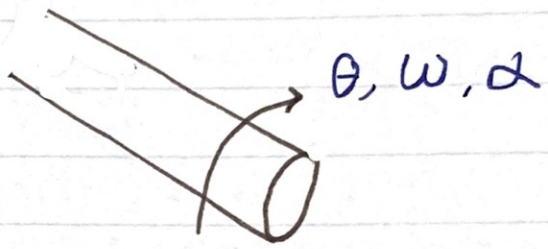
Introduction to Machinery Principles

- **Generator**: Mechanical energy → Electic energy
- **Motor**: Electric energy → Mechanical energy
- **Transformer**: Converts AC Electric energy ab one voltage level to another

Definitions :-

1. Angular Position (θ) : [rad]
   - → + : counterclockwise
   - → − : clockwise



2. Angular Velocity (ω): [rad/s]

$$\omega = \frac{d\theta}{dt}$$

$$f_m = \frac{\omega_m}{2\pi} \quad \text{rev/s}$$

$$n_m = 60 f_m \quad \text{rev/m}$$

3. Angular acceleration (α): [rad/s^2]

$$\alpha = \frac{d\omega^2}{d^2t}$$

4. Torque : τ : Nm

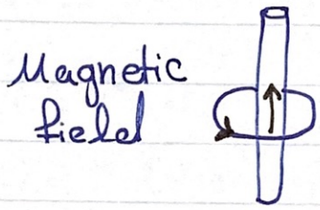
In Rotational movement : $\tau = J\alpha$ ← moment of inertia

5. Work (W) : [J]
   In Rotational movement: $W = \tau\theta$

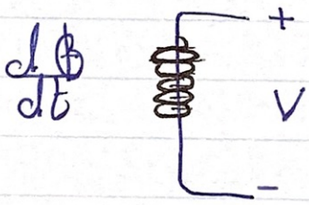
6. Power (P): [J/s]
   ~ ~ ~ : $P = \tau w$

Basic principals of Magnetic field

1. A current carrying a wire produces magnetic field in the area around it.

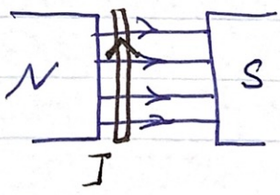


2. A time changing magnetic fiked induces a voltage in a coil of wire if it passes through that coil



3. In a current-carrying wire in the presence of magnetic field has a force induced to it.

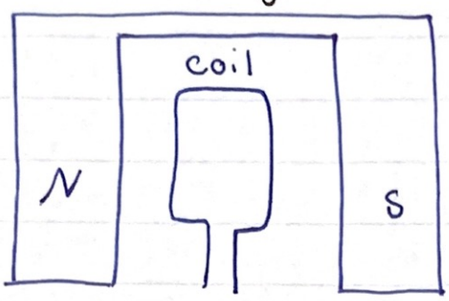
$F = i.(l \times B)$



This force will move the conductor (Mechanical energy)

4. A moving wire in the presence of a magnetic field has a voltage induced to it

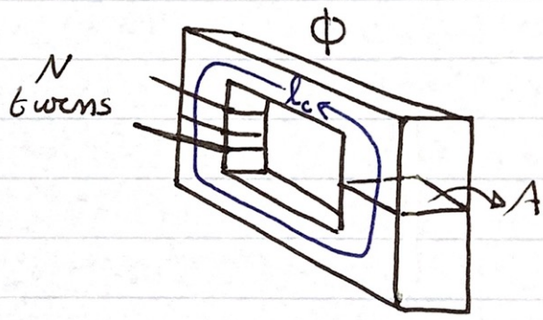
$e_{ind} = l.(V \times B)$
so (electrical energy)



Production of a Magnetic field

$$H = \frac{Ni}{l_c}$$

- magnetic field intensity [A.N/m]



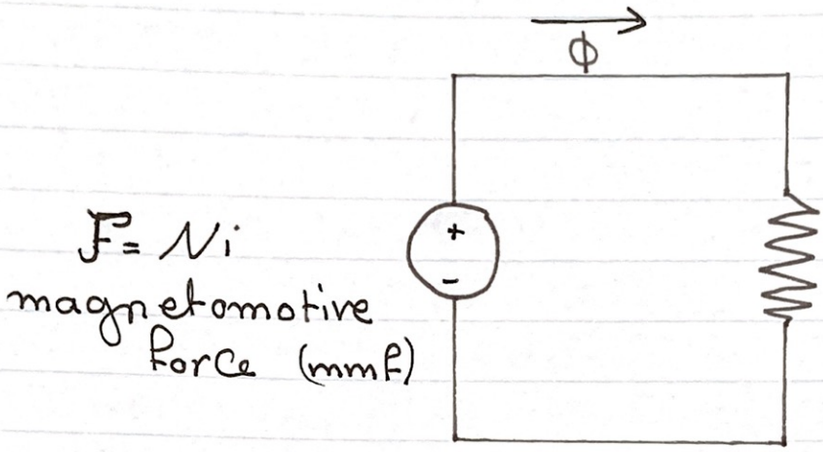
$B = \mu H$ → permeability [Henrys / m]

- magnetic flux density [Webers / m^2 (T)]

for steel
$= 2000 \rightarrow 6000$ $\quad \mu_r = \frac{\mu}{\mu_0}$ → perm. of free space
= Perm. of air = $4\pi \times 10^{-7}$

Flux $\phi = \frac{\mu N i A}{l_c}$ [weber]

Magnetic Circuit



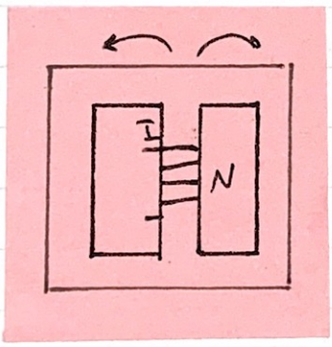
$\mathcal{F} = Ni$ magnetomotive force (mmf)

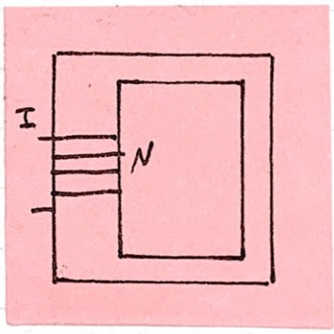
$\mathcal{R}$: Reluctance [A.N/weber]

$\phi = \frac{\mathcal{F}}{\mathcal{R}}$. $\mathcal{R} = \frac{l_c}{\mu A}$

Parallel: $1/\mathcal{R}_{eq} = 1/\mathcal{R}_1 + 1/\mathcal{R}_2 \cdots$

Series: $\mathcal{R}_{eq} = \mathcal{R}_1 + \mathcal{R}_2$



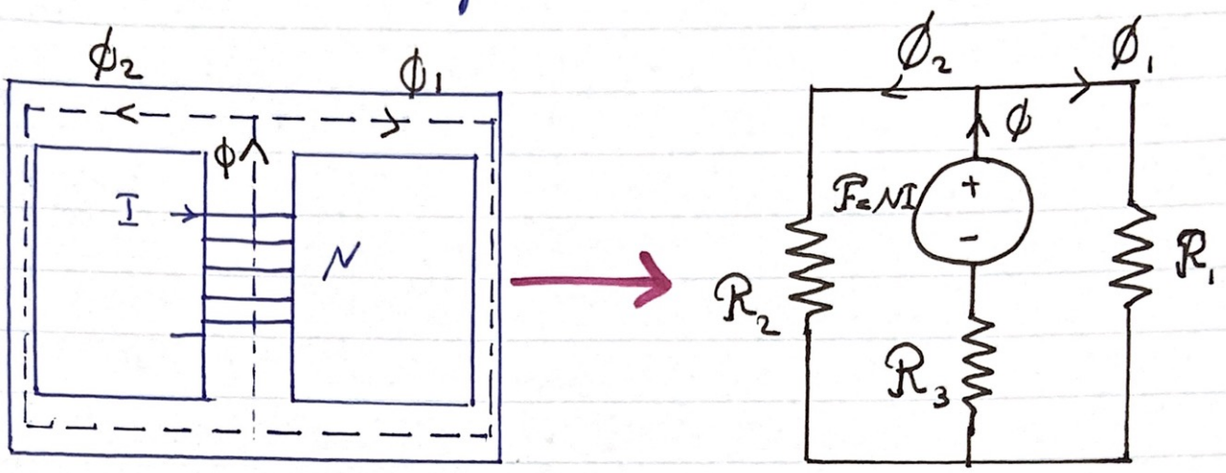


→ permeance

$\mathcal{P} = \frac{1}{\mathcal{R}} \rightarrow \phi = \mathcal{F}\mathcal{P}$ $\mathcal{P} = \frac{\mu A}{l_c}$

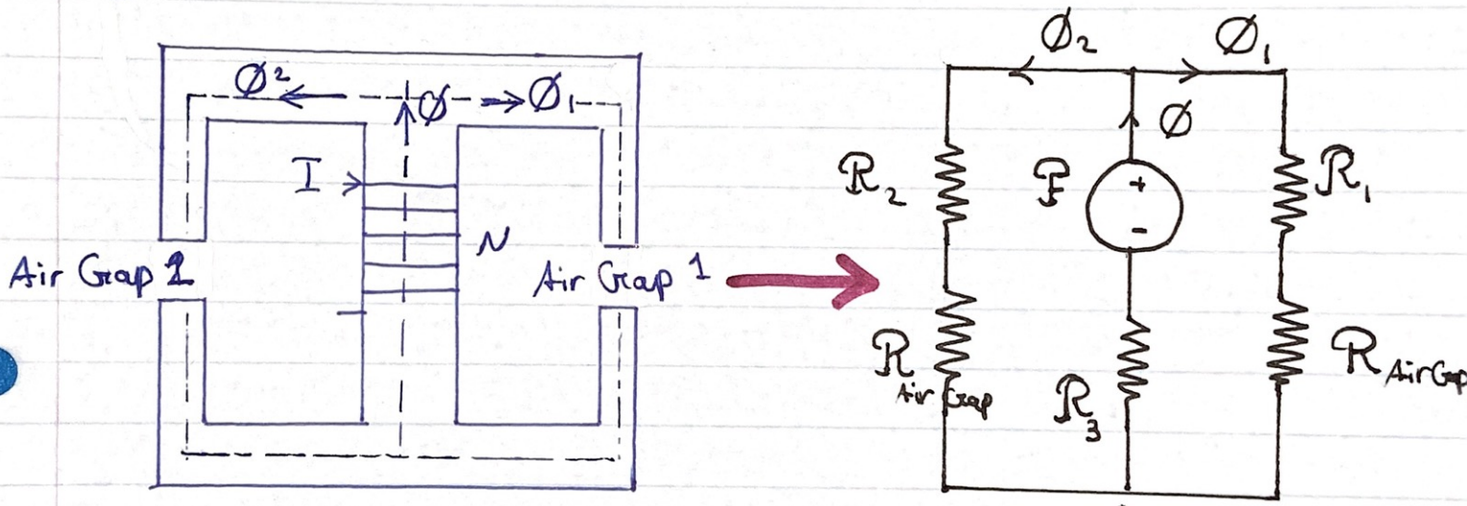
Examples of Magnetic Circuits

(1



- we deal with ϕ like current (You can use current Divider Rule

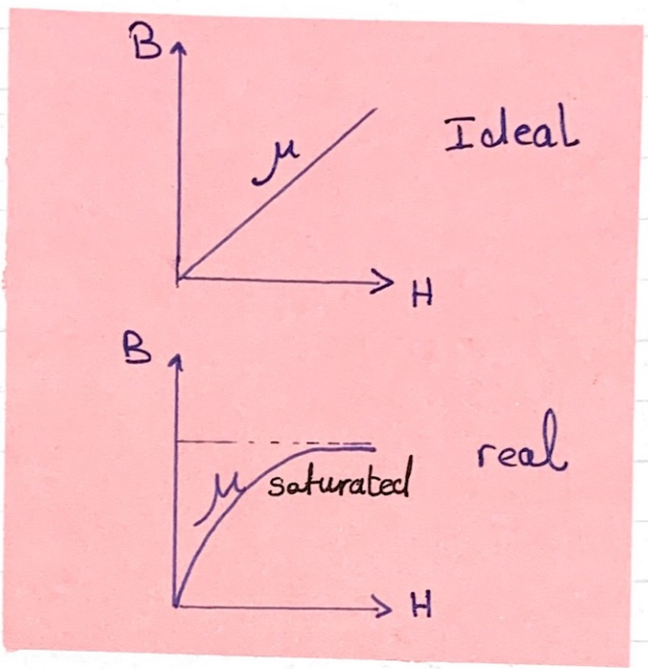
(2



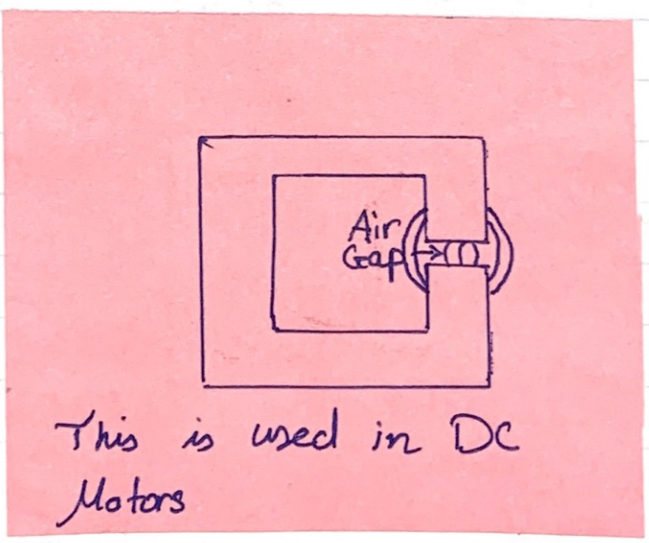
- Air Gap Represents a Resistance

- Inaccuracy in the magnetic circuit approach

1. leakage flux: flux that escapes from the core into surroundings
2. Cross sectional area changet at corners
3. Material's permeability is not constant (Non linearity)



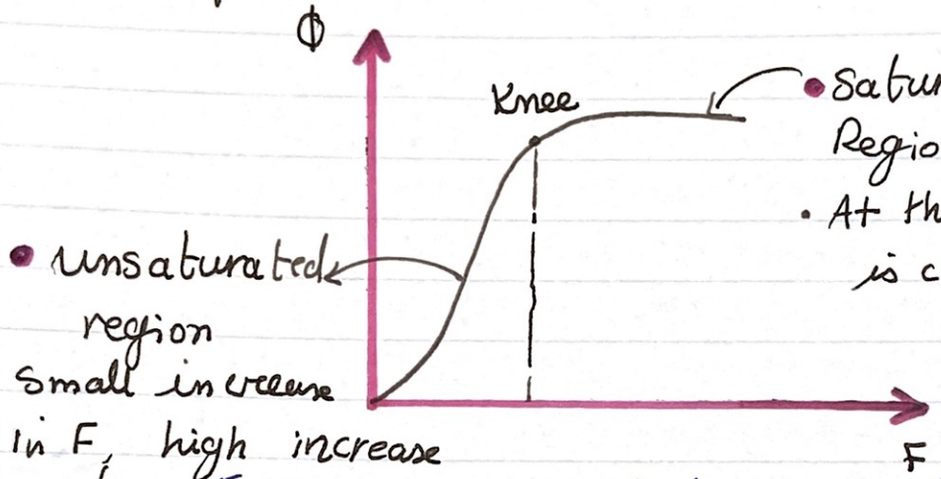
4. Fringing effects : losses of flux Due to air gap



▸ Magnetic behavior of ferromagnetic Materials

In electrical machines, a linear relationship between B and I is desired → by limiting the current

- Magnetization curve : Φ vs $\mathcal{F}$



(so the core must be operated in this region near to the Knee)

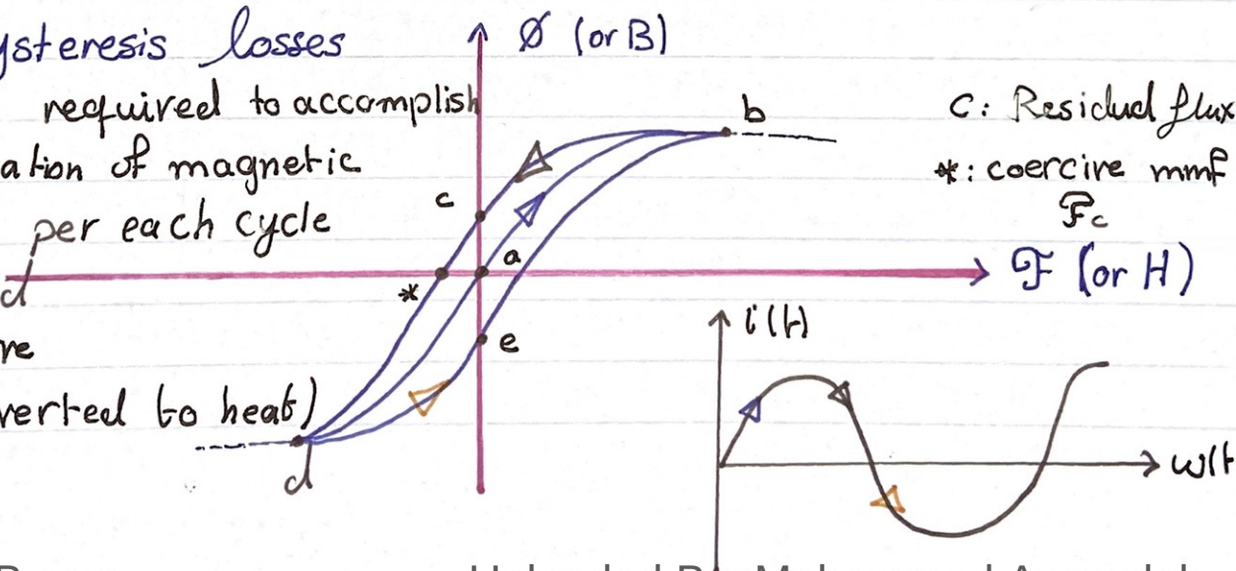
? Why is this curve important ?

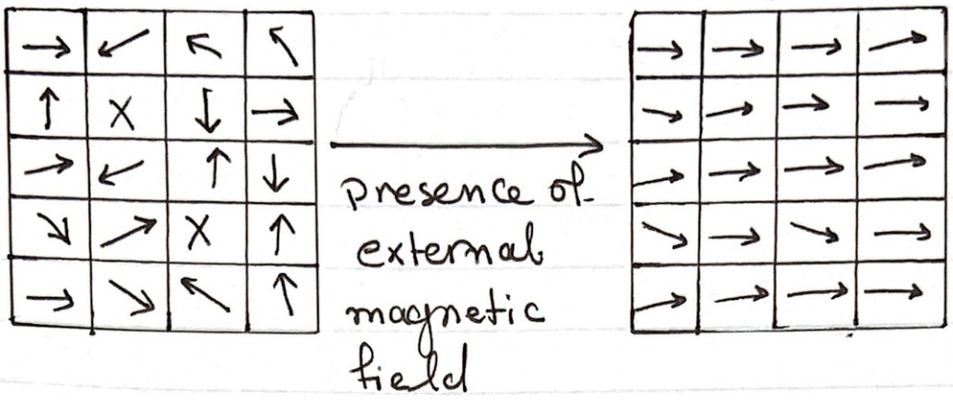
To determine the rated value of the Motor, Generator & transformer

$T = K\Phi i$ ↓ $E_A = K\Phi\omega$ ↓

▸ Hysteresis losses

Energy required to accomplish reorientation of magnetic domains per each cycle of applied Ac curve (It is converted to heat)



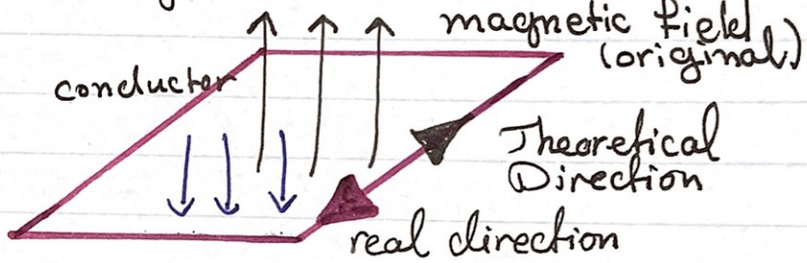


- **Faraday's law:** Induced voltage from a time changing Magnetic field (basis of transformer)

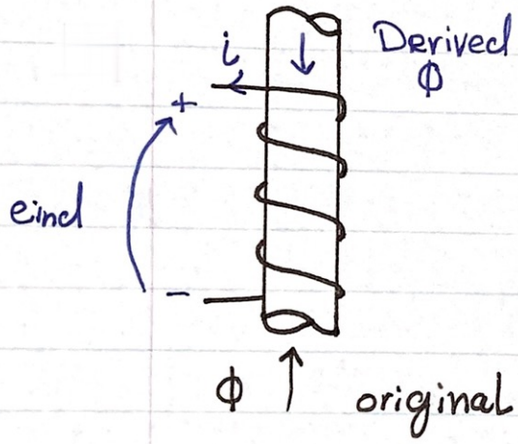
$$e_{ind} = -N\frac{d\Phi}{dt}$$ not calculated

negative sign: due to lenz' law

Value of induced voltage is opposite to reach constant value



Explanation



Flux linkage

$$e_{ind} = \frac{d\lambda}{dt}$$

$$\lambda = \sum_{i=1}^{N} \phi_i$$

- **Eddy Current**

→ Current that flows in the core due to the voltage induced by the time changing flux
→ It causes energy losses

Motor

- Back to principal 3. (basis of motor action)

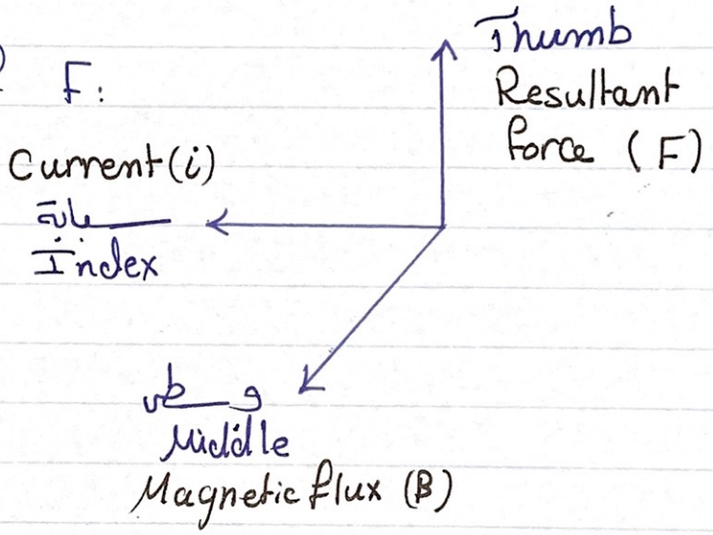
$$F = i(l \times B)$$

l: length of wire
i: current flow in the conductor

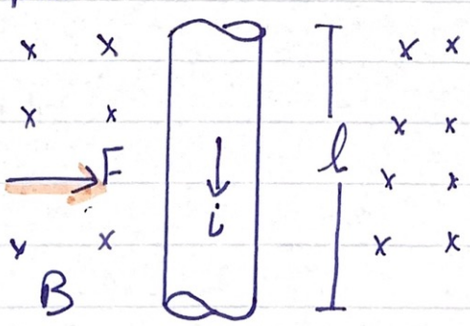
$$F = ilB\sin\theta$$

← Angle between the conductor and the direction of the magnetic field

Direction of F:



▸ For example:



Generator

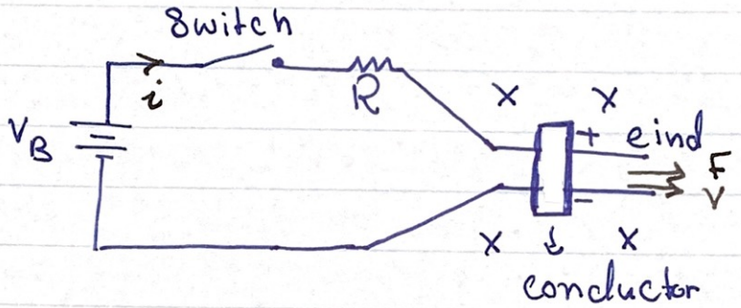
Back to principal 4 (basis of the Generator)

$$e_{ind} = (v \times B)\, l = v B l \cos\theta$$

θ: smallest angle between the conduct and Direction of $(v \times B)$

Polarity voltage polarity is in the direction $v \times B$

The linear DC Machine



When the switch is closed, current flows in the circuit

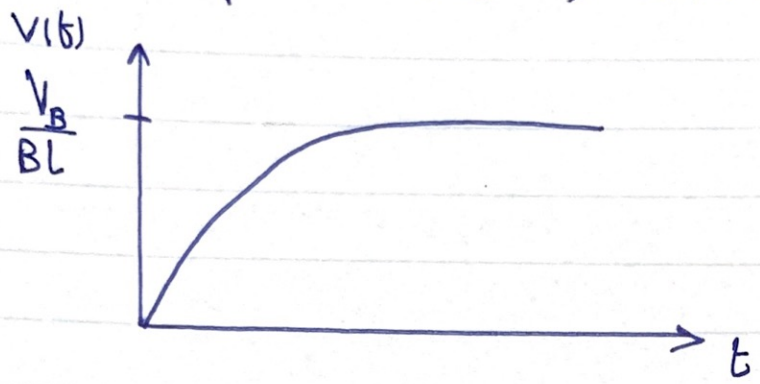
$$i = \frac{V_B - e_{ind}}{R} \qquad (1)$$

- At the beginning, $e_{ind} = 0$ since $v = 0$
- When the force is induced into the conductor due to current flow, $v \uparrow$, $e_{ind} \uparrow$: The Bar accelerates to the right

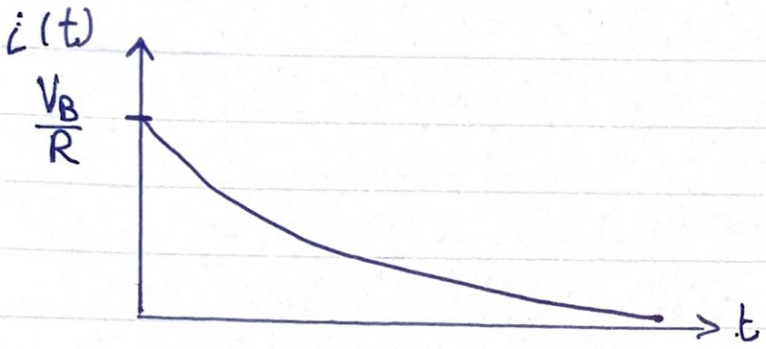
  $F = i\,(l \times B)$ To the right and $e_{ind} = (v \times B)\, l$ positive upwards

- As seen in equation 1: $e_{ind} \uparrow$, $i \downarrow$ until $e_{ind} = V_B$ and constant velocity $v_{steady\ state} = \frac{V_B}{Bl}$

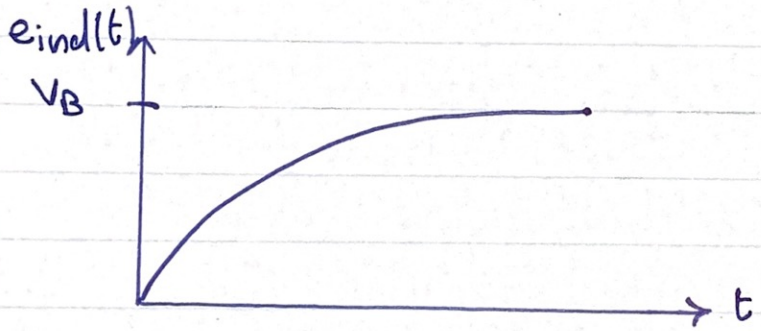
- To explain the Machine's Work: ...



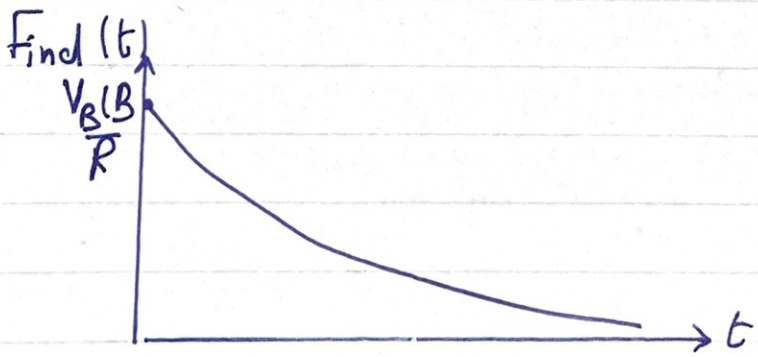
Velocity of the conductor starts at zero, then ↑ until it reach steadi staty ($v = \frac{V_B}{BL}$)



current in the circuit starts at- $\frac{V_B}{R}$ ($e_{ind} = 0$), then v ↑, e_{ind} ↑, I ↓



e_{ind} starts at 0 when r = 0 then increases until it equals V_B (steady state)



Find starts at $\frac{V_B lB}{R}$ = i (lB), then current- i ↓ since e ind ↑

- Assumptions:

1. IF an external force is applied : F_{load} opposite to motion

$$F_{net} = F_{load} - F_{ind}$$

The bar will slow down so V↓

decreases

$$e_{ind} = VBl = V_B - iR$$

So current increases i ↑ and so Find ↑

Increases

$$F_{ind} = ilB$$

Find ↑ until: $F_{ind} = F_{load}$ → Bar at steady state But At lower Speed

Electrical Power → Mechanical Power (Motor)

2. IF an external force is applied : F_{app} same to direction of motion

$$F_{net} = F_{load} + F_{ind}$$

The bar will accelerate, V↑

Increase

$$e_{ind} = VBl = V_B + iR$$

Until $e_{ind} > V_B$: At this point i reverses It's Direction and Find is to the opposite Direction of F_{app}

And so $F_{app} = F_{ind}$ and V of conductor is higher

Mechanical Power → Electrical power (Generator)

Mechanical Power:
$P = F_{ind} \, v$

Electrical Power:
$P = e_{ind} \, i$

$= T_{ind} \, \omega$

Electrical Machines

Generator

- $e_{ind} > V_B$
- Applied force in the
- Direction of Motion

P Mechanical → P Electrical

$e_{ind} = V_B + iR$

$V_{ss} = \frac{e_{ind}}{BL}$

- To solve the Problem of high Starting Curren:
  Extra Resistance (R_{start}) is inserted on Series with R.

Motor

- $e_{ind} < V_B$
- Applied force in the opposite Direction of Motion
- P Electrical → P Mechanical

$e_{ind} = V_B - iR$

$V_{ss} = \frac{e_{ind}}{BL}$

Note:

- To control the speed of a linear dc machine:-
  1- Reducing B → ↑ V_{ss}
  2- Reducing V_B → ↓ V_{ss}