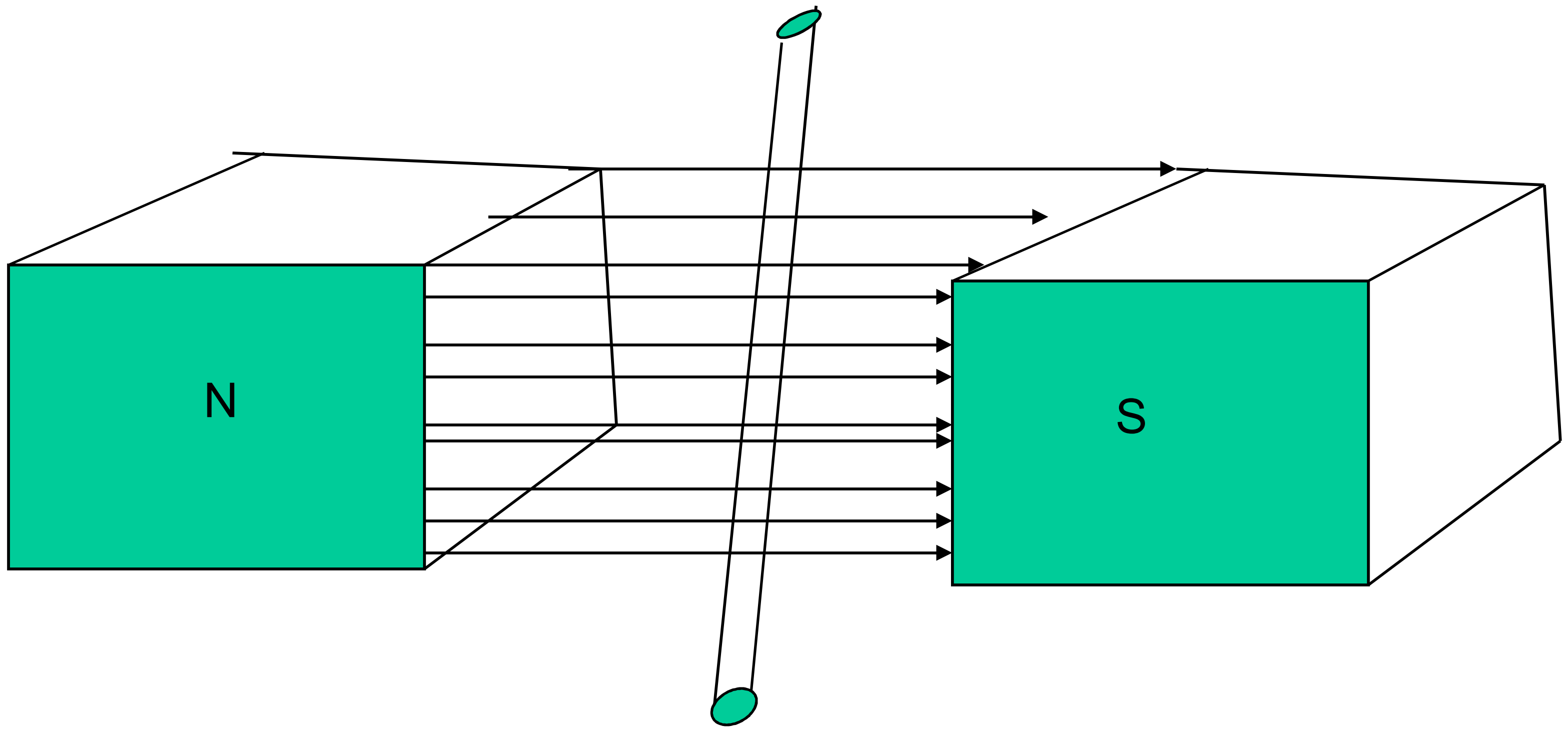
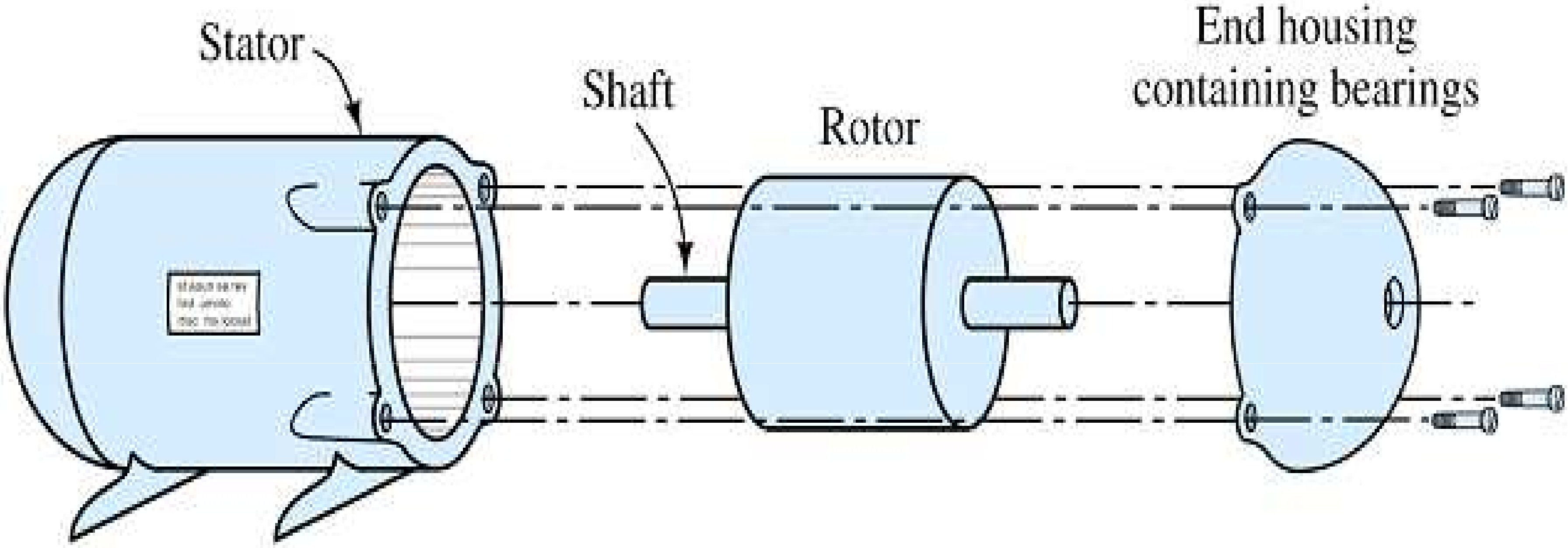
WELCOME TO THE LECTURE ON DC MOTOR

Force on a conductor

- **If a conductor is placed in a magnetic field and current is allowed to flow through the conductor, the conductor will experience a mechanical force.**

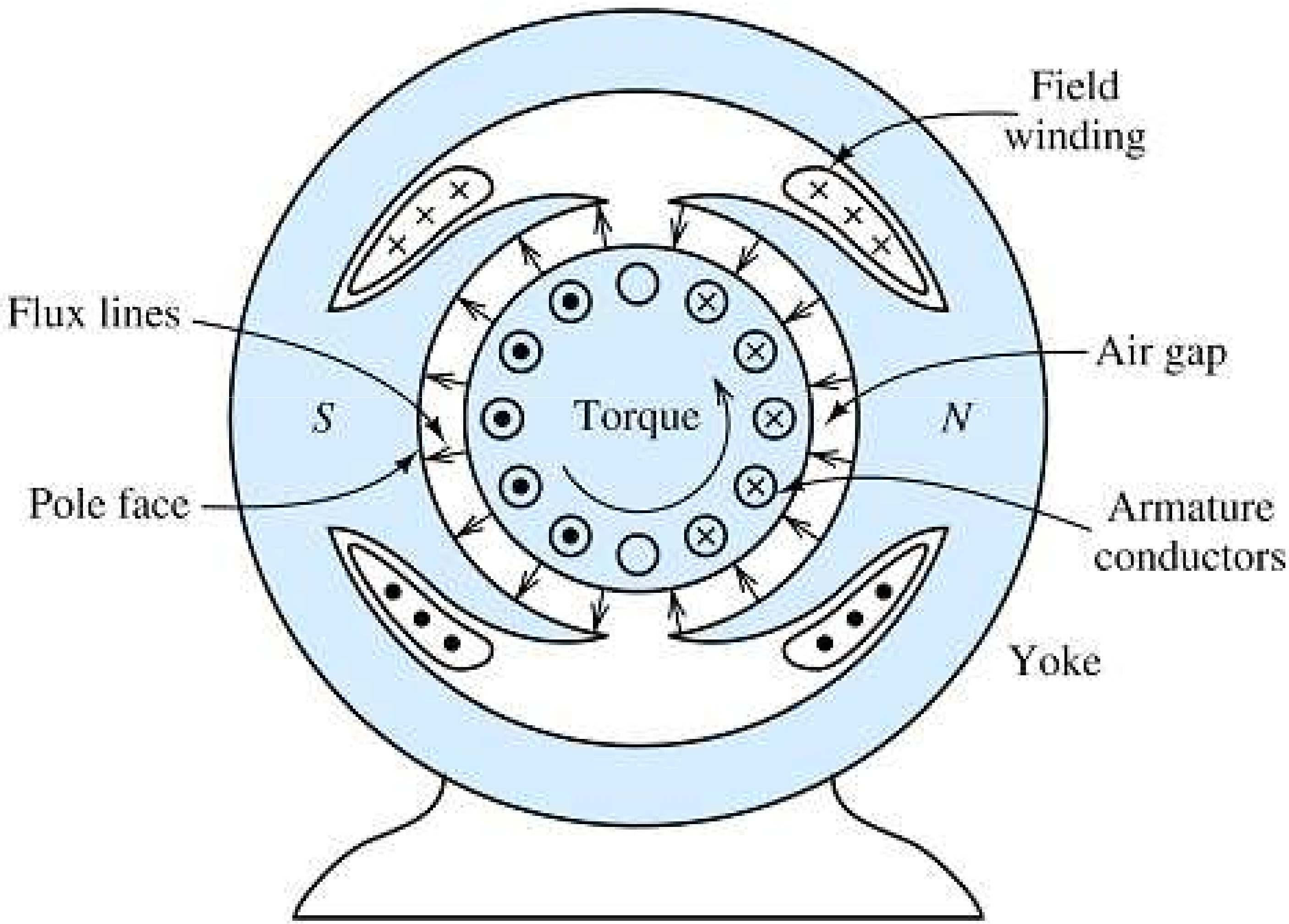


Electric Motor



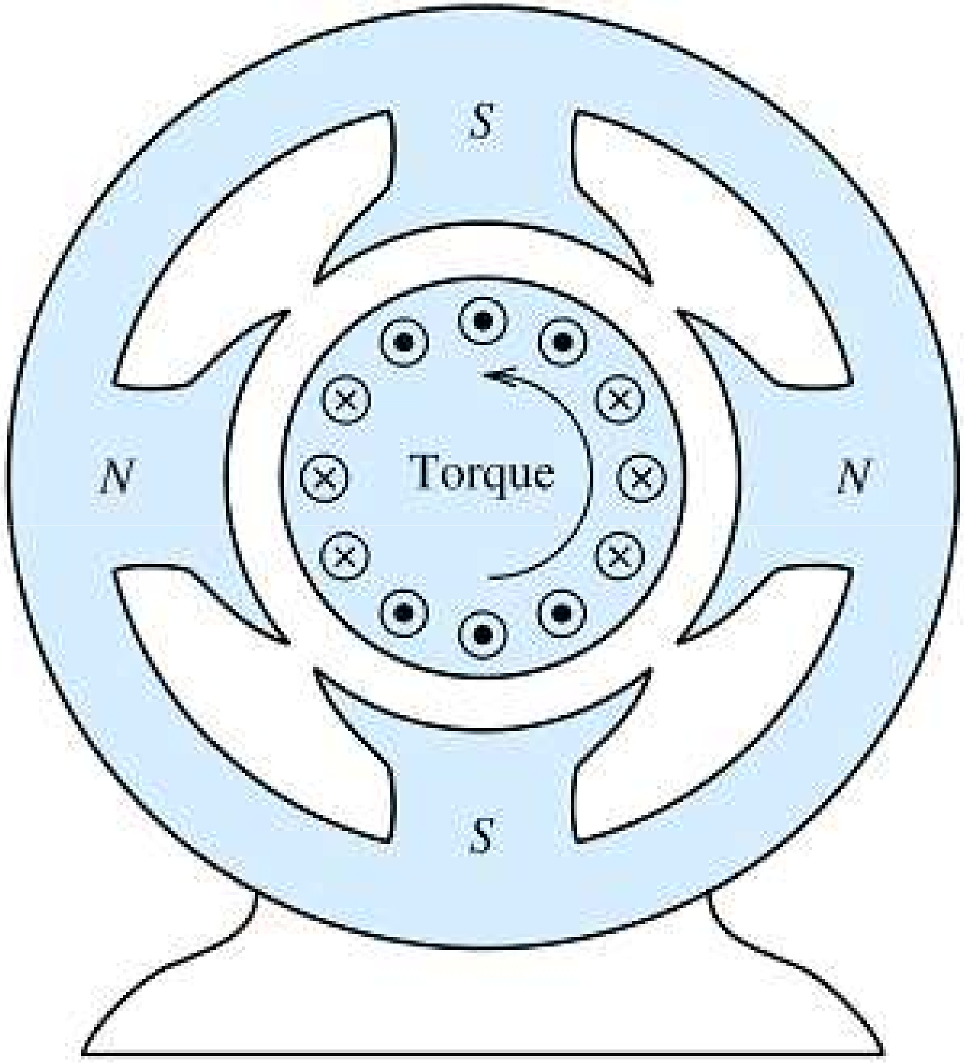
An electrical motor consists of a cylindrical rotor that spins inside a stator.

A Two Pole DC Motor



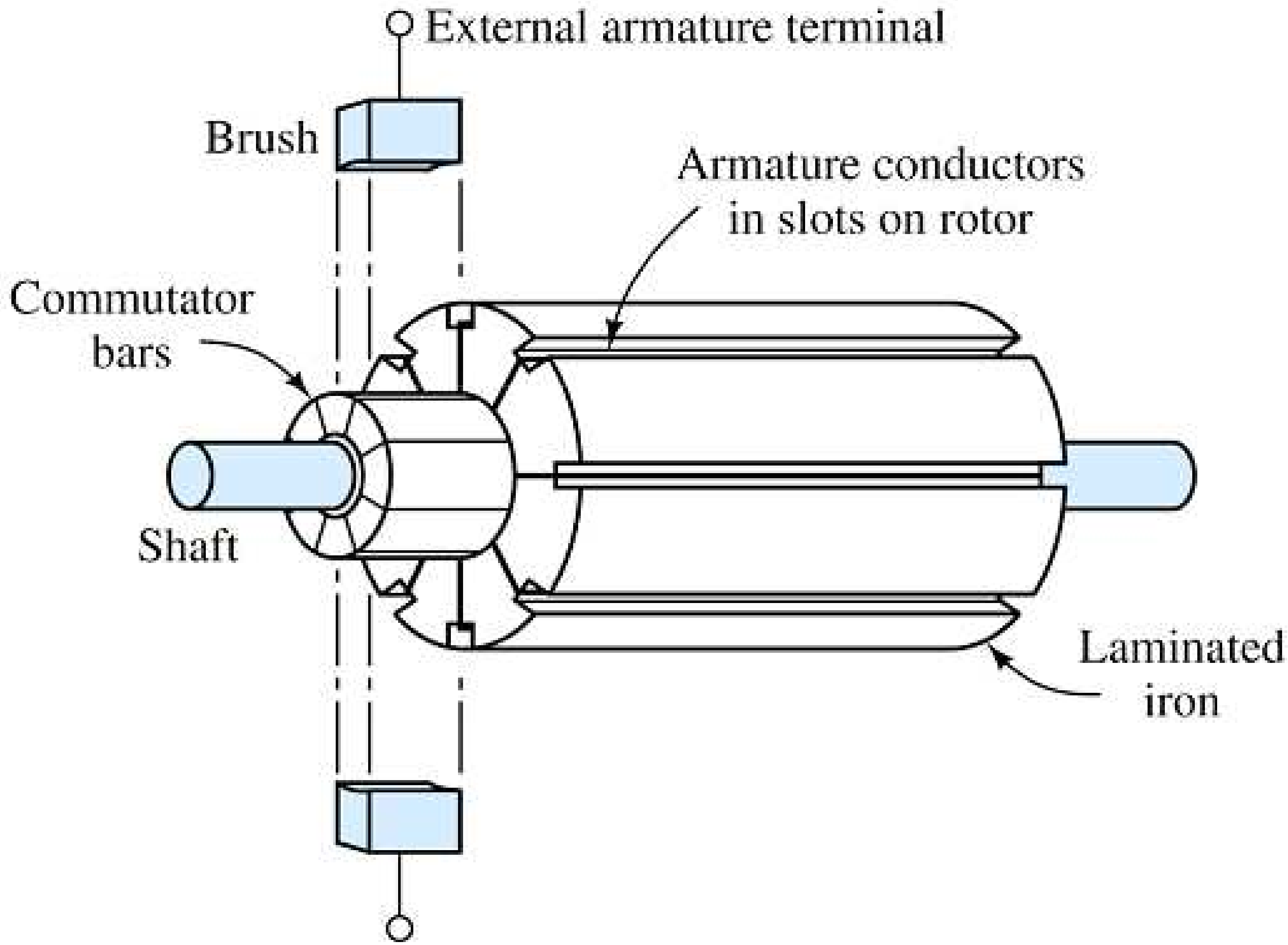
Cross section of a two-pole dc machine

A Four Pole DC Motor

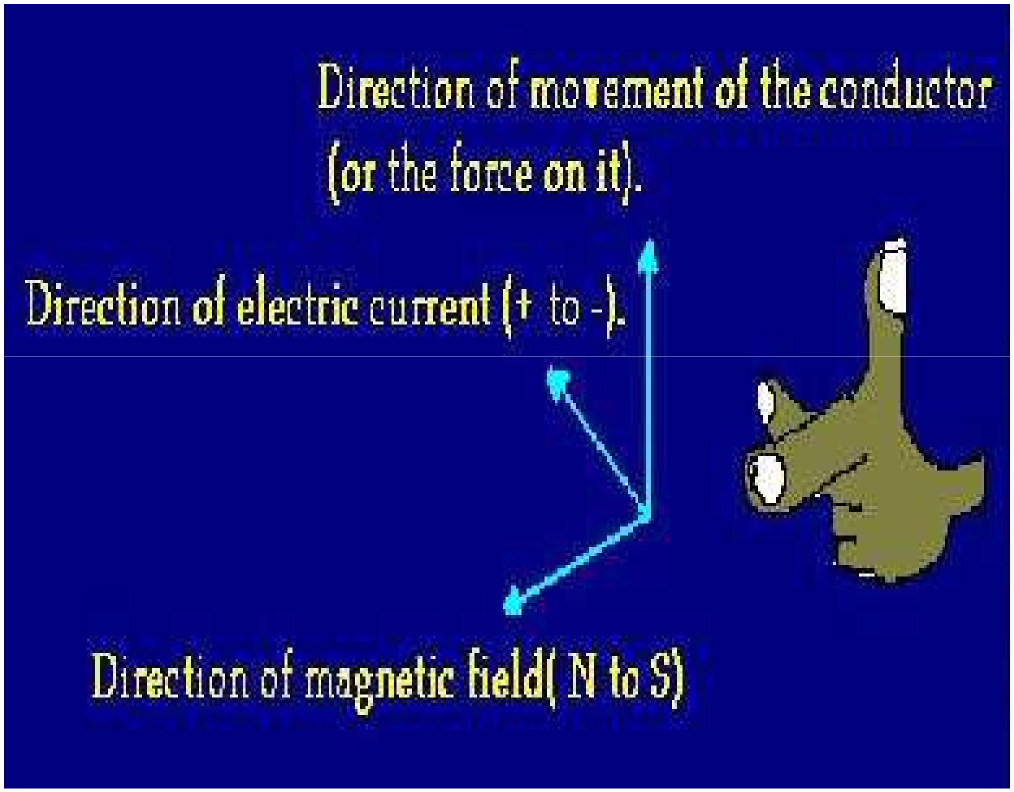


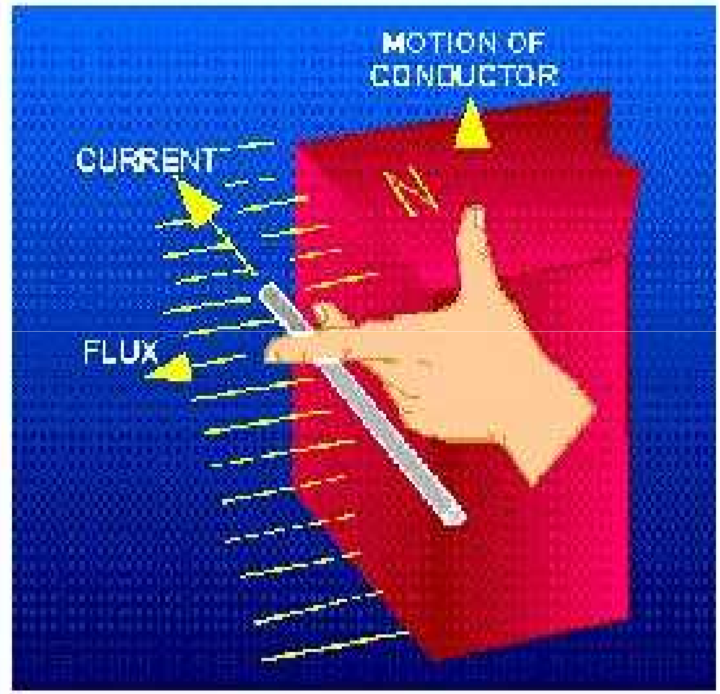
Cross section of a four-pole dc machine

Armature of a DC Motor

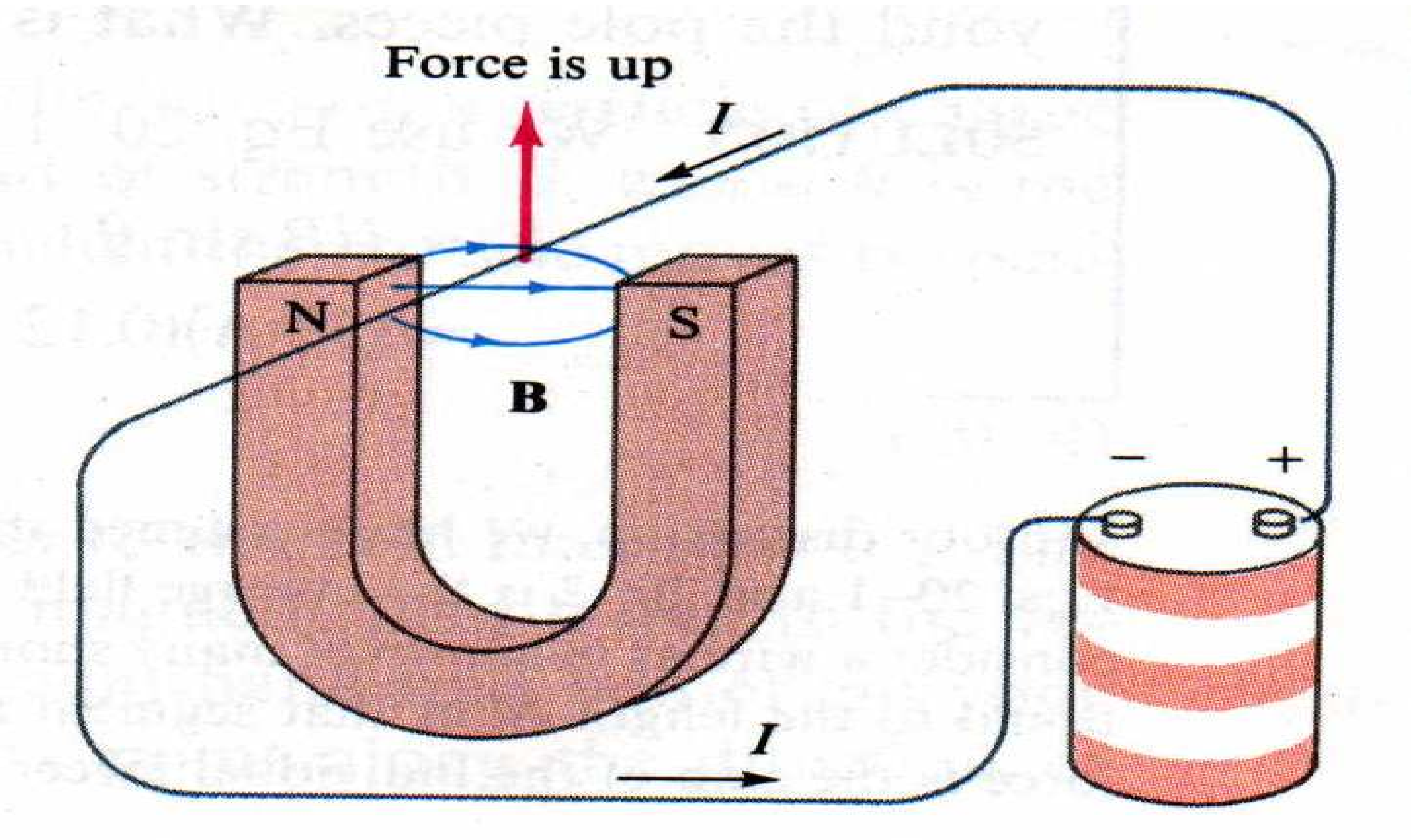


Fleming's Left-Hand Rule





Direction of Force in a Conductor



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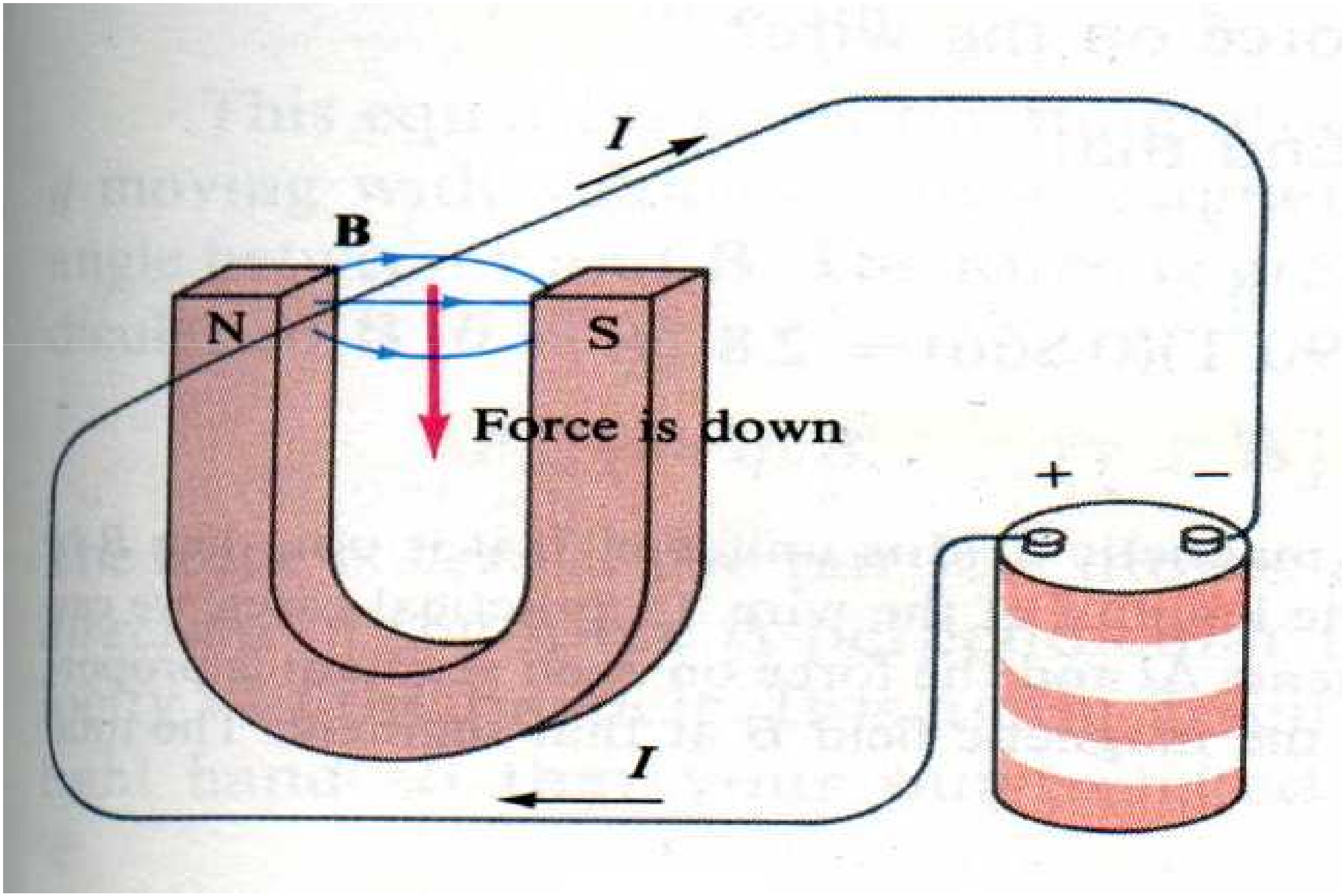
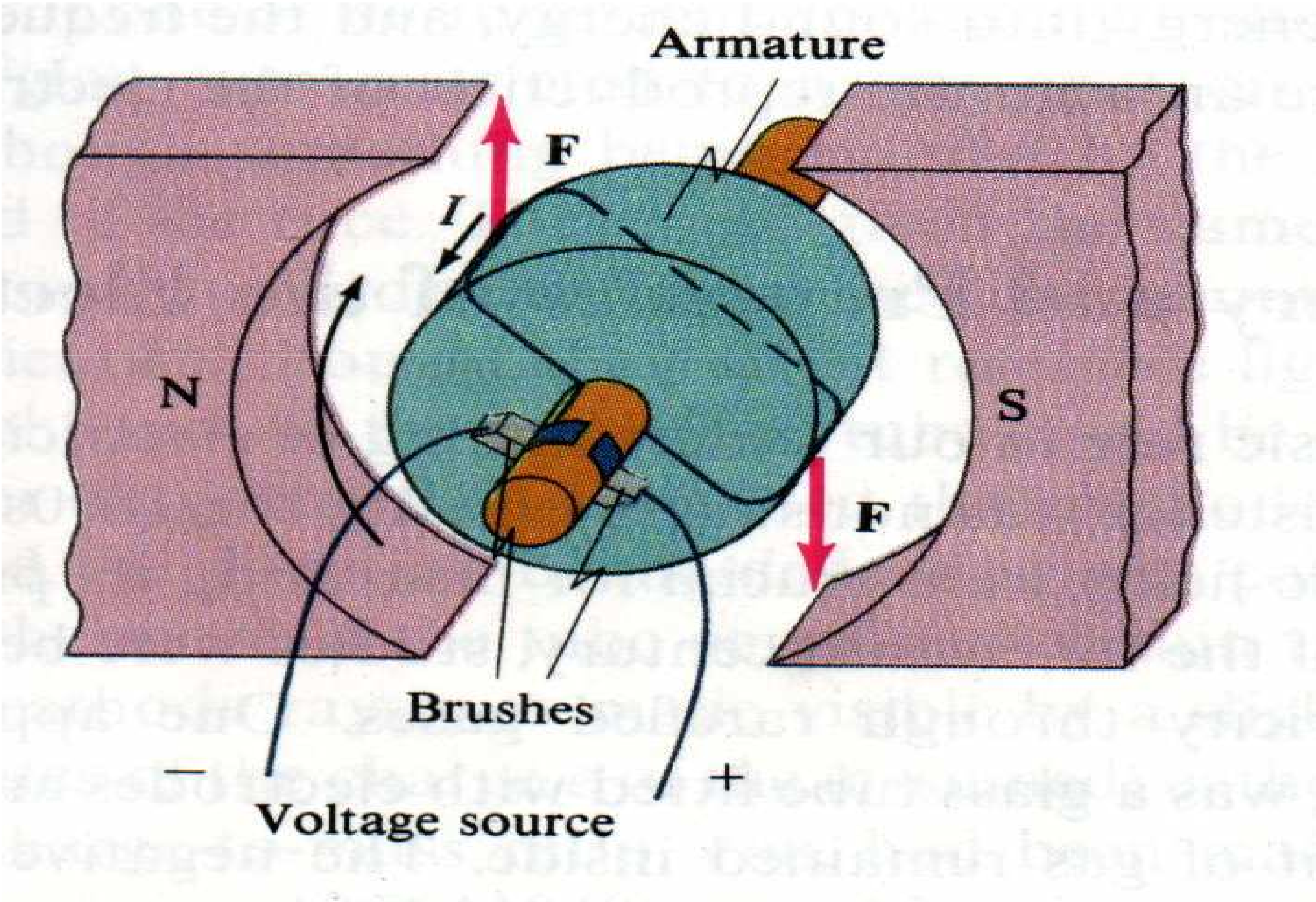


Diagram of a Simple DC Motor

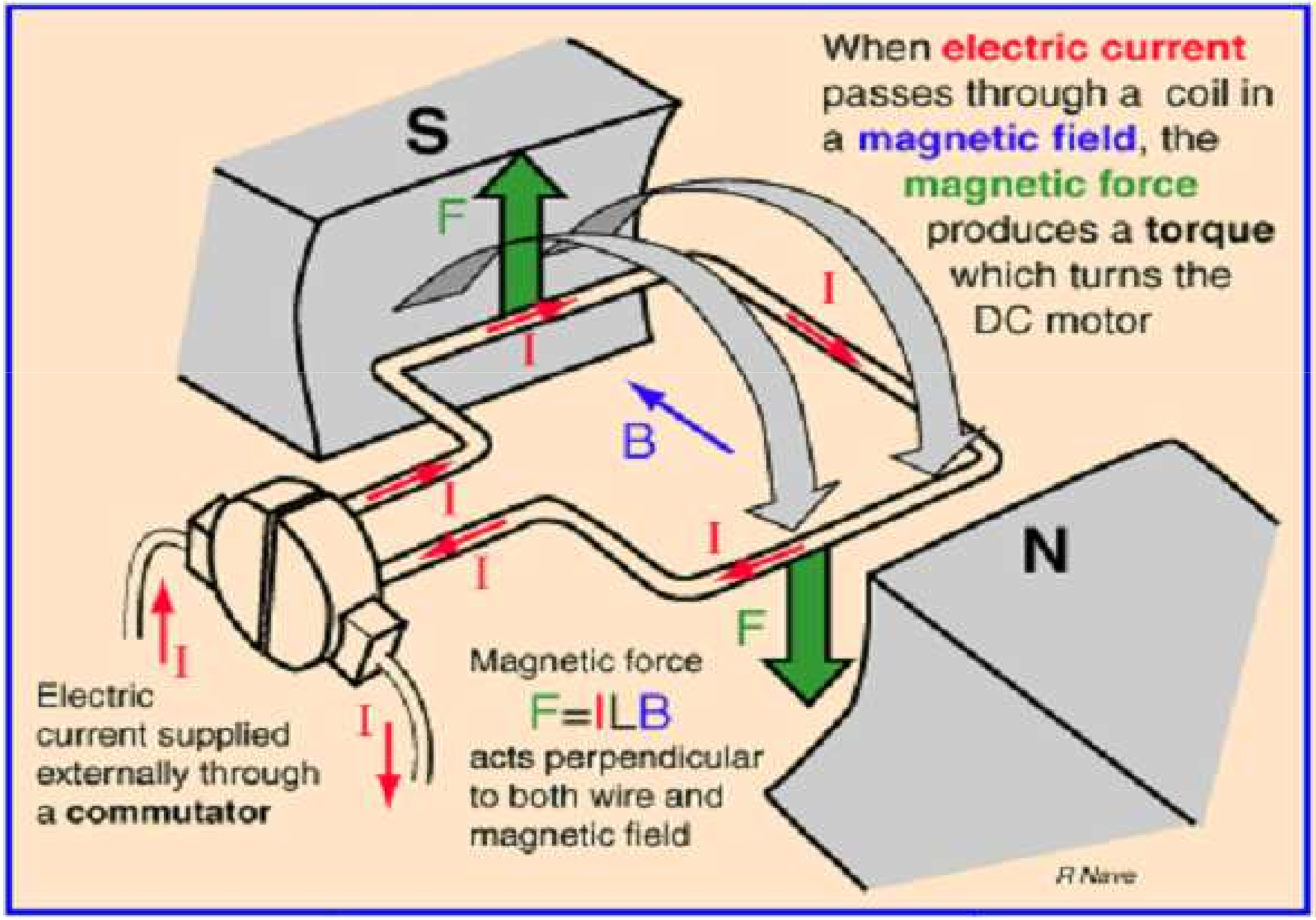


Motor Principle

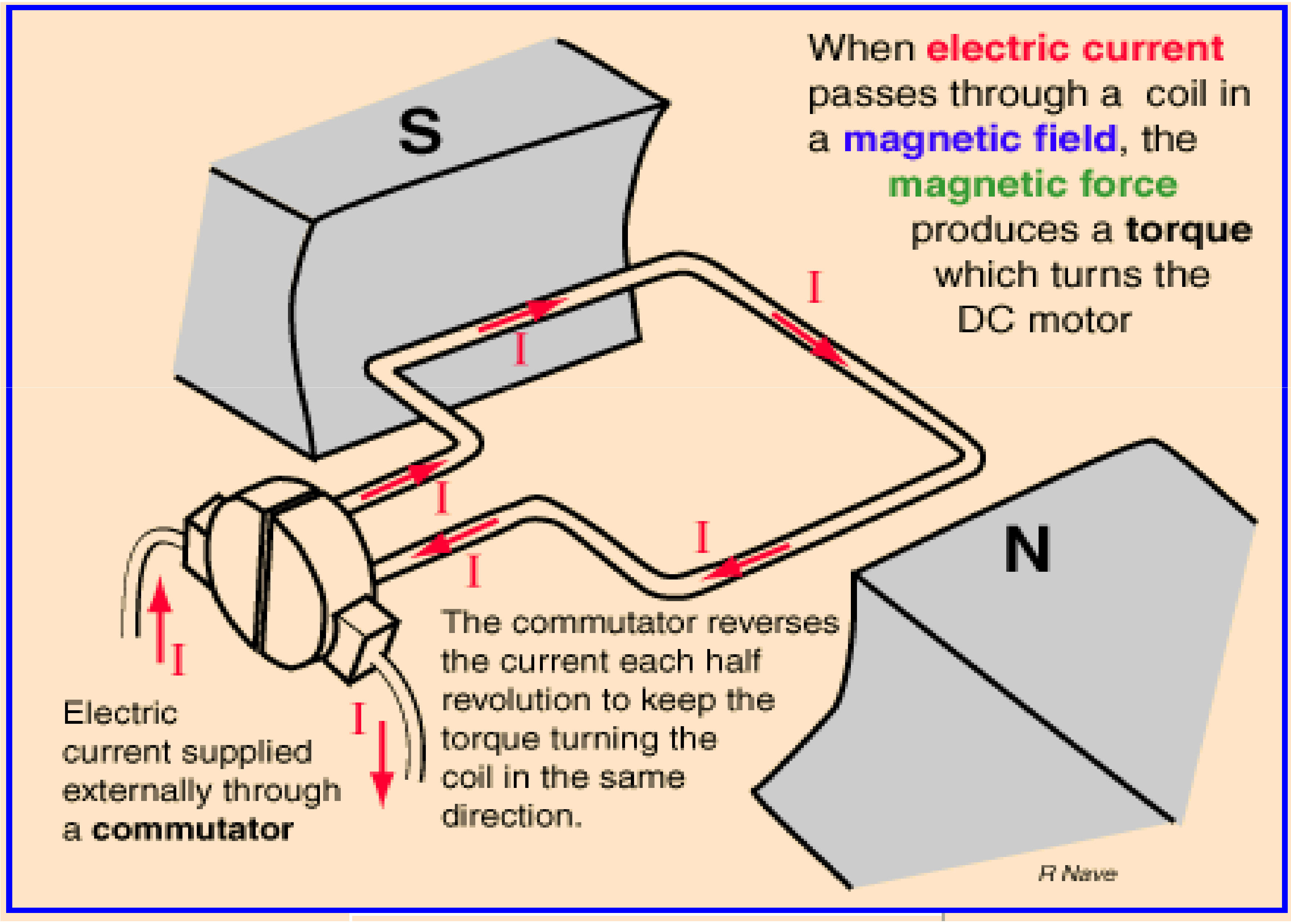
- **An electric motor is a machine which converts electrical energy into mechanical energy.**
- **Principle:** It is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's Left-hand Rule and whose magnitude is given by

  - Force, $\mathbf{F = B\ I\ l}$ newton
  - Where B is the magnetic field in wb/m^2.
  - I is the current in amperes and
  - l is the length of the coil in meter.

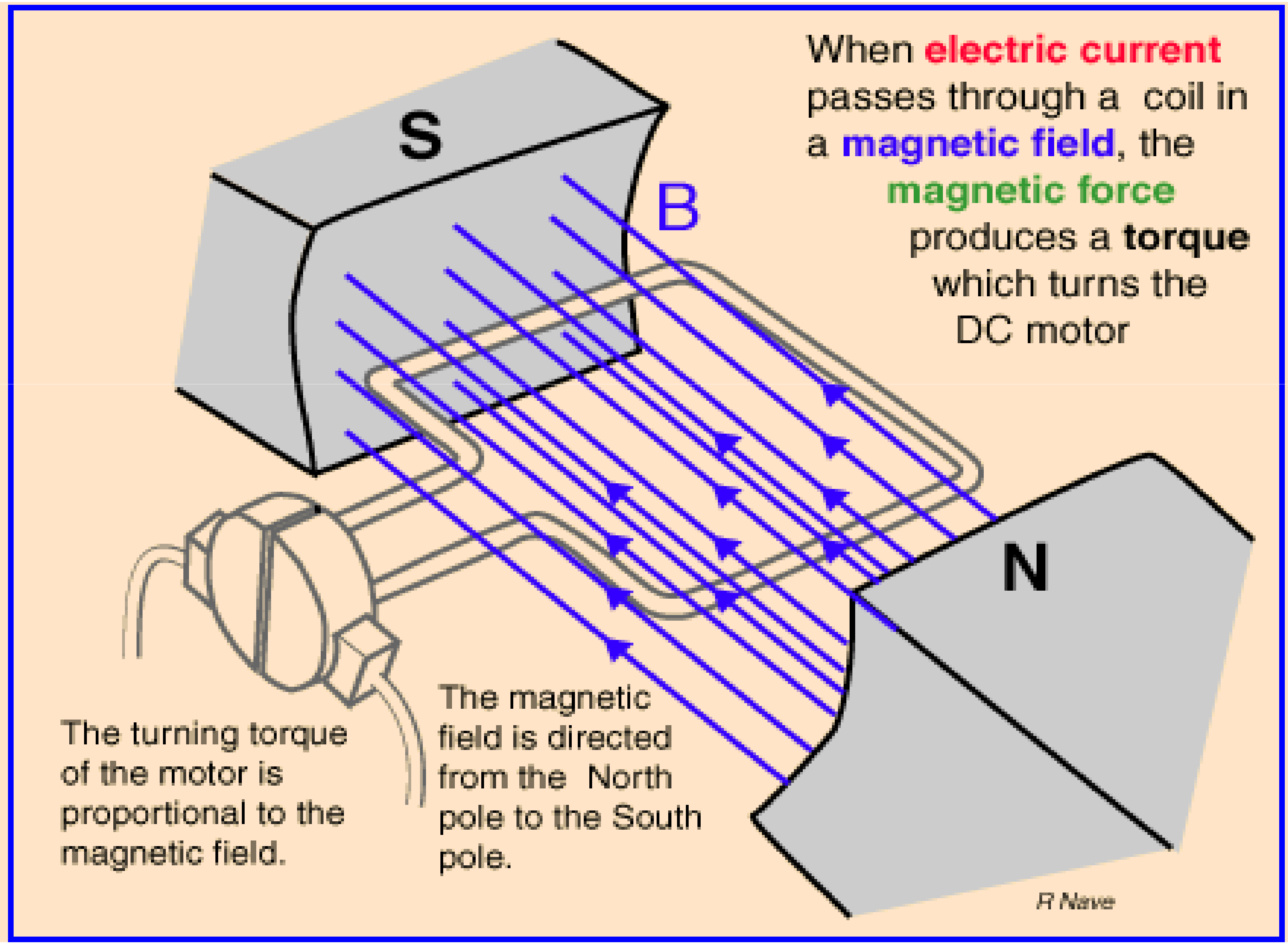
DC Motor Operation



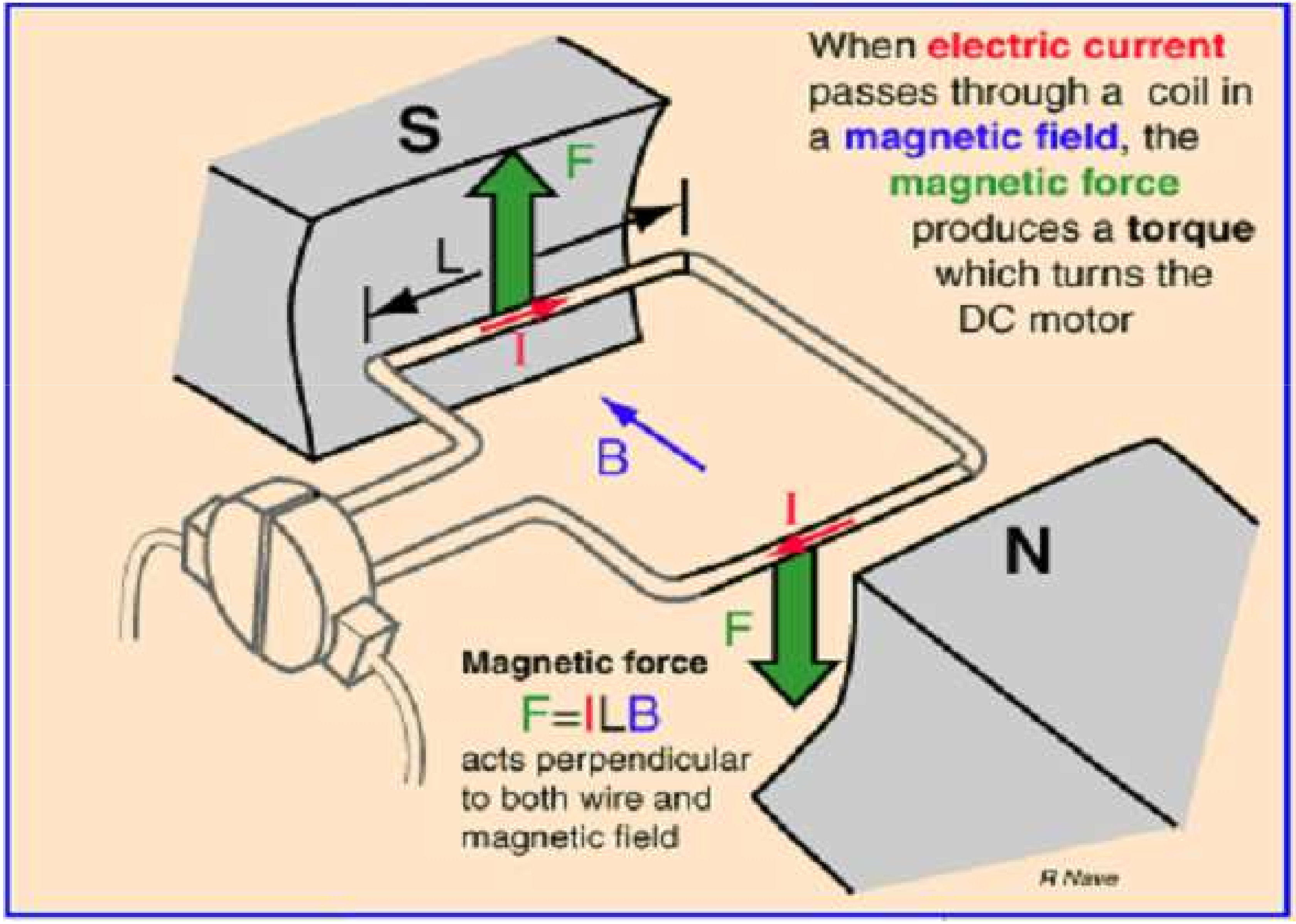
Current in DC Motor



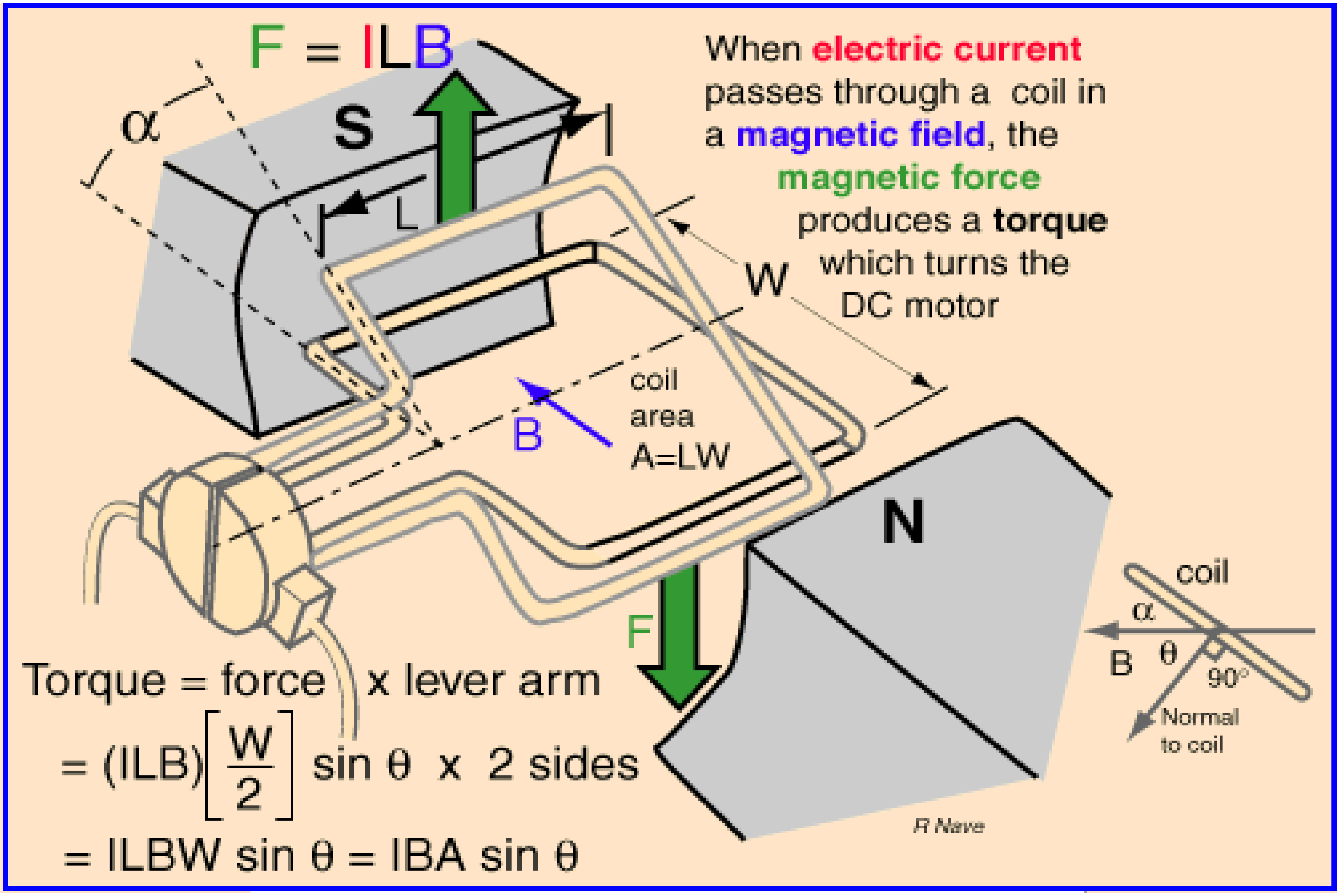
Magnetic Field in DC Motor



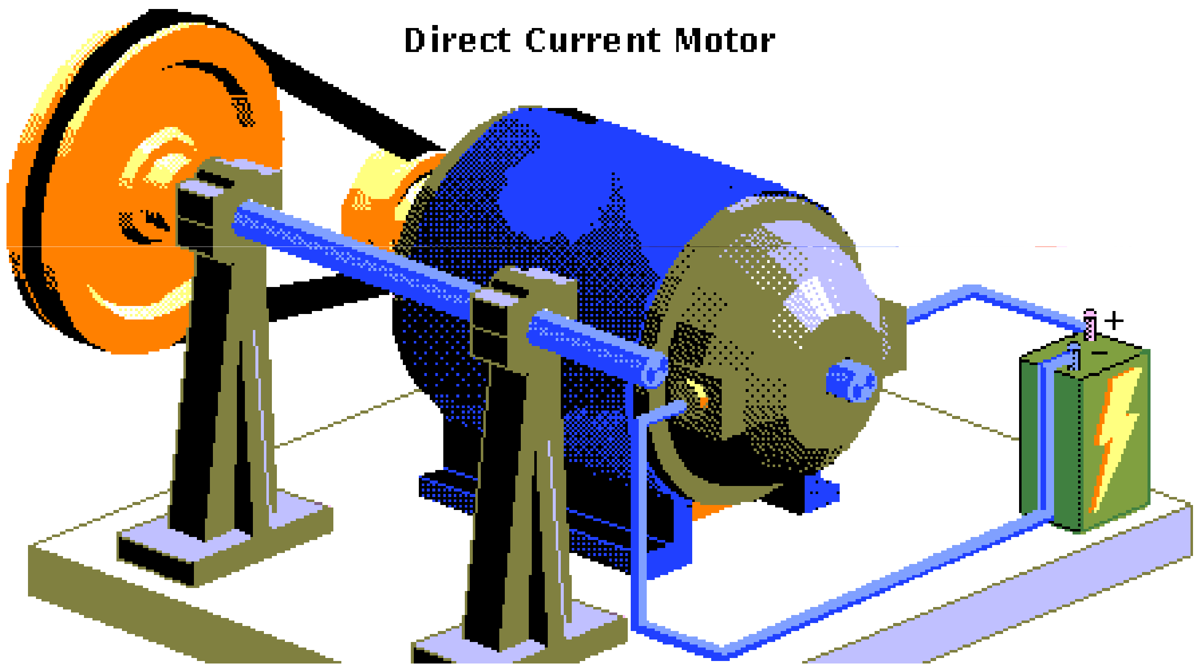
Force in DC Motor



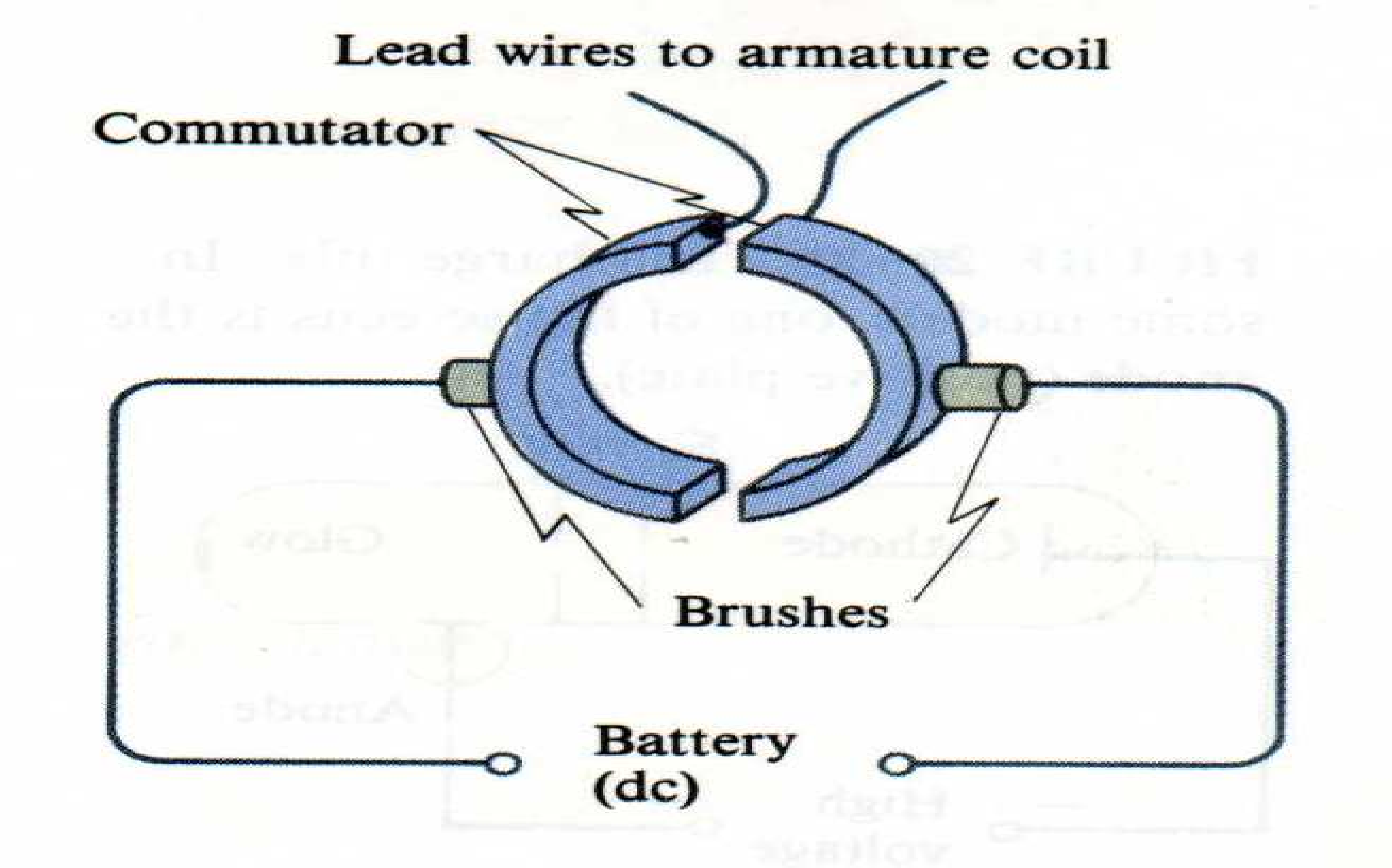
Torque in DC Motor



Electric Motor



Commutator



Comparison of Generator and Motor Action

- Fundamental laws of nature is no energy conversion from one form to another is possible until there is some one to oppose the conversion.
- Magnetic Drag for Generator
- Back e.m.f. for Motor

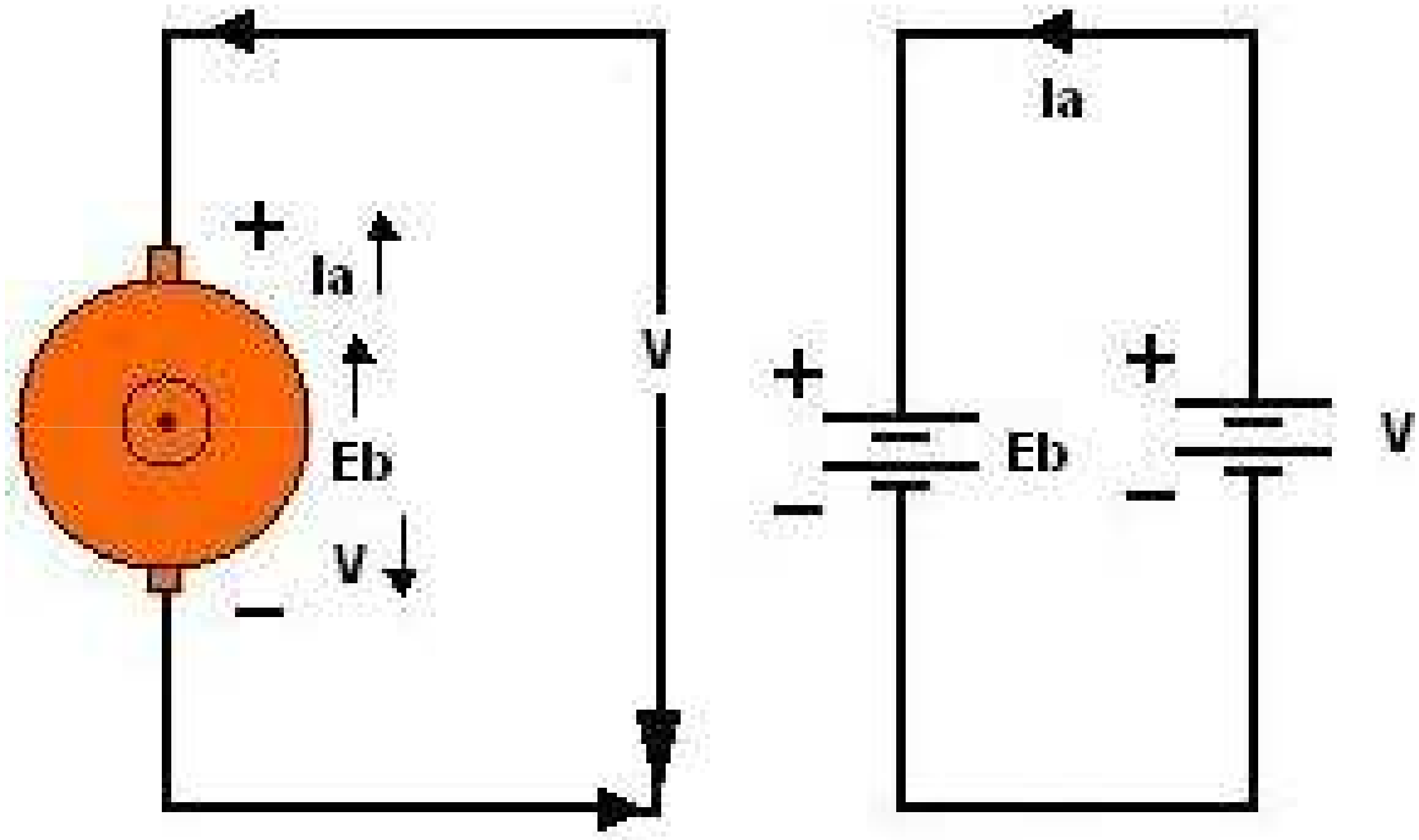
DC Motor Types

- Important DC motor types:
  - Shunt Motors
  - Series Motors
  - Compound Motors

Counter e.m.f or Back e.m.f. of DC Motor

- When the motor armature rotates, the conductors also rotates and hence cut the flux. According to the laws of Electromagnetic Induction, e.m.f. is induced in them whose direction is found by Fleming's Right-hand Rule, is in opposition of the applied voltage. Because of its opposing direction, it is called as counter e.m.f. or back e.m.f.

Equivalent Circuit of a DC Motor



$$V = E_b + I_a R_a + V_{brush}$$

Voltage Equation of a DC Motor

- Multiplying both sides by I_a we get,

$$VI_a = E_b I_a + I_a^2 R_a$$

- VI_a= Electrical Input to the armature,
- $E_b I_a$= Electrical Equivalent of mechanical power developed in the armature,
- $I_a^2 R_a$= Cu loss in armature.
- Motor Efficiency: It is the ratio of power developed by the armature to its input, i.e.

$$E_b I_a / VI_a = E_b / V$$

Condition For Maximum Power

- The gross mechanical power developed by a motor is: $P_m = VI_a - I_a^2 R_a$
- For Maximum Power Condition:

$$\frac{dP_m}{dI_a} = \frac{d}{dI_a}\left(VI_a - I_a^2 R_a\right)$$

$$\Rightarrow V - 2I_a R_a = 0$$

$$\Rightarrow V = 2I_a R_a$$

$$\Rightarrow I_a R_a = \frac{V}{2}$$

$$V = E_b + I_a R_a$$

$$\Rightarrow V = E_b + \frac{V}{2}$$

$$\Rightarrow E_b = \frac{V}{2}$$

Torque

- Torque $T = F \times r$ Newton-metre(N-m)

  where, F= Force, r = radius of the circumference.
- Power developed = $(F \times r) \times 2\pi N$ watt

  where, $2\pi N$ =Angular velocity ω in radian/second
- Power developed= $T \times \omega$ watt

$$\omega = \frac{2\pi N}{60} rad / s$$

$$So, P = \frac{2\pi N}{60} \times T$$

$$\Rightarrow P = \frac{2\pi}{60} \times NT$$

$$\Rightarrow P = \frac{NT}{9.55}$$

Torques in A DC Motor

- There are Two Torques in a dc motor:
  - Armature Torque
  - Shaft Torque

Armature Torque(T_a)

- Power developed in armature = $T_a \times \frac{2\pi N}{60}$ where N is in r.p.m.
- Also, electrical converted into mechanical power in the armature is = $E_b I_a$ watt
- So,

$$T_a \times \frac{2\pi N}{60} = E_b I_a \Rightarrow T_a = \frac{E_b I_a}{2\pi N}$$ N in rps

$$Also, E_b = \Phi Z N \times \left(P/A\right) volt$$

$$Therfore, T_a \times \frac{2\pi N}{60} = \Phi Z N \times \left(\frac{P}{A}\right) \times I_a$$

$$\Rightarrow T_a = \frac{\Phi Z}{2\pi} \times \left(\frac{P}{A}\right) \times I_a$$

$$\Rightarrow T_a = 0.159 \Phi Z \times \left(\frac{P}{A}\right) \times I_a$$ N-m

Armature Torque cont.

$$T_a = 0.159\Phi Z \times \left(\frac{P}{A}\right) \times I_a$$

- From the above equation,we find that, $T_a \propto \Phi I_a$
- In the case of Series Motor:Since field winding carry full armature current:

$$\Phi \propto I_a$$

$$\therefore T_a \propto I_a^{\ 2}$$

- In the case of Shunt Motor: Φ is practically constant.So, $T_a \propto I_a$

Shaft Torque(T_{sh})

- The Torque which is available for doing useful work is known as shaft torque, T_{sh} .

$$Output = T_{sh} \times \frac{2\pi N}{60}$$

$$\Rightarrow T_{sh} = \frac{Output}{2\pi N / 60}$$

$$\Rightarrow T_{sh} = 9.55 \frac{Output}{N}$$

- **Lost Torque:** The differences $(T_a - T_{sh})$ is known as lost torque and is due to iron and friction losses of the motor.

Examples

Ex-1: A 220-V d.c. machine has an armature resistance of 0.5Ω. If the full-load armature current is 20A, find the induced e.m.f. when the machine acts as (i) generator (ii) motor.

Examples cont.

Ex-2: A 440-V shunt motor has an armature resistance of 0.8Ω and field resistance of 200Ω . Determine the back e.m.f. when giving an output of 7.46kW at 85 percent efficiency.

Examples cont.

Ex-3: A d.c. motor takes an armature current of 110A at 480V.The armature circuit resistance is 0.2Ω. The machine has 6-poles and the armature is lap-connected with 864 conductors. The flux per pole is 0.05Wb. Calculate (i) the speed, (ii) the gross torque developed by the armature.

Examples cont.

Ex-4: Determine the developed torque and shaft torque of 220V,4-poles series motor with 800 conductors wave-connected supplying a load of 8.2kW by taking 45A from the mains. The flux per pole is 25mWb and its armature circuit resistance is 0.6Ω.

Speed of A DC Motor cont

- For Series Motor

N_1 = Speed in the 1st case

I_{a1} = armature current in the 1st case

Φ_1 = flux/pole in the 1st case

N_2 = Speed in the 2nd case

I_{a2} = armature current in the 2nd case

Φ_2 = flux/pole in the 2nd case

We can write using the speed equation:

$$N_1 \propto \frac{E_{b1}}{\Phi_1} \quad \text{and} \quad N_2 \propto \frac{E_{b2}}{\Phi_2}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\Phi_1}{\Phi_2}$$

Prior to the saturation of magnetic poles: $\Phi \propto I_a \therefore \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$

- For Shunt Motor

Using the speed equation: $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\Phi_1}{\Phi_2}$ If $\Phi_2 = \Phi_1$,then $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$

Speed Regulation

- The speed regulation is the change in speed when the load on the motor is reduced from rated value to zero, expressed as percent of the rated load speed.

- Speed regulation= $\dfrac{N.L.speed - F.L.speed}{F.L.speed} \times 100 = \dfrac{dN}{N} \times 100$

Torque and Speed of A DC Motor

$$N = K\frac{V - I_a R_a}{\Phi} = K\frac{E_b}{\Phi}$$

$$T_a \propto \Phi I_a$$

- Increase in flux decreases the speed but increases the torque.
- It cannot be happened
- Because torque always tend to produce rotation.Hence, if torque increases, motor speed must increase rather than decrease.
- If torque is decreased by decreasing the field current the following sequences are found:

1. Back e.m.f. $\left(E_b = \frac{N\Phi}{K}\right)$ drops instantly, the speed remaining constant because of the inertia of heavy armature.
2. Due to decrease of E_b, I_a is increased because of $I_a = \frac{(V - E_b)}{R_a}$
3. A small decrease of Φ is more than counterbalanced by a large increase of I_a which means net increase of torque, T_a .
4. This increase in T_a produces an increase in motor speed.

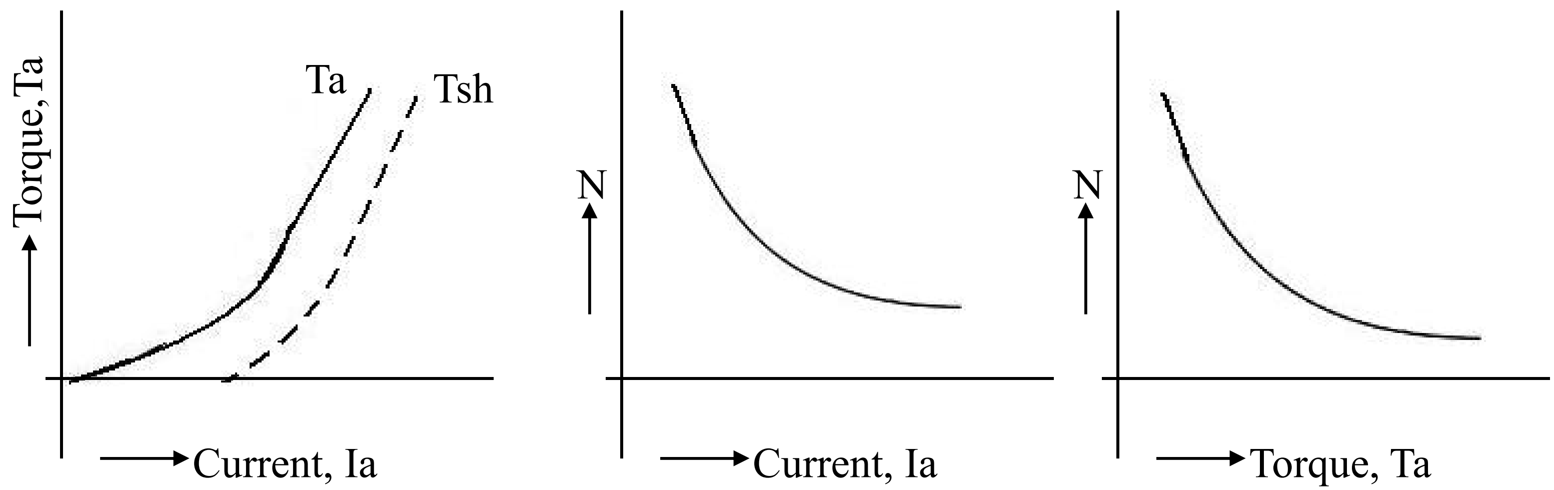
Motor Characteristics

- Torque and armature current i.e. T_a / I_a characteristic.Its known as *Electrical characteristic.*
- Speed and armature current i.e. N / I_a characteristic.
- Speed and torque: i.e. N / T_a characteristic.It is also know as *Mechanical characteristic.*

$$T \propto \Phi I_a \quad \textit{and} \quad N \propto \frac{E_b}{\Phi}$$

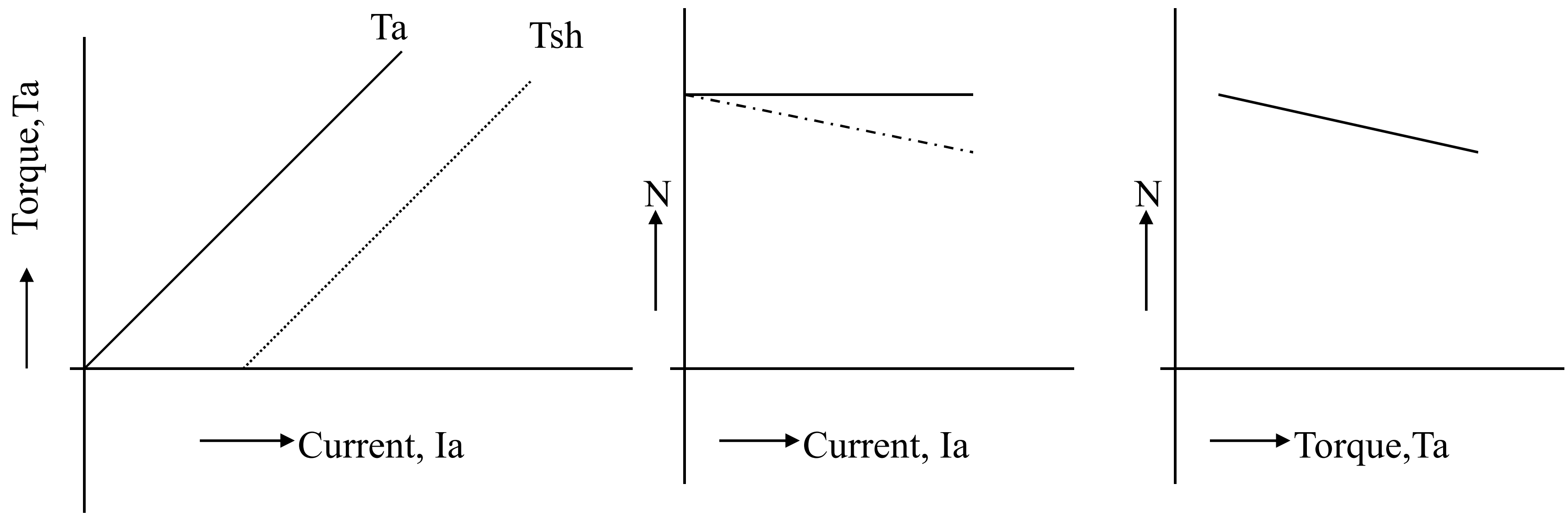
Characteristics of A Series Motor

- T_a / I_a characteristic:. Here, $\Phi \propto I_a$. So, $T_a \propto I_a^2$
- N / I_a characteristic: $N \propto \frac{E_b}{\Phi}$
- N / T_a characteristic:It is found from the above two characteristics.



Characteristics of A Shunt Motor

- T_a/I_a characteristic: Φ is practically constant. So, $T_a \propto I_a$
- N/I_a characteristic: Φ is practically constant. So, $N \propto E_b$
- N/T_a characteristic:It is found from the above two characteristics.



Characteristics of Compound Motor

1) Cumulative-compound Motors
2) Differential-compound Motors

Summary

Type of motor	Characteristics	Applications
Shunt	Approximately constant speed, Adjustable speed, Medium starting torque(Up to 1.5 F.L. torque)	For driving constant speed line shafting Lathes Centrifugal Pumps Machine tools Blowers and fans Reciprocating pumps
Series	Variable speed, Adjustable varying speed, High starting torque	For traction work i.e. Electric locomotives Rapid transit systems Trolley cars etc. Cranes and hoists Conveyors
Compound	Variable speed, Adjustable varying speed, High starting torque	For intermittent high torque loads For shears and punches Elevators Conveyors Heavy Planers Rolling mills; Ice Machines; Printing presses; Air Compressors

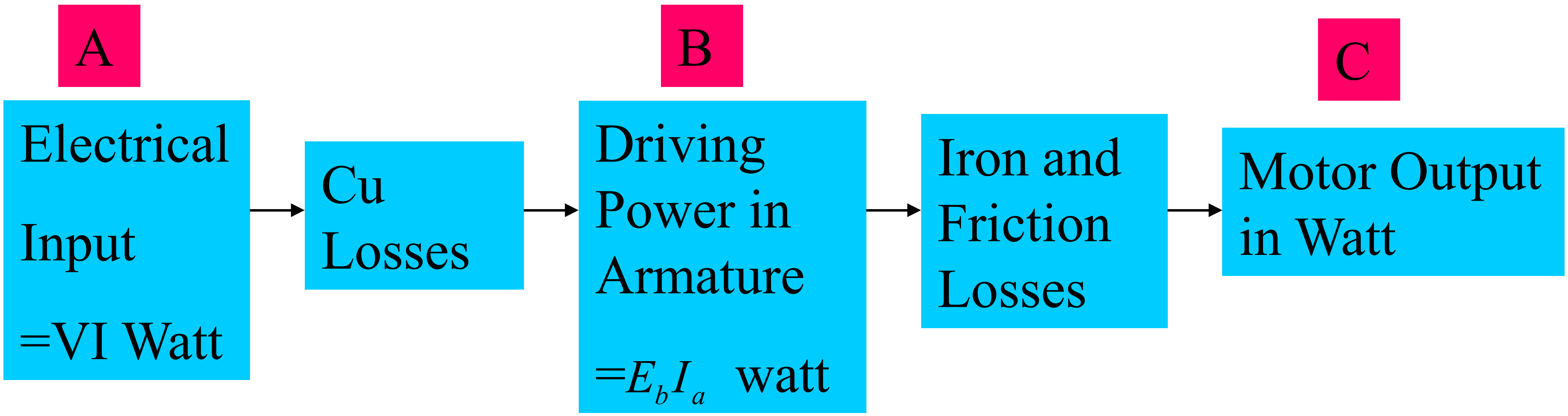
Losses and Efficiency

- Same as dc generator

1) Copper Losses
2) Magnetic Losses
3) Mechanical Losses

- The condition for maximum power developed by the armature is: $I_a R_a = E_b = \frac{V}{2}$
- The condition for maximum efficiency is that armature Cu losses are equal to constant losses.

Power Stages



- Overall efficiency, $\eta_c = \frac{C}{A}$
- Electrical efficiency, $\eta_e = \frac{B}{A}$
- Mechanical efficiency, $\eta_m = \frac{C}{B}$

Examples