Kirchoff’s Laws

Circuit Definitions

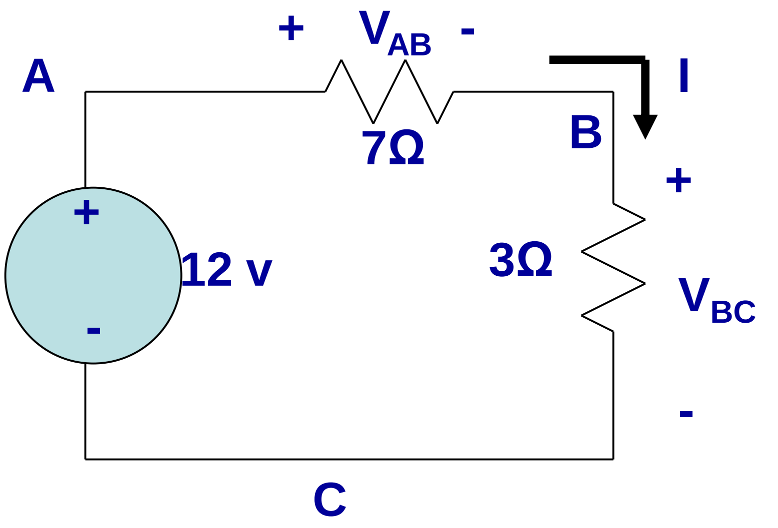
- Node – any point where 2 or more circuit elements are connected together
  - Wires usually have negligible resistance
  - Each node has one voltage (w.r.t. ground)
- Branch – a circuit element between two nodes
- Loop – a collection of branches that form a closed path returning to the same node without going through any other nodes or branches twice

Kirchoff’s Voltage Law (KVL)

- The algebraic sum of voltages around each loop is zero
  - Beginning with one node, add voltages across each branch in the loop (if you encounter a + sign first) and subtract voltages (if you encounter a – sign first)
- Σ voltage drops - Σ voltage rises = 0
- Or Σ voltage drops = Σ voltage rises

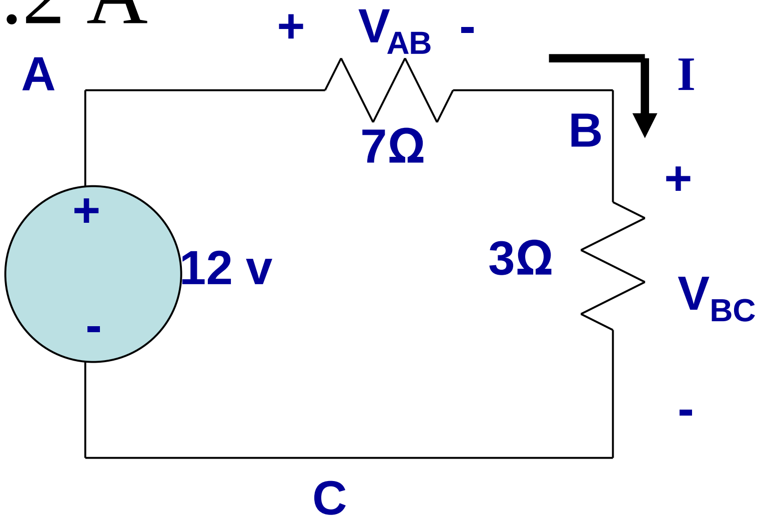
Circuit Analysis

- When given a circuit with sources and resistors having fixed values, you can use Kirchoff's two laws and Ohm's law to determine all branch voltages and currents



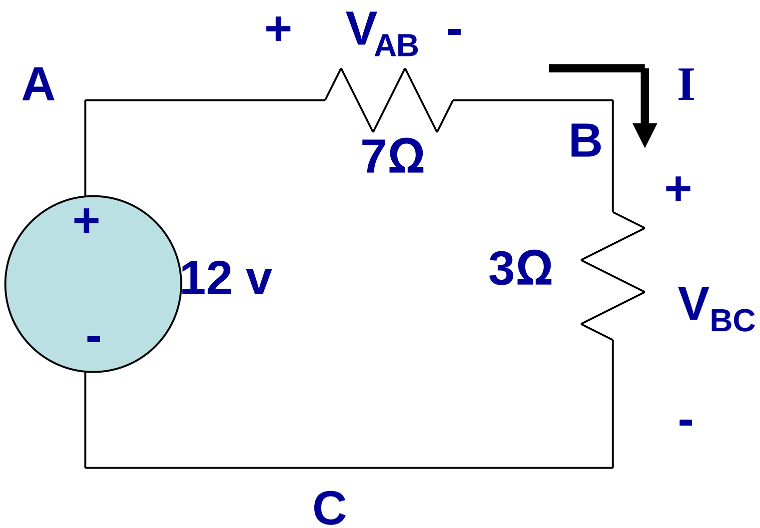
Circuit Analysis

- By Ohm's law: $V_{AB} = I \cdot 7\Omega$ and $V_{BC} = I \cdot 3\Omega$
- By KVL: $V_{AB} + V_{BC} - 12\text{ v} = 0$
- Substituting: $I \cdot 7\Omega + I \cdot 3\Omega - 12\text{ v} = 0$
- Solving: $I = 1.2\text{ A}$



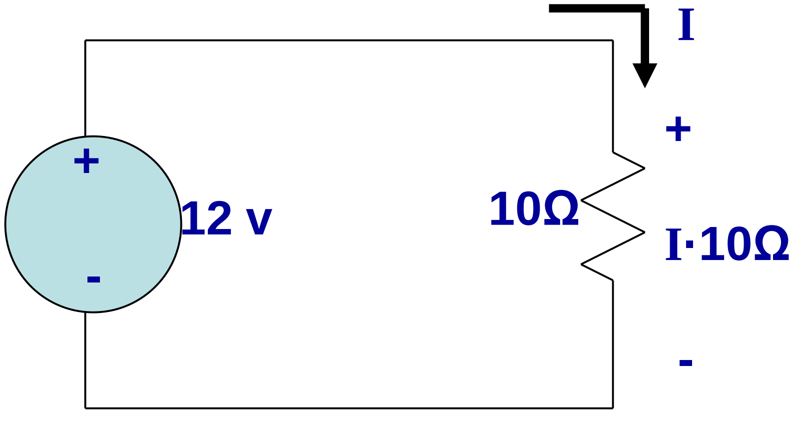
Circuit Analysis

- Since $V_{AB} = I \cdot 7\Omega$ and $V_{BC} = I \cdot 3\Omega$
- And $I = 1.2$ A
- So $V_{AB} = 8.4$ v and $V_{BC} = 3.6$ v



Series Resistors

- KVL: $+I \cdot 10\Omega - 12\text{ v} = 0$, So $I = 1.2$ A
- From the viewpoint of the source, the 7 and 3 ohm resistors in series are equivalent to the 10 ohms



Kirchoff's Current Law (KCL)

- The algebraic sum of currents entering a node is zero
  - Add each branch current entering the node and subtract each branch current leaving the node
- Σ currents in - Σ currents out = 0
- Or Σ currents in = Σ currents out

Parallel Resistors

- The equivalent resistance for any number of resistors in parallel (i.e. they have the same voltage across each resistor):

$$Req = \frac{1}{1/R_1 + 1/R_2 + \cdots + 1/R_N}$$

- For two parallel resistors:

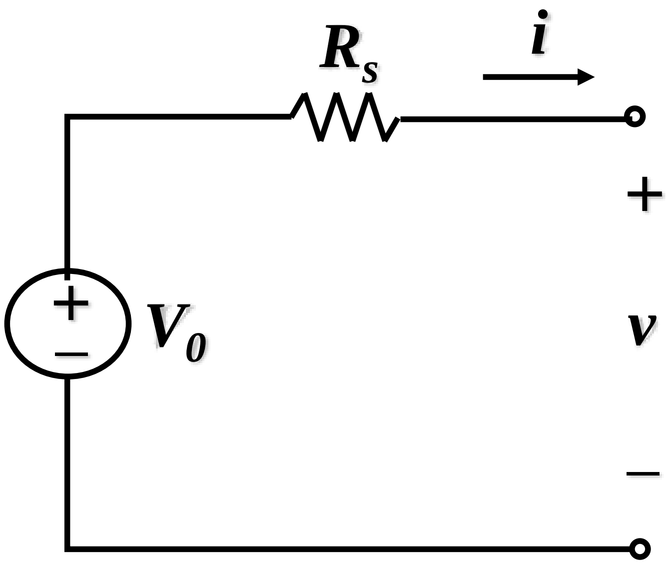
$$Req = R_1 \cdot R_2 / (R_1 + R_2)$$

Superposition Theorem

- The Superposition theorem states that if a linear system is driven by more than one independent power source, the total response is the sum of the individual responses. The following example will show the step of finding branches current using superpostion theorem

Thevenin and Norton Equivalent Circuits

M. Leon Thévenin (1857-1926), published his famous theorem in 1883.



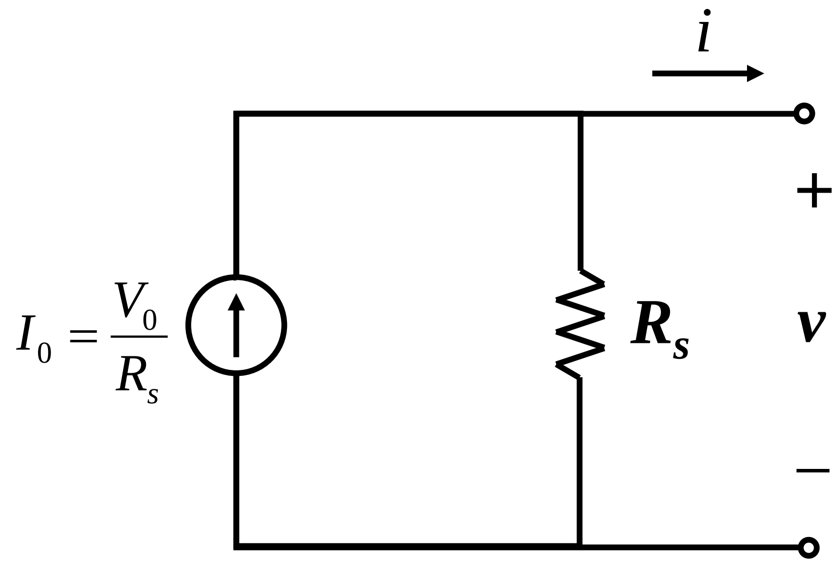


Fig.2.17 (a) Thevenin equivalent circuit ; (b) Norton equivalent circuit

$$v = V_0 - R_s\, i$$

$$i = I_0 - \frac{v}{R_s}$$

The equivalence of these two circuits is a special case of the *Thevenin and Norton Theorem*

Thevenin & Norton Equivalent Circuits

- *Thevenin's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single voltage source and series resistance connected to a load.*

  A series combination of Thevenin equivalent voltage source V_0 and Thevenin equivalent resistance R_s

- Norton's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single current source and parallel resistance connected to a load. Norton form:

  A parallel combination of Norton equivalent current source I_0 and Norton equivalent resistance R_s

Circuit Transformation

- The configuration of circuit connection can be changed to make the calculation easier. There are TWO type of transformations which are Delta (Δ) to star connection (Y) and vice versa.

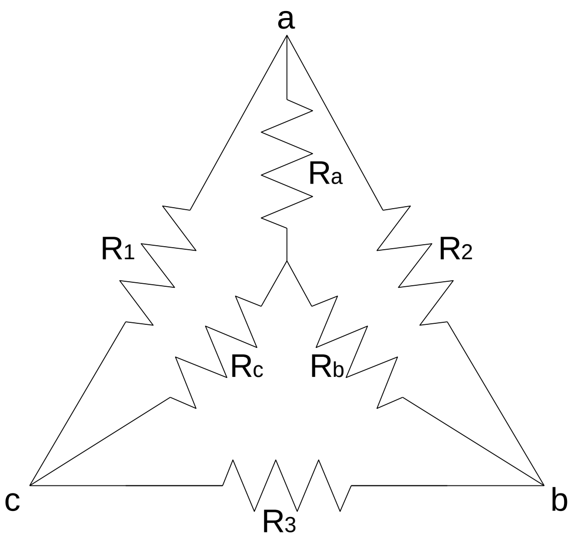


Figure: Delta and Star Circuit Connection

- Delta (Δ) to star (Y) transformation:

$$R_a = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_b = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

$$R_c = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

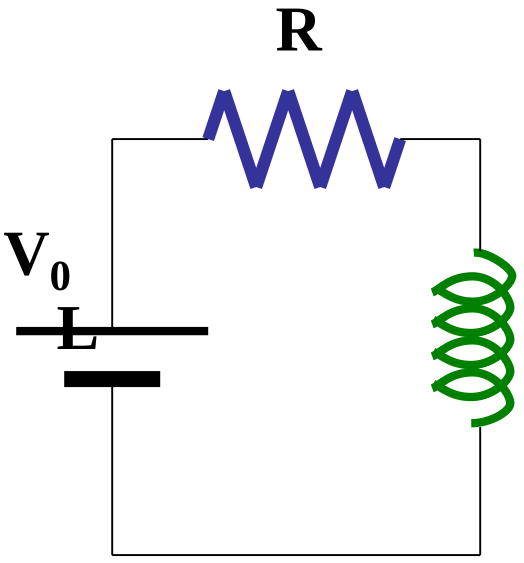
- Star (Y) to Delta (Δ) transformation:

$$R_1 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$

Inductors - how do they work?



$$V_L = L\frac{dI}{dt}$$

RLC circuits with sinusoidal sources

The AC analysis of circuits with inductors is also easy, with the effective resistance (impedance) of an inductor. From a phasor point of view this means that the inductor leads the resistor by 90 degrees.

High pass and low pass filters can be made from inductors as well. However the inductors are usually bulkier and relatively expensive compared to capacitors (and more difficult to make in an integrated circuit) so are not used as commonly.

Introduction

- The Dc machines are of two types namely DC generators and DC motors.
- A DC generators converts mechanical energy into electrical energy whereas a DC motor converts the electrical energy into mechanical energy.
- In order to understand the operating principle of a DC motor, it is necessary to understand how does a current carrying conductor experience a force, when kept in a magnetic field.

- **Magnitude of Force:**

➢ The magnitude of the force experienced by the current carrying conductor placed in the magnetic field is given by,

$$F = BIl \text{ Newton}$$

Where B = Flux density produced by Magnet

I = current flowing through conductor

l = Length of the conductor

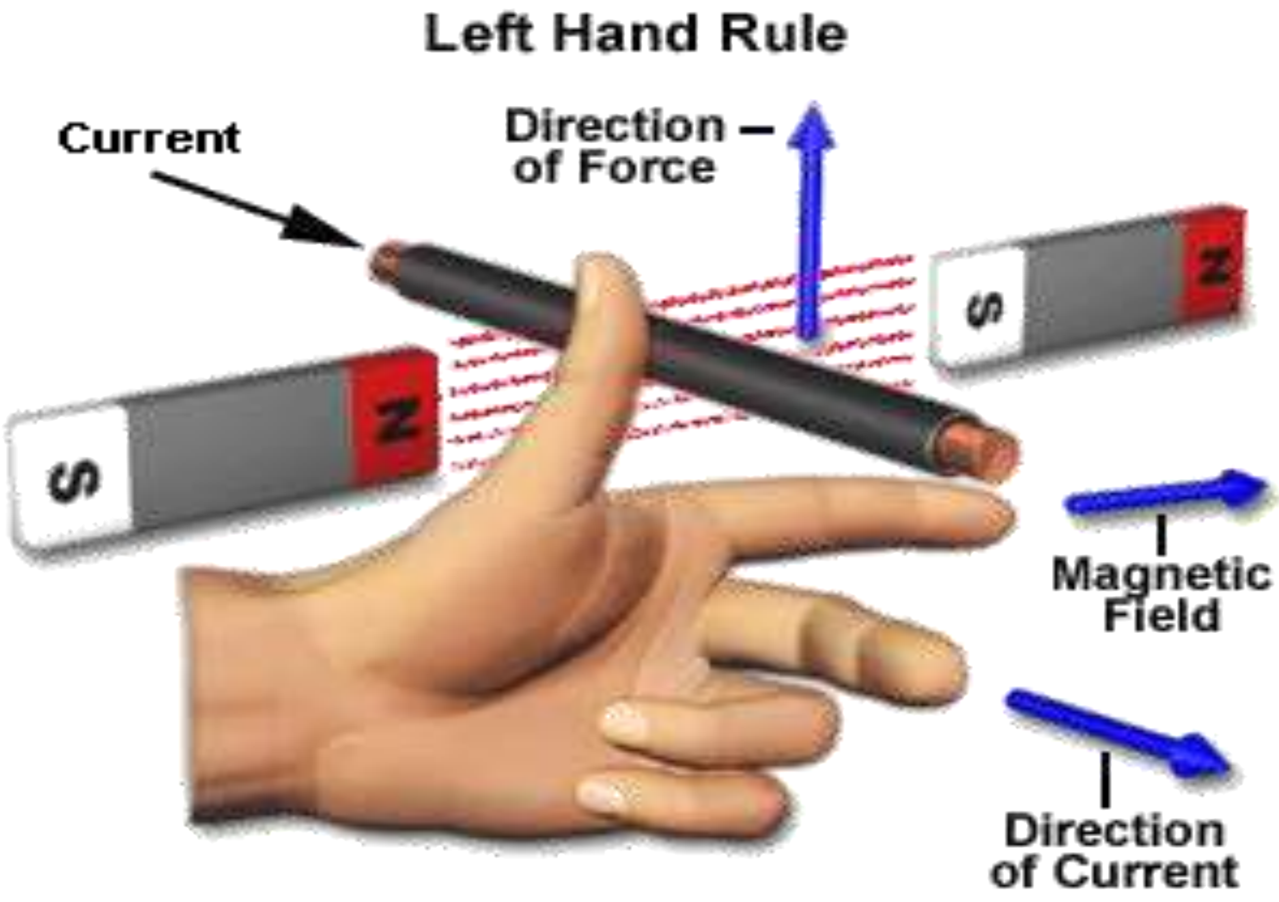


Fig: Fleming’s left hand rule thumb

Windings in DC Machine

- In any dc machines, there are two windings:

1. Field winding 2. Armature winding

- Out of these, the field winding is stationary which does not move at all and armature winding is mounted on a shaft. So it can rotate freely.

- Connection of windings for operation as motor:

To operate the dc machine as a motor, the field winding and armature winding is connected across a dc power supply.

DC Motor

- Principle of operation:
- When current carrying conductor is placed in a magnetic field, it experienced a force.
- In case of DC motor, the magnetic field us developed by the field current i.e. current flowing in field winding and armature winding plays the role of current carrying conductor
- So armature winding experienced a force and start rotating.

Construction of DC Motor

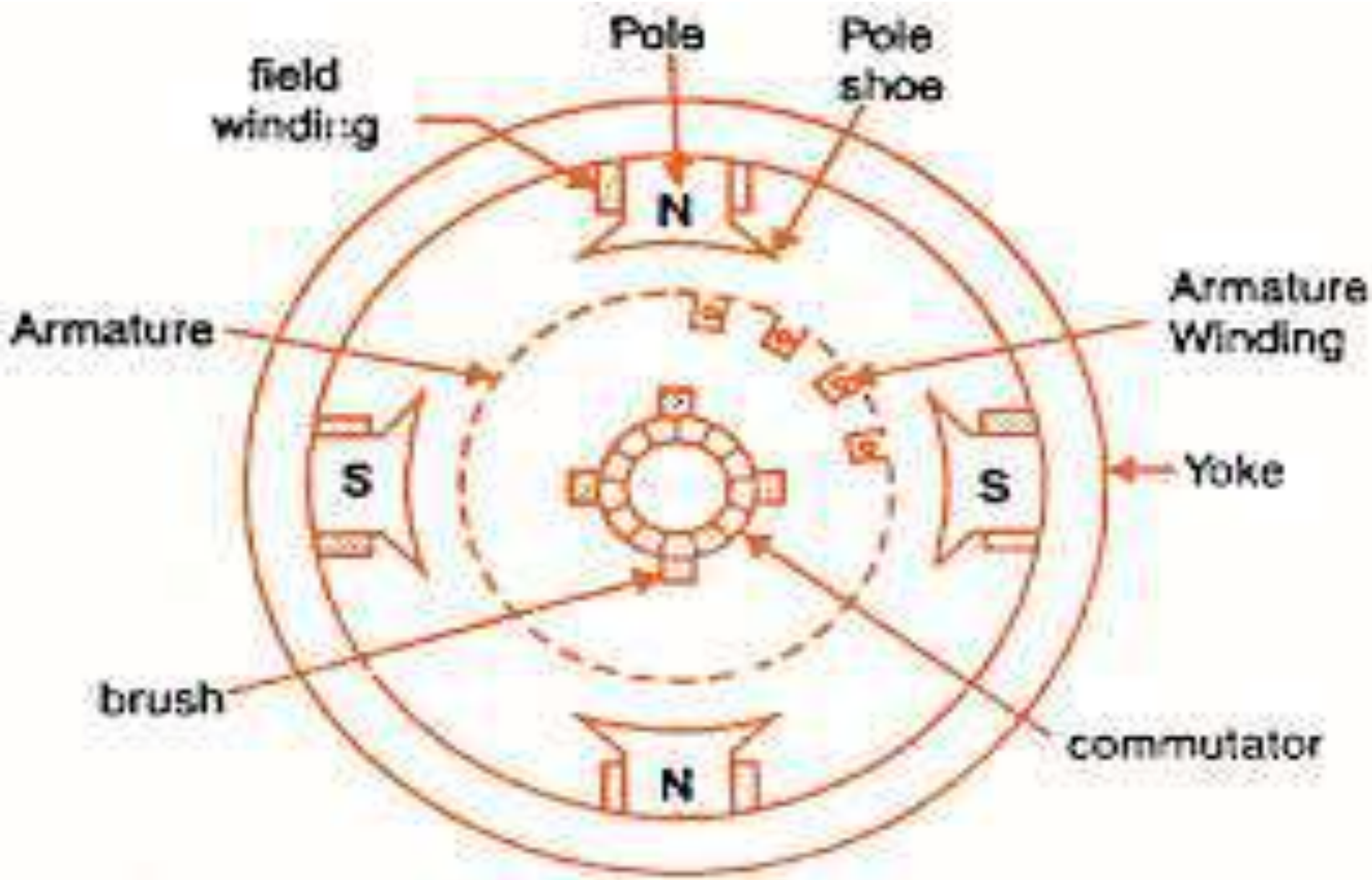


Fig.: construction of DC motor

Back EMF

- When the armature winding of a dc motor starts rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux.
- Hence according to the faraday's laws of electromagnetic induction, there will be an induced emf in the armature winding.
- As per the Lenz's law, this induced emf acts in opposite direction to the armature supply voltage. Hence this emf is called as the back emf and denoted by E_b.

$$E_b = \frac{NP\varphi Z}{60\ A}$$

Voltage Equation of a DC Motor

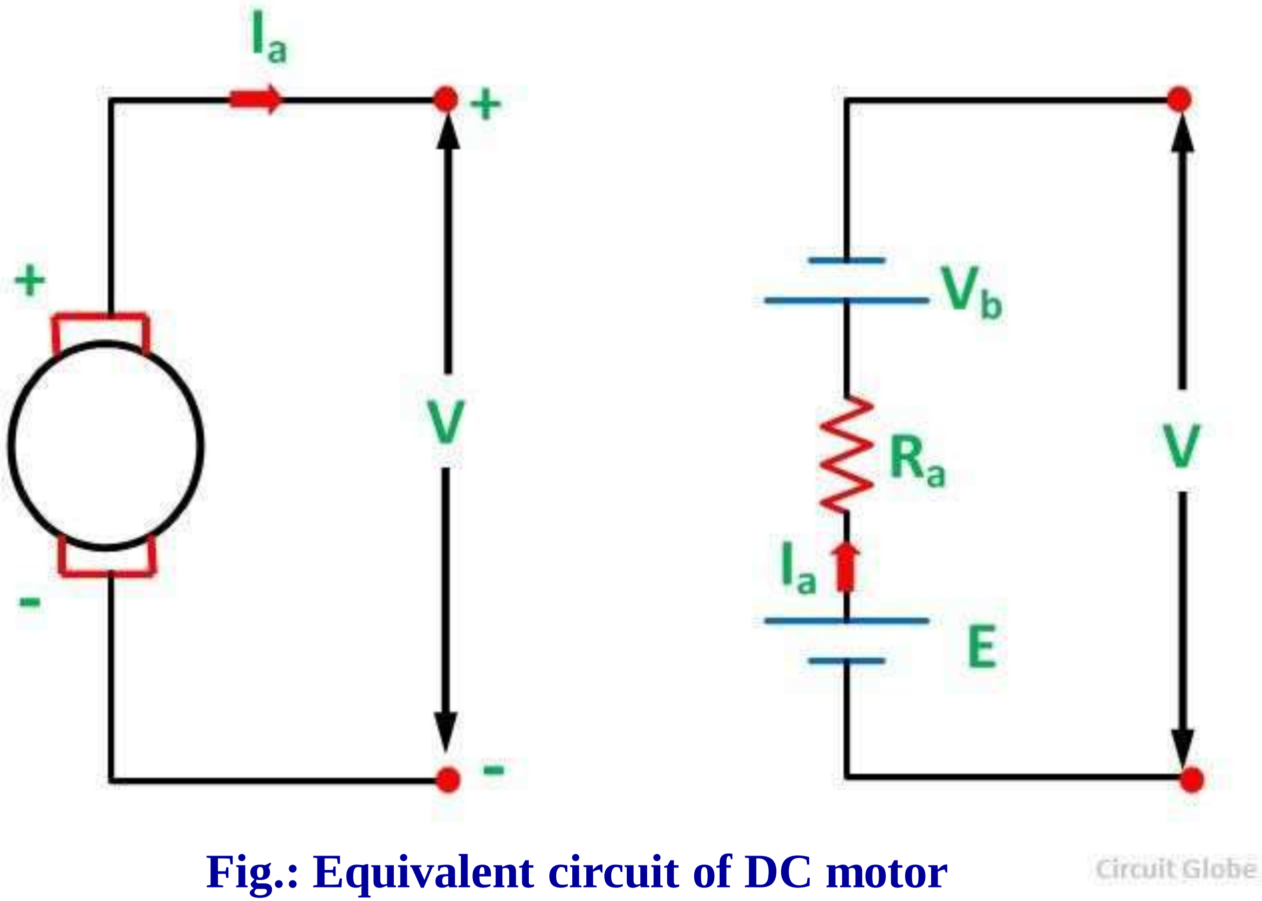


Fig.: Equivalent circuit of DC motor

- As shown in fig.(1), the armature supply voltage V has to overcome the opposition posed by the back emf E_b and some other voltage drops such as brush drop and the voltage drop across R_a.
- From fig.(1), we can write that,

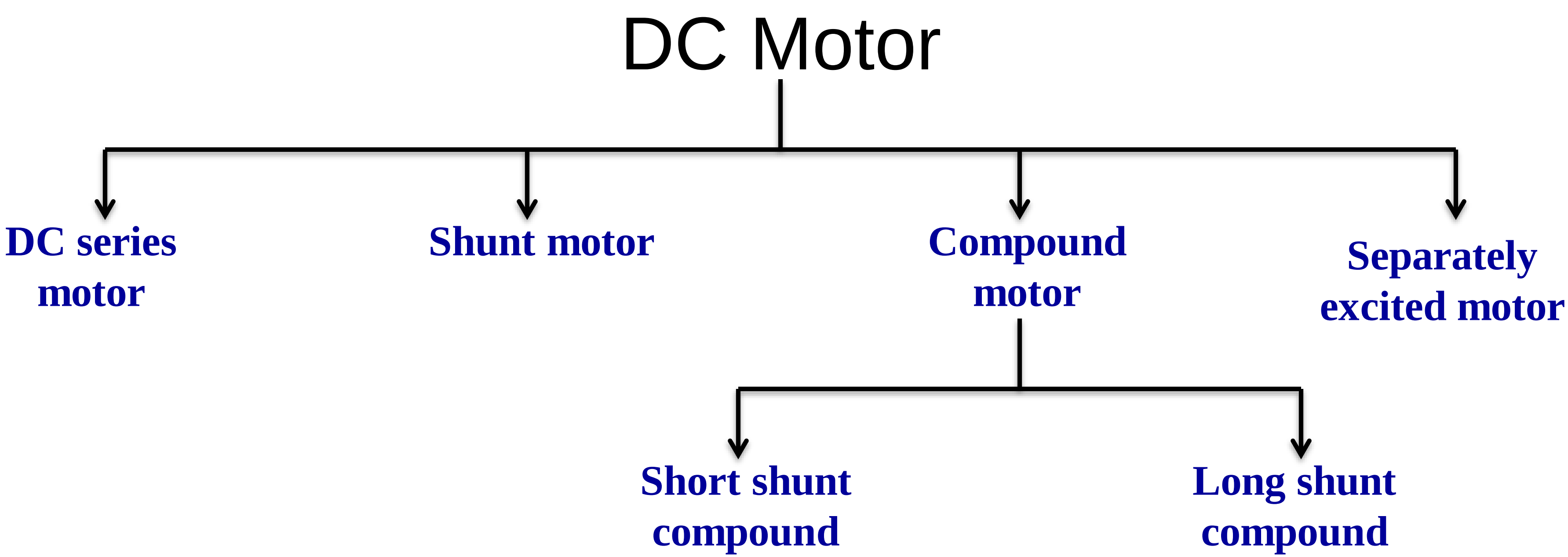
$$V = E_b + I_a R_a + V_b \qquad \text{.......(1)}$$

- But voltage drop across brushes is negligible.

$$\therefore V = E_b + I_a R_a \qquad \text{.......(2)}$$

Types of DC Motors

- Depending on the way of connecting the armature and field windings of a d.c. motors are classified as follows:



DC Shunt Motor

- In DC shunt type motor, field and armature winding are connected in parallel as shown in fig.(1), and this combination is connected across a common dc power supply.
- The resistance of shunt field winding (R_{sh}) is always much higher than that of armature winding (R_a).
- This is because the number of turns for the field winding is more than that of armature winding.

- The field current I_{sh} always remains constant. Since V and R_{sh} both are constant. Hence flux produced also remains constant. Because field current is responsible for generation of flux.

$$\therefore \phi \propto I_{sh}$$

- This is why the shunt motor is also called as the constant flux motors.

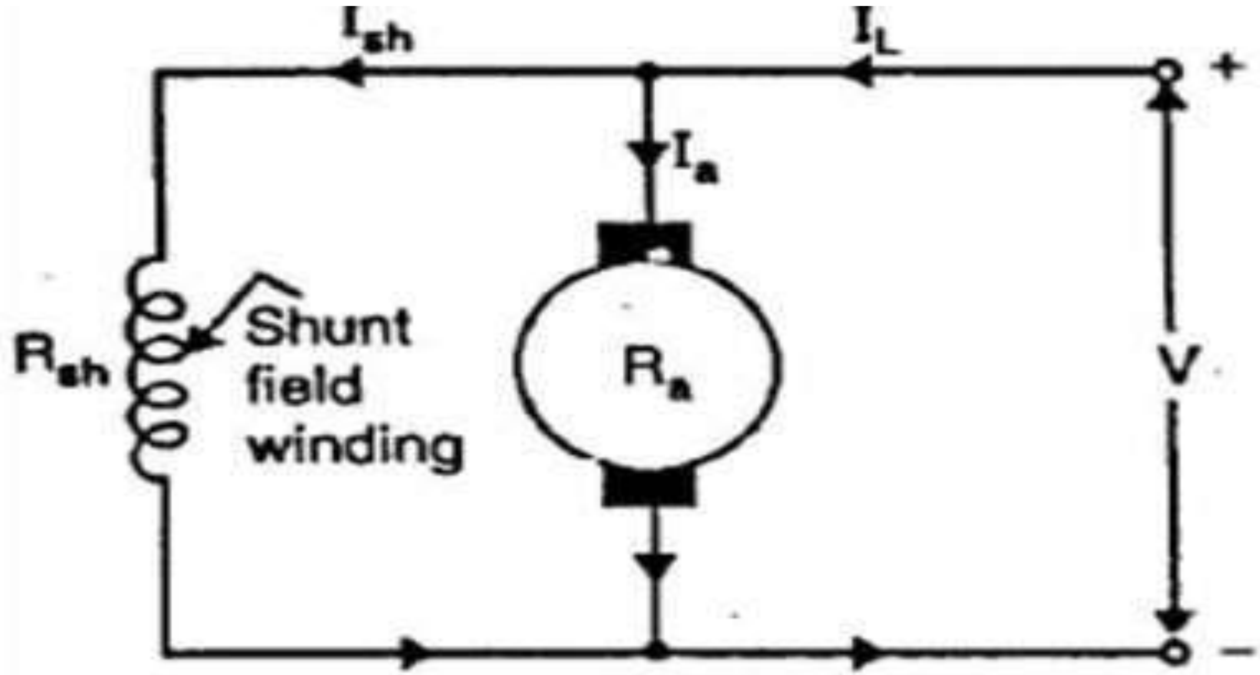


Fig.: DC shunt motor schematic diagram

DC Series Motor

- In DC series motor, the armature and field windings are connected din series with each other as shown in fig.(1).
- The resistance of the series field winding (R_s) is much smaller as compared to that of the armature resistance (R_a).
- The flux produced is proportional to the field current. But in series motor, the field current is same as armature current.

$$\therefore \phi \propto I_a \quad \text{or}$$

$$\therefore \phi \propto I_s$$

Torque & Speed Equations

- **Torque equations:**
- ➢ Torque produced by a motor will always be proportional to the air gap flux ø and the current flowing through the armature winding (I_a).
- ➢ That means $T \propto ø I_a$
- ➢ The flux is produced by the field current hence ø will be proportional to field current. That means,

$$ø \propto I_{field}$$

- ➢ hence torque produced by a dc motor is proportional to the product of I_a and I_{field}. That means,

$$T \propto I_a I_{field} \qquad \text{………..(1)}$$

- ➢ For various types of dc motors the expression for field current will be different. We will substitute them into eq.(1) to get the torque equations.

1. Torque equation of DC shunt motor:

- For DC shunt motor Ifield = V/ R_{sh} = constant
- Hence the flux ø is constant.

$$\therefore T \propto I_a \qquad \text{........(2)}$$

- Hence in dc shunt motor, torque is proportional to only to the armature current.

2. Torque equation DC series motor:

- For DC series motor, the field current is equal to the armature current i.e. $I_{field} = I_a$.
- Hence $T \propto I_a \, I_a$

$$\therefore T \propto I_a^2 \qquad \text{.........(3)}$$

- Hence in dc series motor, torque is proportional to the square of armature current.

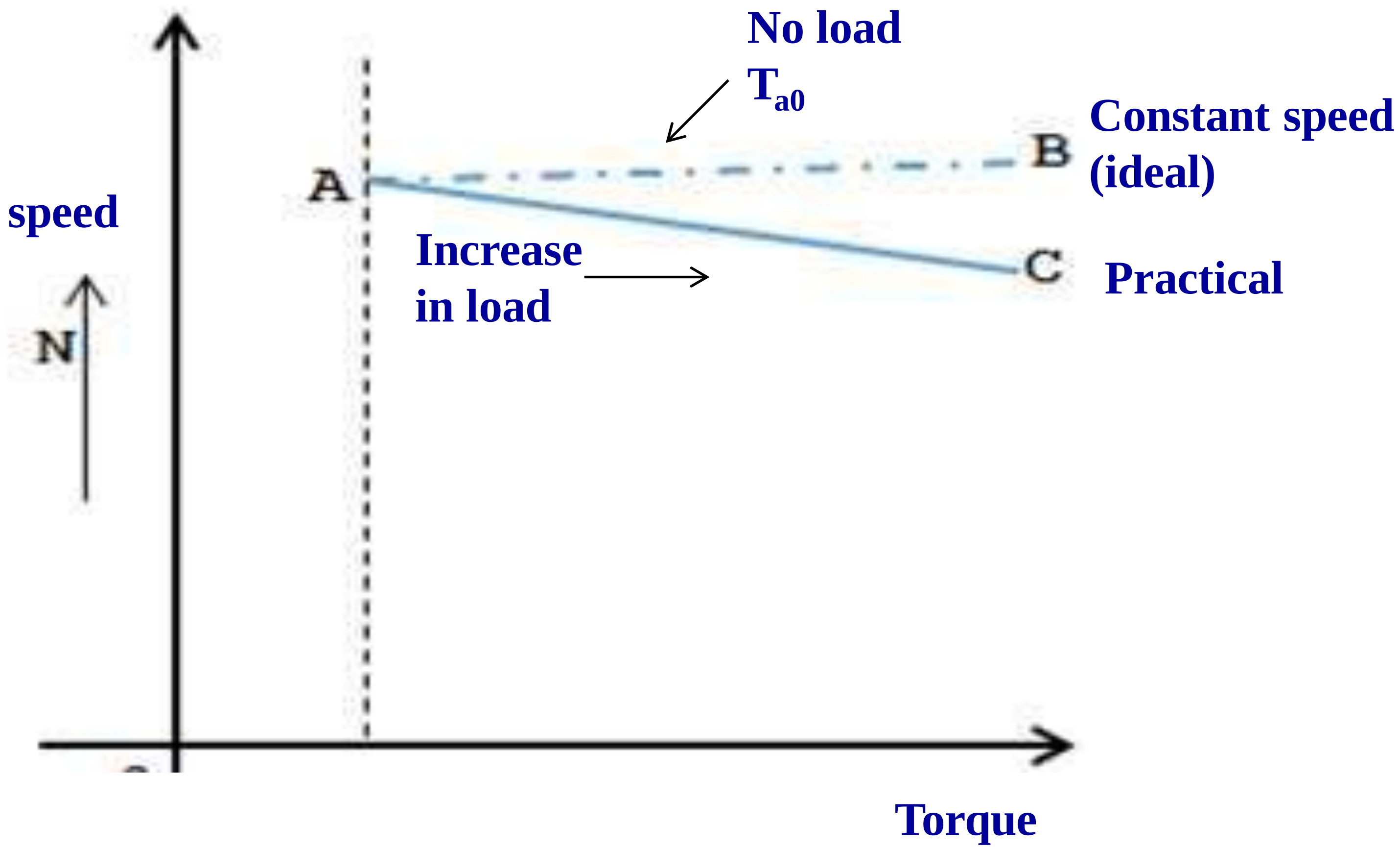
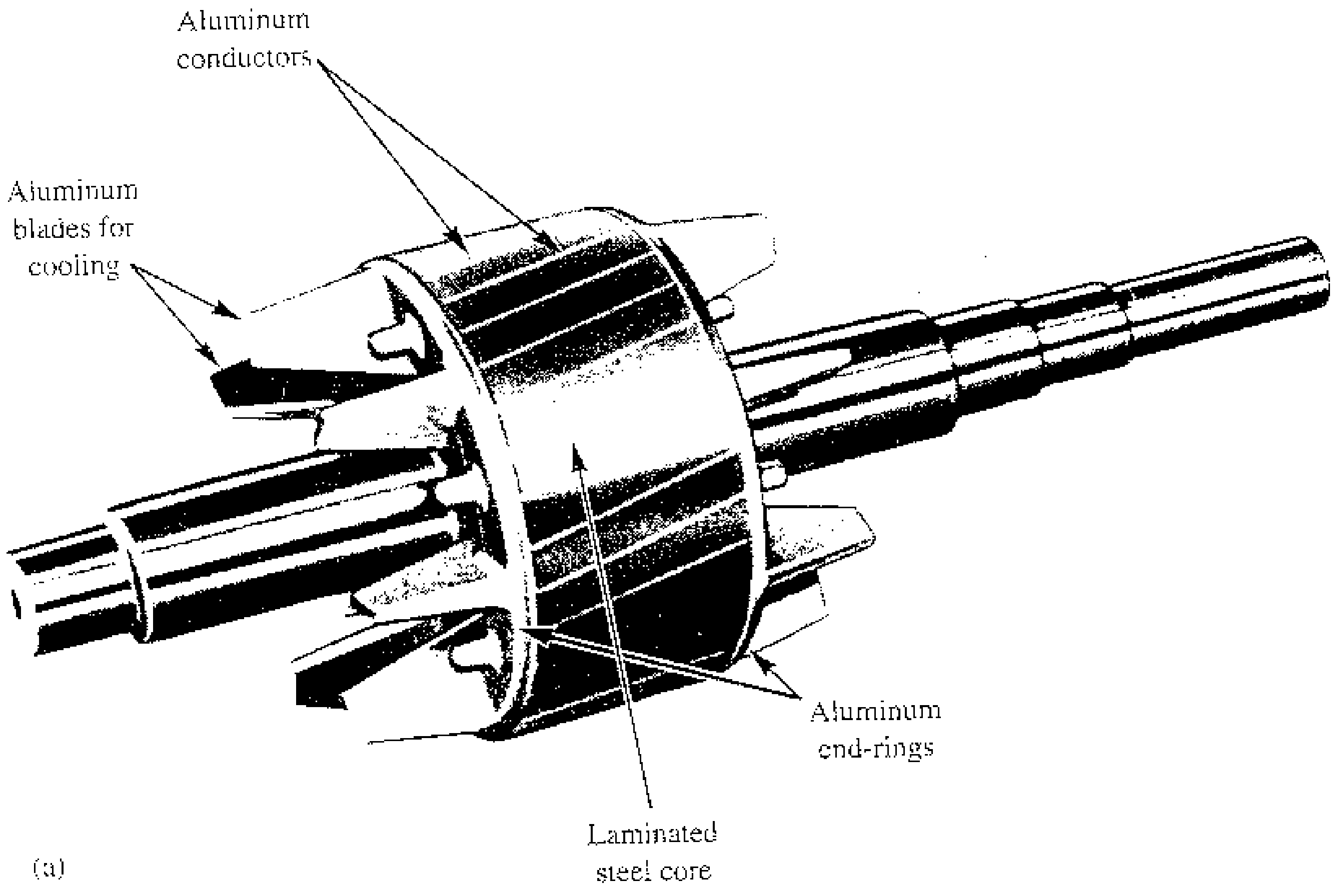
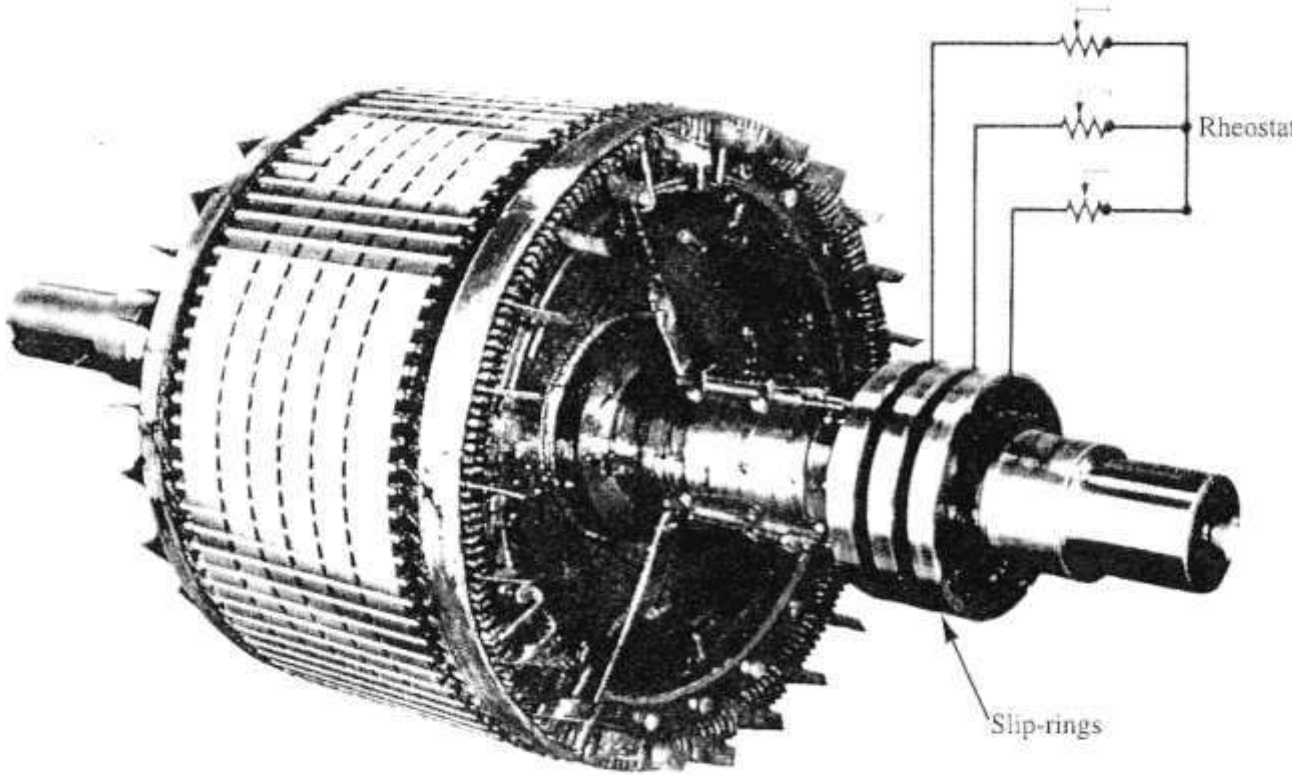


Fig.: speed-torque characteristics of dc shunt motor

Squirrel-Cage Rotor



Wound-Rotor



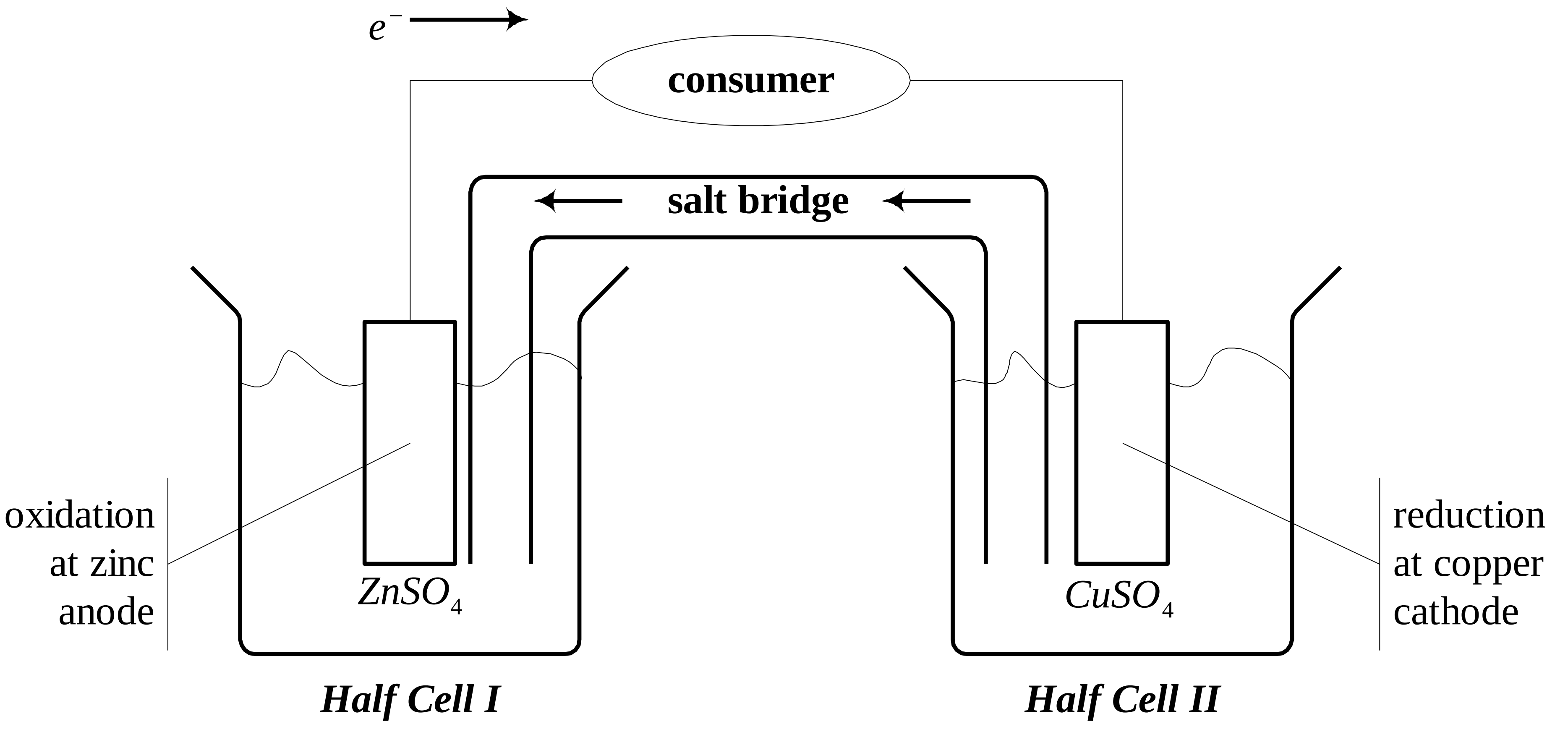
Synchronous Speed

- n_s = synchronous speed (r/min)
  - the speed of the rotating magnetic flux
- $n_s = f_s/(P/2)$ (r/s)
  - where
    - f_s = frequency of the 3-Φ supply
    - n_s = synchronous speed
    - P = number of poles formed by the stator winding
- $n_s = 120(f_s)/P$ (r/min)

Slip

- n_s = synchronous speed of the rotating flux
- n_r = speed of the rotor
- slip speed = n = n_s-n_r
- slip = s = (n_s-n_r) / n_s = per-unit slip
- % slip = s x 100%
- solving for n_r ,
- $n_r = n_s(1-s)$

The Electrochemical Cell



Wire Types

- Marine Grade
  - Type 3 is recommended
- Stranded copper
  - Tinned is preferred

Wire Insulation

- AC cables must be type UL 1426 BC
  - 600 volt insulation
  - Gasoline and Oil resistant
  - Won’t absorb moisture
- DC wires & cables must be Marine Grade
  - 600 volt insulation
  - Gasoline and Oil resistant
  - Won’t absorb moisture
- Color coded wires

Wiring Installation

- Basic Considerations
- Distribution Panel
- Fuses / Circuit Breakers
- Branch Circuits
  - Wire
  - Outlets
  - Switches
- Grounding Systems
- Bonding Systems

Fuses and Circuit Breakers

- Used to protect wiring from over current
  - In positive or hot wire
- Newer boats use circuit breakers
  - Initially more expensive
- Replace blown fuse with correct rating

- Circuit Breakers should be Marine Grade
  - Trip free
  - Manual reset

Branch Circuits - Wires

- Minimum size is 16 AWG
  - See Wire Selection Tables
  - For AC normally #14 for 15A and #12 for 20A
- Must terminate in closed electrical box
- Of sufficient length
- DC negative returned to DC Panel
  - May use several negative feeder terminals
- AC neutrals returned to AC Panel
- Bonding system never used as return wire

Branch Circuits - Switches

- Modern panels use Circuit Breakers
  - Which also double as switches
- Switches / Circuit Breakers
  - Must be Marine Grade
  - Rated for the voltage and current controlled
  - Interrupt the positive (DC) or hot (AC) leg
- Battery Switch
  - Designed for high current service
  - Not located in engine or fuel-tank compartments

Grounding System

- Ground is potential of water around boat
  - Or potential of earth's surface
- DC – Ground Battery negative terminal(s)
  - Also engine block
  - Wire color is Yellow (or Black)
- AC – Transformer center tap on shore
  - Also connected to ground rod at transformer
  - Wire color is Green and uninterrupted wire
    - Isolation transformers and galvanic isolators are exception and covered in Chapter 4 on AC
- Engine, DC negative & AC ground connected