



Unit I

Introduction to Automotive Electrical Systems

By,
Mr. A J Bhosale
Asst. Professor
Dept. of Automobile Engineering
Govt. College of Engineering and Research, Avsari (Kd)



❖ Syllabus:-

Automotive electricity generation, storage & distribution systems, wiring harness, circuit diagrams and symbols, 12/24/42 volt system, positive earth and negative earth, earth return and insulated return systems, Multiplexed wiring systems, Electromagnetic compatibility & interference, Introduction of Controlled Area Networks (CAN) protocols.

Battery: Principle of lead acid battery, Types, Constructional details, Recharging the battery, Battery ratings, Battery Performance, Battery capacities, Battery efficiency, Battery tests, Battery failures, Alkaline battery, maintenance free batteries, hybrid batteries.



❖ Definitions and Laws:

1. Ohm's law

- For most conductors, the current which will flow through them is directly proportional to the voltage applied to them.
- The ratio of voltage to current is referred to as resistance. If this ratio remains constant over a wide range of voltages, the material is said to be 'ohmic'.

Where:

I = Current in amps

V = Voltage in volts

R = Resistance in ohms

$$I = \frac{V}{R}$$

- Georg Simon Ohm was a German physicist, well known for his work on electrical currents.



2. Lenz's law

- The emf induced in an electric circuit always acts in a direction so that the current it creates around the circuit will oppose the change in magnetic flux which caused it.
- Lenz's law gives the direction of the induced emf resulting from electromagnetic induction. The 'opposing' emf is often described as a 'back emf'. The law is named after the Estonian physicist Heinrich Lenz.



3. Kirchhoff's laws

Kirchhoff's 1st law:

- The current flowing into a junction in a circuit must equal the current flowing out of the junction. This law is a direct result of the conservation of charge; no charge can be lost in the junction, so any charge that flows in must also flow out.

Kirchhoff's 2nd law:

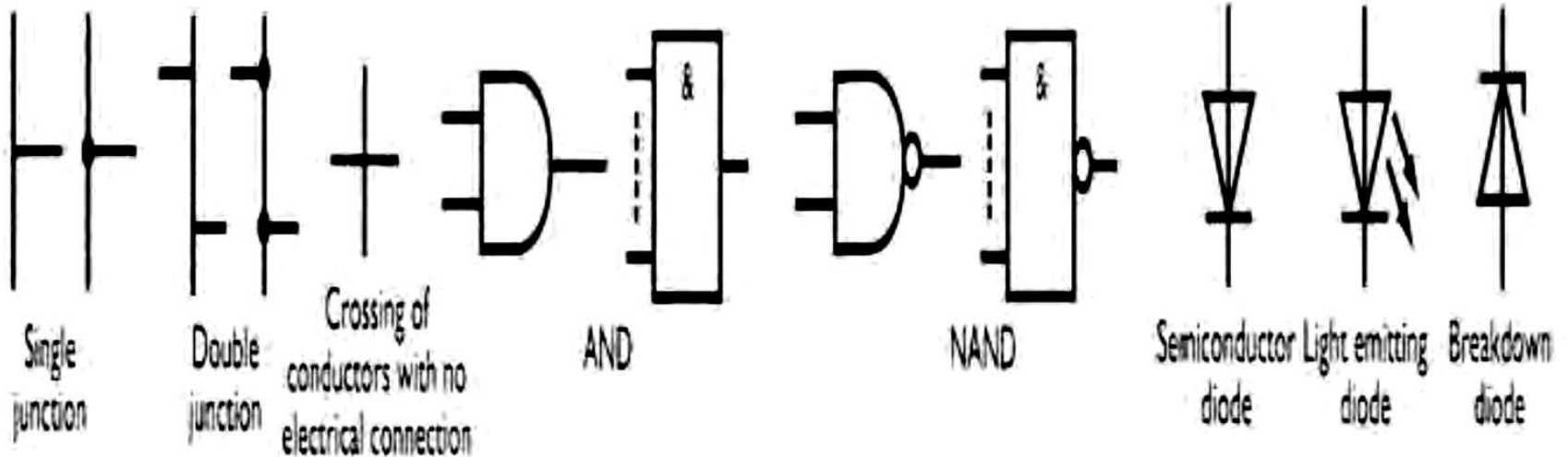
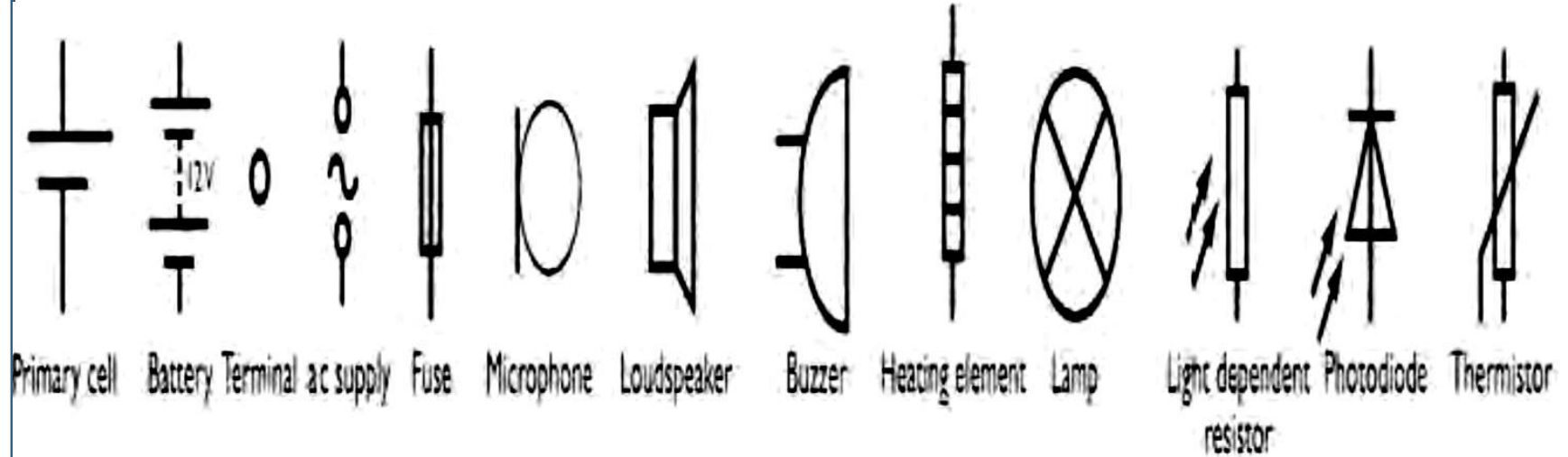
- For any closed loop path around a circuit the sum of the voltage gains and drops always equals zero. This is effectively the same as the series circuit statement that the sum of all the voltage drops will always equal the supply voltage.
- Gustav Robert Kirchhoff was a German physicist; he also discovered cesium and rubidium.



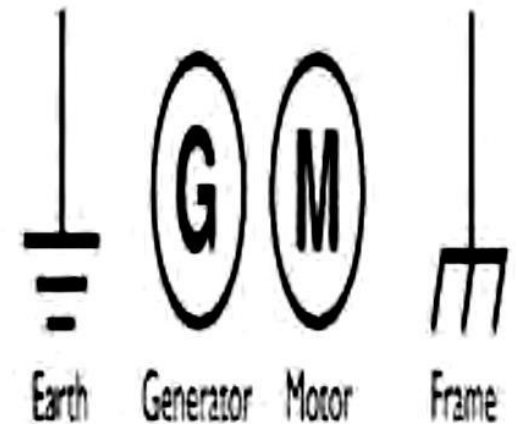
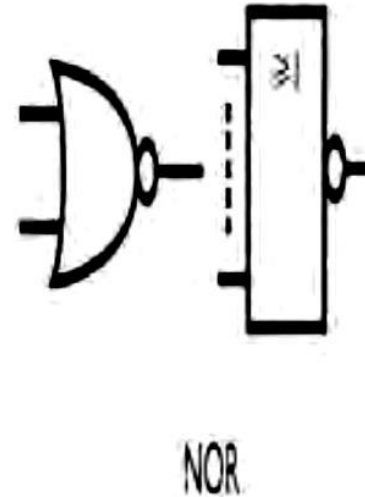
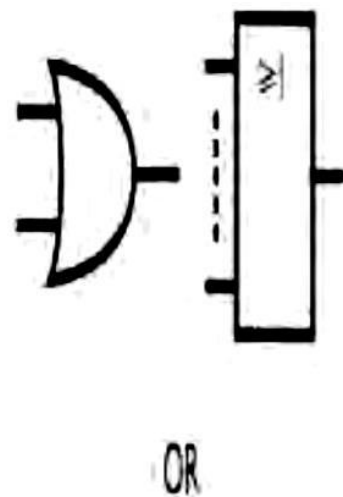
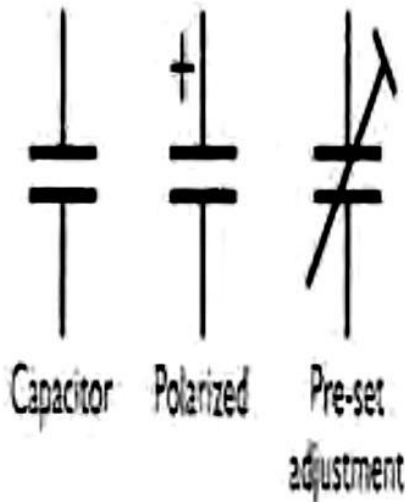
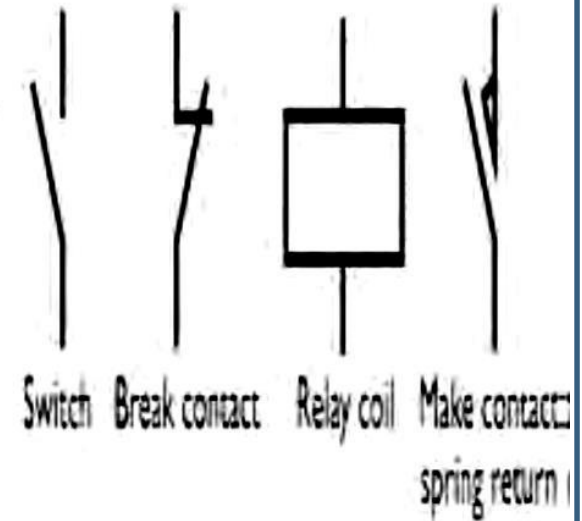
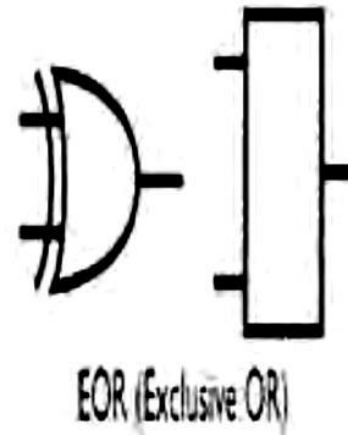
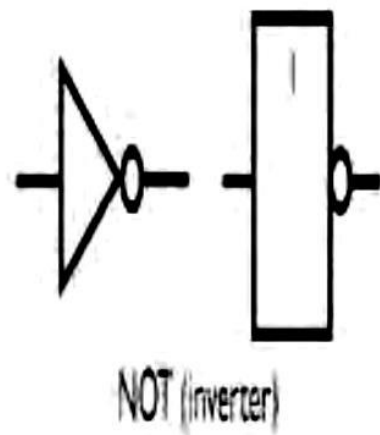
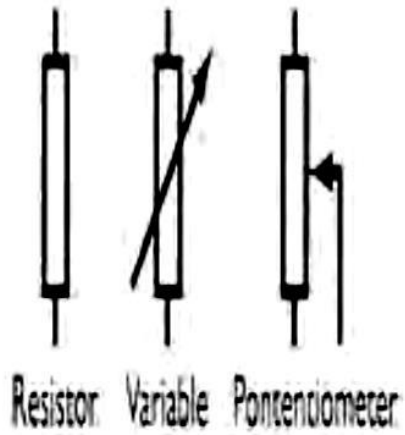
4. Faraday's law

- Any change in the magnetic field around a coil of wire will cause an emf (voltage) to be induced in the coil.
- Michael Faraday was a British physicist and chemist, well known for his discoveries of electromagnetic induction and of the laws of electrolysis.

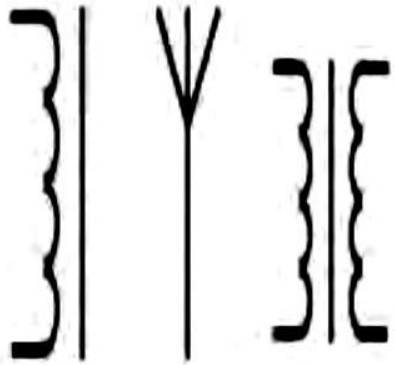
❖ Symbols:



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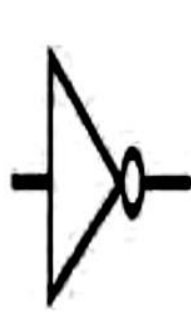
❖ Symbols:



Inductor with magnetic core

Aerial

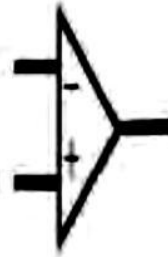
Transformer with magnetic core



Schmitt inverter



RS-bistable



Operational amplifier



PNP transistor



NPN transistor



Ammeter



Voltmeter



Oscilloscope



❖ **Automotive Electricity Generation:**

- The 'current' demands made by modern vehicles are considerable. The electricity generation system must be able to meet these demands under all operating conditions and charge the battery.
- The main component of the electricity generation system is the alternator.
- The alternator generates AC but must produce DC at its output terminal as only DC can be used to charge the battery and run electronic circuits.
- The output of the alternator must be a constant voltage regardless of engine speed and current load.



- To summarize,
- Supply the current demands made by all loads.
 - Supply whatever charge current the battery demands.
 - Operate at idle speed.
 - Supply constant voltage under all conditions.
 - Have an efficient power-to-weight ratio.
 - Be reliable, quiet, and have resistance to contamination.
 - Require low maintenance.
 - Provide an indication of correct operation.

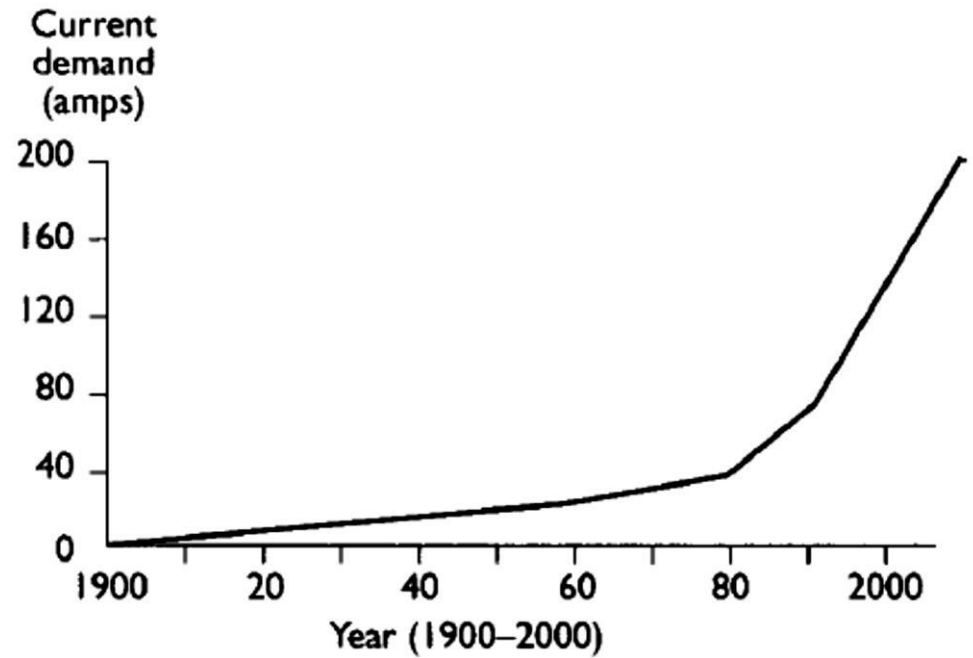


Figure 6.2 How the demands on the alternator have changed



Table 6.1 Typical power requirements of some common vehicle electrical components

Continuous loads	Power (W)	Current at 14 V	28 V
Ignition	30	2.0	1.0
Fuel injection	70	5.0	2.5
Fuel pump	70	5.0	2.5
Instruments	10	1.0	0.5
Total	180	13.0	6.5
Prolonged loads	Power (W)	Current at 14 V	28 V
Side and tail lights	30	2.0	1.0
Number plate lights	10	1.0	0.5
Headlights main beam	200	15.0	7.0
Headlights dip beam	160	12.0	6.0
Dashboard lights	25	2.0	1.0
Radio/Cassette/CD	15	1.0	0.5
Total (Av. main & dip)	260	19.5	9.5



Intermittent loads	Power (W)	Current at 14V	28V
Heater	50	3.5	2.0
Indicators	50	3.5	2.0
Brake lights	40	3.0	1.5
Front wipers	80	6.0	3.0
Rear wipers	50	3.5	2.0
Electric windows	150	11.0	5.5
Radiator cooling fan	150	11.0	5.5
Heater blower motor	80	6.0	3.0
Heated rear window	120	9.0	4.5
Interior lights	10	1.0	0.5
Horns	40	3.0	1.5
Rear fog lights	40	3.0	1.5
Reverse lights	40	3.0	1.5
Auxiliary lamps	110	8.0	4.0
Cigarette lighter	100	7.0	3.5
Headlight wash wipe	100	7.0	3.5
Seat movement	150	11.0	5.5
Seat heater	200	14.0	7.0
Sun-roof motor	150	11.0	5.5
Electric mirrors	10	1.0	0.5
Total	1.7 kW	125.5	63.5



Automotive Electricity Storage:

Requirements:-

- To provide power storage and be able to supply it quickly enough to operate the vehicle starter motor.
- To allow the use of parking lights for a reasonable time.
- To allow operation of accessories when the engine is not running.
- To act as a swamp to damp out fluctuations of system voltage.
- To allow dynamic memory and alarm systems to remain active when the vehicle is left for a period of time

Regulator:

- Regulator regulates the current produced by the generator.

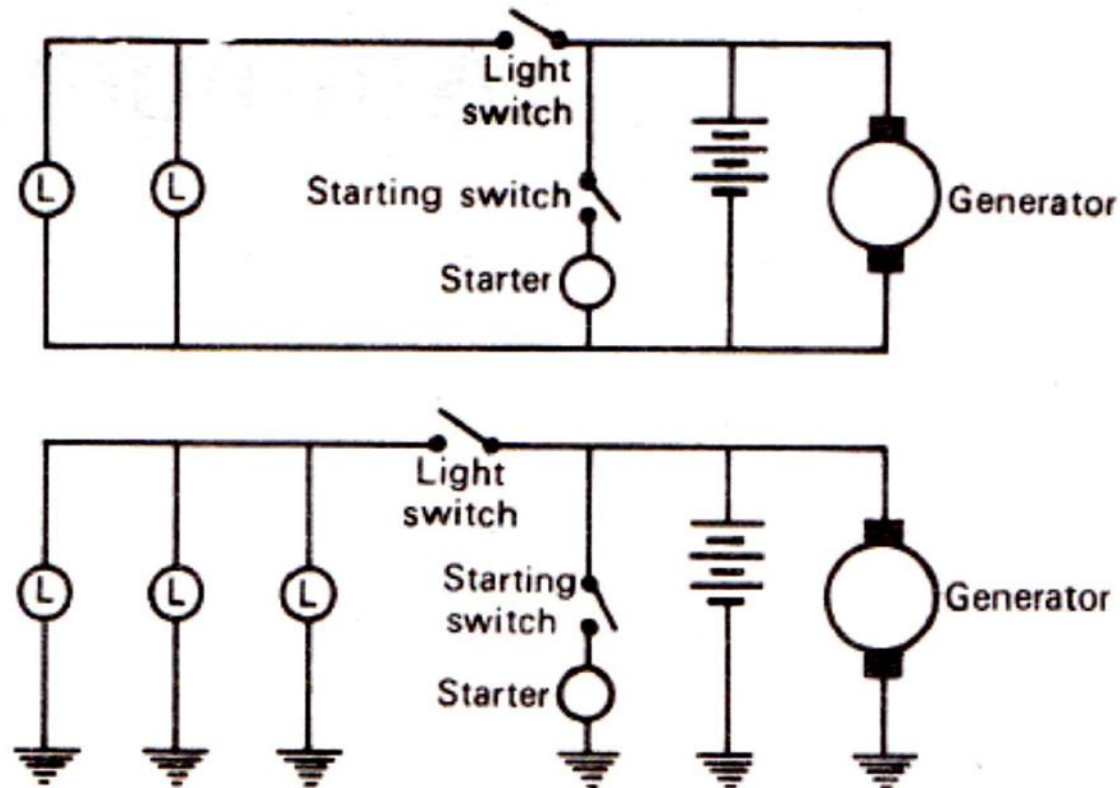


Fig. 2.1 Connection diagram.

Starting System:

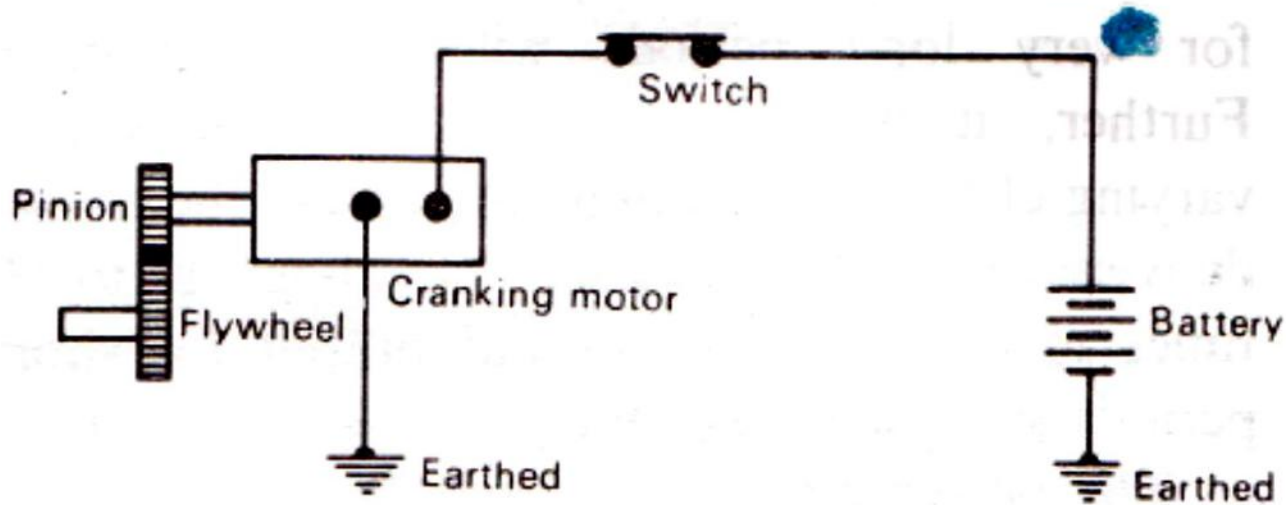


Fig. 2.2 A simple circuit diagram of the cranking motor.

Ignition System:

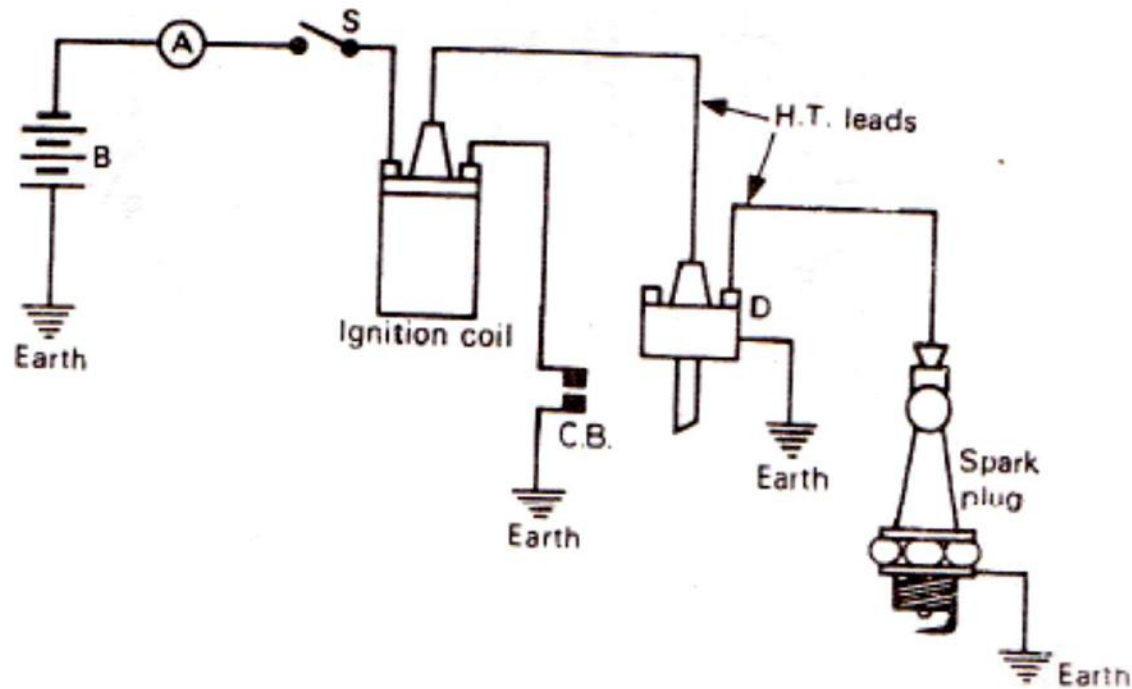


Fig. 2.4 A simple circuit diagram of the coil ignition system.

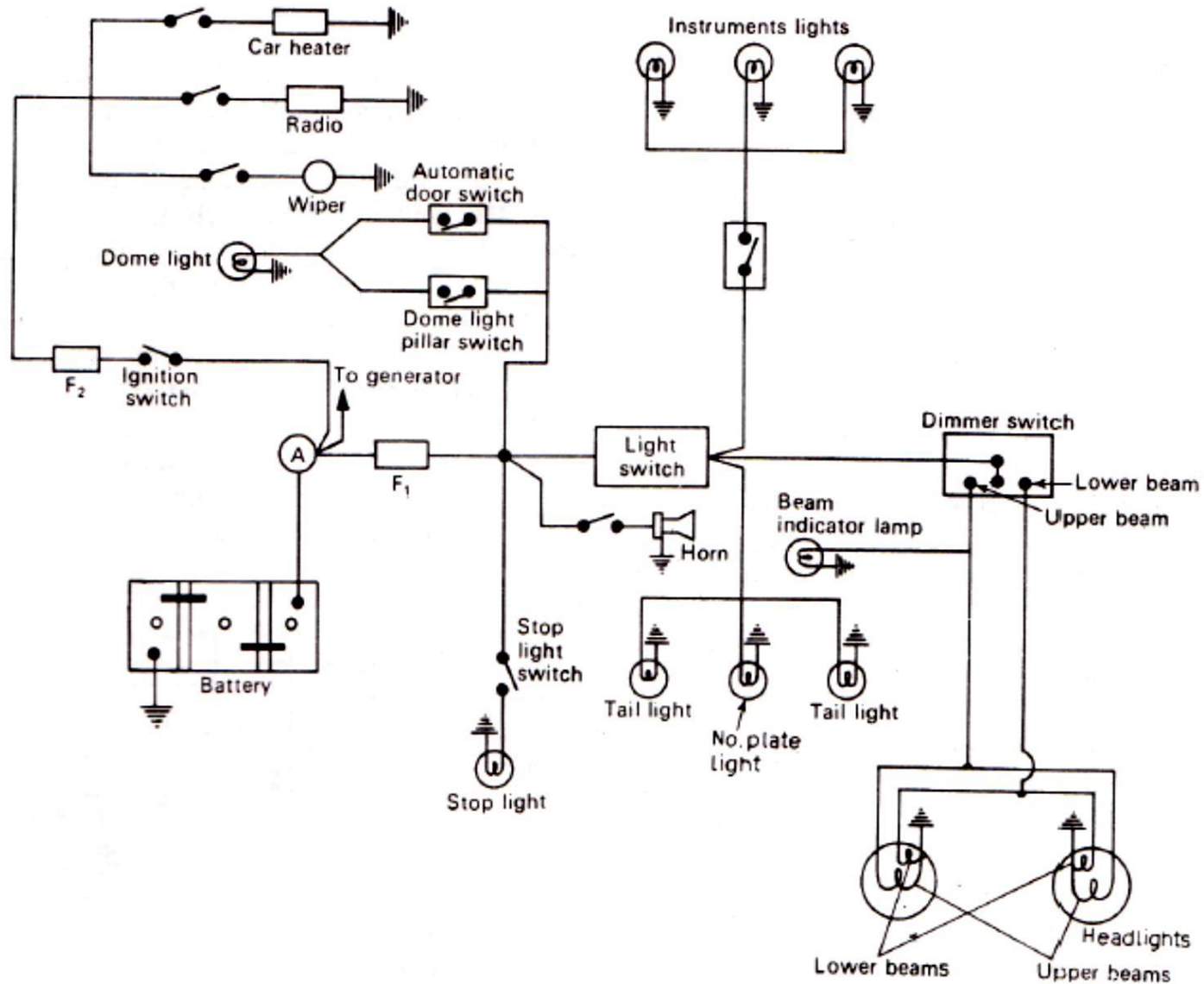
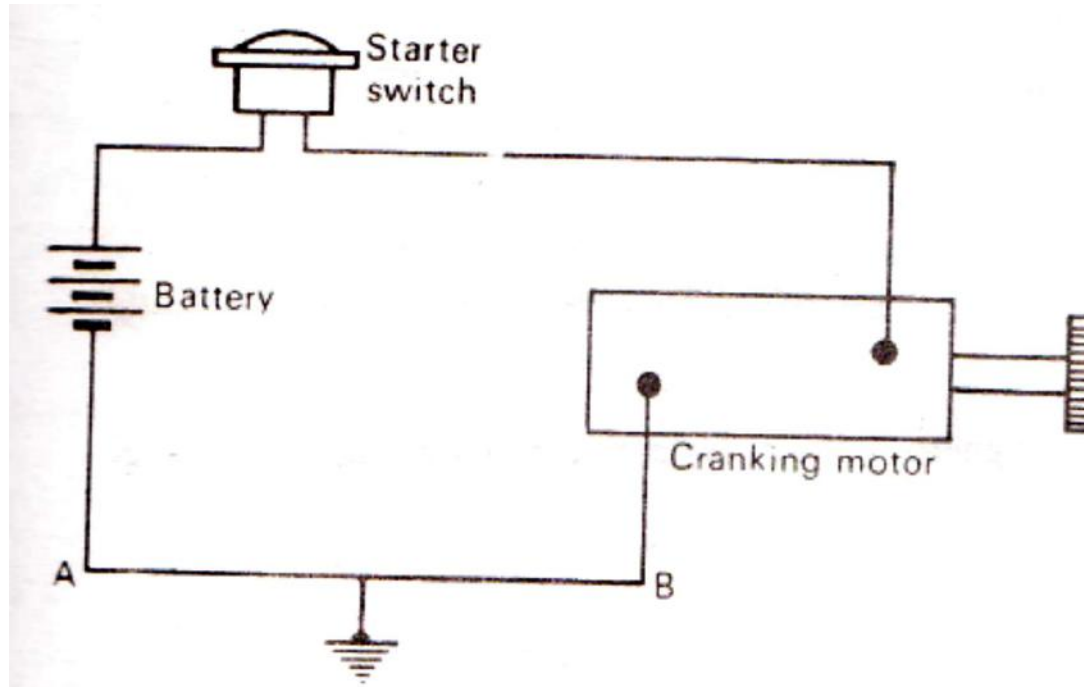


Fig. 2.5 A simple schematic layout of the lighting and accessories systems.

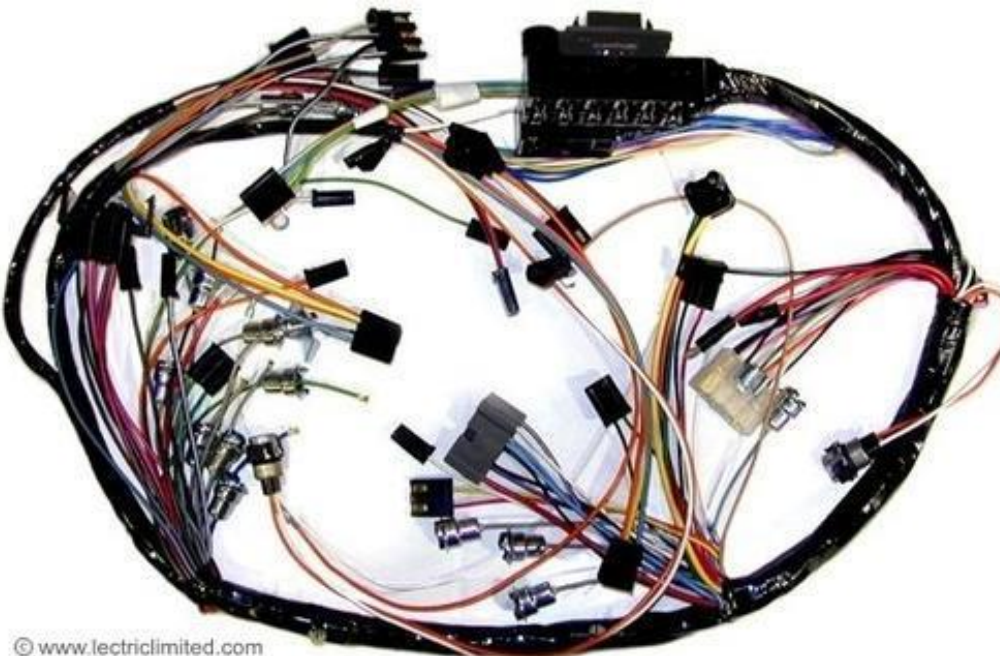
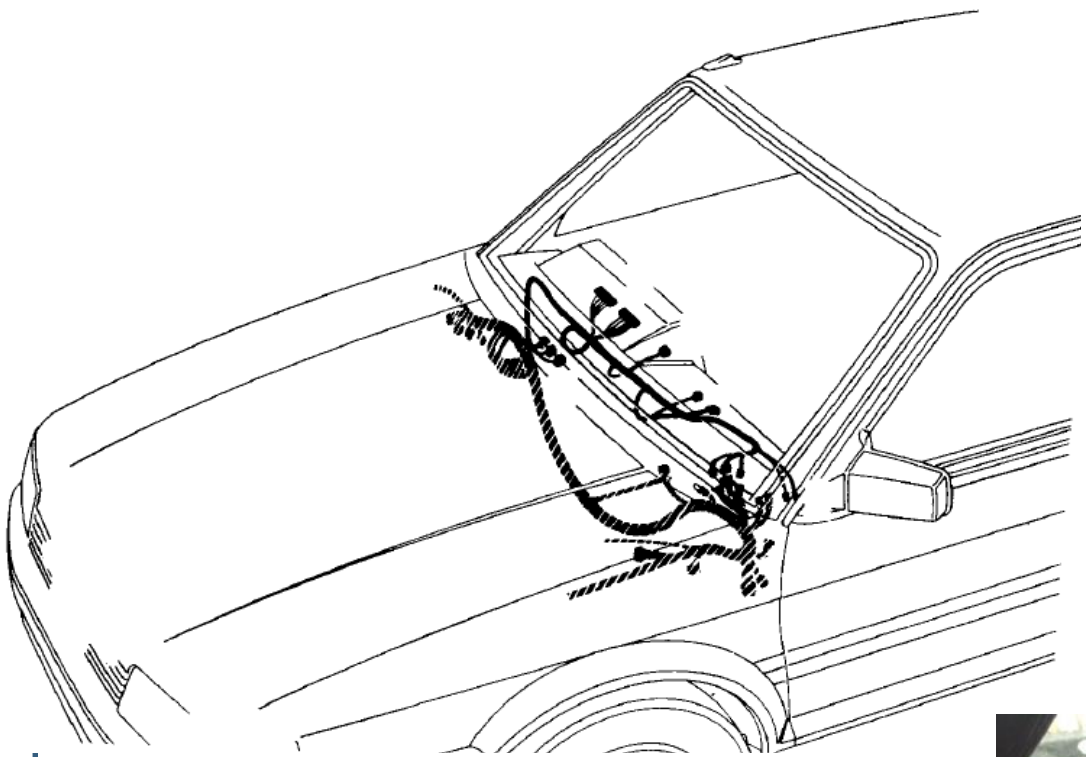
Earth Return & Insulated Return System





❖ **Wiring Harness:**

- The vehicle wiring harness has developed over the years from a loom containing just a few wires, to the looms used at present on top range vehicles containing well over 1000 separate wires.
- Modern vehicles tend to have wiring harnesses constructed in a number of ways. The most popular is still for the bundle of cables to be spirally wrapped in non-adhesive PVC tape. The tape is non-adhesive so as to allow the bundle of wires to retain some flexibility, as shown in Figure
- Another way of grouping cables, as shown in Figure is to place them inside PVC tubes





- When deciding on the layout of a wiring loom within the vehicle, many issues must be considered. Some of these are as follows.
 1. Cable runs must be as short as possible.
 2. The loom must be protected against physical damage.
 3. The number of connections should be kept to a minimum.
 4. Modular design may be appropriate.
 5. Accident damage areas to be considered.
 6. Production line techniques should be considered.
 7. Access must be possible to main components and sub-assemblies for repair purposes.

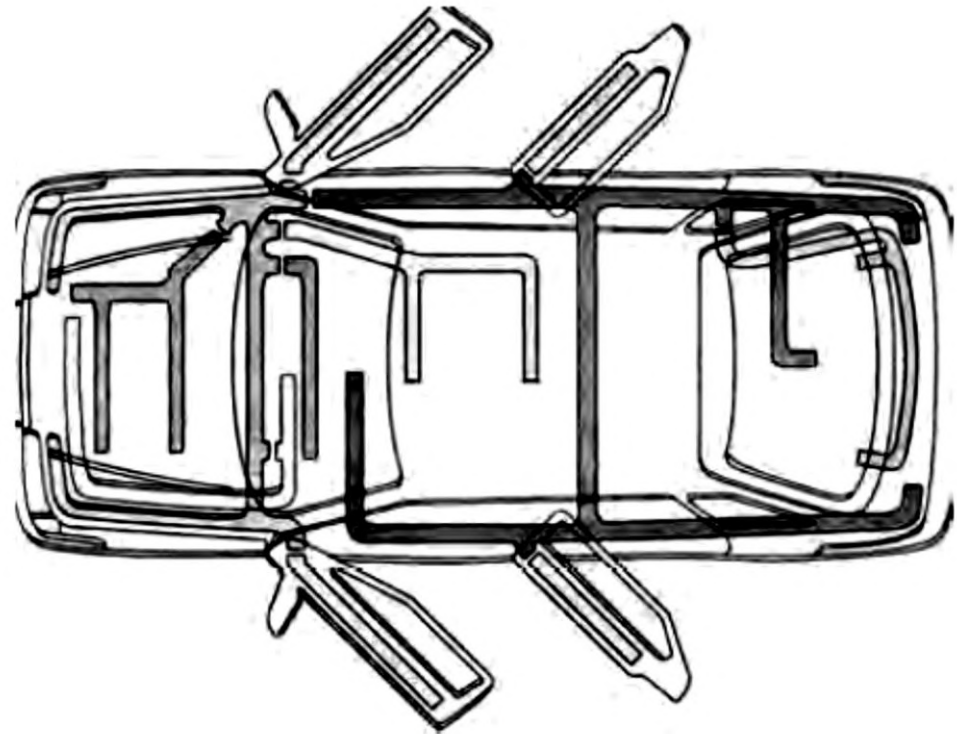
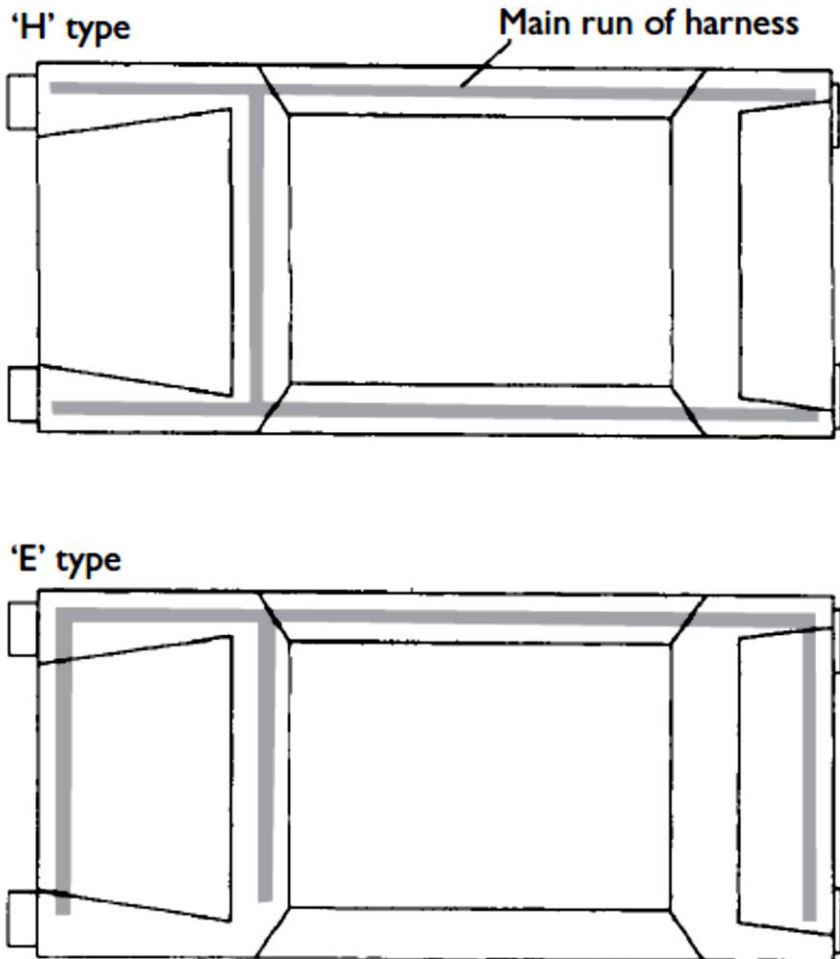


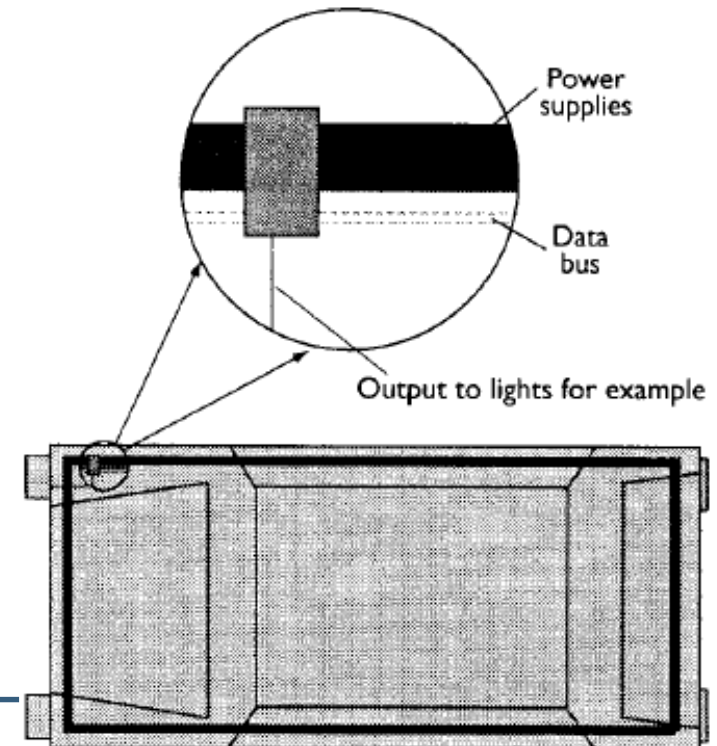
Figure 4.10 Typical wiring harness layout

Figure 4.9 'H' and 'E' wiring layouts



- **Multiplexed Wiring System:**
- The complexity of modern wiring systems has been increasing steadily over the last 25 years or so and, in recent years, has increased dramatically.
- It has now reached a point where the size and weight of the wiring harness is a major problem. The number of separate wires required on a top-of-the-range vehicle can be in the region of 1500!
- The wiring loom required to control all functions in or from the driver's door can require up to 50 wires, the Systems in the dashboard area alone can use over 100 wires and connections.
- This is clearly becoming a problem as, apart from the obvious issues of size and weight, the number of connections and the number of wires increase the possibility of faults developing.

- It has been estimated that the complexity of the vehicle wiring system doubles every 10 years.
- The number of systems controlled by electronics is continually increasing.
- Some examples of these systems are listed below:
 - Engine management.
 - Anti-lock brakes.
 - Traction control.
 - Variable valve timing.
 - Transmission control.
 - Active suspension.
 - Communications.
 - Multimedia.





- All the systems listed above work in their own right but are also linked to each other. Many of the sensors that provide inputs to one electronic control unit are common to all or some of the others.
- One solution to this is to use one computer to control all systems. This, however, would be very expensive to produce in small numbers. A second solution is to use a common data bus.
- This would allow communication between modules and would make the information from the various vehicle sensors available to all sensors.
- Taking this idea a stage further, if data could be transmitted along one wire and made available to all parts of the vehicle, then the vehicle wiring could be reduced to just three wires.



- These wires would be a **mains supply, an earth connection and a signal wire**. The idea of using just one line for many signals is not new and has been in use in areas such as telecommunications for many years.
- Various signals can be ‘multiplexed’ on to one wire in two main ways – frequency division and time division multiplexing.
- Frequency division is similar to the way radio signals are transmitted. It is oversimplifying a complex subject, but a form of time division multiplexing is generally used for transmission of digital signals.
- A ring main or multiplexed wiring system is represented in Figure above. This shows that the data bus and the power supply cables must ‘visit’ all areas of the vehicle electrical system.



- To illustrate the operation of this system, consider the events involved in switching the sidelights on and off.
- First, in response to the driver pressing the light switch, a unique signal is placed on the data bus.
- This signal is only recognized by special receivers built as part of each light unit assembly, and these in turn will make a connection between the power ring main and the lights.
- The events are similar to turn off the lights, except that the code placed on the data bus will be different and will be recognized only by the appropriate receivers as an off code.



4.3.2 Multiplex data bus

- In order to transmit different data on one line, a number of criteria must be carefully defined and agreed. This is known as the communications protocol.
- Some of the variables that must be defined are as follows:
 - Method of addressing.
 - Transmission sequence.
 - Control signals.
 - Error detection.
 - Error treatment.
 - Speed or rate of transmission.



- The physical layer must also be defined and agreed. This includes the following:
 - Transmission medium, e.g. copper wire, fibre optics etc.
 - Type of transmission coding, e.g. analogue or digital.
 - Type of signals, e.g. voltage, current or frequency etc.
- The circuit to meet these criteria is known as the bus interface and will often take the form of a single integrated circuit.
- This IC will, in some cases, have extra circuitry in the form of memory for example. It may, however, be appropriate for this chip to be as cheap as possible due to the large numbers required on a vehicle.
- As is general with any protocol system, it is hoped that one only will be used. This, however, is not always the case.

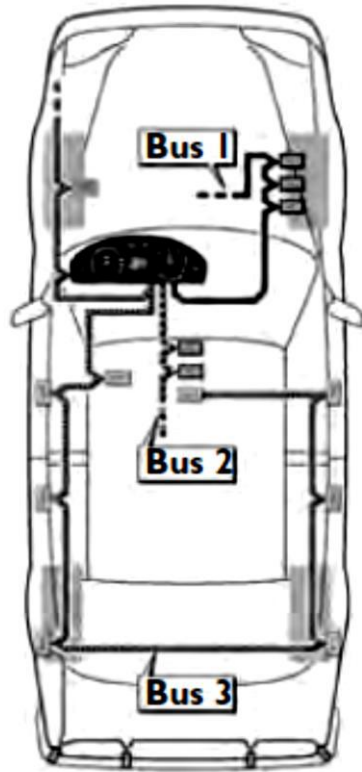


❖ **Controller Area Network**

- Bosch has developed the protocol known as 'CAN' or Controller Area Network. This system is claimed to meet practically all requirements with a very small chip surface (easy to manufacture, therefore cheaper).
- CAN is suitable for transmitting data in the area of drive line components, chassis components and mobile communications. It is a compact system, which will make it practical for use in many areas.
- Two variations on the physical layer are available that suit different transmission rates. One is for data transmission of between 100 K and 1 M baud (bits per second), to be used for rapid control devices.
- The other will transmit between 10 K and 100 K baud as a low-speed bus for simple switching and control operations.

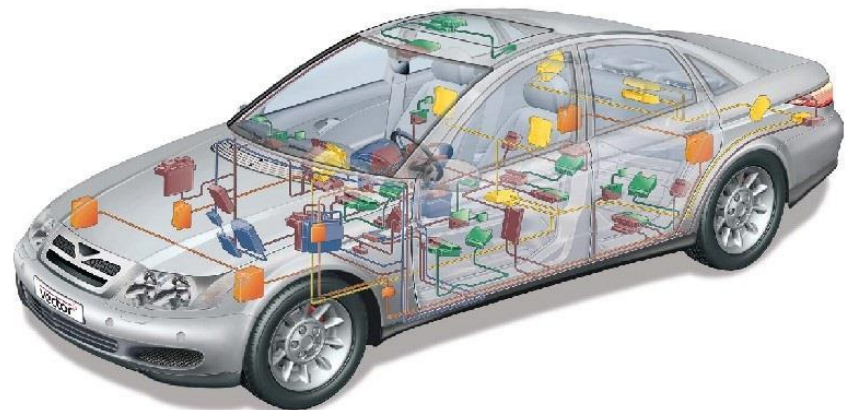


- CAN modules are manufactured by a number of semiconductor firms such as **Intel and Motorola**.
- A range of modules is available in either Voll- CAN for fast buses and basic-CAN for lower data rates. These are available in a stand-alone format or integrated into various microprocessors.
- All modules have the same CAN protocol. It is expected that this protocol will become standardized by the International Standards Organization (ISO).

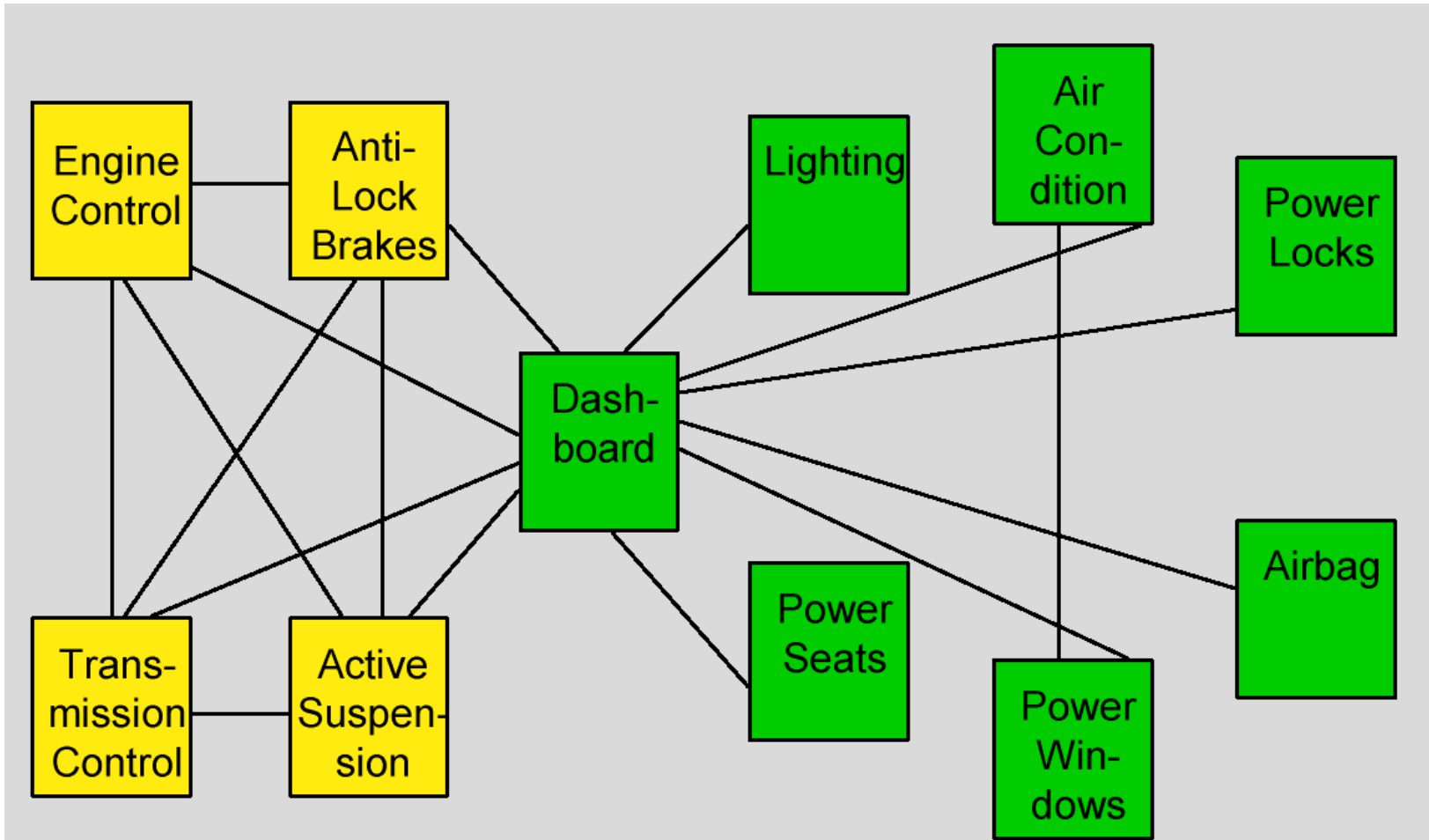


- **Bus 1 Drive train bus**
e.g. Motronic
ABS/ASR/ESP
Transmission control
- - - **Bus 2 Multimedia bus**
e.g. Main display unit
Radio
Travelpilot
- **Bus 3 Body bus**
e.g. Parkpilot
Body computer
Door control units

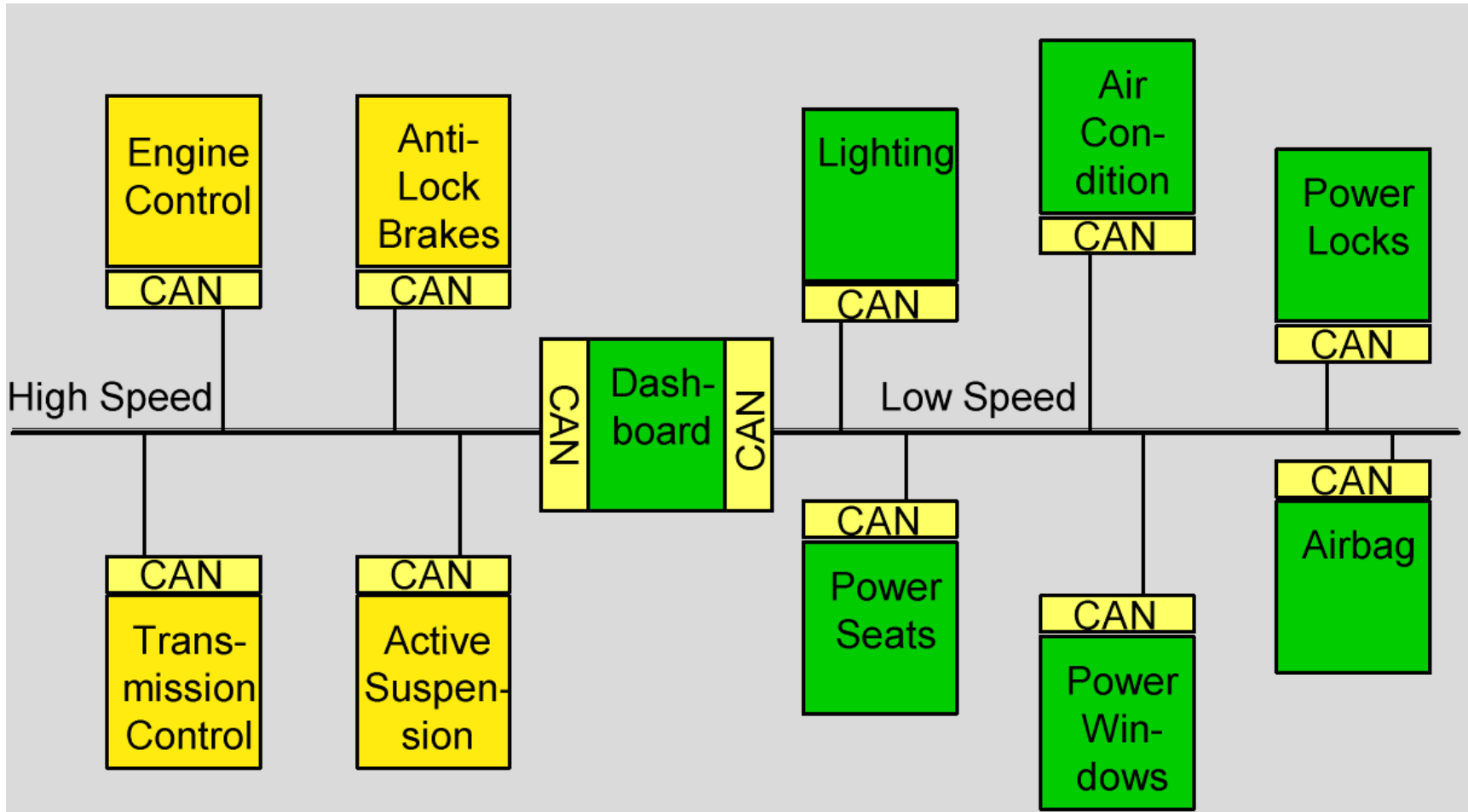
Figure 4.21 CAN (Controller Area Network) instrument cluster (Source: Bosch Press)

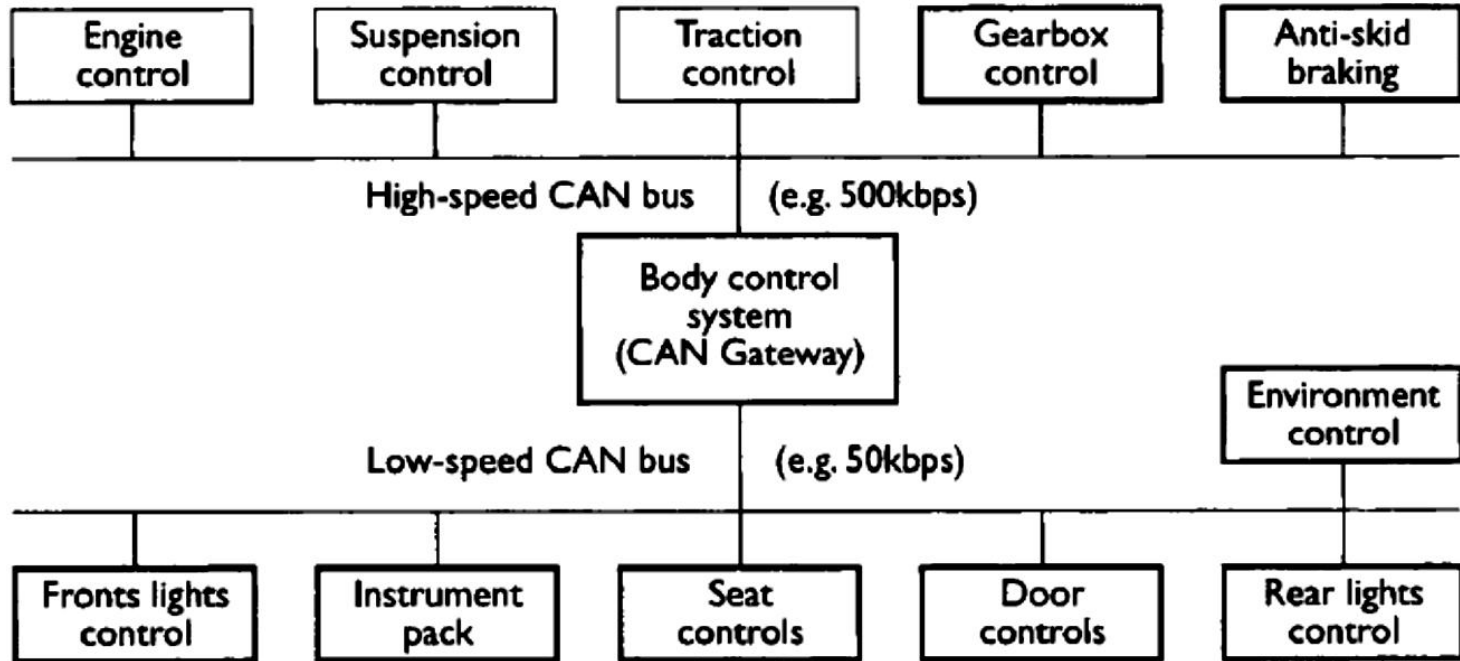


❖ Before CAN

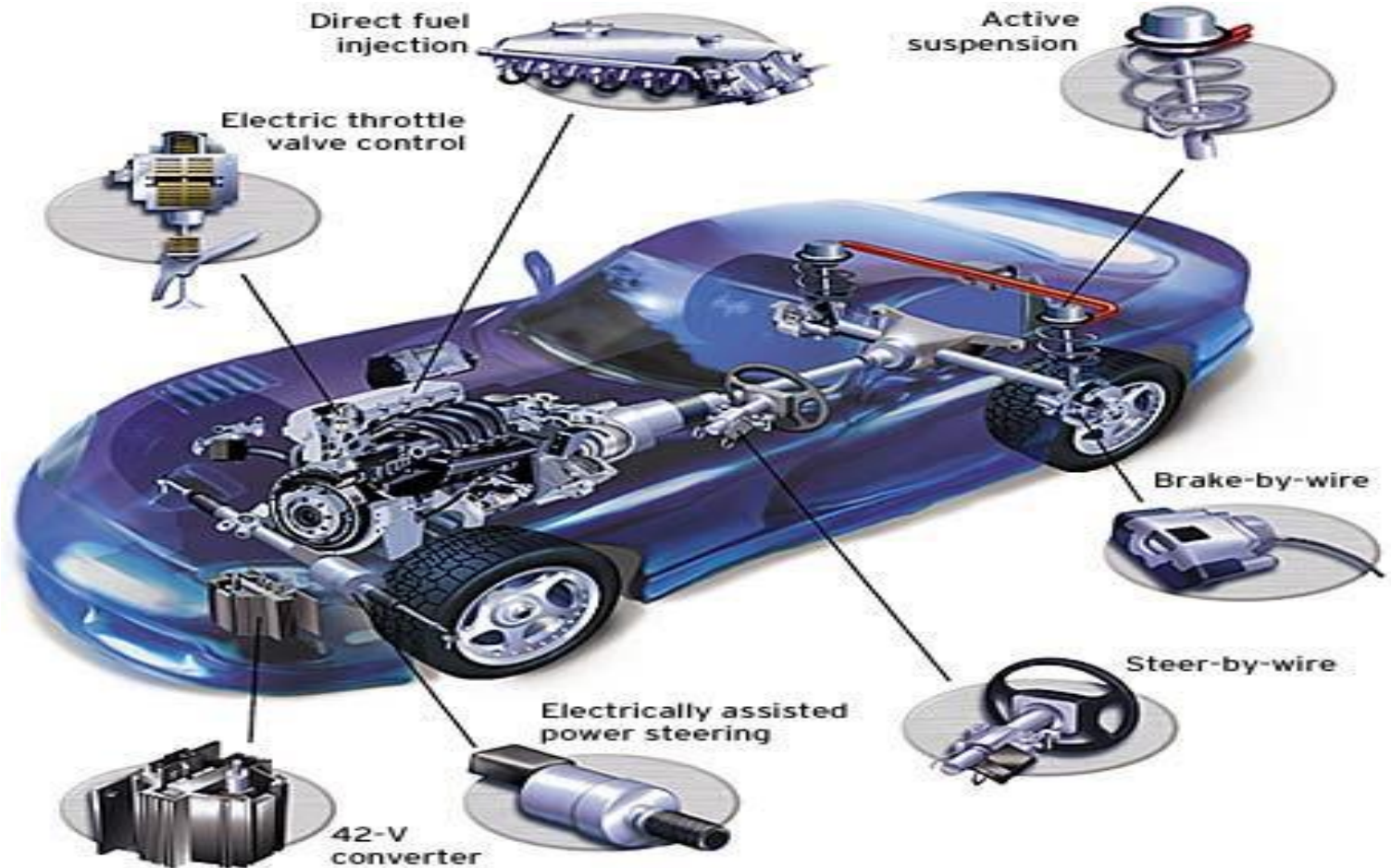


❖ After CAN





Applications:

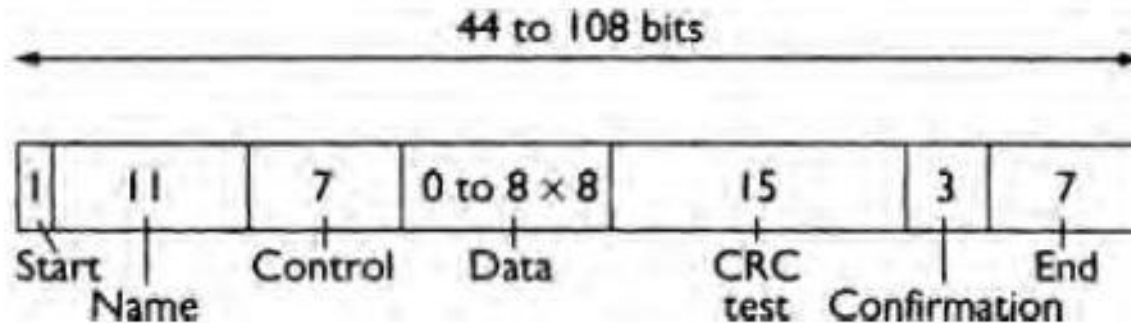




❖ Applications:

- Automotive
- Military vehicles
- Industrial machinery
- Medical systems
- Agricultural machinery
- Marine control and navigation
- Elevator control systems

Data Information Format



- The CAN message signal consists of a sequence of binary digits (bits).
- A voltage (or light in fiber optics) being present indicates the value '1' while none present indicates '0'.
- The actual message can vary between 44 and 108 bits in length.



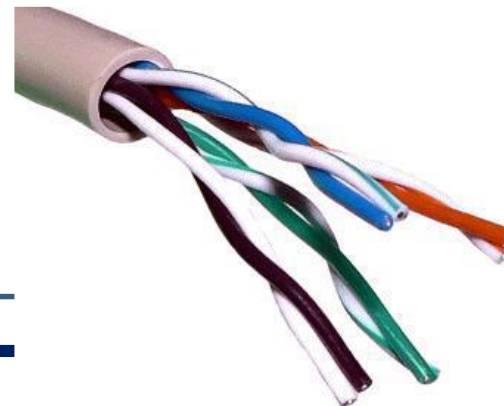
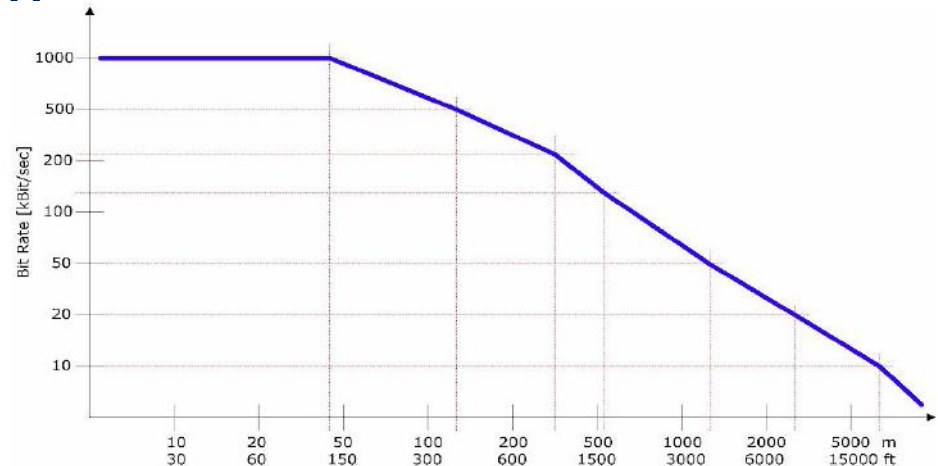
- This is made up of a start bit, name, control bits, the data itself, a cyclic redundancy check (CRC) for error detection, a confirmation signal and finally a number of stop bits
- The name portion of the signal identifies the message destination and also its priority.
- As the transmitter puts a message on the bus it also reads the name back from the bus.
- If the name is not the same as the one it sent then another transmitter must be in operation that has a higher priority.



- If this is the case it will stop transmission of its own message. This is very important in the case of motor vehicle data transmission.
- Errors in a message are recognized by the cyclic redundancy check.
- This is achieved by assembling all the numbers in a message into a complex algorithm and this number is also sent.
- The receiver uses the same algorithm and checks that the two numbers tally.
- If an error is recognized the message on the bus is destroyed.
- This is recognized by the transmitter, which then sends the message again.
- This technique, when combined with additional tests, makes it possible for no faulty messages to be transmitted without being discovered.

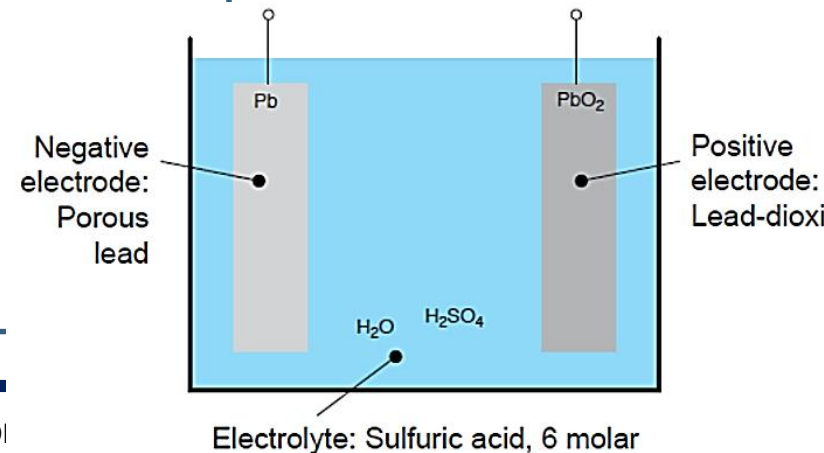
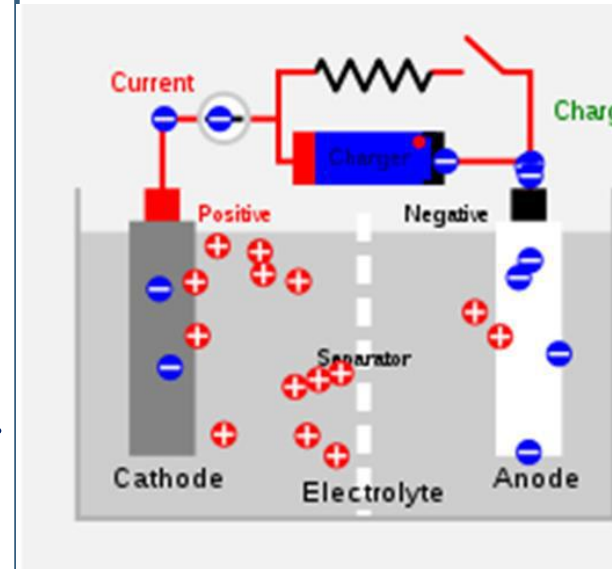
- Twisted Pair Cables are used to get higher speeds.
- The Bit rate of the data transformation is high for short distance and low for long distance.

Bus length in meters	Signal rate in Mbps
40	1
100	0.5
500	0.10
1000	0.05



❖ Battery:-

- An electro-chemical apparatus used for accumulating charge for use at later stage and that's why it also called as “charge accumulator”
- Stores electrical energy in the form of chemical energy and then converts this chemical energy to electrical energy when needed: essentially an electrical energy storage device
- Contains
 - Electrodes (Cathode and Anode)
 - Electrolyte





❖ Requirements:

- To provide power storage and be able to supply it quickly enough to operate the vehicle starter motor.
- To allow the use of parking lights for a reasonable time.
- To allow operation of accessories when the engine is not running.
- To act as a swamp to damp out fluctuations of system voltage.
- To allow dynamic memory and alarm systems to remain active when the vehicle is left for a period of time.
- The final requirement of the vehicle battery is that it must be able to carry out all the above listed functions over a wide temperature range. This can be in the region of -30 to 70°C .

❖ Battery Selection:

- The correct battery depends, in the main, on just two conditions.
 1. The ability to power the starter to enable minimum starting speed under very cold conditions.
 2. The expected use of the battery for running accessories when the engine is not running.
- European standards generally use the figure of -18°C as the cold start limit and a battery to meet this requirement is selected.

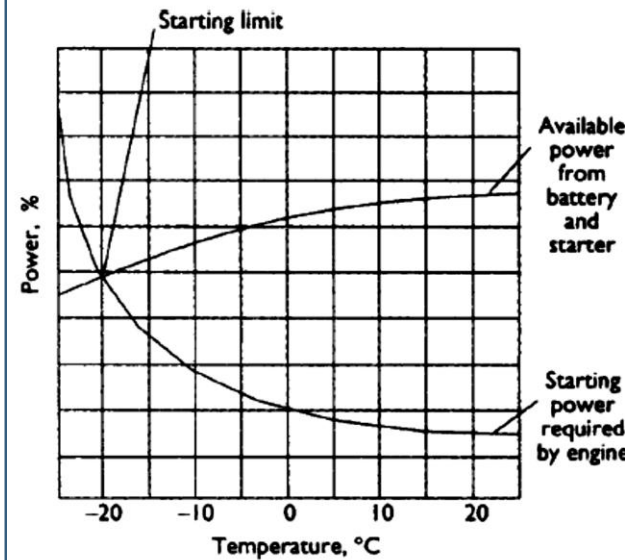


Figure 5.1 Comparison of the power required by the starter and the power available from the battery plotted against temperature



- Research has shown that under ‘normal’ cold operating conditions in the UK, most vehicle batteries are on average only 80% charged.
- Many manufacturers choose a battery for a vehicle that will supply the required cold cranking current when in the 80% charged condition at -7°C .



❖ Positioning The Battery in Vehicle

- Several basic points should be considered when choosing the location for the vehicle battery:
 - Weight distribution of vehicle components.
 - Proximity to the starter to reduce cable length.
 - Accessibility.
 - Protection against contamination.
 - Ambient temperature.
 - Vibration protection.
- As usual, these issues will vary with the type of vehicle, intended use, average operating temperature and so on.
- Extreme temperature conditions may require either a battery heater or a cooling fan. The potential build-up of gases from the battery may also be a consideration.



❖ **Battery Types:**

1. Primary Battery (Disposable Batteries) capable of converting chemical energy into electrical energy and in this process gets exhausted. The chemical reaction is irreversible.

- Examples:- Zinc carbon (flashlights, toys), Heavy duty zinc chloride (radios, recorders), Alkaline (all of the above), Lithium (photoflash), Silver, mercury oxide (hearing aid, watches), Zinc air.

2. Secondary Battery (Rechargeable Batteries): Also called storage cells. Convert chemical energy into electrical energy or vice versa by reactions that are essentially reversible

- Examples:- Nickel cadmium, Nickel metal hydride, Alkaline, Lithium ion, Lithium ion polymer, Lead acid.



Primary Battery	Secondary Battery
Cell reaction is irreversible	Cell reaction is reversible.
Must be discarded after use	May be recharged
Have relatively short shelf life	Have long shelf life
Function only as galvanic cells .	Functions both galvanic Cell & as electrolytic cell.
They cannot be used as storage devices	They can be used as energy storage devices(e.g. solar/thermal energy converted to electrical energy)
They cannot be recharged	They can be recharged
Dry cell.	Lead acid



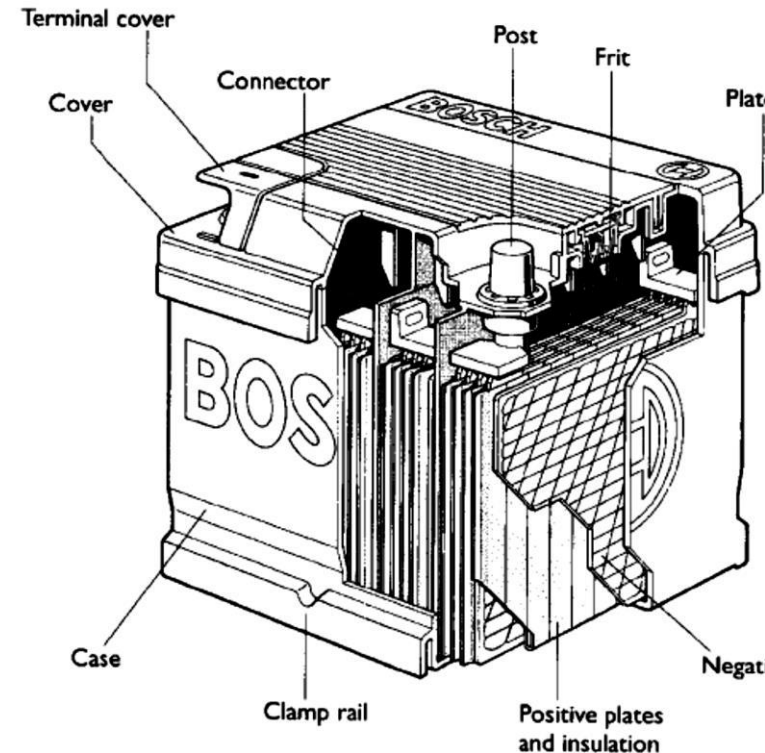
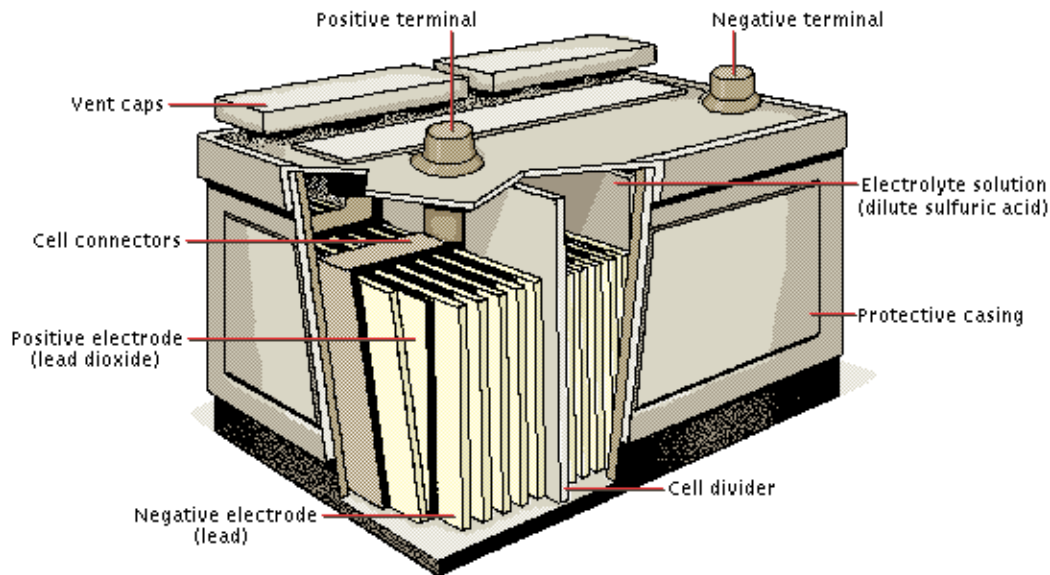
❖ Working Principle:(Lead Acid Battery)

- The storage battery or secondary battery is such battery where electrical energy can be stored as chemical energy and this chemical energy is then converted to electrical energy as when required.
- The conversion of electrical energy into chemical energy by applying external electrical source is known **as charging of battery.**
- Whereas conversion of chemical energy into electrical energy for supplying the external load is known **as discharging of secondary battery.**
- During charging of battery, current is passed through it which causes some chemical changes inside the battery. This chemical changes absorb energy during their formation.
- When the battery is connected to the external load, the chemical changes take place in reverse direction, during which the absorbed energy is released as electrical energy and supplied to the load.



❑ Materials used for Lead Acid Storage Battery Cells

- The main active materials required to construct a lead-acid battery are
 1. Lead peroxide (PbO_2).
 2. Sponge lead (Pb) and
 3. Dilute sulfuric acid (H_2SO_4).





Lead Peroxide (PbO_2)

- The positive plate is made of lead peroxide. This is dark brown, hard and brittle substance.

Sponge Lead (Pb)

- The negative plate is made of pure lead in soft sponge condition.

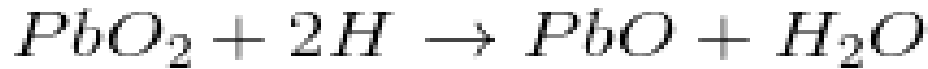
Dilute Sulfuric Acid (H_2SO_4)

- Dilute sulfuric acid used for lead acid battery has ratio of water : acid = 3:1. (65% water and 35% H_2SO_4)
- The lead acid storage battery is formed by dipping lead peroxide plate and sponge lead plate in dilute sulfuric acid.



❖ Discharging:-

- Consider a battery is in fully charged condition and a load is connected externally between these plates.
- In diluted sulfuric acid the molecules of the acid split into positive hydrogen ions (H^+) and negative sulfate ions (SO_4^{--}).
- The hydrogen ions when reach at PbO_2 plate (positive plate), they receive electrons from it and become hydrogen atom which again attack PbO_2 and form PbO and H_2O (water).
- This PbO reacts with H_2SO_4 and forms $PbSO_4$ and H_2O (water).



- SO_4^{--} ions are moving freely in the solution so some of them will reach to pure Pb plate where they give their extra electrons and become radical SO_4 . As the radical SO_4 cannot exist alone it will attack Pb and will form $PbSO_4$.
- As H^+ ions take electrons from PbO_2 plate and SO_4^{--} ions give electrons to Pb plate, there would be an inequality of electrons between these two plates. Hence there would be a flow of current through the external load between these plates for balancing this inequality of electrons. This process is called **discharging of lead acid battery**.



- The lead sulfate (PbSO_4) is whitish in color.
- During discharging,
 1. Both of the plates are covered with PbSO_4 .
 2. Specific gravity of sulfuric acid solution falls due to formation of water during reaction at PbO_2 plate.
 3. As a result, the rate of reaction falls which implies the potential difference between the plates decreases during discharging process.



❖ Charging:

- Now we will disconnect the load and connect PbSO₄ covered PbO₂ plate with positive terminal of an external DC source and PbSO₄ covered Pb plate with negative terminal of that DC source.
- During discharging, the density of sulfuric acid falls but there still sulfuric acid exists in the solution.
- This sulfuric acid also remains as H⁺ and SO₄^{- -} ions in the solution.
- Hydrogen ions being positively charged, move to the electrode (cathode) connected with negative terminal of the DC source.



- Here each H⁺ ion takes one electron from that and becomes hydrogen atom. These hydrogen atoms then attack PbSO₄ and form lead and sulfuric acid.



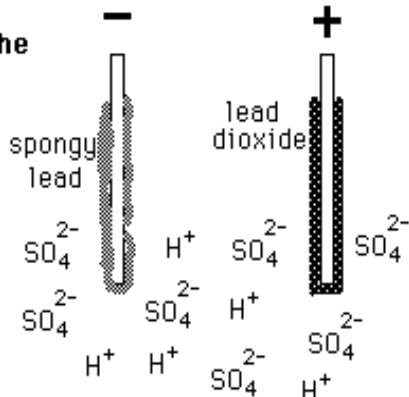
- SO₄ ^{- -} ions (anions) move towards the electrode (anode) connected with positive terminal of DC source where they will give up their extra electrons and become radical SO₄.
- This radical SO₄ cannot exist alone hence reacts with PbSO₄ of anode and forms lead peroxide (PbO₂) and sulfuric acid (H₂SO₄).





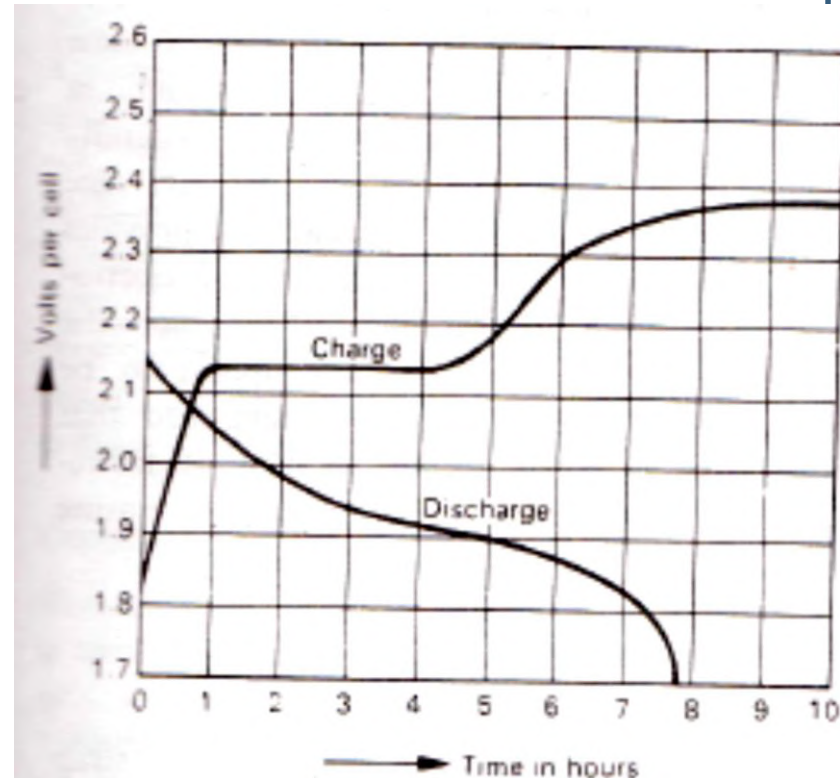
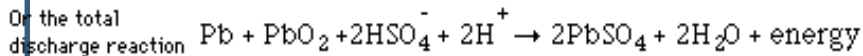
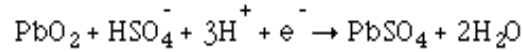
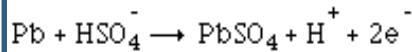
- Hence by charging the lead acid storage battery cell,
 1. Lead sulfate anode gets converted into lead peroxide.
 2. Lead sulfate of cathode is converted to pure lead.
 3. Terminal; potential of the cell increases.
 4. Specific gravity of sulfuric acid increases.

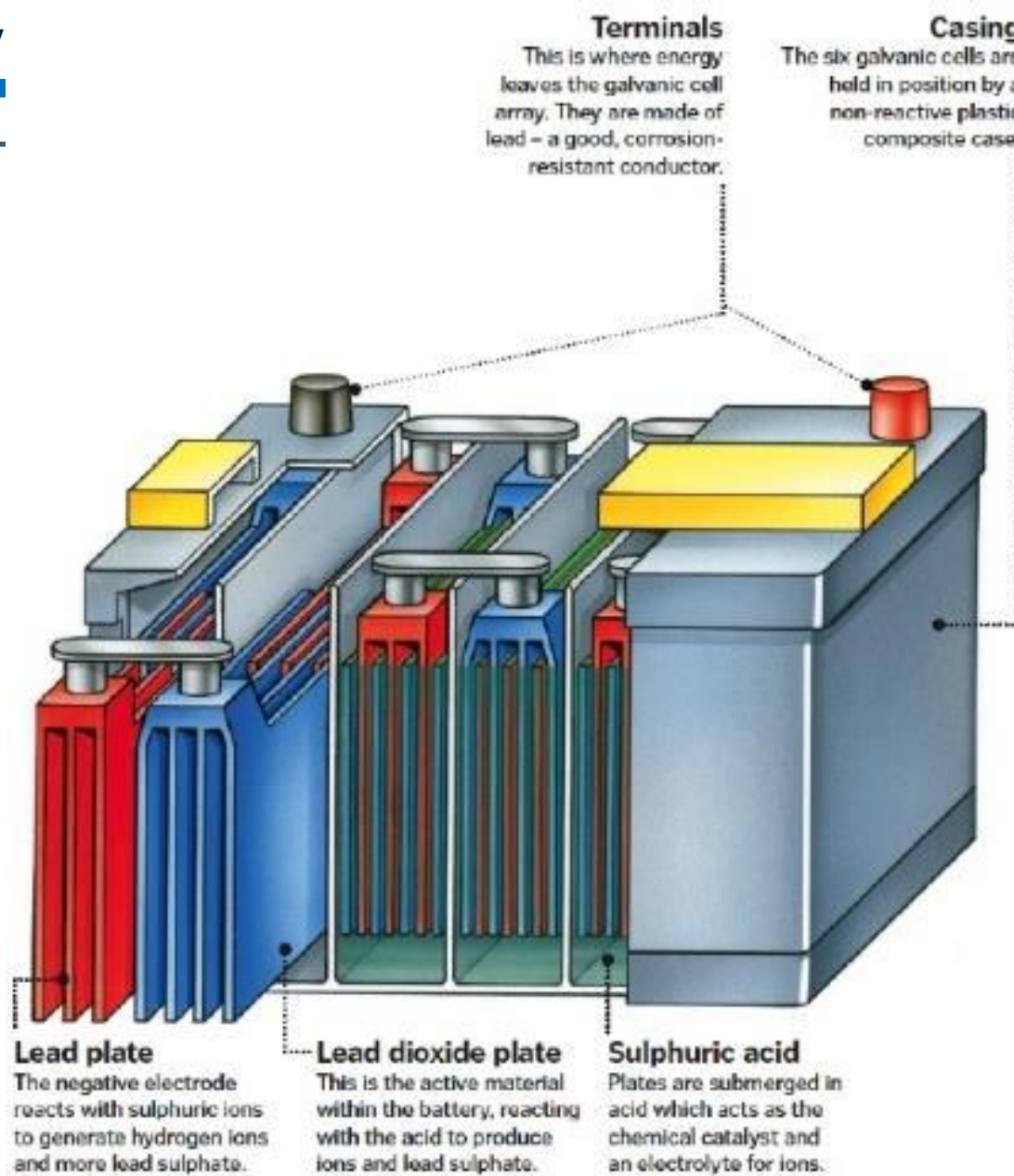
The chemistry of the production of a voltage by a lead-acid battery

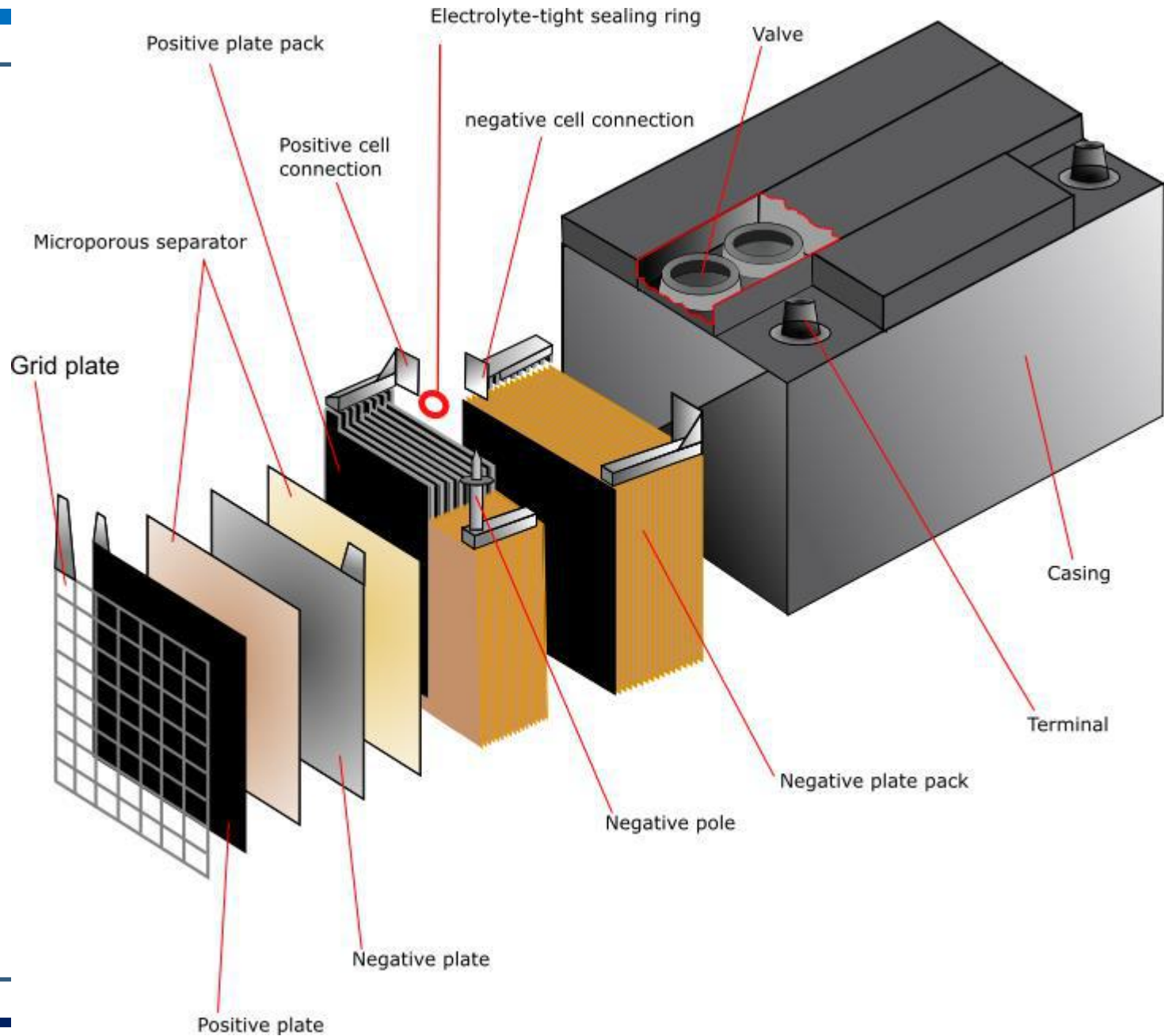


$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$
 Lead electrode must supply positive ions and is left negative

$PbO_2 + H_2SO_4 \rightarrow PbSO_4$
 Lead dioxide electrode must supply electrons and is left positive



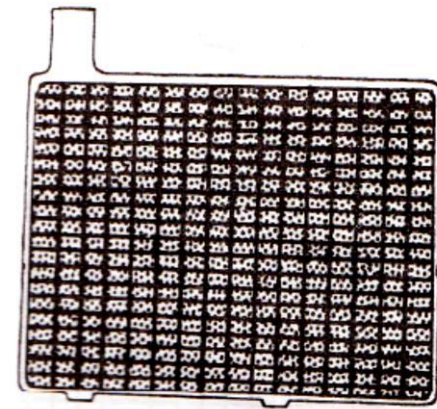
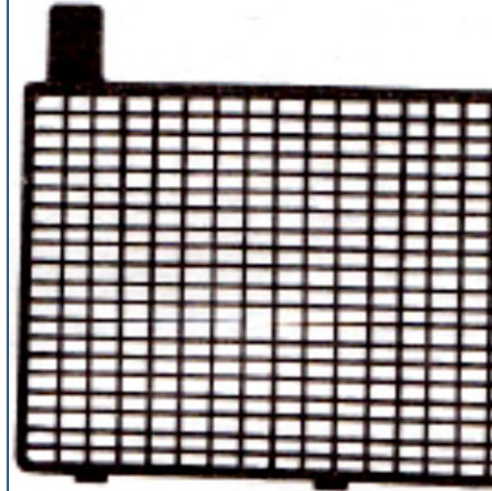




❖ Construction:

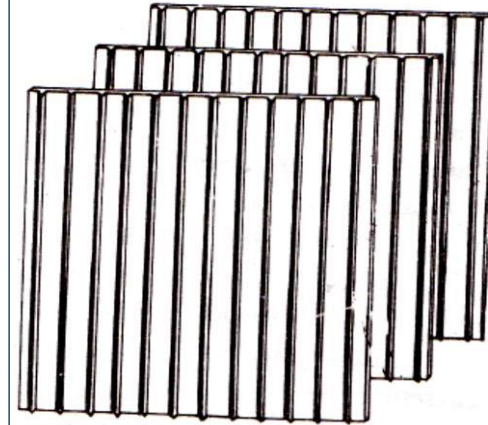
1. Plates:

- Rectangular lattice like grid shape made by **lead-antimony alloy**.
- The active material is held in place by horizontal and vertical bars.
- They further serve to distribute current evenly over the plate.
- Should provide the large surface area to electrolyte
- Should be in close contact with active material for better conductivity.
- Should withstand bumps and vibration



2. Separators:

- A small clearance/gap is kept between positive and negative plates.
- In order to prevent the positive and negative plate from actually touching separators are employed in between these plates.
- May be of micro-porous rubber, non-conducting ebonite, glass-mat or micro-porous PVC.
- May be in ribbed shape or simply flat.
- Should have long life
- Should not provide resistance to flow of electrolyte.

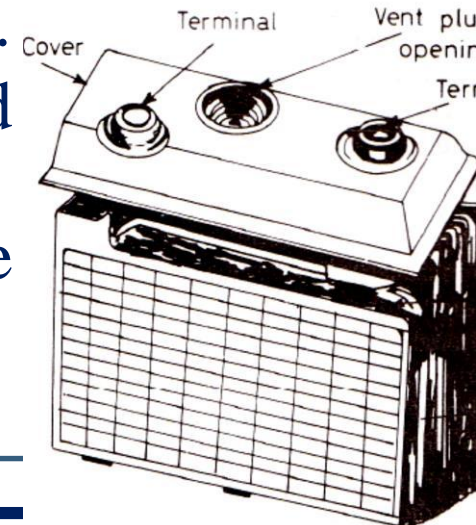
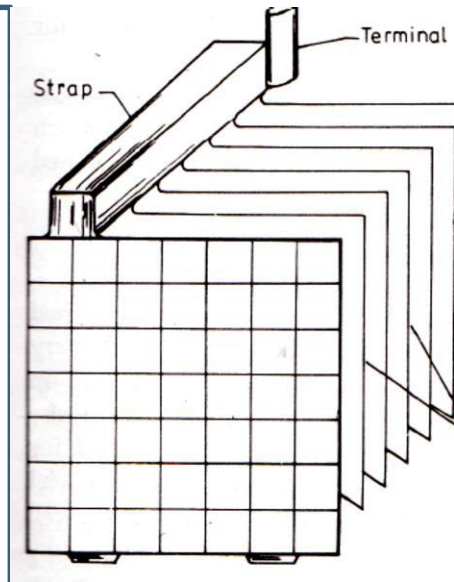


3. Group:

- The plates are welded to **lead antimony strap** for forming the battery plate group
- The strap is provided with round terminal post protruding through the cell cover hole.

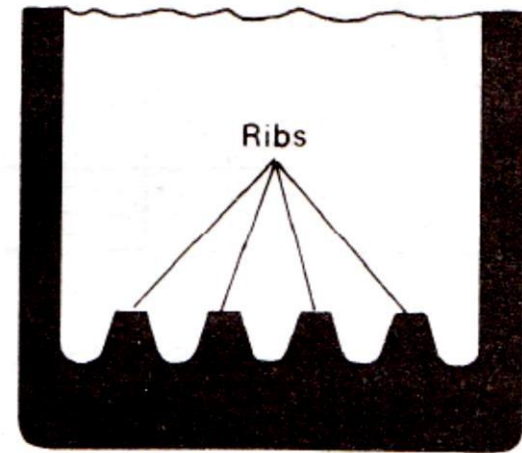
4. Element:

- The battery element consists of two groups of plates- positive and negative assembled together.
- Generally one -ve plate is more than +ve plates.
- For eg. 19 plates element will have 10 -ve and 9 +ve plates.
- Because of more chemical activity at +ve plate area it is essential to have lesser +ve plates.



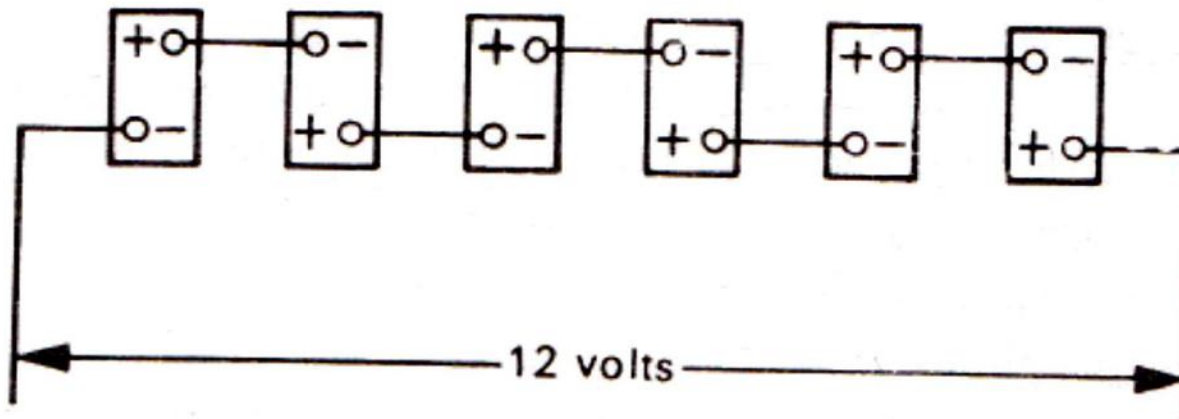
5. Container:

- The battery elements are placed in hard rubber, leak proof container with 6 compartments
- The plates rest on ribs formed at bottom of container, the space below and between ribs is meant for storing the sediments formed in normal battery action.
- Short circuiting is also avoided by this arrangement.



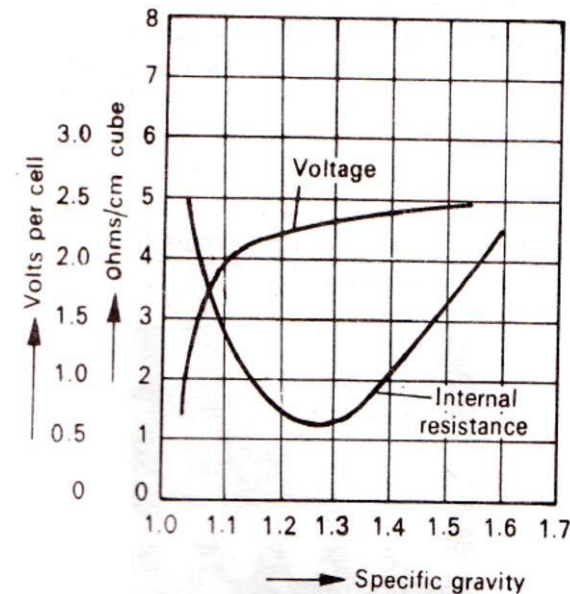
6. Cell Connectors:

- The lead bar cell connectors are attached to the cell terminals.
- The individual battery cells are connected in series, thus adding up their voltages.
- Heavy coating of sealing is used to protect them from leakage of current.



❖ Electrolyte:

- Electrolyte is made by diluting sulfuric acid with water.
- The electrolyte used in automobiles battery is of higher density because of two main reason.
 - The volume of electrolyte is limited keeping in view of the size and weight of battery.
 - Automobile batteries are frequently required to give heavy discharge currents due to starting motors.





Advantages:

- Batteries of all shapes and sizes, available in
- Maintenance-free products and mass-produced
- Best value for power and energy per kilowatt-hour
- Have the longest life cycle and a large environmental advantage
- Ninety-seven percent of the lead is recycled and reused in new batteries

Disadvantages:

- Lead is heavier compared to alternative elements
- Certain efficiencies in current conductors and other advances continue to improve on the power density of a lead-acid battery's design



❖ **Battery Ratings:**

- In simple terms, the characteristics or rating of a particular battery are determined by **how much current it can produce and how long it can sustain this current.**
- The rate at which a battery can produce current is determined by the speed of the chemical reaction. This in turn is determined by a number of factors:
 - **Surface area of the plates.**
 - **Temperature.**
 - **Electrolyte strength.**
 - **Current demanded.**
- The actual current supplied therefore determines the overall capacity of a battery. The rating of a battery has to specify the current output and the time.



❖ Ampere hour capacity (20 H Rate)

- This is now occasionally used but describes how much current the battery is able to supply for either 10 or 20 hours. The 20-hour figure is the most common.
- For example, a battery quoted as being 44Ah (ampere-hour) will be able, if fully charged, to supply 2.2 A for 20 hours before being completely discharged (cell voltage above 1.75 V & temperature 27°C).



❖ Reserve capacity (25 A)

- A rating system used now on all new batteries is reserve capacity. This is quoted as a time in minutes for which the battery will supply 25 A at 27° C to a final voltage of 1.75 V per cell.
- This is used to give an indication of how long the battery could run the car if the charging system was not working.
- Typically, a 44 Ah battery will have a reserve capacity of about 60 minutes.



❖ Cold Cranking Rate:

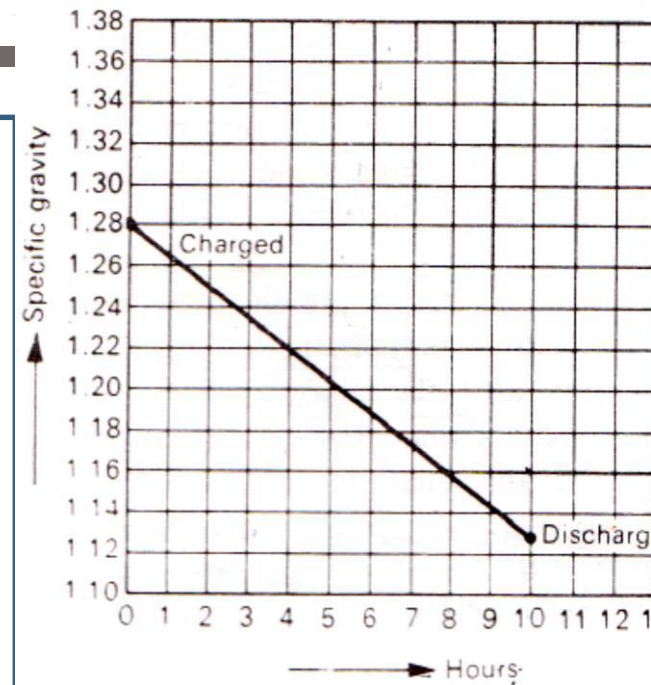
- Batteries are given a rating to indicate performance at high current output and at low temperature.
- A typical value of 170 A means that the battery will supply this current for one minute at a temperature of -18°C , at which point the cell voltage will fall to 1.4 V (BS – British Standards).
- A 100 Ah battery with 20h rate may be in position to deliver 300 A for a period of 3.6 min at -18°C .

❖ 4h rate:

- Used in case of heavy vehicles like buses and trucks.
- It represents Ah rating of a battery discharged in 4h.

❖ Battery Performance:

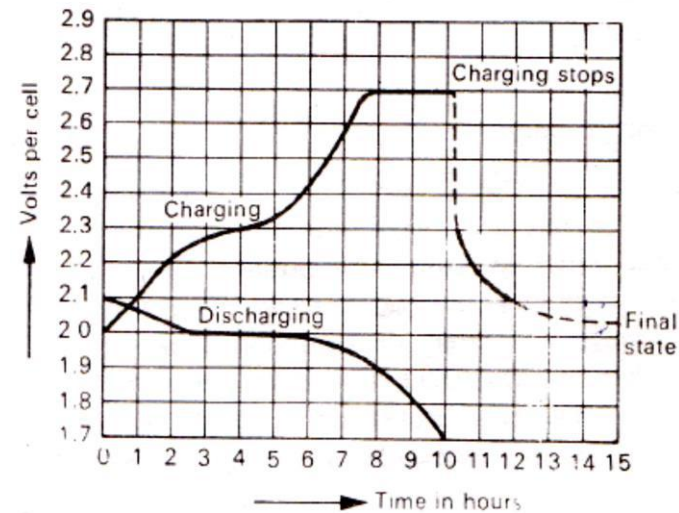
- Fig. shows the changes in the sp. Gravity of electrolyte when the cell is being discharged over the period of 10 hours.
- The graph characteristic depends upon the rate of discharge and permissible final sp. Gravity of electrolyte.
- Sp. Gravity in charged condition is about 1.28 has been discharged over 10h to 1.125.
- A battery should not be discharged fully and then left over for long period because **insoluble lead sulfate** is formed which might cause distortion of plates.



(a)

Sl. No.	Approximate sp. gravity	State of charge of battery
1.	1.260-1.280	Fully charged
2.	1.230-1.260	3/4 charged
3.	1.200-1.230	Half charged
4.	1.170-1.200	1/4 charged
5.	1.140-1.170	About run down
6.	1.110-1.140	Discharged

- From a fig. it can be seen that, when a cell is being charged, its voltage rises continuously for a period of six hours.
- After that there is rapid increase in the cell voltage and it attains the max. voltage of 2.70 V after about 10hrs.
- As the charging current is switched off the cell voltage falls rapidly to about 2.20 V and then finally settles about 2.05 V.



❖ Battery Discharge Rate:

- The effect of battery discharge rate on the capacity of the battery and also the terminal voltage per cell at discharge period (for 50 Ah battery based on 20h rating) can be seen from the figure.
- It can be seen that for 10h rating gives 85% of the 20h rating
- In case of 4h rate discharge the battery capacity drops to about 70% of the 20h rating

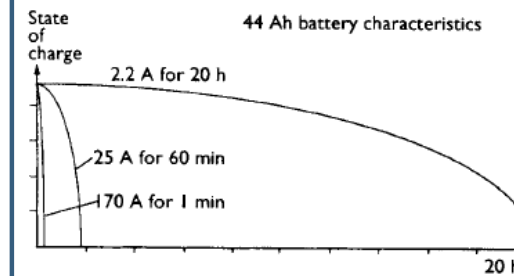
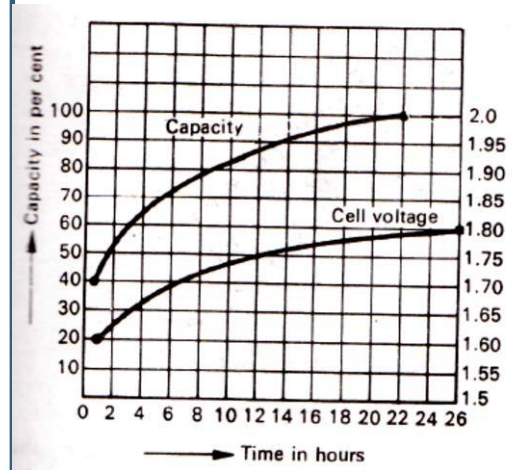


Figure 5.3 Battery discharge characteristics compared



❖ **Battery Capacity:**

- In case of cars having 1000 cc engine the batteries used are 40Ah at 20 h rating.
- For 1500-2000 cc engine cars, 43 to 50Ah and cars with engine upto 3000cc use 50 to 70 Ah batteries at 20h ratings.
- American cars having 300 bhp, 400 bhp use 70 to 75 Ah batteries.
- For 200 to less than 300 bhp use 45 to 55 Ah batteries.
- In commercial vehicles, batteries of 90 to 140 Ah at 10h rating in 6v units are used.
- Vehicles having diesel engine use batteries of 300 Ah capacities because these engines need higher current for starting motors.
- Ashok Leyland trucks use two batteries of each 12v or four batteries of 6v each having capacity of 78 to 135 Ah at 20 h rating



❖ Battery Efficiency:

- The efficiency of battery is generally defined in terms of Amperes-hours or watt-hours and energy efficiency.
- The battery is far more efficient when discharged at slow rate than when it is discharged rapidly.
- **The lower the temperature the lower the efficiency.** The chemical activity is greatly reduced at lower temperatures and sulfuric acid is not in the position to work so actively on the active materials.

- Battery Efficiency,

$$\text{Ah Efficiency} = \frac{Ah_{discharging}}{Ah_{charging}} \times 100,$$

$$\text{Wh efficiency} = \frac{Wh_{discharging}}{Wh_{charging}} \times 100$$

- At the 20 hour rate this can be as much as 90%.



Energy Efficiency,

$$\text{Energy efficiency} = \frac{P_d \times t_d}{P_c \times t_c} \times 100\%$$

where P_d = discharge power, t_d = discharge time,
 P_c = charging power, t_c = charging time.

- A typical result of this calculation is about 75%. This figure is lower than the Ah efficiency as it takes into account the higher voltage required to force the charge into the battery.



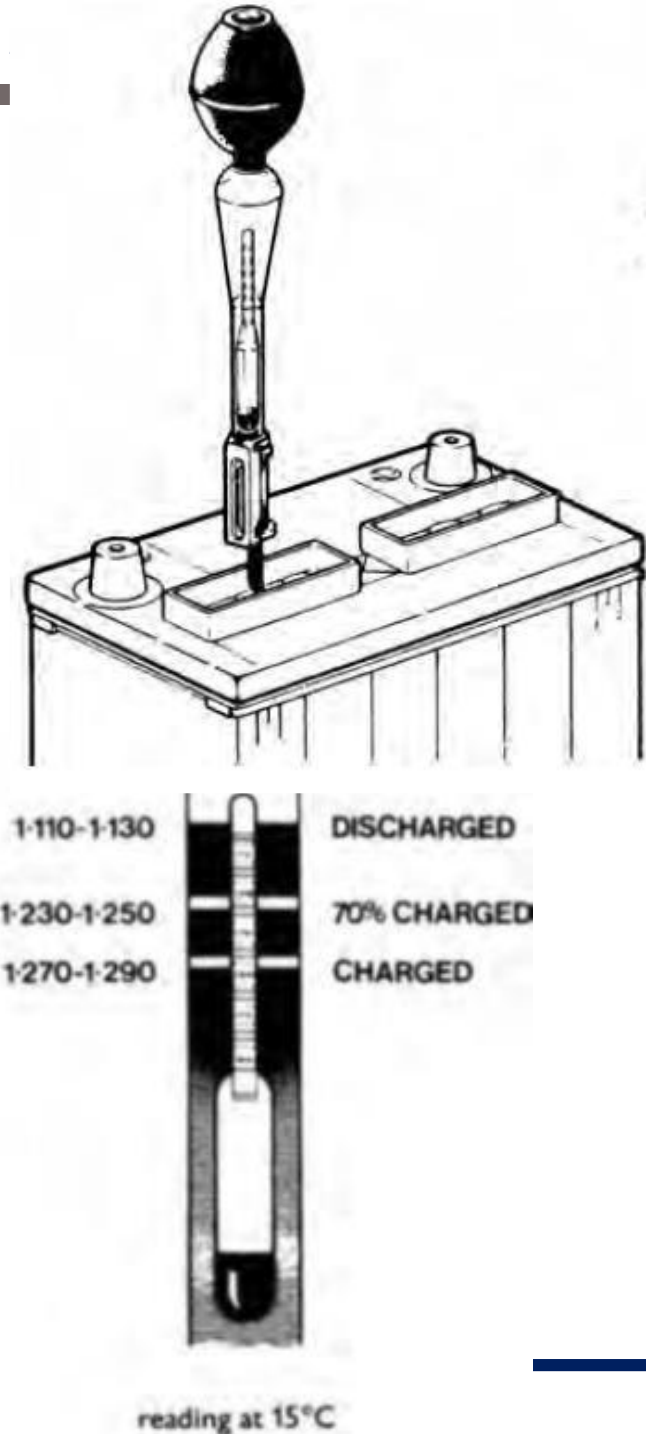
❖ **Self-discharge:**

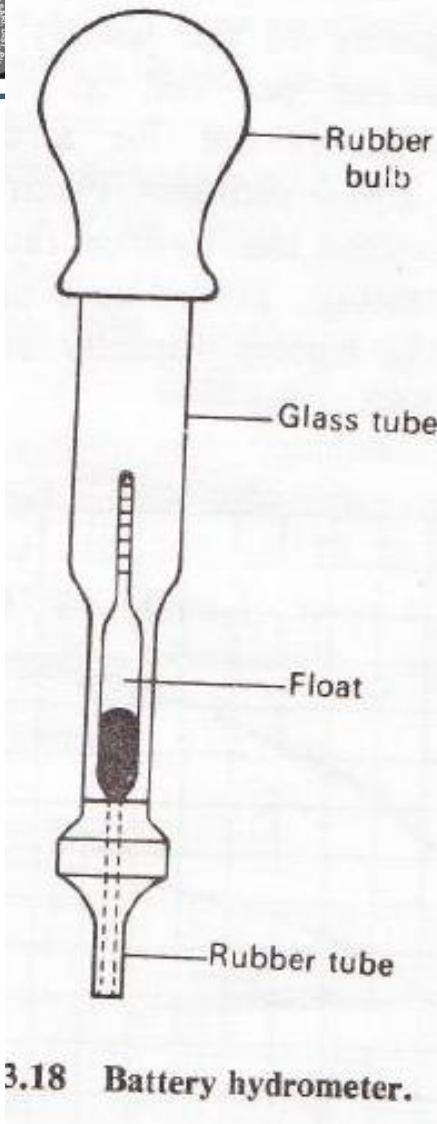
- All batteries suffer from self-discharge, which means that even without an external circuit the state of charge is reduced.
- The rate of discharge is of the order of **0.2–1% of the Ah capacity per day**. This increases with temperature and the age of the battery.
- It is caused by two factors. First, the chemical process inside the battery changes due to the material of the grids forming short circuit voltaic couples between the antimony and the active material. Using calcium as the mechanical improver for the lead grids reduces this.
- Impurities in the electrolyte, in particular trace metals such as iron, can also add to self-discharge.
- Second, a leakage current across the top of the battery, particularly if it is in a poor state of cleanliness, also contributes to the self-discharge.
- The fumes from the acid together with particles of dirt can form a conducting film. This problem is much reduced with sealed batteries.

❖ Battery Tests:

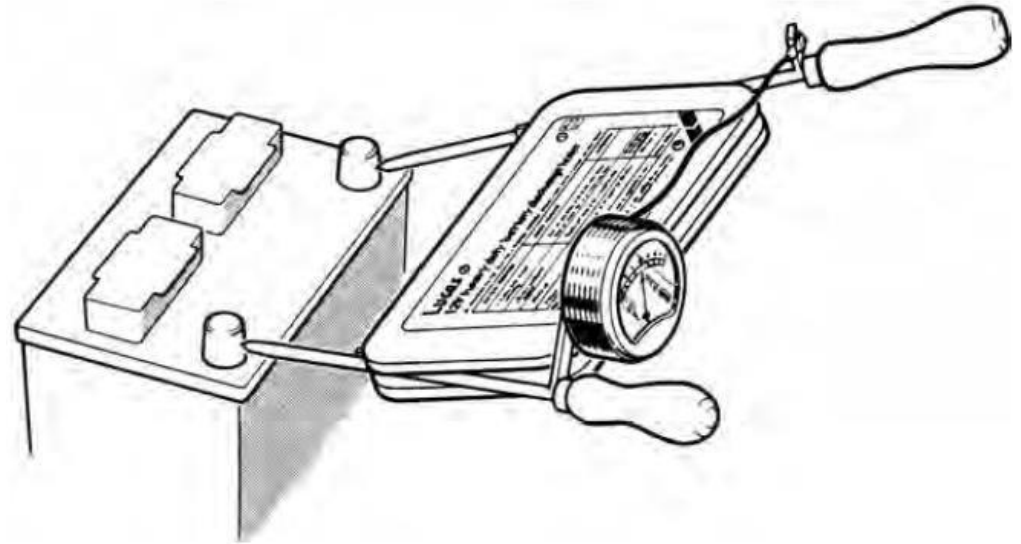
1. Hydrometer Test

- For testing the state of charge of a non-sealed type of battery, a hydrometer can be used, as shown in Figure.
- The hydrometer comprises a syringe that draws electrolyte from a cell, and a float that will float at a particular depth in the electrolyte according to its density.
- The density or specific gravity is then read from the graduated scale on the float. A fully charged cell should show 1.280, 1.200 when half charged and 1.130 if discharged.





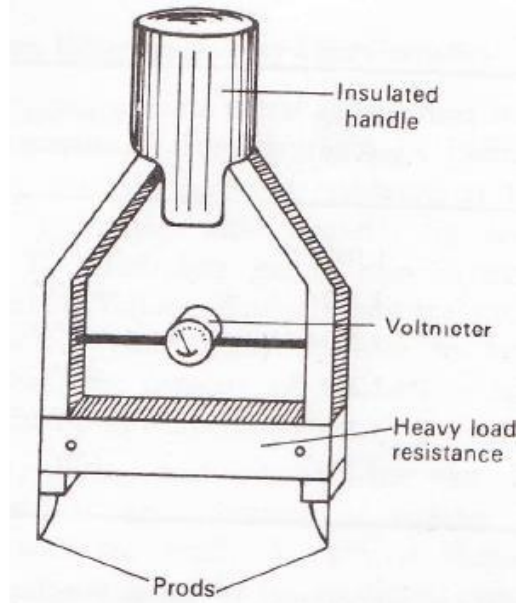
Hydrometer



Heavy Duty Discharge Tester

2. Heavy Duty Discharge Tester:

- Most vehicles are now fitted with maintenance free batteries and a hydrometer cannot be used to find the state of charge.
- This can only be determined from the voltage of the battery, as given in Table An accurate voltmeter is required for this test
- A heavy-duty (HD) discharge tester as shown in Figure is an instrument consisting of a low-value resistor and a voltmeter connected to a pair of heavy test prods.
- The test prods are firmly pressed on to the battery terminals. The voltmeter reads the voltage of the battery on heavy discharge of 200–300 A.





- Assuming a battery to be in a fully charged condition, a serviceable battery should read about 10V for a period of about 10 s. A sharply falling battery voltage to below 3 V indicates an unserviceable cell.

Table 5.3 State of charge of a battery

Battery volts at 20° C	State of charge
12.0	Discharged (20% or less)
12.3	Half charged (50%)
12.7	Charged (100%)

Table 5.4 Factors affecting the voltage of a battery

Acid density	Cell voltage	Battery voltage	% charge
1.28	2.12	12.7	100
1.24	2.08	12.5	70
1.20	2.04	12.3	50
1.15	1.99	12.0	20
1.12	1.96	11.8	0



❑ Exide Double Check Tester

▪ State of Charge Test:

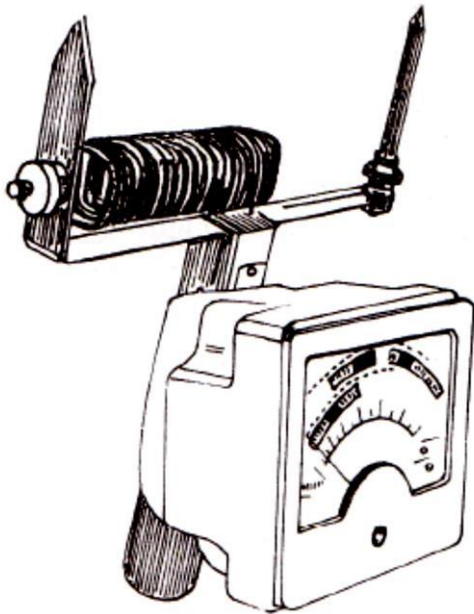


Fig. 3.20 Exide double-check tester (courtesy: Chloride and Exide).

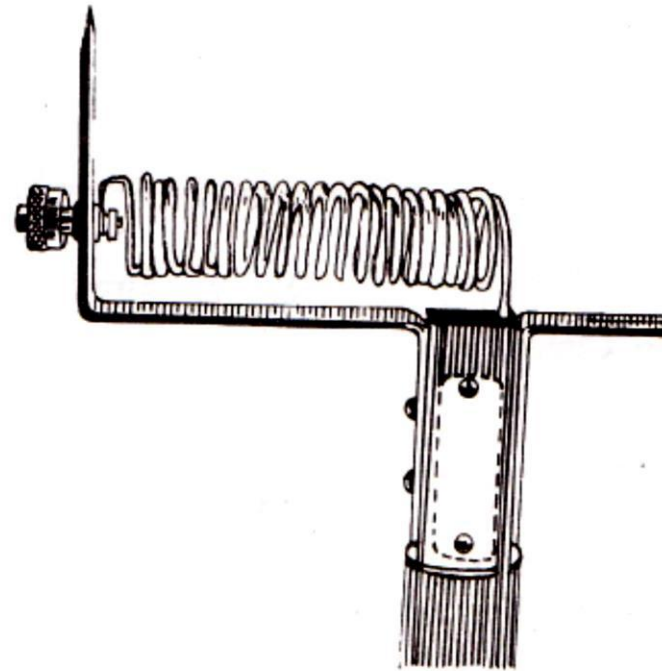


Fig. 3.21 Knurled nut unscrewed (courtesy: Chloride and Exide).

■ Battery Discharge Test:

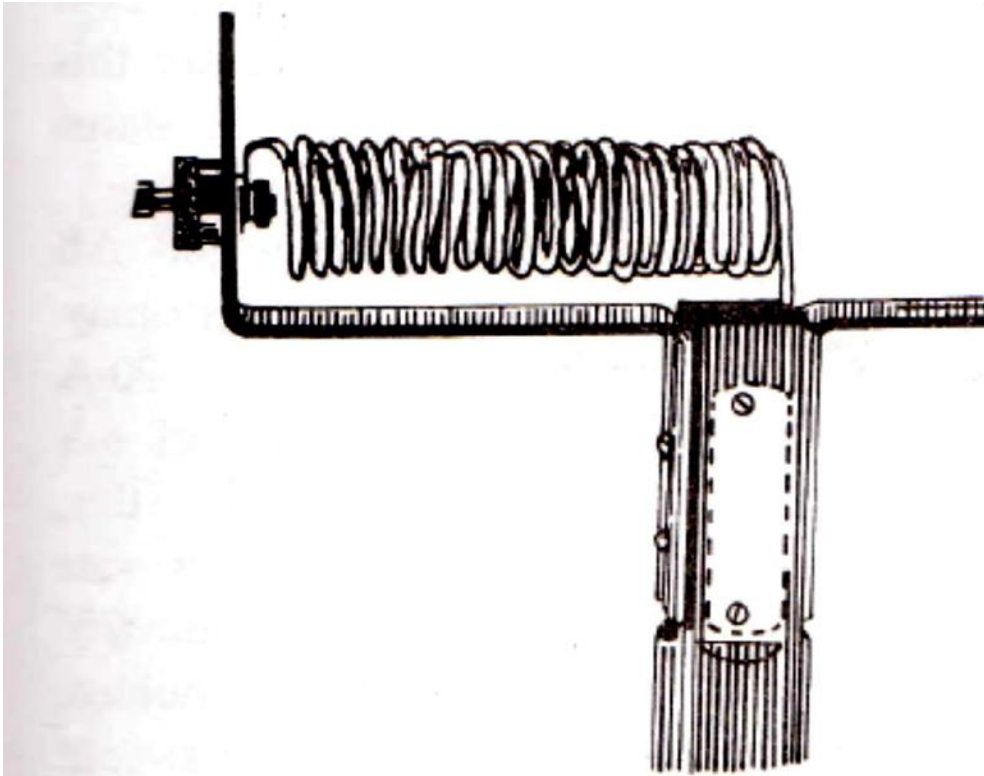


Fig. 3.22 Knurled nut screwed down on to the surface of flat prod (*courtesy: Chloride and Exide*).



■ **Battery Charge Test:**

- The knurled nut is unscrewed so that the resistor is out of circuit, as shown in figure above. All the lights are switched on for three minutes. (unless the state of charge test has shown the battery in a discharged state).
- Now the lights are switched off and the engine is started. The engine is kept running at moderate speed (i.e at engine speed equivalent of 50Km per hour in top gear).
- The prods are no applied across the cell or to the battery terminals. The meter reading should increase slightly and then remain constant. This constant reading is the true value of charging.
- If the two previous checks indicate a healthy battery, the reading on the charging scale will indicated whether a low, satisfactory or too high charge ins being given.



Cranking Motor Test:

- Before making this test the electrolyte level in all the cells should be correct, there should be no apparent defects in the battery, and it should be at least half charged.
- Further, the motor should not be operated for more than 30s at a stretch. Before operating it again, it must be allowed to cool, otherwise it may be overheated and get damaged.
- For making the test, earth the ignition primary lead at the distributor, so that the engine does not start. Now operate the cranking motor and check the voltage of each battery cell.
- Generally, if during the test, the cell voltage fall below 1.5V or there is a difference of 0.2V or more between cells, battery trouble may be suspected. Before final conclusion, recharge the battery and check it again.



Cadmium Test:

- The previously described test are a good indication of battery condition but no satisfactory indication is given as regards the chemical condition of the plates.
- To know the chemical condition of the battery plates, it is necessary to perform cadmium test.
- It consists of finding out the voltage between the negative or positive plate and the cadmium testing strip immersed in the battery electrolyte. A perforated ebonite tube is generally used to enclose the cadmium strip.
- One end of the strip is connected by an insulated conductor to negative terminal of the voltmeter. The other voltmeter terminal is connected to the negative or positive plate, as the case may be.
- The cell voltage is equal to algebraic difference of the cadmium to negative and cadmium to positive voltage readings.



- For conducting the cadmium test, it is essential to have a high grade high resistance voltmeter.
- Further, it should be scaled to give a positive reading of 3V and negative reading of 0.2V. It may even be a 3V center zero instrument. Further, for making this test, the battery should be either on charge or on discharge.
- In a battery in good condition nearing completion of charge at normal rate, the cadmium to positive voltage should be 2.35-2.50V and cadmium to negative voltage -0.1-0.14V, giving a cell voltage of 2.45-2.64 V.
- For a battery discharged at normal rate, its cadmium to negative voltage should not be more than +0.2V and that of cadmium to positive voltage not less than 2.0V, thus giving cell voltage of 1.8V.
- If the cadmium to positive voltage is sufficiently less than 2.0V, the chemical condition of the positive group of plates is not up to the mark. If the cadmium to negative voltage approaches +0.3V, it indicates a poor condition of negative group of plates



Table 5.2 Common problems with lead-acid batteries and their likely causes

❖ Battery Failures:

1. Overcharging Failures
2. Cycling Failure
3. Sulphation Failure
4. Internal Short circuits

Symptom or fault	Likely causes
Low state of charge	Charging system fault Unwanted drain on battery Electrolyte diluted Incorrect battery for application
Low capacity	Low state of charge Corroded terminals Impurities in the electrolyte Sulphated Old age – active material fallen from the plates
Excessive gassing and temperature	Overcharging Positioned too near exhaust component
Short circuit cell	Damaged plates and insulators Build-up of active material in sediment trap
Open circuit cell	Broken connecting strap Excessive sulphation Very low electrolyte
Service life shorter than expected	Excessive temperature Battery has too low a capacity Vibration excessive Contaminated electrolyte Long periods of not being used Overcharging