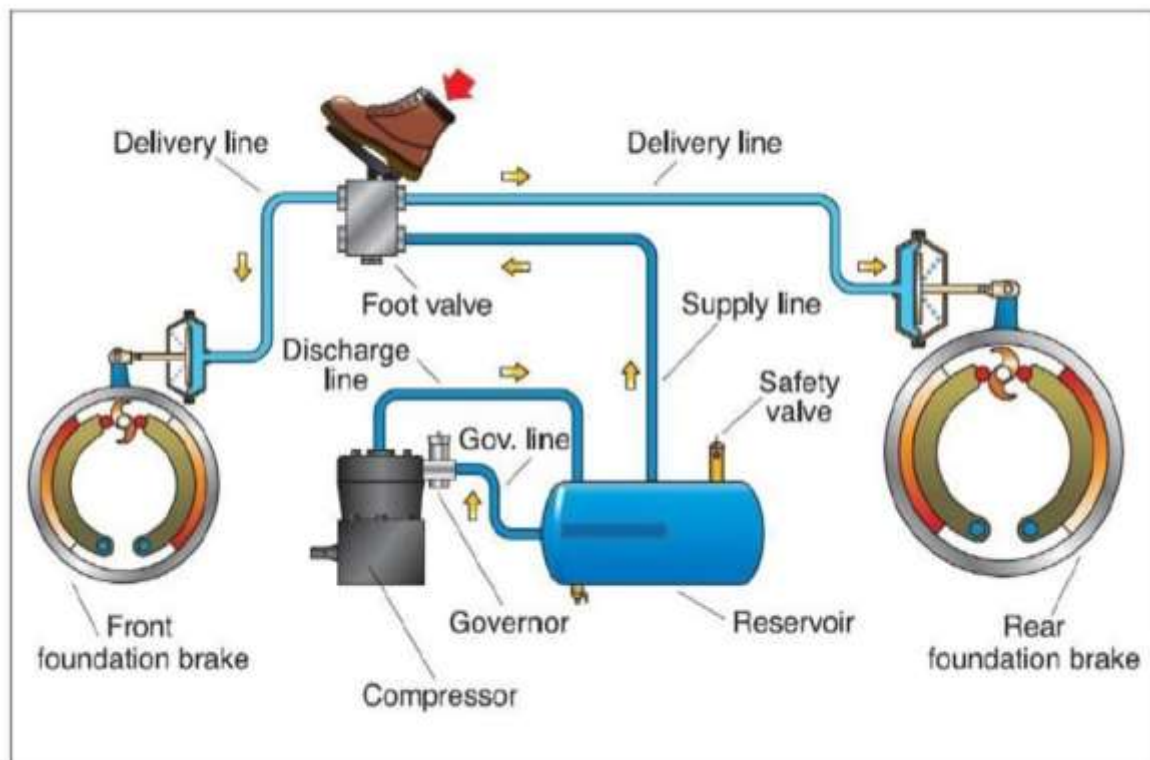


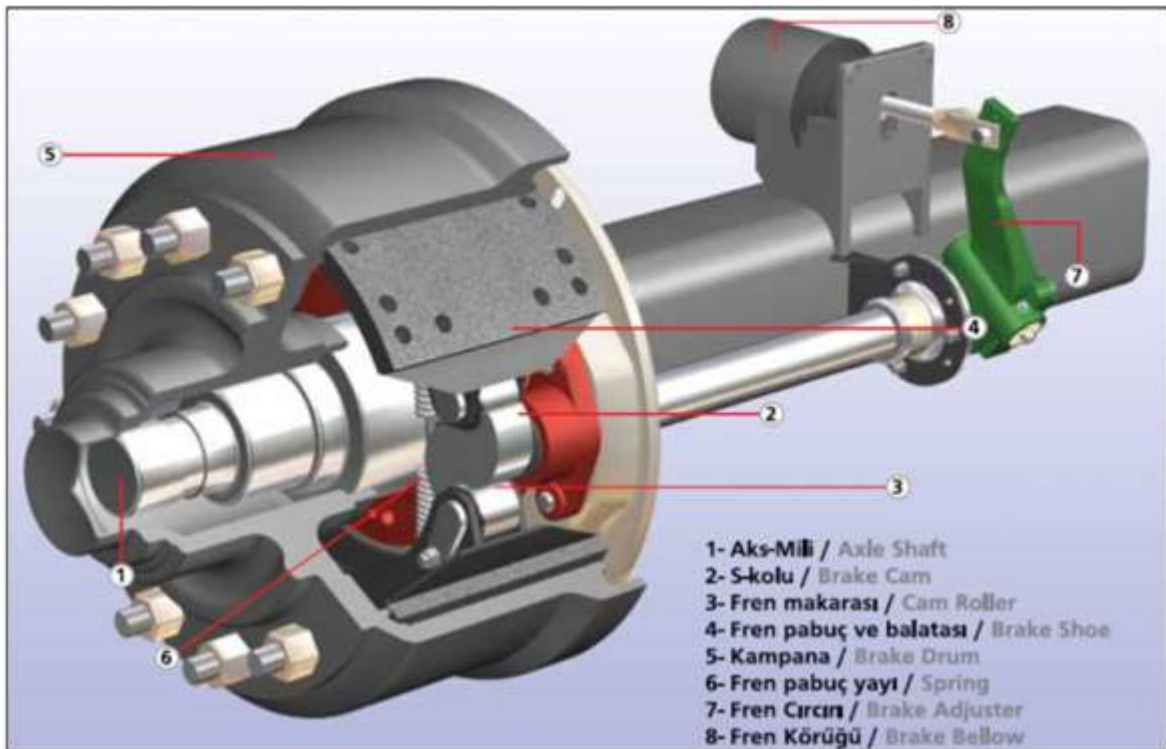
buses, trailers, and semi-trailers in addition to their use in railroad trains. These are not suitable for use in light vehicles being expensive, bulky and heavy.

The engine drives an *air compressor* which supplies compressed air at a pressure of 690 ~ 790 KPa. The air is passed through an *air dryer* to absorb the moisture present in it.

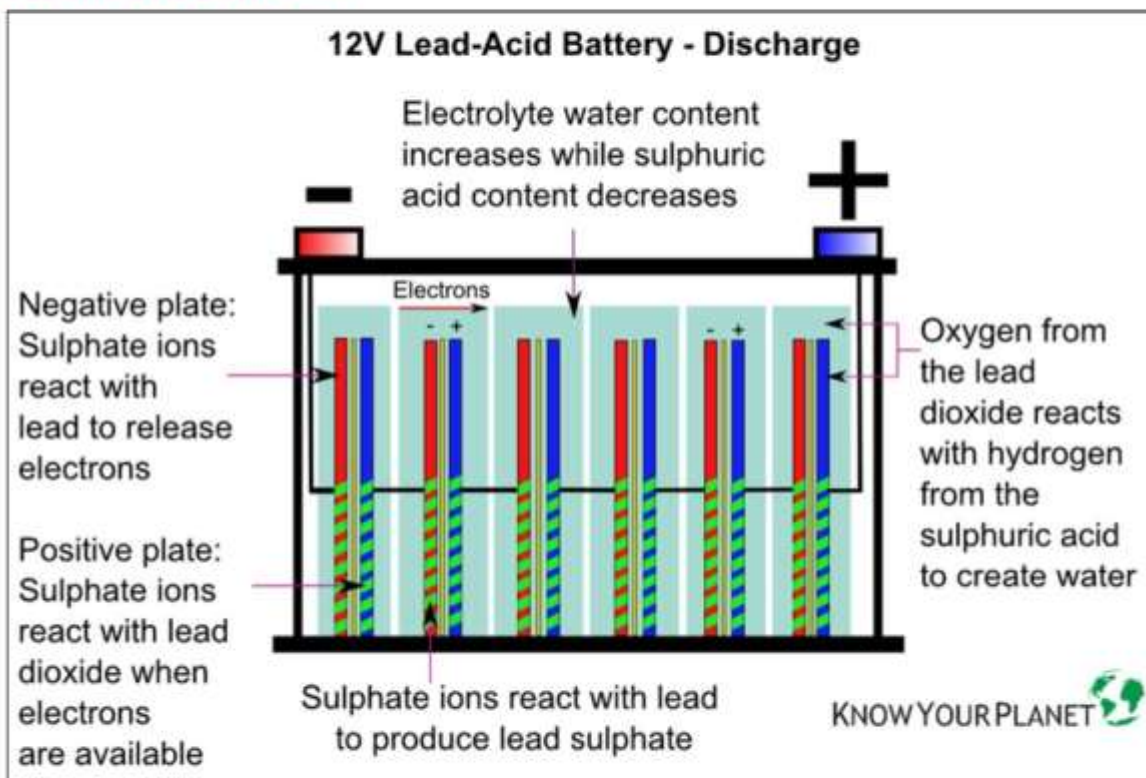
When the brake pedal is depressed, the *brake valves* varies its position and compressed air is admitted into the *wheel brake chambers*. In the chambers the air acts upon *flexible diaphragms* which moves them and pushes out the rods connected with the levers of the *brake gear cams (Normally S-shaped)*. The cams turn and forces the shoes against the brake drums thus braking the wheels.

When the brake pedal is released, the supply of compressed air is cut off from the brake chambers and the air inside is vented to the atmosphere. The pressure in the chambers drops, the brake shoes are returned to their initial position and the wheels run free.





## AUTOMOTIVE BATTERY



The automotive battery supplies *electric current* to operate the *starting motor and ignition system* while starting the engine. It also acts as a voltage stabiliser by supplying current for the *lights, radio and other electrical accessories* when the alternator is not handling the load.



In addition, the battery supplies a small current to the volatile memory of the *electronic control module (ECM)* when the ignition key is switched off.

The battery is an *electrochemical device*. It uses chemicals to produce electricity. The amount of electricity it can produce is limited. As the chemicals in the battery are depleted, the battery runs and down and gets *discharged*. It can be *recharged* by supplying it with electric current from the engine driven alternator. The depleted chemicals are restored to their original condition and the battery becomes recharged.

### Automotive Battery Chemicals and Electrochemistry

The automotive battery is of "*Lead-acid storage type*". The chemicals used are: -

- ❖ Sponge lead Pb (solid) – *Negative active material*
- ❖ Lead peroxide PbO<sub>2</sub> (paste) – *Positive active material*
- ❖ Sulphuric acid H<sub>2</sub>SO<sub>4</sub> (40%) and water (60%) - *Electrolyte*

When the sulfuric acid dissolves, its molecules break up into positive hydrogen ions (2H<sup>+</sup>) and sulphate negative ions (SO<sub>4</sub><sup>-</sup>) and move freely. If the two electrodes are immersed in solutions and connected to DC supply then the hydrogen ions being positively charged moves towards the electrodes and connected to the negative terminal of the supply. The SO<sub>4</sub><sup>-</sup> ions being negatively charged moved towards the electrodes connected to the positive terminal of the supply main (i.e., anode).

When the lead acid cell is undergoing charging or discharging certain chemical changes takes place. This can be considered as two reactions, *one at positive plate and one at the negative plate*.

#### ❖ Discharge Chemistry: -

*In the discharged state, both the positive and negative plates become lead(II) sulfate (PbSO<sub>4</sub>).* The electrolyte loses much of its dissolved sulfuric acid and becomes primarily water. The discharge process is driven by the conduction of electrons from the negative plate back into the cell at the positive plate in the external circuit.

*Negative plate reaction:*  $\text{Pb(s)} + \text{HSO}_4^-(\text{aq}) \rightarrow \text{PbSO}_4(\text{s}) + \text{H}^+(\text{aq}) + 2\text{e}^-$

*Positive plate reaction:*  $\text{PbO}_2(\text{s}) + \text{HSO}_4^-(\text{aq}) + 3\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$

Combining these two reactions,

*Overall reaction:  $\text{Pb(s)} + \text{PbO}_2(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{HSO}_4^-(\text{aq}) \rightarrow 2\text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$*

*This means the net outcome is production of lead sulphate together with consumption of sulphuric acid. At the negative plate, the neutral lead liberates two electrons to the solution which constitutes current flow if the anode and cathode are connected electrically.*

#### ❖ Charge Chemistry: -

This type of battery can be recharged. In the charged state, each cell contains negative plates of elemental lead (Pb) and positive plates of lead oxide (PbO<sub>2</sub>) in an electrolyte



of approximately 4.2 M sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). *The charging process is driven by the forcible removal of electrons from the positive plate and the forcible introduction of them to the negative plate by the charging source.*

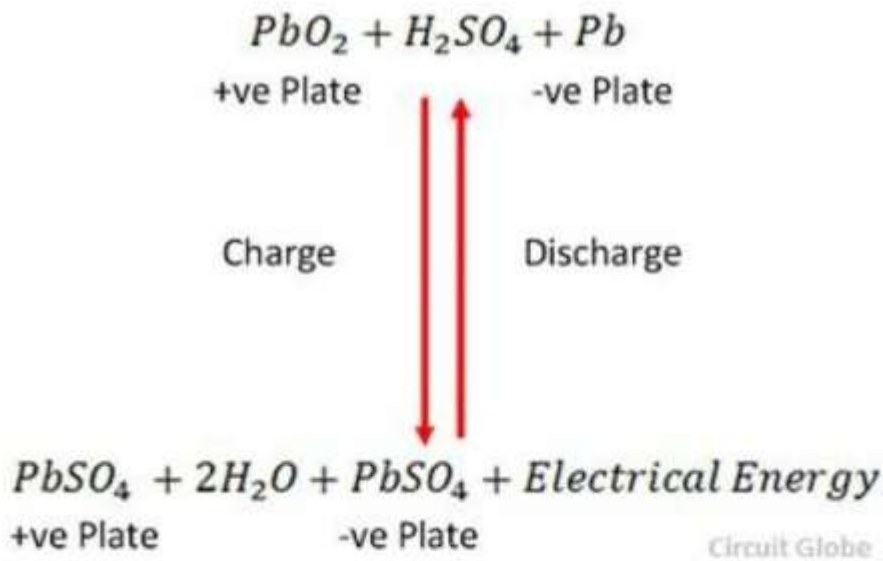
*Negative plate reaction:*  $\text{PbSO}_4(\text{s}) + \text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s}) + \text{HSO}_4^-(\text{aq})$

*Positive plate reaction:*  $\text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{PbO}_2(\text{s}) + \text{HSO}_4^-(\text{aq}) + 3\text{H}^+(\text{aq}) + 2\text{e}^-$

Combining these two reactions,

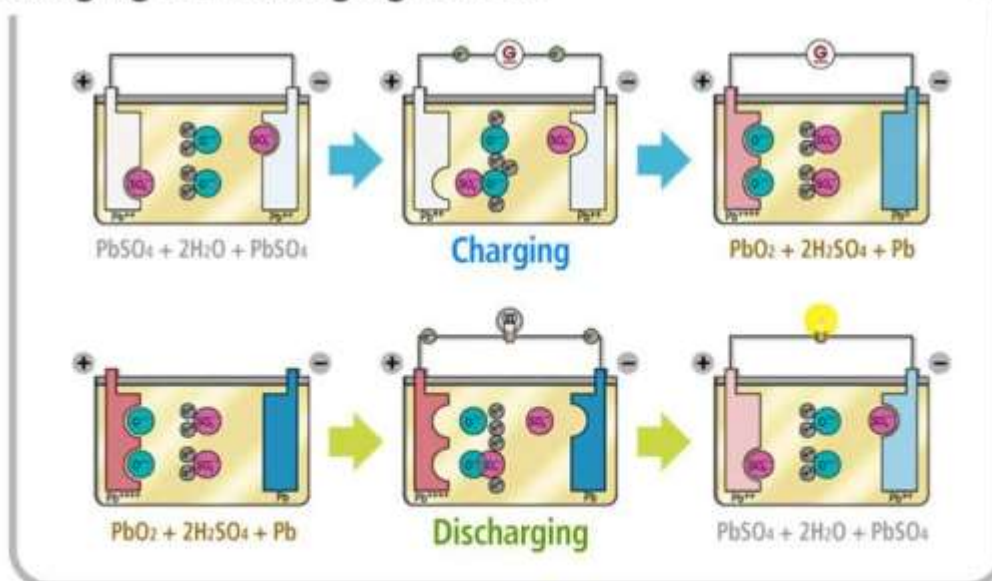
*Overall reaction:*  $2\text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Pb}(\text{s}) + \text{PbO}_2(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{HSO}_4^-(\text{aq})$

*The charging and discharging reaction are therefore exactly opposite to each other. This is summarized pictorially below.*



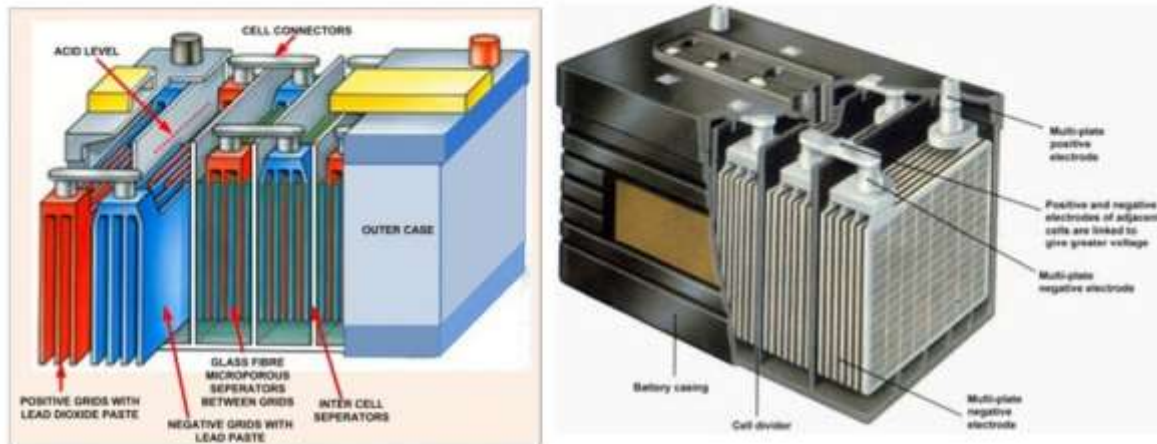
*The equation should be read downward for discharge and upward for recharge.*

### Charging & Discharging Process



## Automotive Battery Construction

Internal construction of an automotive battery is shown in the figures below.



The **battery case** is made of moulded plastic. The plates are welded to **plate straps** to form plate groups. To make a **single battery cell**, a positive plate group fits into a negative plate group. **Porous separators** are placed between the plates to prevent touching of positive and negative plate groups while free circulation of electrolyte between them.

The assembly of plate groups and separators is called an **element**. The elements fit into battery compartments to form **cells**. **Heavy lead connectors** attach to the cell terminals and connect the cells in series. A **plastic cover** forms the top of the battery. Some batteries have openings in the cover containing **filler plugs or vent caps** to add water. **Maintenance-free** batteries however do not have removable vent caps.

Some batteries are **top-terminal batteries** having two main terminals or posts in the cover. The **positive terminal post is larger than the negative terminal post**. Other batteries are of **side-terminal batteries** which have terminals on one side of the battery.

The 12 Volt battery has six-cells which are connected in series. Each cell has a voltage of about 2.15 Volt at full charge. Thus, a fully charged battery has a voltage of 12.90 Volts.

### Battery Rating

Two methods of rating of automotive batteries are used viz. **"Reserve capacity"** and **"Cold cranking rate"**. An older rating is **"Ampere-hour (AH)"** which is the current that a battery can deliver for 20-hours under standard temperature of 25°C till the cell voltage drops down to 1.75 Volt. Explanation of other two ratings are given below: -

- ❖ **Reserve Capacity (RC):** This is the length of time in minutes that a fully charged battery at 27°C can deliver 25 Amperes of current until the terminal voltage drops down to 10.50 Volt (for a 12 Volt) battery or 5.25 Volt (for a 6 Volt) battery. A typical rating is 125 minutes which means battery can be discharged @25 Amperes for 125-minutes till the above values of terminal voltages are reached.
- ❖ **Cold Cranking Rate (CCR):** This is a measure of the ability of the battery to crank an engine when the battery is cold. Two ratings are used for this.



*“Cold cranking amperes (CCA)”* denotes the number of amperes that a 12 Volt battery can deliver for **30-seconds** when it is at **-18°C** without the battery voltage falling below **7.20 Volts**. A typical rating for a battery of reserve capacity 125-minutes is 430 Amperes.

A second cold-cranking rating starts with battery temperature at **-29°C**. This rating allows the battery terminal voltage to drop down to **6 Volts**. A typical rating for a battery of reserve capacity 125-minutes is 320 Amperes.

### Variation in Terminal Voltage

When battery is being *charged*, terminal voltage increases with: -

- ❖ Increasing charging rate – Voltage must go-up to increase the charging rate.
- ❖ Increasing state of charge – It takes higher voltage to force current through a fully-charged battery.
- ❖ Decreasing battery temperature – Lower temperature means reduced chemical activity requiring higher voltage to maintain charging rate.

When battery is being *discharged*, terminal voltage decreases with: -

- ❖ Increasing discharge rate
- ❖ Decreasing state of charge
- ❖ Decreasing battery temperature

### Testing of Battery

Testing of battery is required to determine: -

- ❖ Battery is in good condition.
- ❖ Battery needs recharging.
- ❖ Battery is defective and should be discarded.

Batteries are tested in two ways viz.

- ❖ **For state of charge:** Determined by a hydrometer (for vent-cap batteries) which measures the specific gravity of the electrolyte. For a SMF battery, the in-built hydrometer or charge indicator provides this information.
- ❖ **Battery Capacity Test or Battery Load Test:** This test indicates the performance of the battery and is performed only after the battery has passed the state-of-charge test. In this test, the terminal voltage is measured while the battery is discharging at a high rate through a tester that has a voltmeter, ammeter and variable resistor. The load is applied as per the manufacturer’s recommendation of cold cranking rate.

## **AUTOMOTIVE ELECTRICAL SYSTEM**

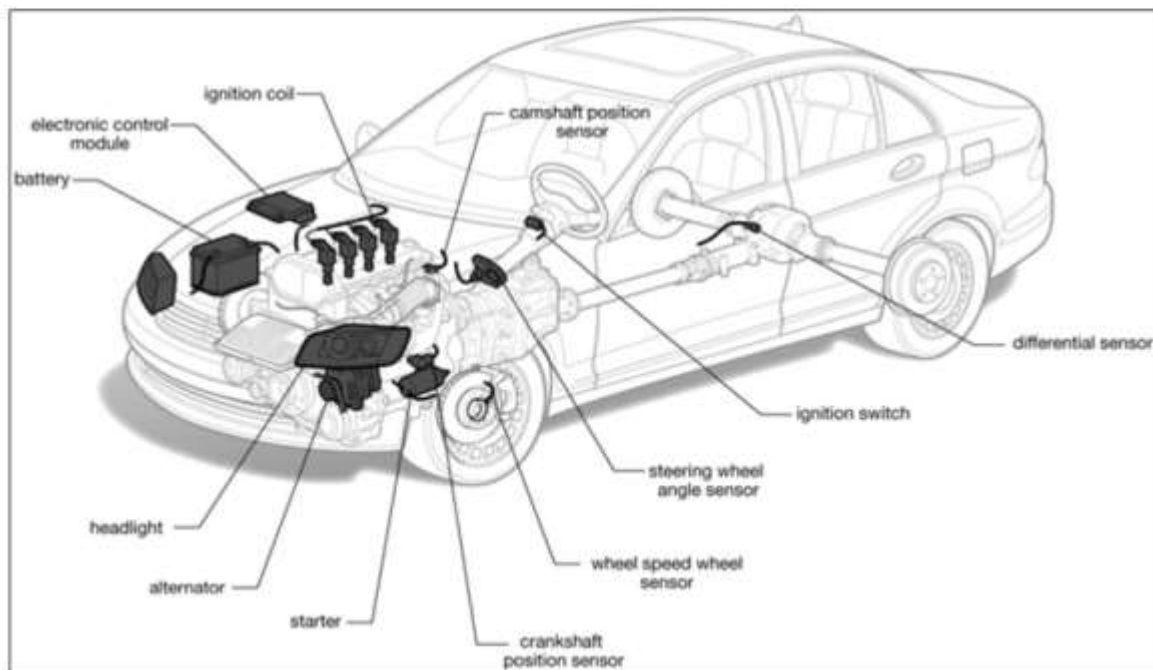
### Purpose

The automotive electrical system does several jobs. It *produces* electrical energy in the alternator. It *stores* electrical energy in chemical form in battery. It *delivers* electrical energy from these sources on-demand to any other electrical component in the vehicle.

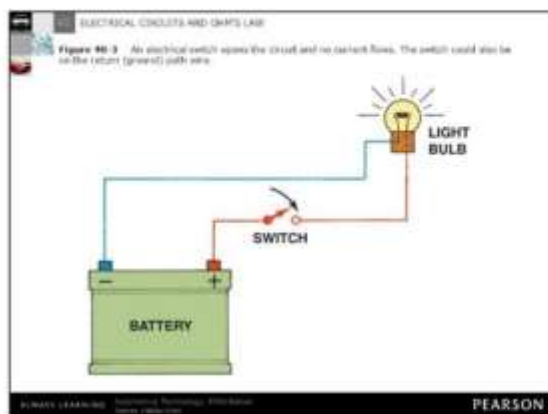


The electrical system supplies electrical energy to crank the starter motor, supplies energy to spark plugs in a SI engine and keeps the batteries charged. Other electric and electronic devices include electronic engine / transmission / traction / braking control system, horn, lights, instrument panel indicators and other driver information systems, various motors such as windshield wiper, power window, windshield washer, door locks, trunk lid etc.

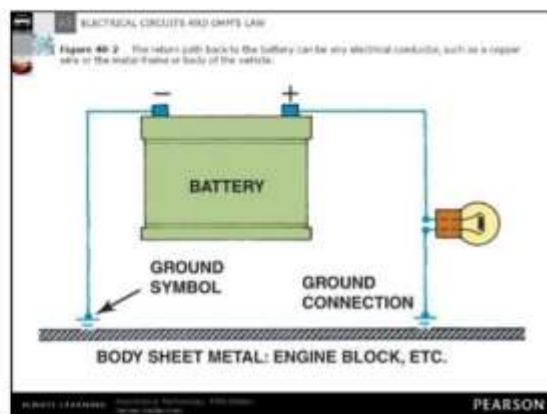
All these components use electric current and voltage. These components may be computer controlled and are connected by insulated wires and ground-return system.



### One-Wire System



Two-Wire



One-Wire

The electrons in the circuit must have a complete path to flow. They leave the negative terminal, go through the circuit and electrical devices and return back to the positive terminal. To reduce the amount of cabling and thereby reduce the complexity of the circuit and bring down the cost, the metal engine, chassis and body parts are made as the return path. This is

known as *“One-wire or Ground-return system”*. Only one wire or cable connects to the electrical device. Attaching one end of the device to the grounded part of the vehicle completes the circuit. This is known as *“Case ground”*. The *negative terminal is grounded*. It is used in starter motor and other electrical equipment.

Most automotive electrical circuits can be divided into two parts for diagnosis and testing. These are the *“Insulated circuit”* and *“Ground circuit”*. The insulated circuit is from the battery positive terminal to the light or electrical devices. The ground circuit is from the light or device back to the battery negative terminal.

### Electrical Circuit Components

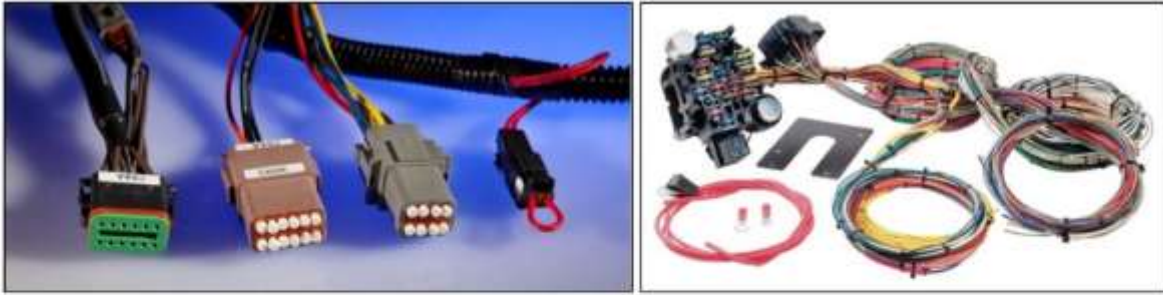
An automotive electric circuit contains *eight basic parts*. These are: -

- ❖ A source of electrical energy such as *battery or alternator*.
- ❖ *Conductors* which connect between the source and other components in the circuit to provide a path for electric current.
- ❖ *Terminals* at the end of conductors which eliminates the need for soldering together wires and components.
- ❖ *Circuit protector such as a fuse, fusible link or circuit breaker* to open the circuit and stop the current flow when the circuit begins to overheat due to excessive current flow.
- ❖ *Connectors* which join one pair of terminals or multiple connectors that conveniently connect or disconnect two or more pairs of terminals. Connectors usually have a locking tang to prevent separation unless released.
- ❖ *Switch* which opens or closes to stop or allow the current flow in the circuit.
- ❖ *Loads* such as starter motor or headlights.
- ❖ *Ground or the return path* to the source for the electric current which is usually the engine or the metal chassis body.

### Wiring Harness

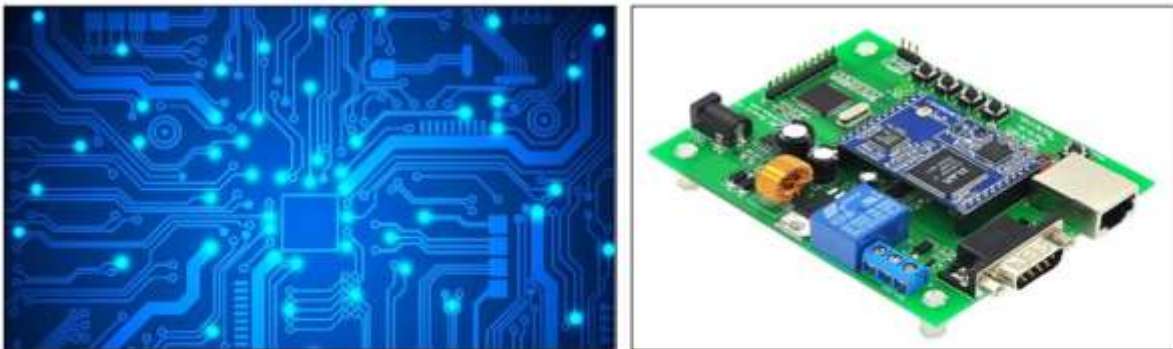






The automotive electrical system in an average car includes about 1500 metres of wire. The size of the wire depends on the magnitude of the current it carries. Groups of wire are wrapped together with electrical tape or flexible conduit to form a *“Wiring harness”*. Multiple connectors make it easy to install and remove than many separate wires. The colour of the insulation identifies each wire in the wiring harness. *The circuit diagrams in the manual show the connections, components and defines the colour of wires in the circuit.*

### Printed Circuit Boards (PCB)



*The printed circuit board (PCB)* is a flat piece of insulating material with a series of conducting strips printed on it. The PCB mechanically supports and electrically connects electronic components or electrical components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of the non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it.

*An example of application in automobile is – Instrument panel where space behind it is limited and there are many wires and connections. Crowding of these wires could cause problems in making connections to all the gauges and indicators. By using a PCB, the conducting strips carry current to respective gauges and indicators. For example, when the indicator lamps are installed, the contacts on the lamps rest on the metallic strip thereby completing the circuit.*

### Circuit Protection Devices

“Circuit protection devices” are used in automobile to protect the electrical and electronic devices if high current starts to flow. This can happen if a short circuit or ground connection develops. These devices open the circuit to stop the flow of current, thereby providing the protection.



**Fuses, fusible links and circuit breakers** fall under circuit protection devices. These are briefly explained below: -

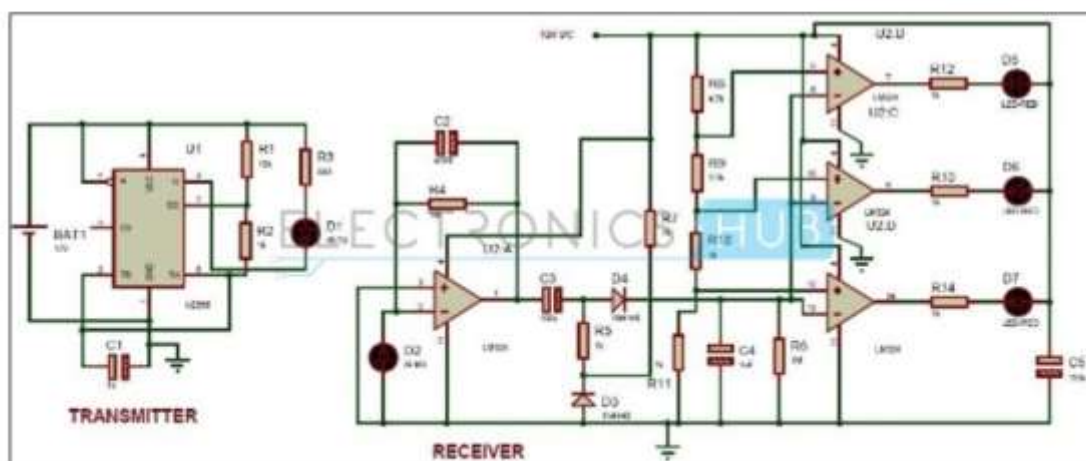


**Fuses** use a metal strip which melts when excess electric current flows in it, thereby breaking the circuit and stopping the current flow. Older designs used **"Cartridge type fuse"** which had the metal strip mounted between both ends. Most cars these days use **"Blade fuse"** which is of plug-in type and easily installed and removed with fingers. The number on the end of the fuse is its **load rating** which means the amount of current in amperes that it can carry before it blows. **Blade fuses are colour coded by their load rating.**

**"Fusible link"** is a short length of insulated wire connected in series in a circuit. **It is generally four gage sizes smaller than the wire it is protecting.** It may be replaceable like a fuse or integrated into the wires outside wiring harness. If excessive current flows, the fusible link melts or blows interrupting the current flow in the circuit and thereby protecting the electrical and electronic components. **Wiring harnesses use several fusible links.** A blown fusible link usually has a discoloured insulation or bare wire may be sticking out.

**"Circuit breakers"** provide a resettable and reusable alternative over standard fuses for circuit protection and can altogether replace fuses and fusible links in most applications. One design uses a bimetallic strip which bends during flow of excessive current thereby separating the contacts and opening the circuit. The advantage of this type of circuit breaker is that it resets itself. When the bimetallic strip cools, it straightens and closes the contacts. Thus, it can be used repeatedly. Circuit breakers are used to protect head lamps, wind shield-wiper circuits etc.

**A specimen electronic circuit diagram for "Reverse camera" in a car is shown below: -**



# AUTOMOTIVE ENGINES



Inline Engine



Vee-Engine



Horizontal Engine



Horizontally Opposed



Rotary Piston Wankel



Radial Piston

The internal combustion engine (IC) engine is a *heat engine that converts chemical energy in a fuel into mechanical energy*. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. This thermal energy raises the temperature and pressure of the gases within the engine and the high-pressure gas then expands to drive the mechanism of the engine. Power is usually made available on a rotating output shaft known as crank shaft. The crankshaft in turn is connected to a transmission and/or power train to transmit the rotating mechanical energy to the desired final use. These engines are widely used for the propulsion of a vehicle (i.e., automobile, truck, locomotive, marine vessel, aircraft etc). Other applications include stationary engines to drive generators or pumps and portable engines for things like chain saws and lawn mowers.

Most internal combustion engines are reciprocating engines having pistons that reciprocate back and forth in cylinders internally within the engine. However other types of IC engines also exist in much fewer numbers such as the "Rotary Piston Engine (Wankel engine)" and "Radial Piston Engine".



## **Classification of Engine**

Internal combustion engines can be classified in a number of different ways. These are explained below: -

### ❖ Types of Ignition:

Two kinds of piston engines exist under this category viz. *"Spark Ignition (SI) Engine"* and *"Compression Ignition (CI) Engine"*. The difference between these engines are in terms of fuel used, the method of inducting fuel into the engine cylinders and the method of ignition.

### ❖ Cycle of Operation (Thermodynamic cycle):

Three types of classifications under this category for engines using different thermodynamic cycles viz. *"Otto Cycle"*, *"Diesel Cycle"* and *"Dual Cycle"*. These thermodynamic cycles are explained later in Module-II.

### ❖ Number of Strokes per Engine Cycle:

Based on number of strokes per cycles, engines are classified as. *"Four Stroke"* and *"Two Stroke"* engines.

### ❖ Type of Fuel Used:

Several types of fuel are used in engines viz. *"Hydrocarbons in liquid form (Petrol and Diesel)"*, *"Alcohols (Methanol and Ethanol)"*, *"Gaseous fuels (LPG, CNG)"*, *"Hydrogen"* etc.

### ❖ Method of Cooling:

Engines can be *"Air cooled"* or *"Liquid cooled (Water or any other liquid)"*.

### ❖ Based on Design:

Engines can be of *"Reciprocating type"* or *"Rotary type"*.

### ❖ Based on Position and Number of Cylinders in Reciprocating Engine:

Several ways of classifications exist under this category. Engines can be *"Single cylinder"* or *"Multi-cylinder (2, 4, 6, 8, 12, 16 cylinders etc.)"*.

Further multi-cylinder reciprocating engines can be *"In-line or Straight"*, *"V-Engine"* with angle between banks ranging from  $15^{\circ} \sim 120^{\circ}$  ( $60^{\circ} \sim 90^{\circ}$  is most commonly used), *"Opposed Cylinder engine"*, *"W-Engine"* (3-banks containing 12-cylinders with angle between banks  $60^{\circ}$ ), *"Opposed Piston Engine"*, *"Radial Engine"* etc.

### ❖ Based on Air Intake Process:

Engines can be classified as *"Naturally aspirated"*, *"Turbo-charged"*, *"Super-charged"*, *"Crankcase compressed"* under this category.



❖ Based on Method of fuel Input:

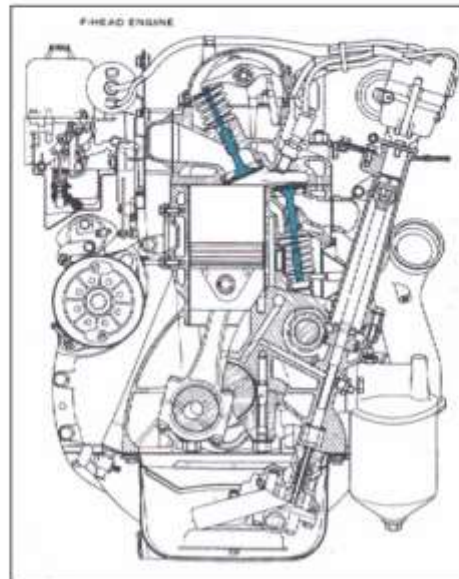
SI engines falling under this category can be “*Carburetted engines*”, “*Multi-point fuel injection engines*”, “*Throttle body fuel injection engines*”.

CI engines falling under this category are “*Inline or Rotary injection*”, “*Individual control pump*”, “*Common rail direct injection (CRDI)*” and “*Unit injection*”.

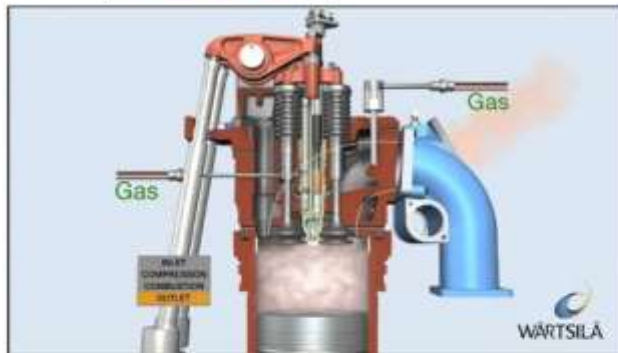
❖ Based on Valve Location:



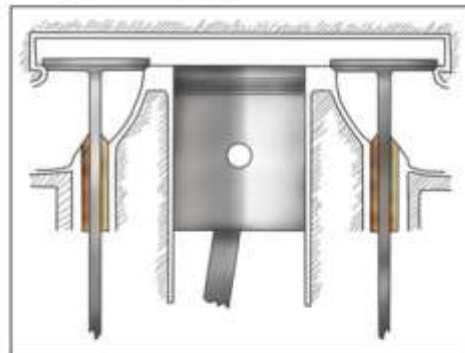
L-Head or Flat



F-Head



I-Head



T-Head

Based on location of the inlet and exhaust valves, engines can be classified as “*L-head or Flat-head*”, “*F-Head*”, “*I-head*” and “*T-head*”. These are explained below: -

- In a “*L-head engine*”, both inlet and exhaust valves are located on one side of the cylinder. This is simple design and uses a single cam shaft. However, this design has two drawbacks viz. the engine can not achieve high compression ratio and it

causes greater pollution in terms of HC and CO as the combustion chamber surfaces being large runs cool.

- A modification of “L-head engine” is the “*T-head engine*” which has valves on both sides of the cylinder head. This engine therefore uses two camshafts.
- An “*I-head engine also known as Overhead valve engine*” has both the valves located on the cylinder head. Most of the current automobiles use this configuration. This reduces the cost of engine block and allows better engine breathing by providing a large inlet port on one side and large exhaust fort on other side. The cylinder head however becomes a very complex and intricate casting as it is required to accommodate valve mechanisms, air flow passages, exhaust gas passages, coolant flow passages and lubricating oil passages.
- In a “*F-head engine*”, one valve is located in the cylinder block and the other valve in the cylinder head. This arrangement uses a single camshaft. This has many of the advantages and disadvantages of both L-head and I-head engines. However, this has very limited use.

❖ Based on Type of Lubrication System:

Engines can be classified as using “*Wet-sump lubrication*” or “*Dry-sump lubrication*”.

❖ Based on Field of application:

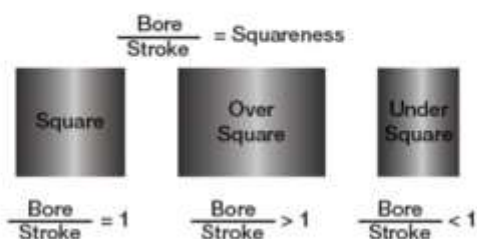
Based on field of application, engines can be classified as being used in: -

- Automobiles (Trucks, Buses, Cars)
- Locomotives
- Marines
- Aircrafts
- Stationary (Pumping systems, Power generation etc.)
- Small portables (Chain saw, portable gensets, model aeroplanes etc.)

## Engine Nomenclature or Terminology

Production of power is the primary function of an engine. In order to determine how well an engine is performing or to compare performance of one engine with another, it is necessary to define a set of parameters that can be measured, analysed and can be expressed in standard engineering units. These parameters or nomenclatures or terminology are very important with respect to defining of engine specifications and analysing its performance. These are explained below: -

❖ Bore, Stroke and Stroke ratio:



“**Bore (d)**” is defined as the diameter of the cylinder.

“**Stroke (ℓ)**” is defined as the distance travelled by the piston from top to bottom of the cylinder.

“**Stroke ratio**” is defined as the ratio between “Bore / Stroke”.

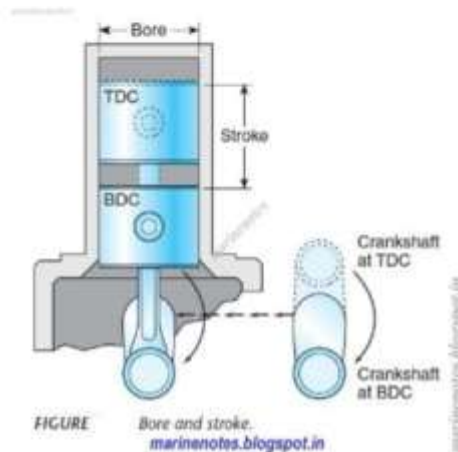
❖ **Cylinder Displacement or Swept volume ( $V_d$ ):**

“Cylinder displacement” is defined as the volume displaced by the piston as it travels through one stroke. Displacement can be given for one cylinder or for the entire engine. This is also known as “**Swept volume**”.

**Total Swept volume of an engine =  $\pi \times \frac{\text{Bore}^2}{4} \times \text{Stroke} \times \text{Number of cylinders}$**

4

❖ **Top Dead Centre (TDC) and Bottom Dead Centre (BDC):**



“**Top dead centre (TDC)**” is defined as the farthest point of forward travel of the piston in the cylinder.

“**Bottom dead centre (BDC)**” is defined as the lowest point of backward travel of the piston in the cylinder.

❖ **Clearance Volume ( $V_c$ ):**

The “**Clearance volume**” is defined as the volume of the cylinder above the piston when it is at TDC.

❖ **Total Volume ( $V_t$ ):**

“**Total volume**” is defined as sum of swept volume and clearance volume i.e.  $V_t = V_d + V_c$

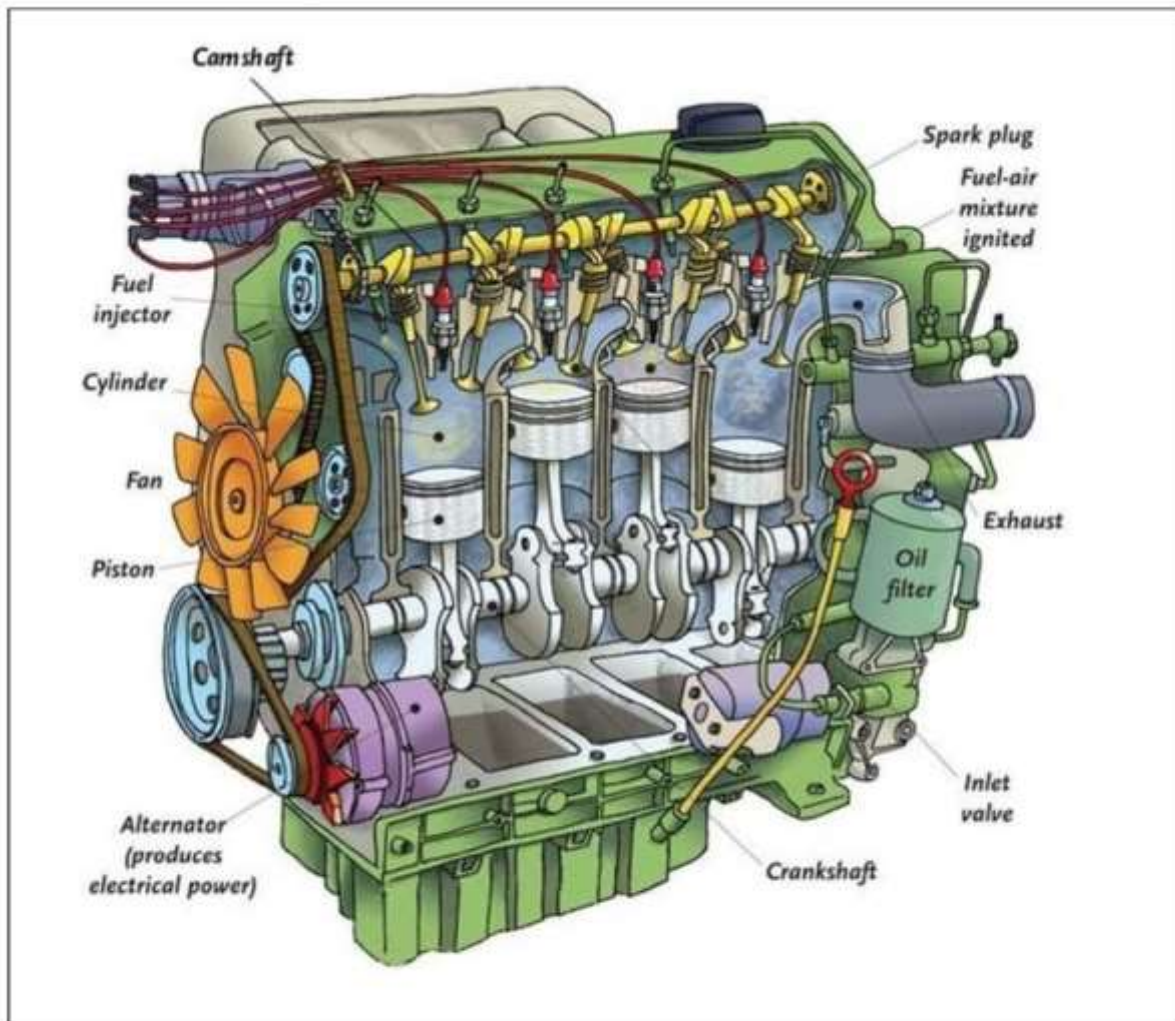
❖ **Compression Ratio (r):**

This is defined as ratio between total volume and clearance volume i.e.

$$r = V_t / V_c = (V_d + V_c) / V_c$$

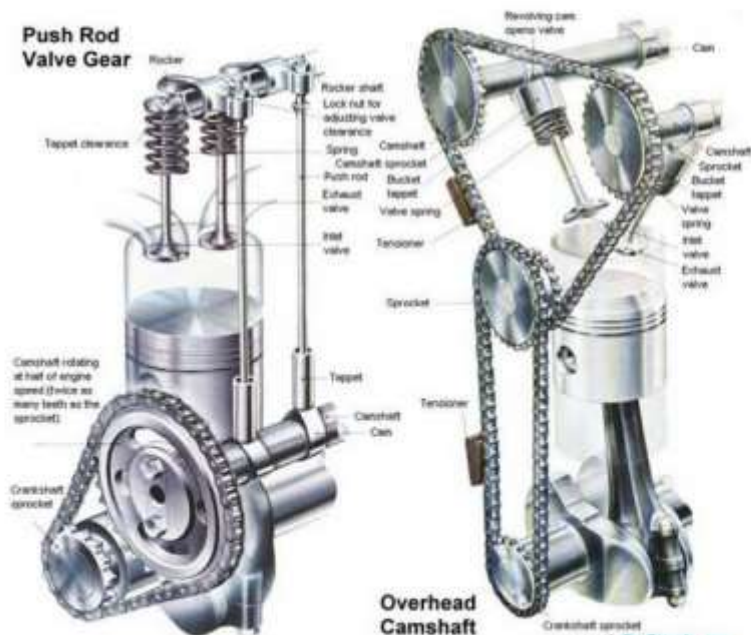


## Components of Engine





**Push Rod Valve Gear**



**Overhead Camshaft**

webS@anh.vn

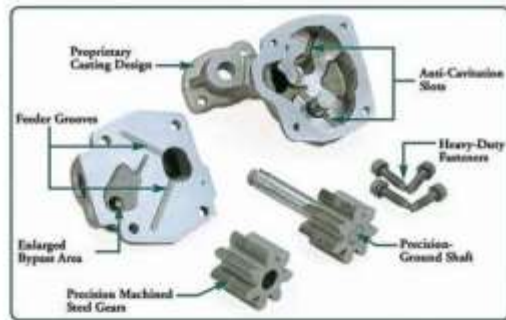
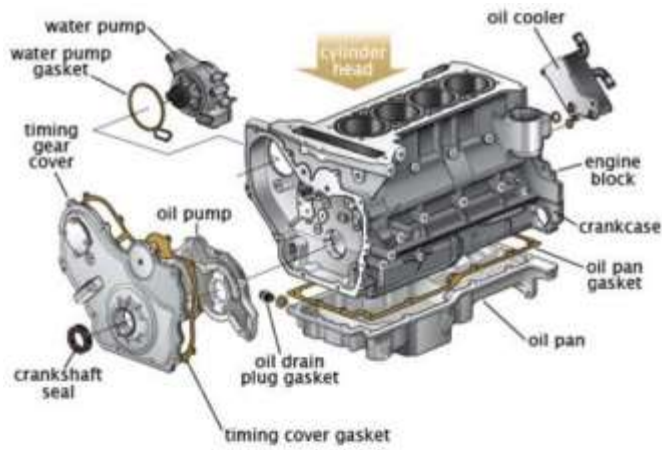
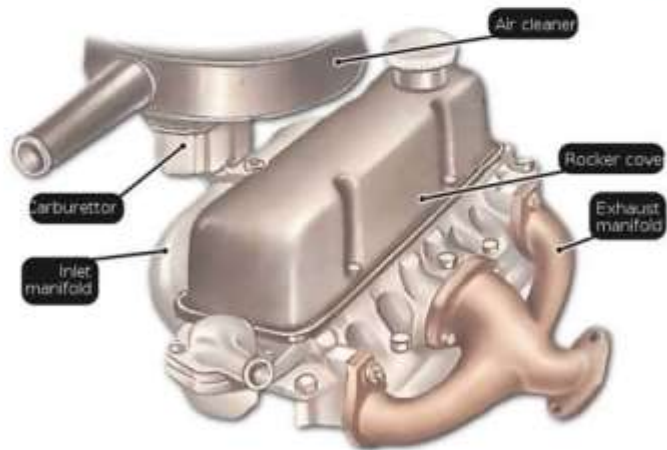
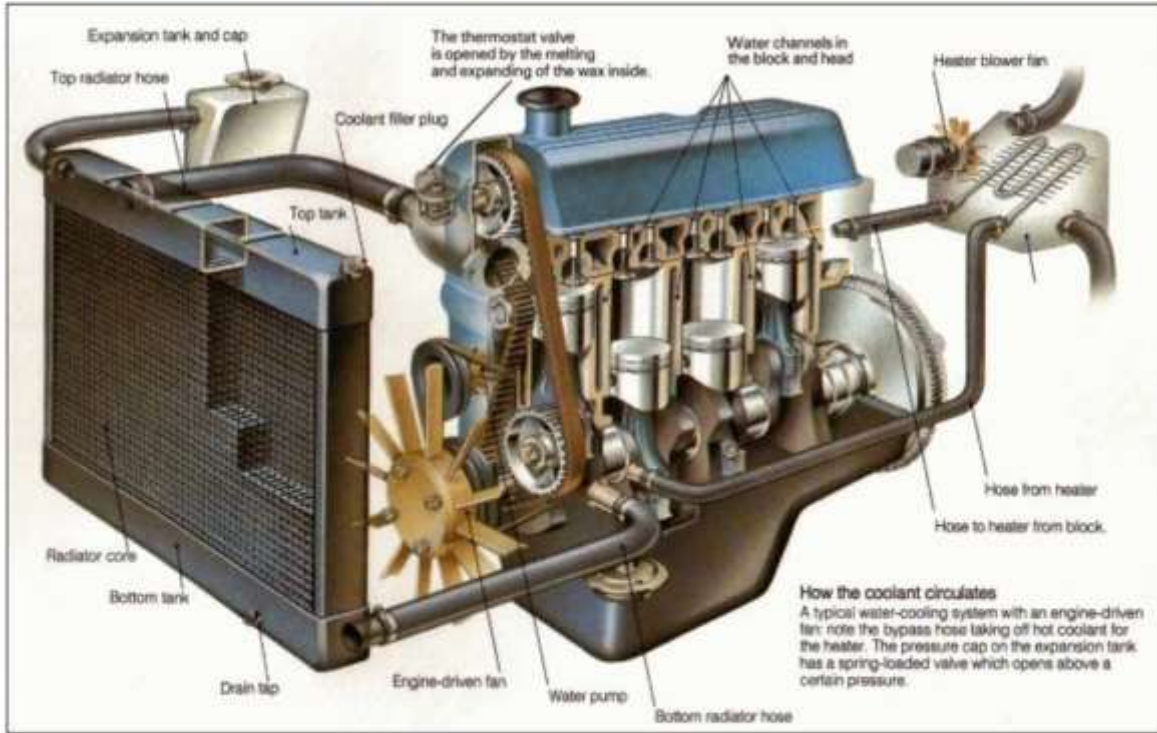
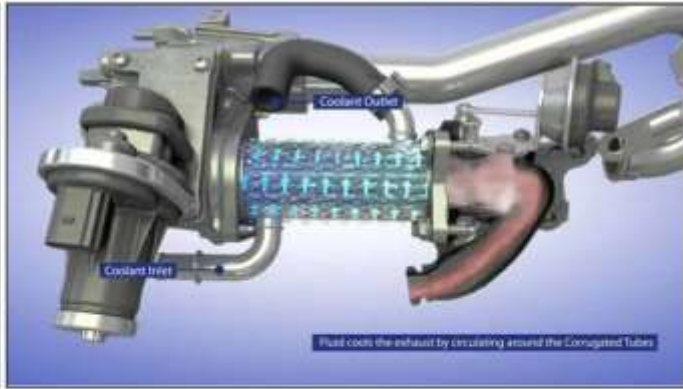
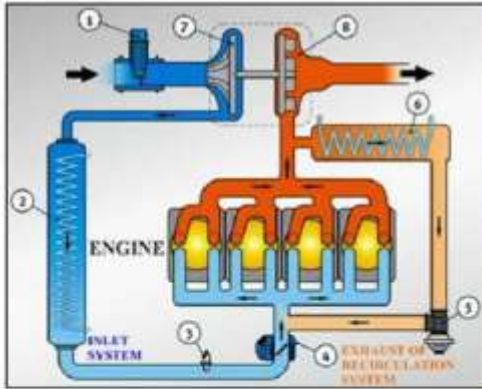
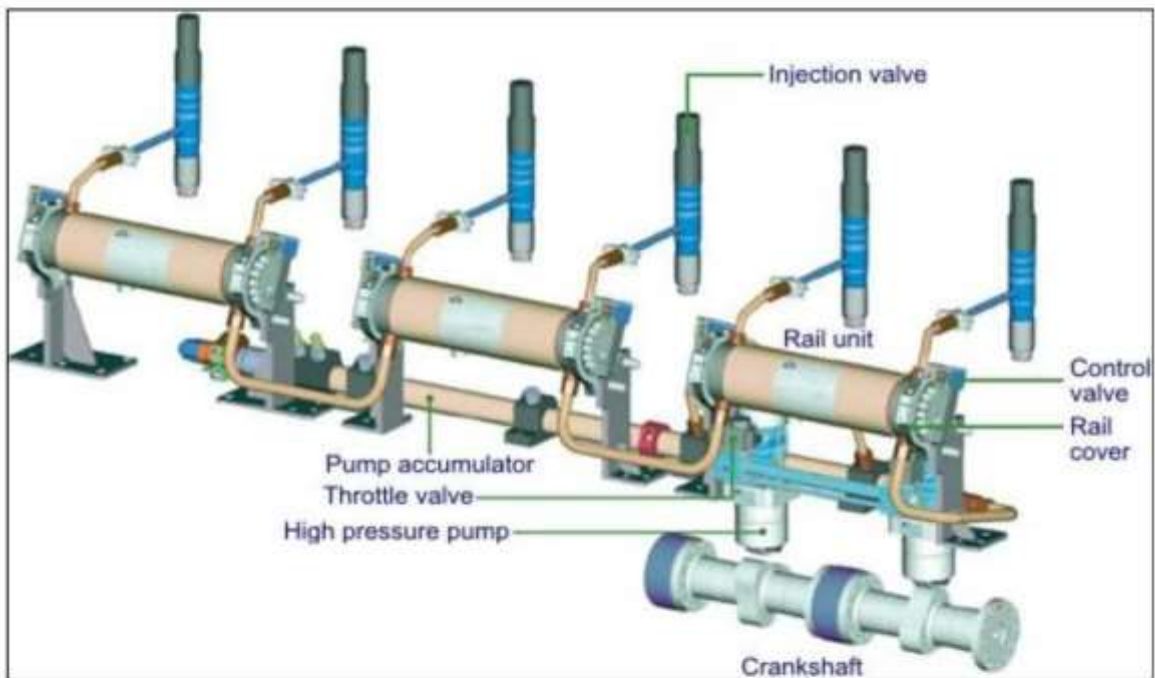
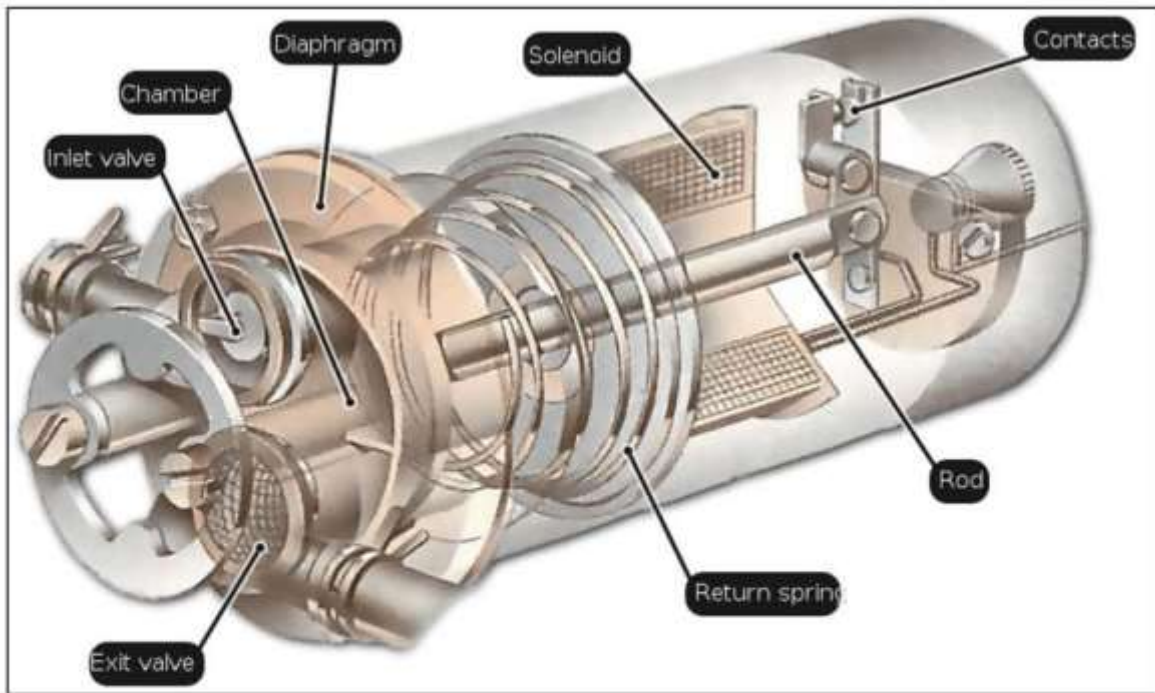


Image courtesy of [ClearMechanic.com](http://ClearMechanic.com)



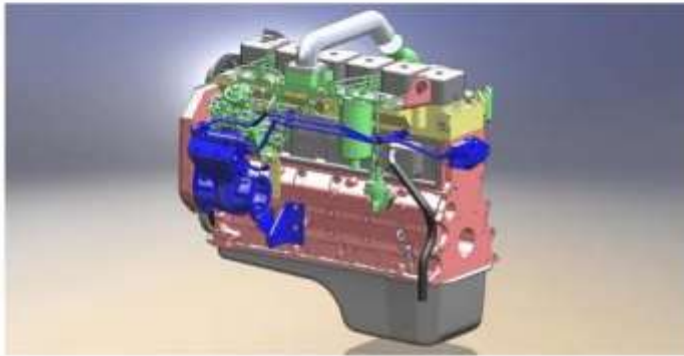
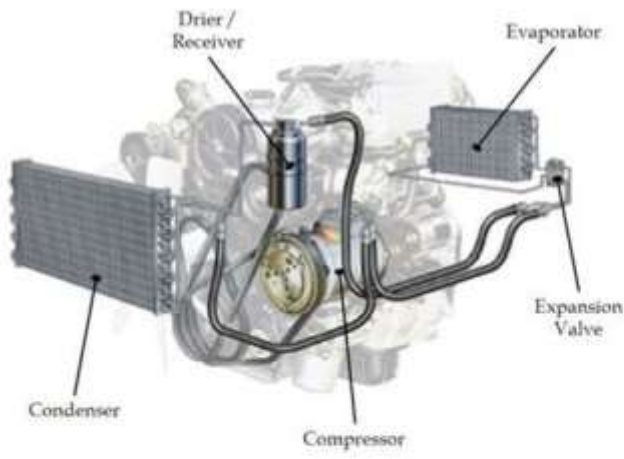




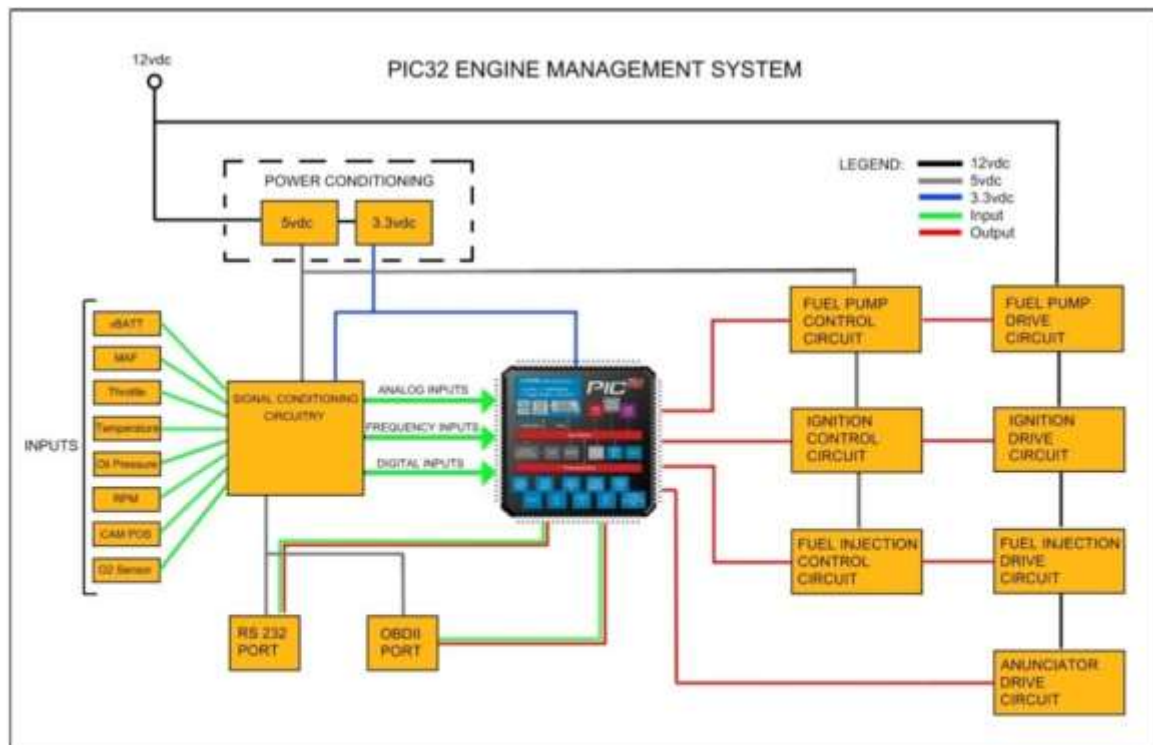












A reciprocating internal combustion engine has many components. The following is a list of major components used in most engines: -

- ❖ Cylinder block
- ❖ Cylinder head
- ❖ Piston, Piston Pin and Piston rings
- ❖ Connecting rod
- ❖ Crankshaft
- ❖ Camshaft
- ❖ Valves and valve mechanism
- ❖ Crankcase
- ❖ Lubrication pump, Strainer
- ❖ Carburettor and Throttle
- ❖ Intake air filter
- ❖ Inlet manifold
- ❖ Exhaust manifold
- ❖ Supercharger and Turbocharger, Intercooler
- ❖ Exhaust gas recirculation (EGR) system, if used
- ❖ Radiator and thermostat
- ❖ Water pump
- ❖ Cooling fan
- ❖ Fuel filter
- ❖ Fuel pump
- ❖ Common rail diesel injection (CRDI) and Fuel injectors (for CI engines)
- ❖ Multi-point fuel injection (MPFI), if used (for SI engines)
- ❖ Gasoline direct Injection (GDI), if used (for SI engines)



- ❖ Spark plug (for SI engines)
- ❖ Glow plug
- ❖ Flywheel and vibration damper
- ❖ Starter motor
- ❖ Alternator
- ❖ Air-conditioning compressor
- ❖ Air compressor for braking system, if used
- ❖ Hydraulic Power steering pump, if used
- ❖ Engine accessories drive mechanism (Belt drive and Geared drive)
- ❖ Engine Control Unit (ECU) or Engine Management System (ECM)

## Engine Performance Parameters

The various parameters considered for assessing performance of an automotive internal combustion engine are as below: -

- ❖ **Bore** – Already explained earlier.
- ❖ **Stroke** – Already explained earlier.
- ❖ **Swept Volume** – Already explained earlier.
- ❖ **Clearance volume** – Already explained earlier.
- ❖ **Compression ratio** – Already explained earlier.
- ❖ **Volumetric Efficiency (VE)** – This is a measure of how completely the cylinder fills with air-fuel mixture during the suction stroke. This is defined as: -

$$\eta_v = \frac{\text{Actual mass of charge inducted}}{\text{Theoretical mass of charge inducted}}$$

Actual mass is less because the mixture has to pass through intricate passages, mixture gets heated and expands, inlet valve opening lasts for fraction of a second etc. Good volumetric efficiency for a high-speed engine is about 80%. This can be improved by incorporating two-inlet valves or by supercharging or turbocharging.

- ❖ **Indicated Horse Power (IHP)** – This is the power developed inside the combustion chamber. It is determined by measuring the pressure in the engine cylinder and is named so as this is measured by an instrument called “Engine indicator”. This is defined as: -

$$i_p = \frac{p_i \times L \times A \times n}{60,000} \text{ Pa} \quad \text{where,}$$

$i_p$  = Indicated horse power in Kilowatt

$p_i$  = Indicated mean effective pressure (imep) in Pascals

$L$  = Length of stroke in metre

$A$  = Cross sectional area of cylinder in  $m^2$  (for multi cylinder engine = Area of each cylinder x Number of cylinders)

$n$  = No. of power impulses / minute or no. of strokes / minute. **Values of “n” for different engine cycles are: -**

- n = N/2 for "Single-acting, Four-stroke engine"
- = N for "Single-acting, Two-stroke engine"
- = N for "Double-acting, Four-stroke engine"
- = 2N for, "Double-acting, Two-stroke engine"

- ❖ **Indicated Mean Effective Pressure (imep)** – This is defined as the algebraic sum of the mean pressures acting on the piston during each stroke over one complete cycle. Pressures are considered positive when acting in the direction of piston movement and negative when acting in opposite direction to piston movement. It is measured through indicator diagram drawn by an indicator.

$$imep (p_i) = \frac{\text{Area of indicator diagram}}{\text{Length of indicator diagram} \times \text{Spring scale}}$$

- ❖ **Brake Horse Power (BHP) or Shaft horse power (SHP)**– This is defined as the actual work output of an engine or the actual work available at the crankshaft. BHP is measured by engine dynamometers where braking load is applied on the crankshaft to absorb the power generated by the engine. Mathematically: -

$$BHP = \frac{2\pi NT}{60,000} \text{ KW} \quad \text{where,}$$

- N = Speed of rotation of crankshaft in RPM
- T = Resisting or braking torque on the dynamometer shaft

- ❖ **Rated Horse Power** – This is defined is the power output of an engine measured at the maximum engine speed under SAE-defined standardized atmospheric pressure, humidity, and temperature. Rated speed is the maximum speed an engine will reach while under full load.

- ❖ **Brake Mean Effective pressure (Bmep)** – This is defined as the mean effective pressure which could have developed power equivalent to BHP calculated as per above formula, if acted upon the piston. Unlike Imep, this cannot be measured directly. This is used as a comparative measure of the power capabilities of the engines, which operate with the same engine displacement and speed. Mathematically: -

$$Bmep (b_p) = \frac{60,000}{L \times A \times N} \text{ Pa}$$

- ❖ **Friction Horse Power (Fhp)** – This is defined as the power lost due to friction in working surfaces of the engine like piston rings, bearings, valves fluid friction or pumping losses ( in intake and exhaust processes) etc. Fhp can be determined by use of an "Electrical dynamometer operating as a motor". Relationships between various power terms are:-

$$Fhp = Ihp - Bhp$$

Pictures below show an actual engine test cell and the control panel room for measurement of various test parameters.



- ❖ **Engine Torque (T)** – Engine torque is directly related to Bmep. The relationship between engine torque and Bmep are given by: -

$$BHP = \frac{2\pi NT}{60,000} = \frac{p_b \times L \times A \times N}{60,000}$$

$$\text{Or, } T = \frac{L \times A \times N \times p_b}{2\pi N}$$

- ❖ **Mean Piston Speed ( $V_{ps}$ )** – Mean Piston speed of an engine is the average speed of the piston in a reciprocating engine. It is a function of stroke and RPM. Mathematically: -

$$V_{ps} = \frac{2 \times N \times \text{Stroke}}{60}$$

- ❖ **Air Standard Efficiency of Otto Cycle ( $\eta_{Otto}$ ):** - Air standard efficiency of an engine is a function of the compression ratio and method of combustion. These are theoretical efficiencies calculated by considering air as the working fluid. ASE for an engine using Otto cycle is given by the formula: -

$$\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}} \quad \text{where,}$$

$r$  = Compression ratio

$\gamma$  =  $C_p / C_v$

- ❖ **Air Standard Efficiency of Diesel Cycle ( $\eta_{Diesel}$ ):** - ASE for an engine using Diesel cycle is given by the formula: -

$$\eta_{diesel} = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left[ \frac{\rho^\gamma - 1}{\rho - 1} \right] \quad \text{where,}$$

$r$  = Compression ratio

$\gamma$  =  $C_p / C_v$

$\rho$  = Cutoff ratio



- ❖ **Air Standard Efficiency of Dual Cycle ( $\eta_{Dual}$ ):** - ASE for an engine using Dual cycle is given by the formula: -

$$\eta_{dual} = 1 - \frac{1}{(r)^\gamma - 1} \cdot \frac{(\beta \cdot \rho^\gamma - 1)}{[(\beta - 1) + \beta\gamma(\rho - 1)]}$$

where,

$r$  = Compression ratio

$\gamma = C_p / C_v$

$\rho$  = Cutoff ratio

$\beta$  = Pressure or Explosion ratio

- ❖ **Indicated Thermal Efficiency ( $\eta_i$ ):** - This indicates what fraction of heat supplied is converted into indicated work and given by the formula: -

$$\begin{aligned} \eta_i &= \frac{\text{Indicated work in heat units}}{\text{Energy supplied by fuel}} \\ &= \frac{60 \times i_p}{w_f \times h_v} \quad (w_f = \text{Fuel supplied in Kg/min; } h_v = \text{Calorific value of fuel in KJ/Kg.}) \end{aligned}$$

- ❖ **Brake Thermal Efficiency ( $\eta_b$ ):** - This indicates the fraction of heat supplied that is converted into engine shaft work and given by the formula: -

$$\begin{aligned} \eta_b &= \frac{\text{Brake work in heat units}}{\text{Energy supplied by fuel}} \\ &= \frac{60 \times b_p}{w_f \times h_v} \quad (w_f = \text{Fuel supplied in Kg/min; } h_v = \text{Calorific value of fuel in KJ/Kg.}) \end{aligned}$$

- ❖ **Specific Fuel Consumption (SFC):** - **Total fuel consumption** by an engine under test conditions is the "Volume or weight of fuel consumed in a given time". **Specific fuel consumption** is defined as "Total fuel consumption per hour per KW developed" or "SFC is rate of fuel consumption per Kwh developed".

When indicated power is used, this is known as "**Indicated Specific Fuel consumption (ISFC)**" and when brake power is used, this is known as "**Brake Specific Fuel Consumption (BSFC)**". Mathematically: -

$$\begin{aligned} ISFC &= \frac{60 \times w_f}{i_p} = \frac{3600}{\eta_i \times h_v} \text{ Kg / i.Kwh} \\ BSFC &= \frac{60 \times w_f}{b_p} = \frac{3600}{\eta_b \times h_v} \text{ Kg / b.Kwh} \end{aligned}$$

- ❖ **Mechanical Efficiency ( $\eta_m$ ):** - This is defined as the ratio of power delivered by the engine to power developed within the engine. Mathematically: -

$$\eta_m = \frac{\text{BHP}}{\text{IHP}} = \frac{\eta_b}{\eta_l}$$

Mechanical efficiency reflects the mechanical losses in the engine. The various losses can be grouped into four head as below: -

- Friction losses in piston, bearings, gears and valves (about 7~10% of  $i_p$ )
- Ventilating action of flywheel (about 1~3% of  $i_p$ )
- Loss in suction and exhaust processes (about 2~6% of  $i_p$ )
- Power absorbed by auxiliaries like fuel pump, water pump, lub. oil pump, alternator, radiator fan, magneto drive, distributor etc. (about 1~9% of  $i_p$ ).

Thus, combined losses can be 11~28% resulting in  $\eta_m$  varying from 72%~89%.

- ❖ **Engine Rating:** - Generally three methods are adopted to define the rated power of an automobile engine. These are: -

- **Maximum Continuous load carried by an engine:** This load is indicated either on the basis of the mean effective pressure, kPa or by the piston displacement in mL per kW per sec. However, both are identical. Automobile engines using petrol, the m.e.p. varies from 640 kPa. Every engine should be capable of withstanding overload of 10 to 20% in case of emergency.
- **Maximum Power developed by an engine:** In this case the engines are rated in terms of their maximum capacity, i.e. maximum brake horse power that can be developed.
- **RAC rating:** The formula adopted by the "Royal Automobile Club (RAC) of England" is used for taxation purpose. As per this: -

$$\text{Brake Horse Power} = \frac{(\text{Cylinder diameter in inch}^2) \times (\text{Number of cylinders})}{2.5} = \frac{D^2 N}{2.5}$$

This is however based on following assumptions: -

Piston speed = 1000 feet/minute (305 m/min)

Mean effective Pressure = 90 psi (620 kPa)

Mechanical Efficiency = 75%

In SI units, *Brake Horse Power* =  $\frac{460 \times D^2 \times N}{2.5}$  (D is in meters)

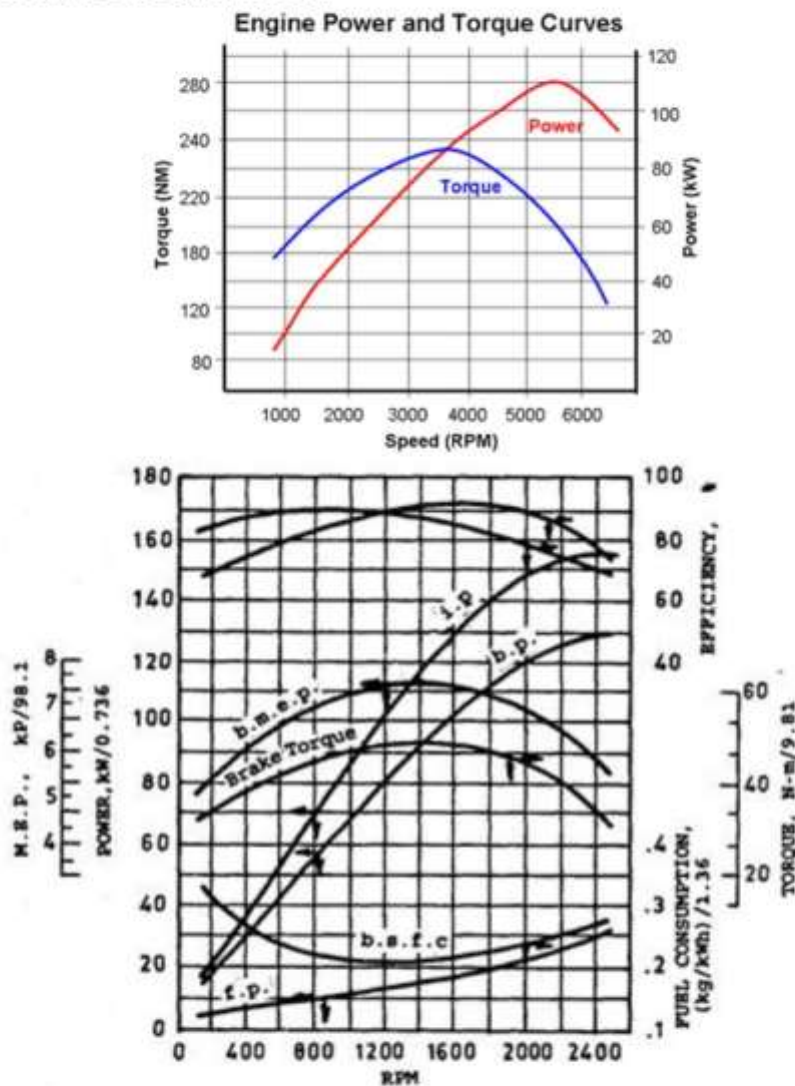
- **SAE rating:** The Society of Automotive Engineers (SAE) have specified the method of measuring power output of an engine. Prior to 1972, gross horsepower was measured by running the engine without accessories like alternator, air filter, cooling fan etc. However, this method gave unrealistic readings. Since then the more conservative **SAE net power rating is used**, which takes into account engine accessory, emissions, and exhaust drags (but not transmission losses) in the standard.

- Deutsches Institut für Normung 70020 (DIN 70020) rating:** DIN 70020 is a German DIN standard for measuring road vehicle horsepower. Similar to SAE net power rating, and unlike SAE gross power, DIN testing measures the engine as installed in the vehicle, with cooling system, charging system and stock exhaust system all connected. *DIN 70020 is often seen abbreviated as "PS", derived from the German word for horsepower Pferdestärke.* DIN hp is measured at the engine's output shaft, usually expressed in metric horsepower rather than mechanical horsepower.

The conversion factor is:  $1 \text{ PS} = 0.9859 \text{ HP}$        $1 \text{ HP} = 0.746 \text{ KW}$

## Engine Performance Curves

The word performance for an engine is generally used for designating the relationship between power, speed and fuel consumption. In variable speed engines (like automobile engines), the rated power at a particular speed does not provide enough information. Under such situations, the performance curves help to obtain necessary information. Some sample performance curves are given below: -

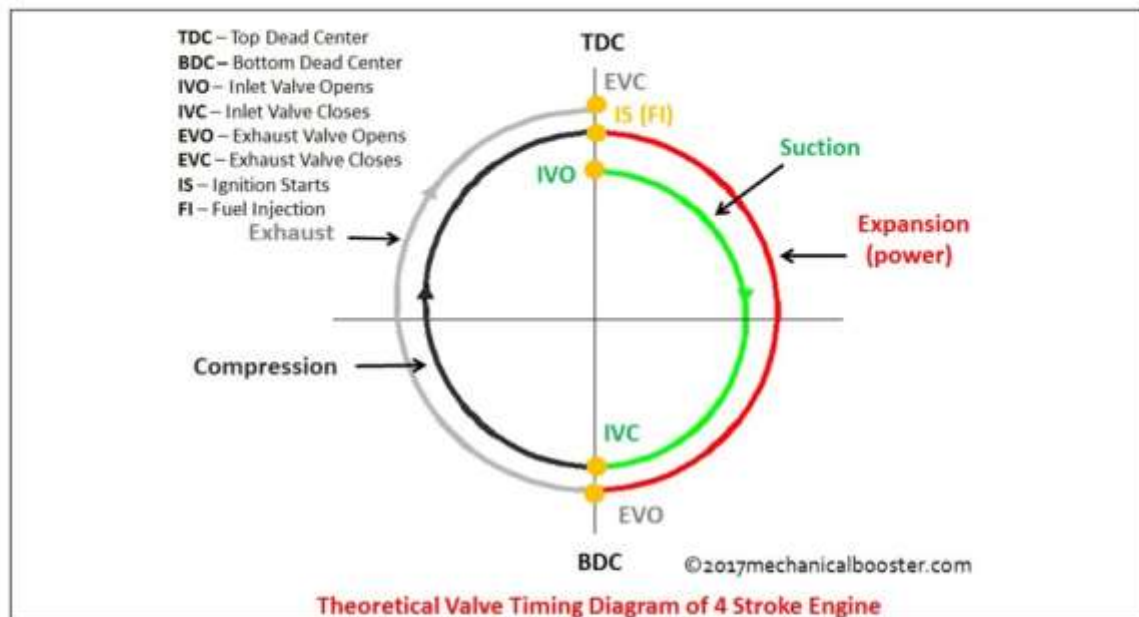


Performance Curve of 6-cylinder CI Engine (110 x 135 mm),  $r = 15:1$ ,



## Valve Timing Diagram of SI and CI Engines

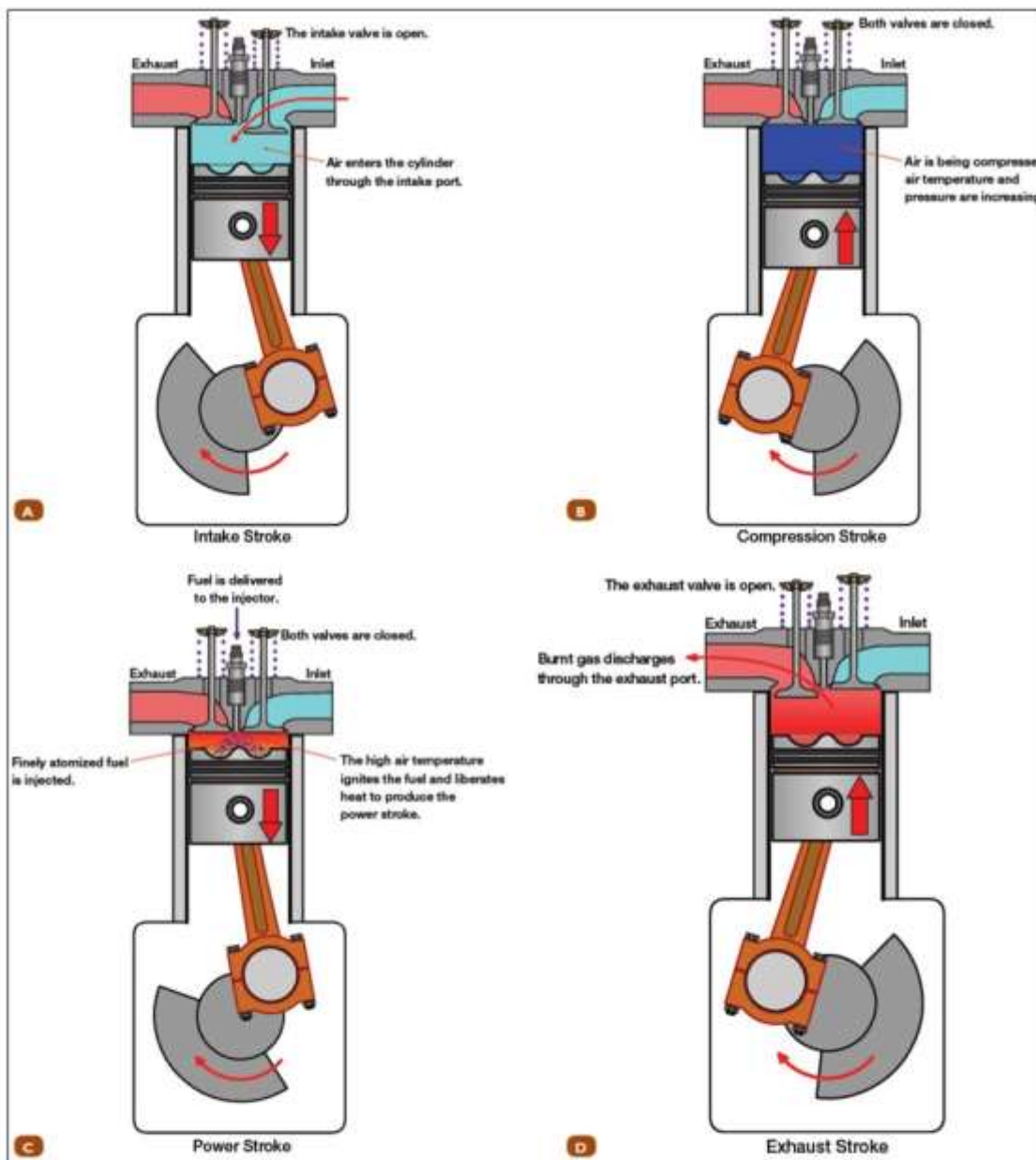
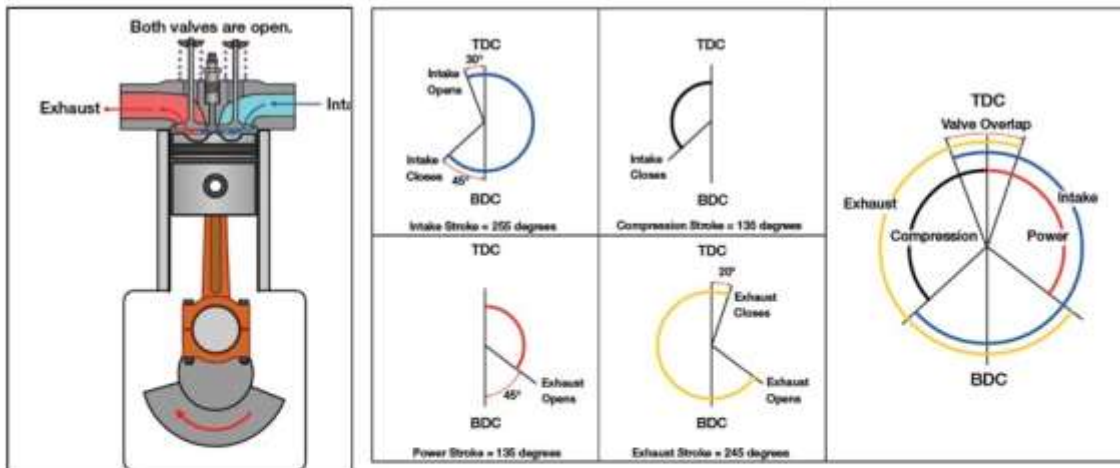
A theoretical valve timing diagram based on theoretical air standard cycles is shown below: -



An engine would operate if the intake valve simply opened and closed at TDC and BDC. However, changing the time when the intake valve opens and closes can improve engine performance and increase volumetric efficiency. *Today's engines do not simply open and close the intake or exhaust valves at the top and bottom of each stroke.* Instead, various factors influence the precise timing of valve opening and closing. These factors include: -

- ❖ **The momentum or inertia of intake air or air-fuel mixture:** For the intake valve, this typically means opening the inlet valve before TDC and closing the intake valve after the piston begins an upward stroke. Even though the piston begins to move upward, piston movement is initially slow, and gas inertia is high, which enables the cylinder to fill with more air.
- ❖ **Late valve closing after TDC for the exhaust valve:** This allows moving exhaust gas momentum to pull more exhaust gases out of the cylinder. Clearance volume pressure can actually become negative as the departing exhaust gas pulse pulls exhaust gases, which might ordinarily linger in the clearance volume area, out the exhaust port. Leaving the exhaust valve open after TDC at the end of the exhaust stroke helps empty, or scavenge, exhaust gases from the cylinder and make room for fresh air intake.

When both intake and exhaust valves are open together at the beginning of the intake stroke and end of the exhaust stroke, the condition is known as **"Valve overlap"**. Longer overlap periods enhance scavenging. **"Scavenging"** is the process of cleaning exhaust gases from the cylinder. Intake air passing across pistons and exhaust valves leaves with the departing exhaust thereby helping to cool the piston crown and exhaust valves.



❖ **Valve Timing Diagram of a 4-Cylinder SI Engine:**

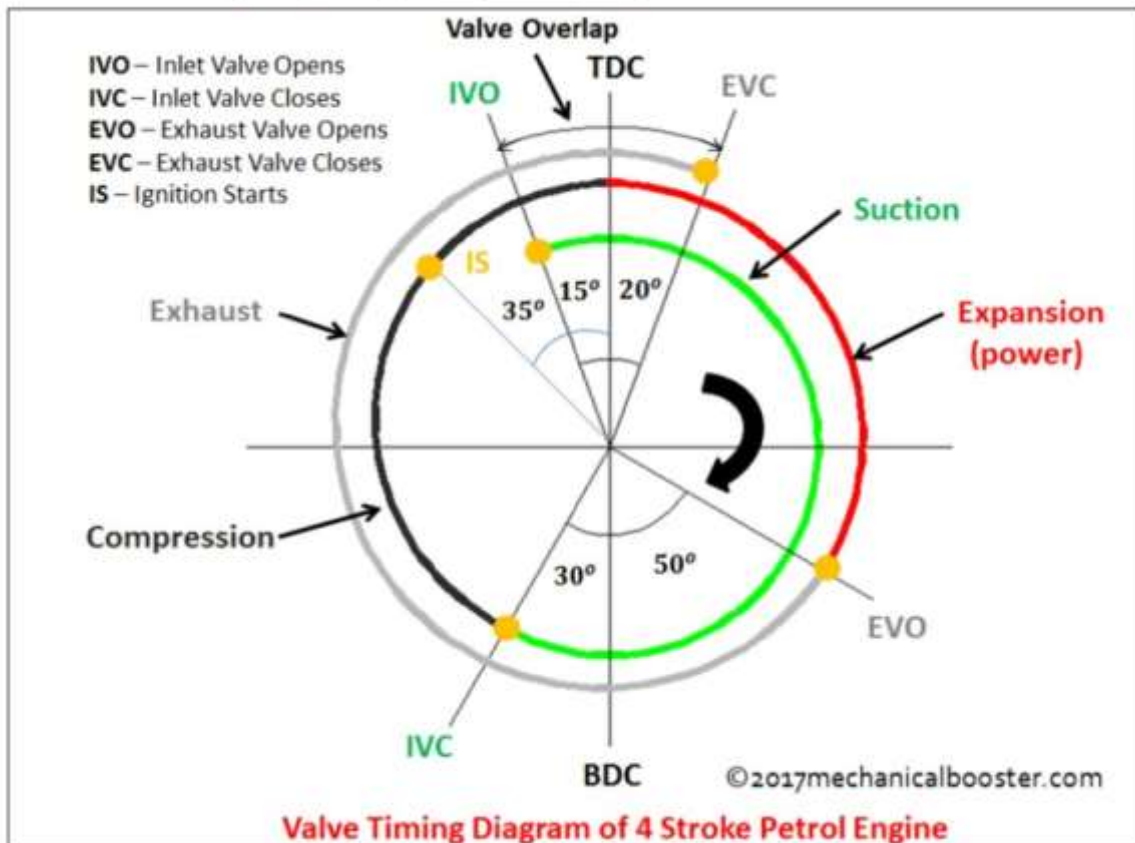


Figure above shows the valve timing diagram for a four-stroke cycle petrol engine. The inlet valve opens 10-30° before the top dead centre position. The air-fuel mixture is sucked into the engine cylinder till the inlet valve closes. The inlet valve closes 30-40° or even 60° after the bottom dead centre position. The air-fuel mixture is compressed till the spark occurs. The spark is produced 20-50° before TDC. It gives sufficient time for the fuel to burn. Both pressure and temperature increase. The burnt gases are expanded till the exhaust valve opens.

The exhaust valve opens 30-60° before BDC. The exhaust gases are forced out from the cylinder till the exhaust valve closes. The exhaust valve closes 8-20° after TDC. Before closing, the inlet valve again opens 10-30° before TDC. If the piston is positioned between fourth stroke (exhaust) and the first stroke (intake) at TDC, both valves are open. The period between IVO and EVC is known as valve overlap period. The angle of valve overlap is the sum of the angle of opening the intake valve before TDC and closing of the exhaust valve after TDC.



### ❖ Valve Timing Diagram of a 4-Cylinder CI Engine:

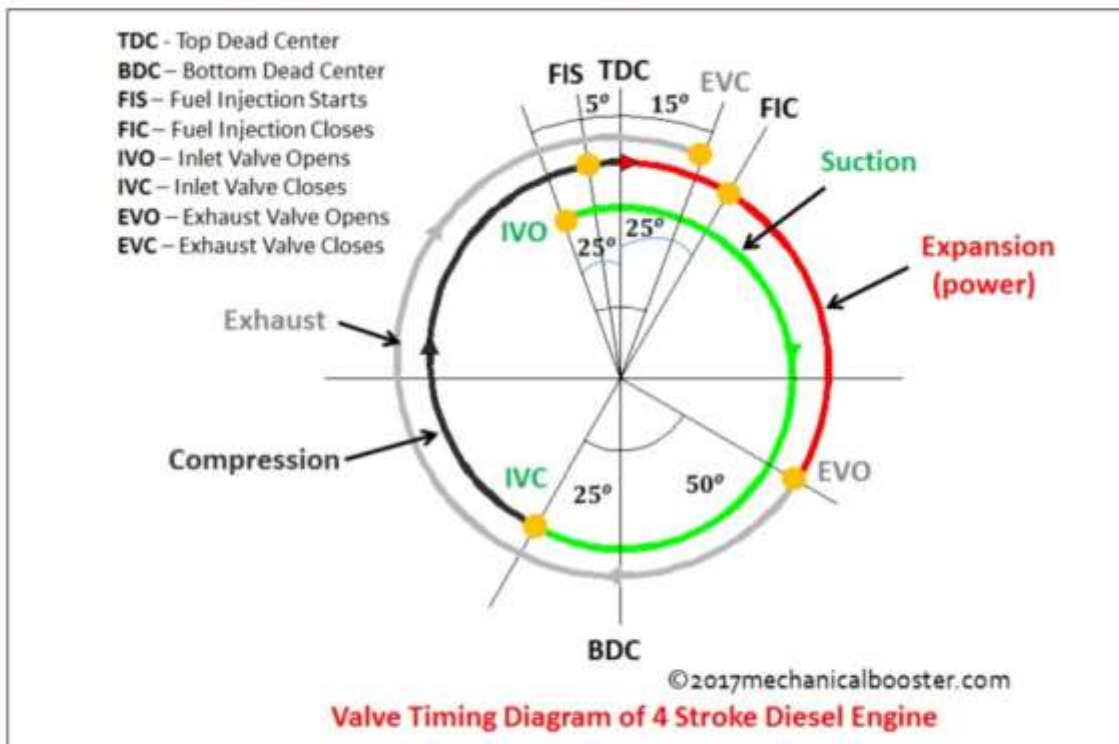


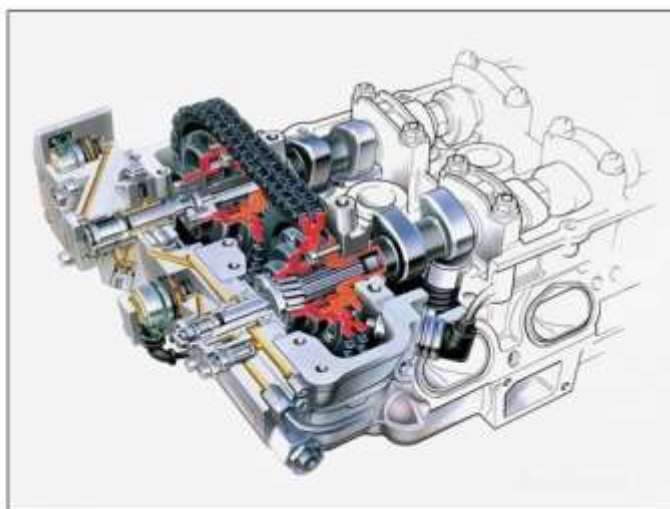
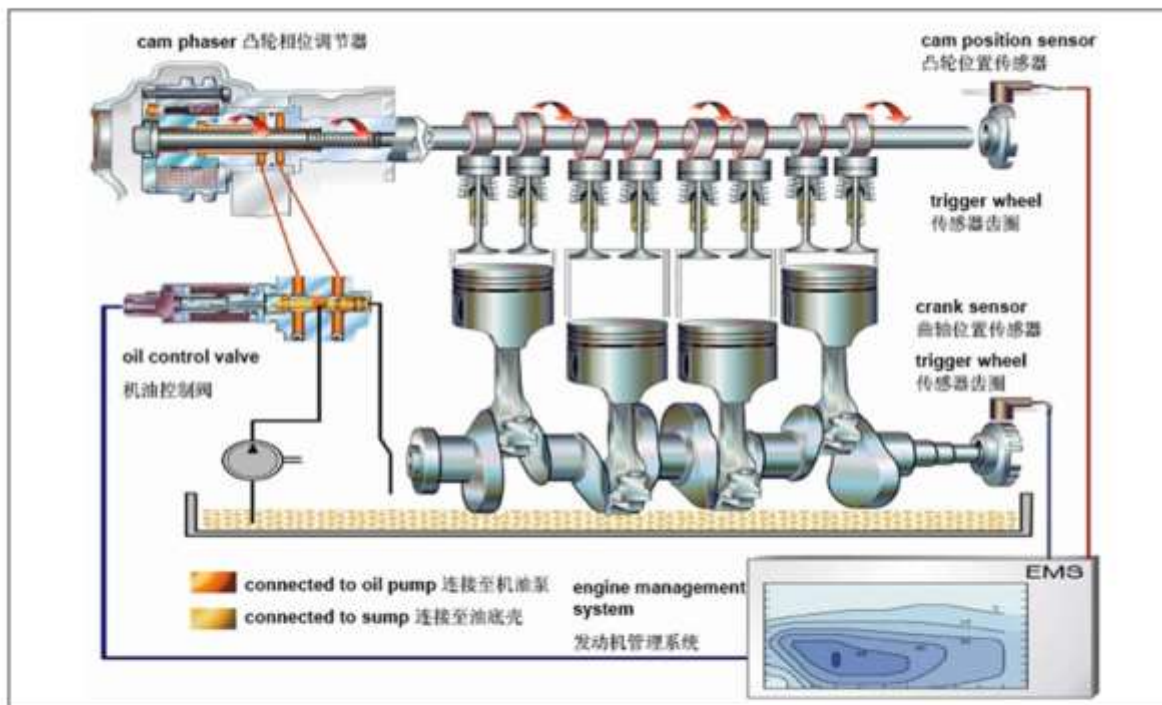
Figure above shows the actual valve-timing diagram for four-stroke diesel (CI) engine. The inlet valve opens (IVO) 10° to 25° before TDC. Fresh air is sucked into the engine cylinder till the inlet valve closes. The inlet valve closes (IVC) 25° to 50° after BDC. The air is compressed till the fuel is injected. The fuel injection starts (FIS) 5° to 10° before TDC in the compression stroke. The air-fuel mixture burns. Both temperature and pressure increase. The burning gases are expanded till the exhaust valve opens. The exhaust valve opens (EVO) 30° to 50° before BDC. The exhaust gases are forced out of the cylinder till the exhaust valve closes. The exhaust valves close (EVC) 10° to 15° after TDC. Before closing the exhaust valve, the inlet valve again opens 10° to 25° before TDC. The period when both the inlet and exhaust valves are opened is known as valve overlap period. The angle between these two events is known as angle of valve overlap.

### **Variable Valve Timing (VVT)**

The engine has a lower volumetric efficiency at high speeds. The intake valves are open for a much shorter time resulting in less time for air-fuel mixture to enter into the engine cylinders. If the inlet valves open earlier at high speeds, more air-fuel mixture will enter into the engine cylinders.

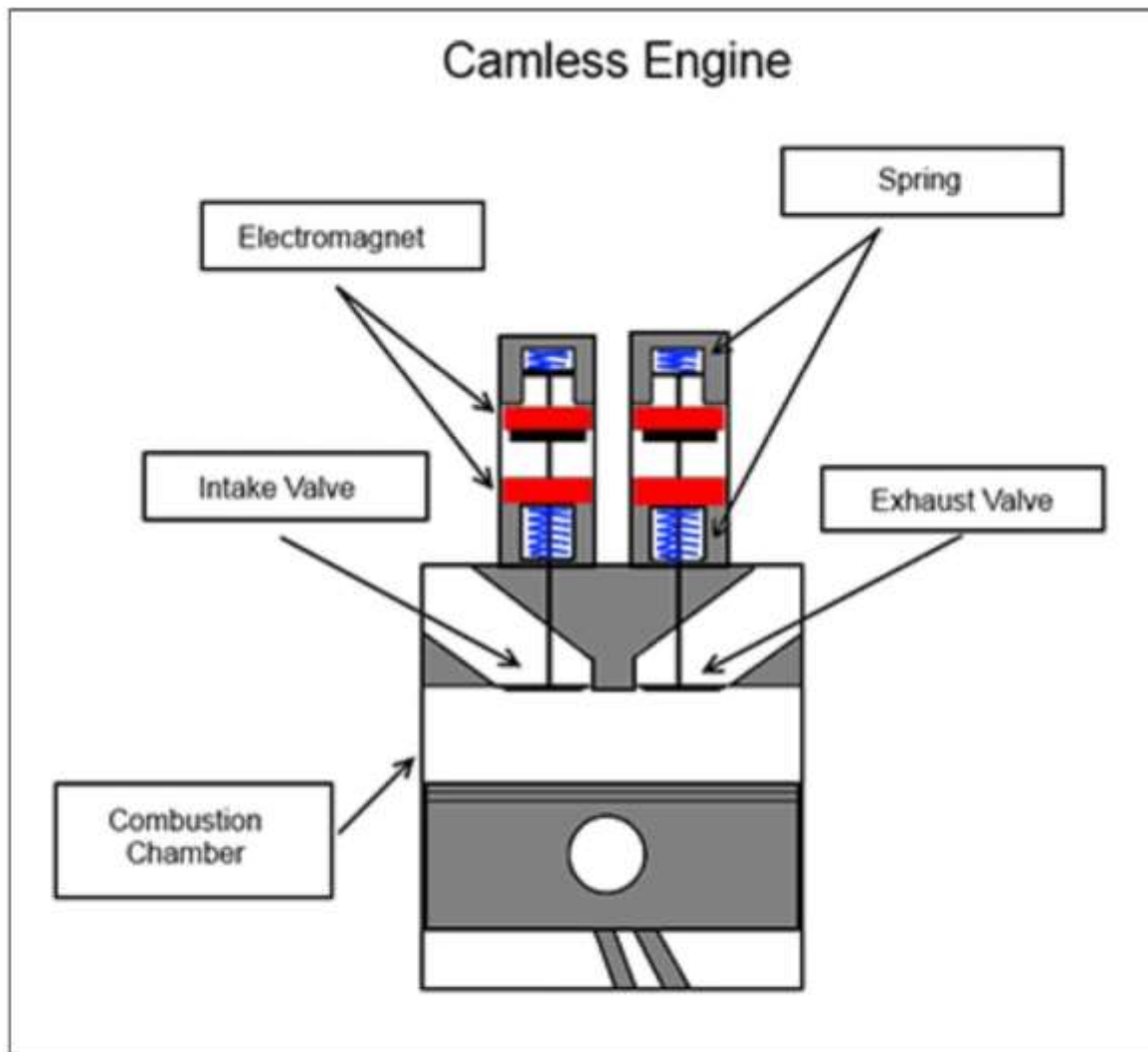
One way to open intake valves earlier is to use a “Variable Valve Timing (VVT) mechanism”. It has a flexible connection between the camshaft sprocket and the camshaft. The connection includes a hydraulic piston operated by engine oil pressure and a solenoid operated oil control valve. When the ECM signals the solenoid to close the valve, the oil pressure forces the piston forward i.e. towards the camshaft. As the piston moves, the internal teeth of the piston slide up the inclined teeth on the helical drive gear. This moves

the camshaft ahead and advances the timing by about 100. The intake valve opens earlier. This arrangement is known as “Phaser type Variable Valve Timing System”



Another method being developed is to use electric solenoids to drive the valves instead of using camshafts. Such engines are known as “Cam less engines”. Here each valve is driven by a solenoid whose plunger presses against the end of valve stem. A host of sensors send information on engine speed, load and other variables to the ECM which decides when and how long the valves are to be kept opened. At proper time, the ECM send a signal to the appropriate solenoid which then operates the valve. At higher speeds, the ECM opens the valves earlier and may hold them open longer.





## MODERN DEVELOPMENTS IN ENGINE TECHNOLOGY

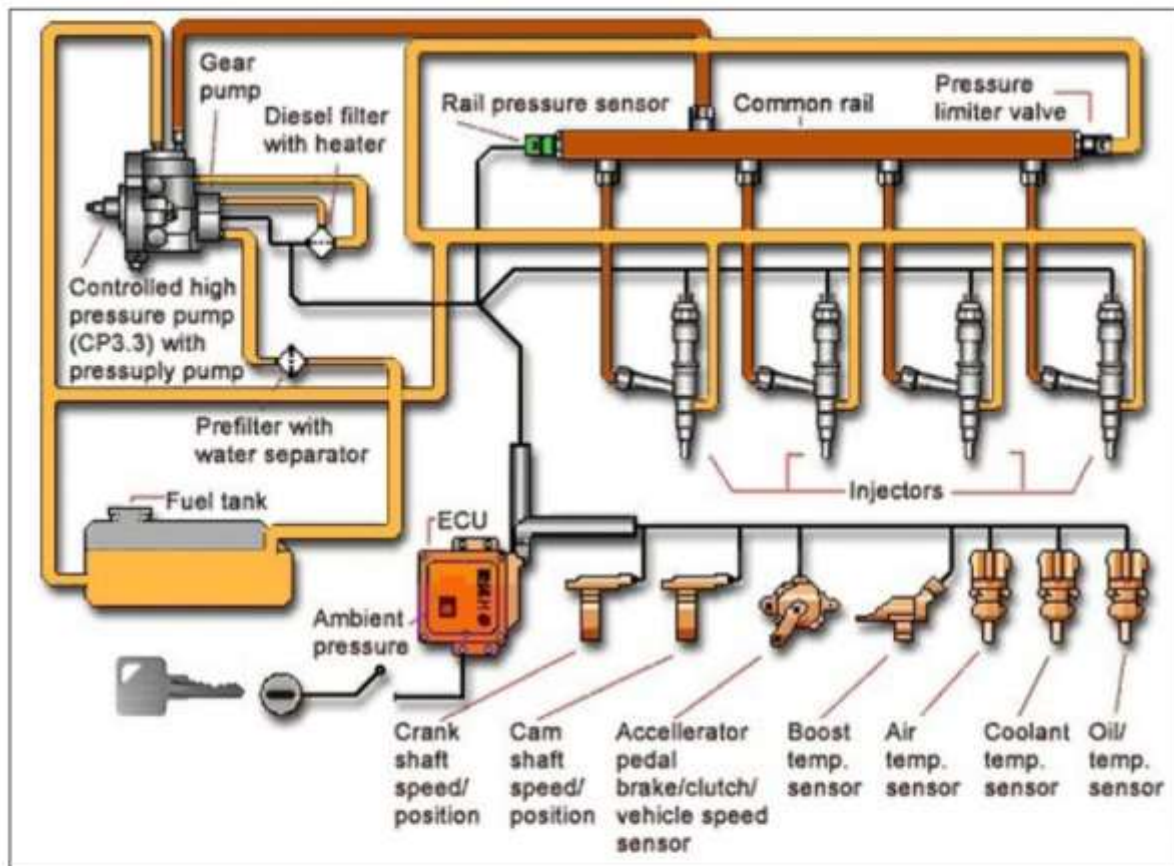
Since their introduction around a century ago, IC engines have played a key role both socially and economically in shaping the modern World. Their suitability as an automotive power plant coupled with lack of other practical and commercially viable alternative meant that road transport (both goods and passengers) could not exist without them. Also, there has been enormous demand on their performance parameters (power, speed, torque, cost of operation, life time cost etc) by customers to suit variety of applications. *However fast depletion of petroleum reserves and environmental impact of the gaseous and particulate emissions have raised serious concerns about their use in recent decades. All these have led to imposing heavy taxations on fuel and introducing continuously stringent legislations that restrict the amount of pollutants released by these engines into the atmosphere.* These two major factors have led to massive pressure on vehicle manufacturers to develop and produce ever cleaner and more fuel-efficient vehicles. Some of the modern technologies that have been introduced towards achieving above objective are: -



- ❖ CRDI : Common Rail Direct Injection
- ❖ GDI : Gasoline direct Injection
- ❖ HCCI : Homogeneous Charge Compression Ignition
- ❖ SCSi : Stratified Charge Spark Ignition Engine
- ❖ Dual Fuel Engine

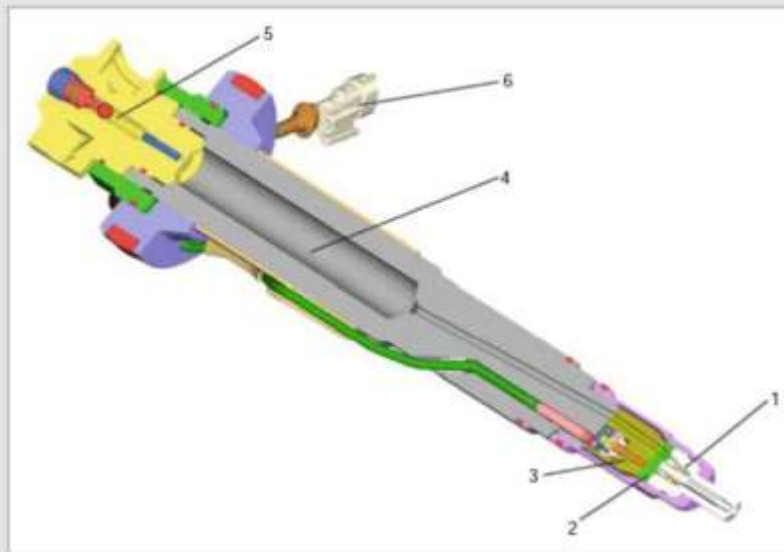
These technologies are briefly explained below: -

❖ Common Rail Direct Injection:

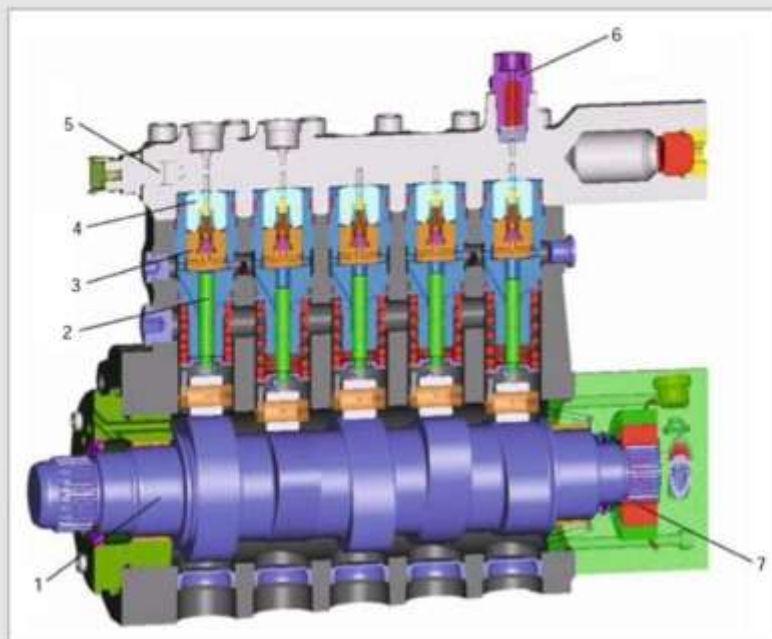


This technology is a direct fuel injection system *for diesel engines*. The key feature of this technology is that metering and control functions have been taken away from the injector pump altogether whose sole job is to produce a constant supply of fuel at *enormously high pressure — up to about 30,000psi (2,000bar)*. From the pump, the pressurised fuel passes to a thick-walled tube (the 'common rail') or to an equally rugged reservoir from which injector pipes carry it to electronically controlled injectors.

*The advantages of the system* are that the higher pressure means that the fuel spray from each injector is much finer while the electronic control means that the amount of fuel, the timing and duration of each squirt and even the number of squirts per cycle can be varied by the electronic processor to give increased fuel efficiency, less toxic exhaust gas, and lower noise levels. *The disadvantages of the system* are that it is costly than the conventional engine, requires high degree of engine maintenance and costly spare parts. Also, this technology cannot be employed for ordinary engines.



**Fig. 5-50**  
 Injector for a modular common rail system.  
 1 Nozzle; 2 Orifice plate; 3 Solenoid valve;  
 4 Injector body with accumulator; 5 Flow  
 limiter; 6 Electrical connector



**Fig. 5-51**  
 High pressure pump for a modular common rail  
 system. 1 Camshaft; 2 Pump element; 3 Suction  
 valve; 4 Pressure valve; 5 Accumulator;  
 6 Pressure limiting valve; 7 Low pressure pump

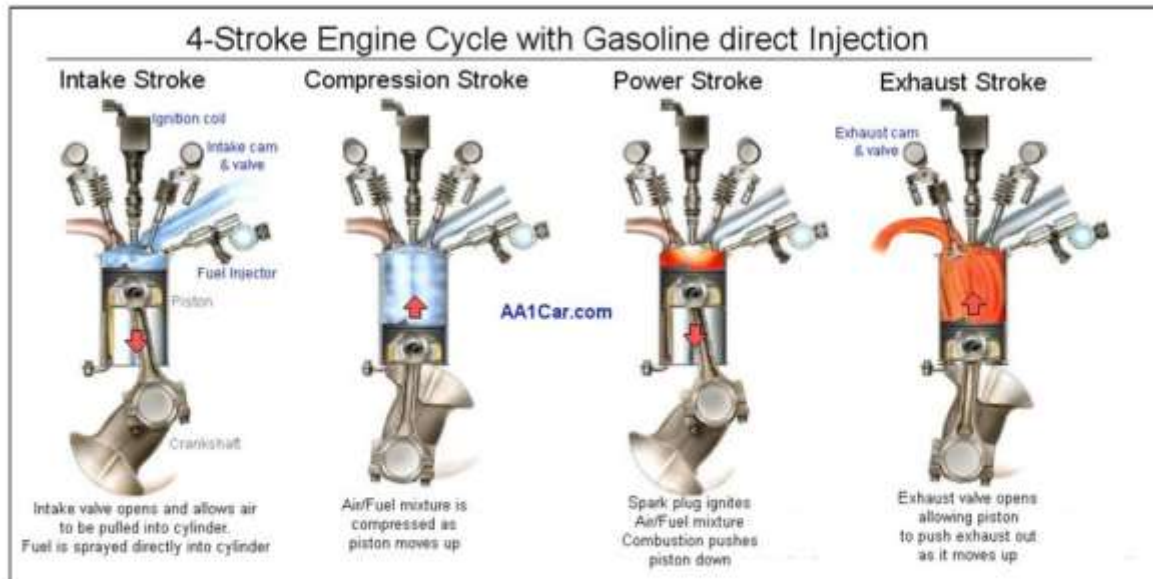
This technology is used widely by several manufacturers such as: -

- Mahindra - Scorpio - CRDe - Common Rail Diesel Engine
- Hyundai - Getz/Accent/Verna/Sonata/Tucson - CRDi - Common Rail Direct Injection
- Tata - Indigo/Safari - DICOR - Direct Injection Common Rail
- Maruti - Swift - DDiS - Direct Diesel Injection System
- Mercedes - CDI - Common Diesel Injection
- Chevrolet - Optra Magnum - CRDi - Common Rail Direct Injection



- Toyota - Innova - CRDi - Common Rail Direct Injection

### Gasoline Direct Injection:



Gasoline direct injection (GDI) also known as “Petrol direct injection”, “Spark-ignited direct injection (SIDI)” and “Fuel-Stratified injection (FSI)” is used in **non-diesel internal combustion engines**. This system is very similar to the common rail direct injection system used in diesel engines and is a variant of fuel injection employed in modern two-stroke and four-stroke gasoline engines.

Engines with gasoline direct injection produce the air-fuel mixture directly in the combustion chamber. Only fresh air flows into the intake port through the open intake valve. *The gasoline is highly pressurized to about 350 bars in a high-pressure circuit and injected via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional multipoint fuel injection that injects fuel into the intake tract or cylinder port.* The high-pressure injectors are fitted to the fuel rail which meter and atomize the fuel at high pressure extremely rapidly to provide optimum mixture preparation directly in the combustion chamber.

*Advantages of the GDI system* include better power output compared to carburetted engines (due to combustion chamber cooling by direct spraying of fuel enabling manufacturers to use higher compression ratio resulting in increased efficiency and performance), better fuel efficiency because of accurate electronic controlled monitoring, better emission performance again due to precise fuel monitoring (very less HC emissions due to almost zero unburnt fuel), engines can accommodate alternate fuels, providing smooth drivability because of smooth running of the engine, enhanced diagnostic capabilities etc.

*The major disadvantage of GDI engine* is a carbon build-up over time in the intake valves that occurs which reduces the airflow to the cylinders and therefore reduces power. Fuel contains various detergents and can keep the intakes clean. When fuel is no longer being sprayed in the intake valves, small amounts of dirt from intake air and blowback carbon from the crankcase ventilation system cakes on the intake walls. This build-up can become severe



enough so that a piece can break off and has been known to burn holes in catalytic converters. It can also cause sporadic ignition failures. These problems have been known for some time and technologies have been improved to reduce the carbon build-up.

GDI is used by several manufacturers such as: -

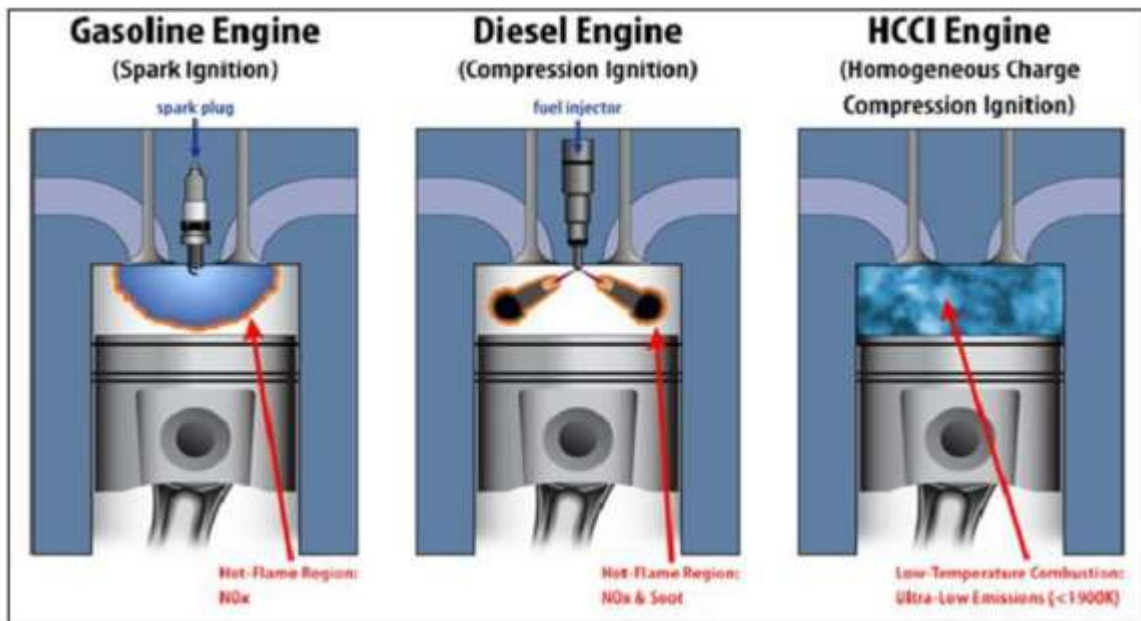
- 3.0L TFSI Supercharged DOHC V-6 (Audi A6)
- 2.0L N20 Turbocharged DOHC I-4 (BMW Z4/528i)
- 3.0L N55 Turbocharged DOHC I-6 (BMW 335i coupe)
- 3.6L Pentastar DOHC V-6 (Chrysler 300S/Jeep Wrangler)
- 2.0L EcoBoost DOHC I-4 (Ford Edge)
- 5.0L DOHC V-8 (Ford Mustang Boss 302)
- 2.0L Turbocharged DOHC I-4 (Buick Regal GS)
- 1.6L DOHC I-4 (Hyundai Accent/Kia Soul)
- 2.0L Skyactiv DOHC I-4 (Mazda3)
- 3.5L DOHC V-6 HEV (Infiniti M35h)

#### ❖ Homogeneous Charge Compression Ignition (HCCI):

The HCCI technique is used *in gasoline engines*. It is the process by which a homogeneous mixture of air and fuel is compressed until auto-ignition occurs near the end of the compression stroke, followed by a combustion process that is significantly faster than either compression ignition (CI) or spark ignition (SI) combustion. The air/fuel mixture quality in HCCI engines is generally lean which auto-ignites in multiple locations and is then burnt volumetrically without discernible flame propagation. Combustion occurs when the homogeneous mixture reaches its chemical activation energy and is fully controlled by chemical kinetics rather than by a spark or injection timing.

HCCI combines characteristics of conventional gasoline engine and diesel engines. Gasoline engines combine homogeneous charge (HC) with spark ignition (SI) abbreviated as HCSI. Diesel engines combine stratified charge (SC) with compression ignition (CI), abbreviated as SCCI.

As in HCSI, HCCI injects fuel during the intake stroke. However, rather than using an electric discharge (spark) to ignite a portion of the mixture, HCCI raises density and temperature by compression until the entire mixture reacts spontaneously.



Stratified charge compression ignition (*SCCI*) also relies on temperature and density increase resulting from compression. *However, it injects fuel later, during the compression stroke.* Combustion occurs at the boundary of the fuel and air, producing higher emissions, but allowing a leaner and higher compression burn, producing greater efficiency.

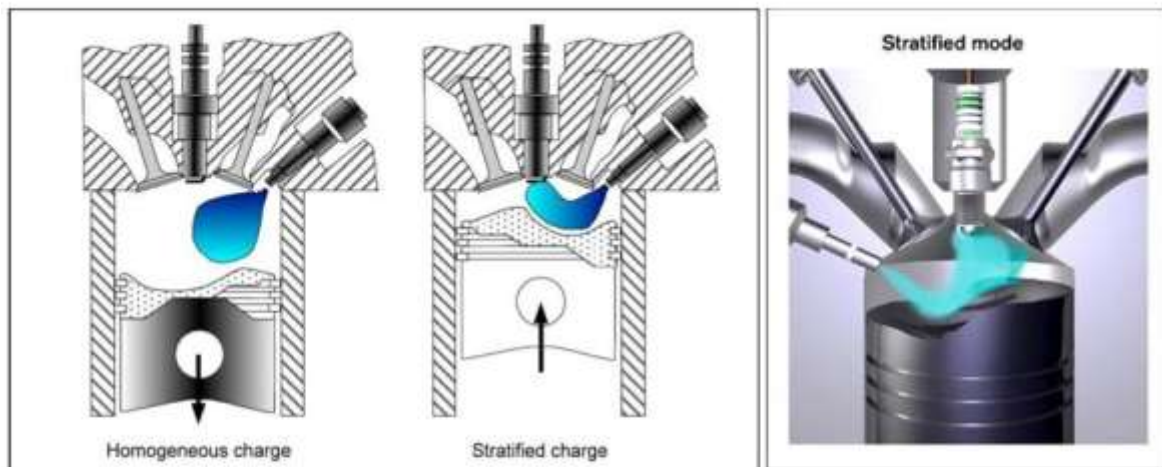
*Advantages of HCCI engine* include lean fuel operation (due to diesel like compression ratios > 15), cleaner combustion and less emission because of homogeneous mixing of air and gasoline, engine can operate on gasoline / diesel / other fuels, avoids throttle loss leading to increased efficiency.

*Disadvantage of HCCI engine* include smaller power range, inferior cold start capability, greater engine wear because of high heat release and pressure rise rates, difficulty in controlling auto-ignition (spark ignition and fuel injection methods are better controlled), HCCI engines have a small power range (constrained at low loads by lean flammability limits and high loads by in-cylinder pressure restriction), higher pre-catalyst CO and HC emissions compared to a SI engine (because of incomplete oxidation due to the rapid combustion event and low in-cylinder temperatures and trapped crevice gases).

*As of 2017 no HCCI engines were produced at commercial scale.* However, several car manufacturers had functioning HCCI prototypes. Mazda is developing an HCCI engine called "Mazda SkyActiv-X HCCI Engine" likely to Debut In 2019. The new engine will be the world's first commercial petrol engine to use compression ignition similar to a diesel engine. Contrary to popular reports, the SkyActiv-X Homogeneous charge compression ignition (HCCI) engine does not exclude the use of spark plugs. Instead, Mazda's proprietary combustion method called Spark Controlled Compression Ignition was the crucial breakthrough that enables the engine to switch between spark and compression ignition.



### ❖ Stratified Charge Spark Ignition (SCSI):



The SCSI technique is used *in gasoline engines*. “*Stratified charge means variable air-fuel ratio*”. The stratified charged engine is an internal combustion engine in which air-fuel ratio is not equal throughout the cylinder. The fuel charge consists of two layers. A rich mixture is provided close to the spark plug by a small auxiliary inlet valve whose combustion promotes ignition of a lean mixture in the remainder of the cylinder through the main inlet valve. Thus, this design provides a variable air-fuel ratio across the combustion chamber with overall lean mixture which not only reduces fuel consumption but also reduces exhaust emission.

The stratified charge engine works by creating a swirl of input air in the cylinder. Fuel is injected into the engine just before ignition which permits use of higher compression ratios without “knocking” and leaner air-fuel mixture compared to conventional engines. As the fuel is burnt, the surrounding air aids in complete combustion of the lean mixture before opening of exhaust port.

*The advantages of SCSI* are reduced emission, reduced fuel consumption, power on demand and reduced heat loss. The *disadvantage* includes increased injector cost and complexity, higher fuel pressure requirement, carbon build up on the back of intake valve (due to lack of gasoline passing by it which works as a cleansing agent), increased NO<sub>x</sub> emissions due to exhaust gas temperature (though most of this is negated by adopting “Exhaust Gas Recirculation” technique).

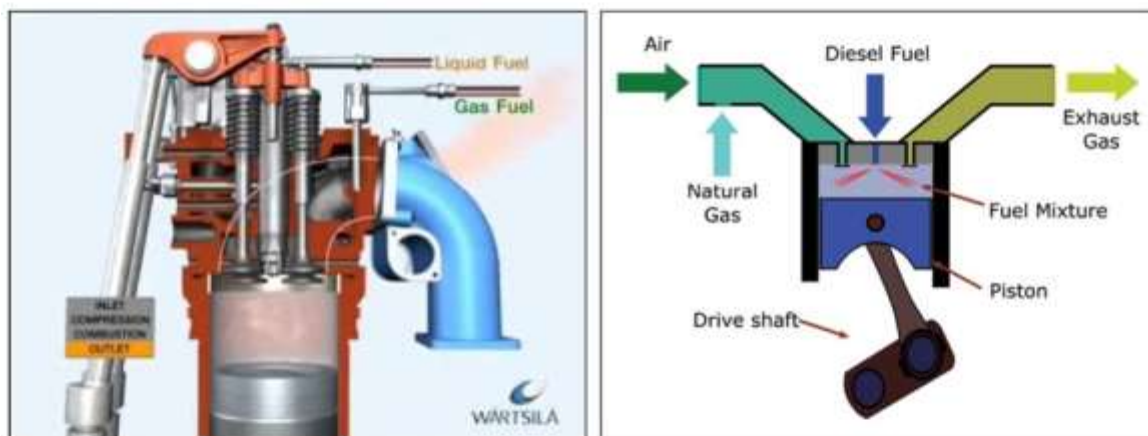
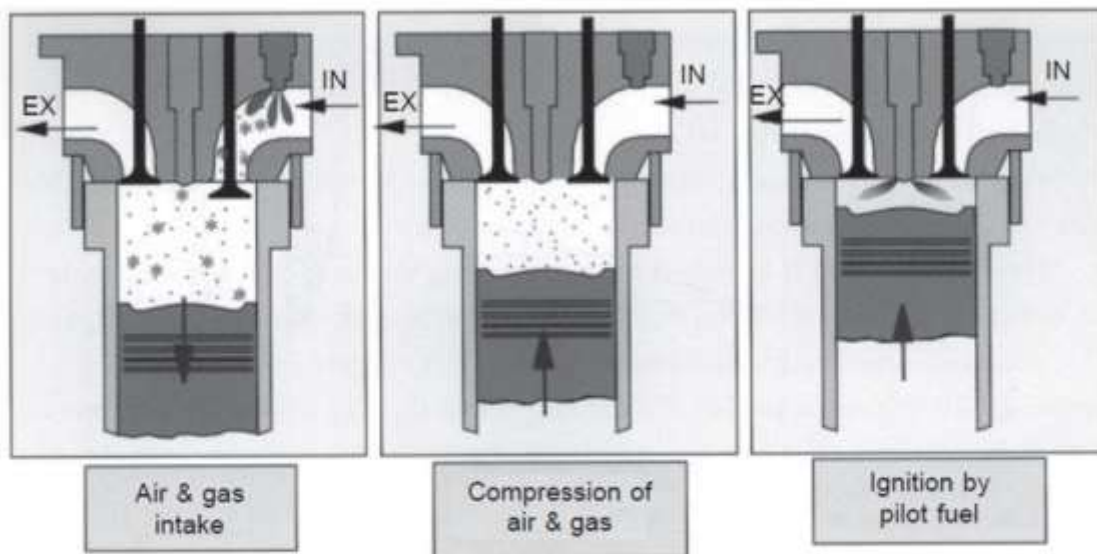
“Volkswagen” currently uses stratified charge on its direct injection 1.2, 1.4, 1.5, 1.8 and 2.0 litres TFSI (Turbo fuel stratified injection) gasoline engines in combination with turbocharging. Mercedes Benz has been employing stratified charge engines with its Blue DIRECT system.

### ❖ Dual Fuel Engine:

“Bi-fuel engines” or “Dual fuel engines” are multifuel IC engines capable of running on two fuels (Liquid fuel and gaseous fuel). This engine works on the “Dual cycle which is a combination of Otto and Diesel cycle”. One of the fuel is gasoline or diesel and the other is an alternate fuel such as natural gas (CNG), LPG, or hydrogen. The two fuels are stored in



separate tanks and the engine runs on one fuel at a time. In some cases, both fuels are used in unison. Bi-fuel vehicles have the capability to switch back and forth from gasoline or diesel to the other fuel, manually or automatically.



**Dual fuel engine is a compression ignition engine.** According to its name, it uses two fuels to complete a power stroke. **It uses gaseous fuel as the main fuel and diesel fuel as pilot fuel.** In these engines, *intake air is mixed with gaseous fuel and the mixture is drawn into the engine cylinder.* In the cylinder this mixture is compressed. This mixture however does not auto ignite as gaseous fuels are not good compression ignition fuel. So, a small quantity of diesel oil is injected into the compressed mixture. As happens in the diesel engine, the diesel ignites due to temperature rise in compression. This fuel is known as pilot fuel. This ignites the whole mixture of air and gaseous fuel and a rapid combustion take place inside the cylinder which produces power.

Dual fuel offers many advantages such as low cost of operation, easy availability of fuel, environment friendly engine (as gaseous fuels are less polluting), less wear and tear of engine parts because of clean combustion, engine generates high power than diesel fuel at higher load conditions (makes it very suitable for large capacity marine and stationary applications),

The drawbacks of dual-fuel engine are tendency of vapor lock while using lighter fuels, tendency of wear and tear due to low lubrication, difficulty in addressing requirement of injecting different volumes of fuel.

Dual fuel passenger cars like Fiat Punto, Chevrolet Cavalier, Dacia Logan, Chevrolet Spark Bifuel, Volkswagen Polo Bifuel, Mazda2 Bifuel etc. are available in the market.



# Thanks