High-Speed Electronics in Practice

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Recall for MM2

Field

$\bar{E}$	$\left[\frac{V}{m}\right]$	ρ	$\left[\frac{A \cdot s}{m^3}\right]$
$\bar{D}$	$\left[\frac{A \cdot s}{m^2}\right]$	ρ_s	$\left[\frac{A \cdot s}{m^2}\right]$
V	$[V]$		
$\bar{H}$	$\left[\frac{A}{m}\right]$	$\bar{J}$	$\left[\frac{A}{m^2}\right]$
$\bar{B}$	$\left[\frac{V \cdot s}{m^2}\right]$	$\bar{J}_s$	$\left[\frac{A}{m}\right]$

Medium constant

μ $\left[\frac{H}{m}\right]$ Permeability

σ $\left[\frac{S}{m}\right]$ Conductivity

ε $\left[\frac{F}{m}\right]$ Permittivity

High-Speed Electronics in Practice

MM3. Magnetic Field

MAGNETIC FIELD

Targets:

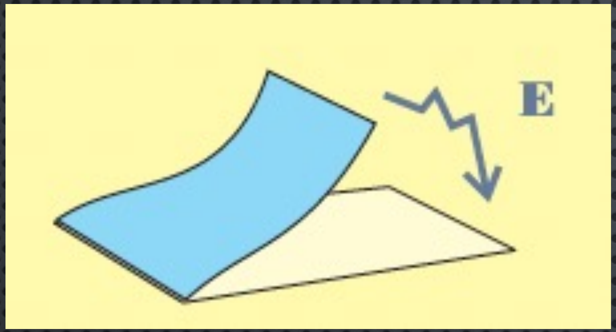
1. Read “Quasistatiske elektriske og magnetiske felter” (Page 57-96) (before or after the lecture)

2. Be able to calculate magnetic field and magnetic circuit (lecture)

3. Finish the exercise (after the lecture)

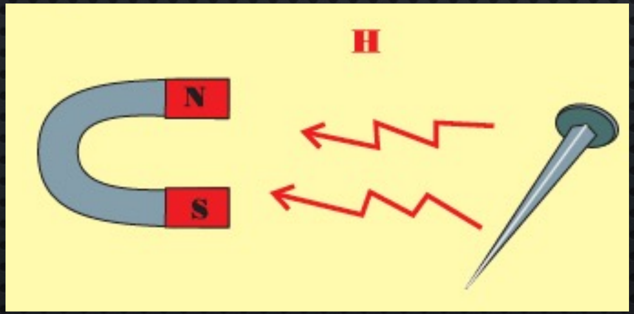
Magnetic Field

Electric field



Paper and foil stick together where a force works

Magnetic field



The nail is attracted, where a force works.

4 forces govern our universe.

1. Strong force
   (nuclear force, very very strong)

2. Weak force
   (also nuclear force, only 1E-14 of strong force)

3. Electromagnetic force
   (1E-2 of strong force)

4. Mass attraction force
   (gravity force, only 1E-41 of strong force)

Blackboard (1)

Magnetic Field

Many authors call **H**, not **B**, the "magnetic field." Then they have to invent a new word for **B**: the "flux density," or magnetic "induction" (an absurd choice, since that term already has at least two other meanings in electrodynamics). Anyway, **B** is indisputably the fundamental quantity, so I shall continue to call it the "magnetic field," as everyone does in the spoken language. **H** has no sensible name: just call it "**H**".[4]

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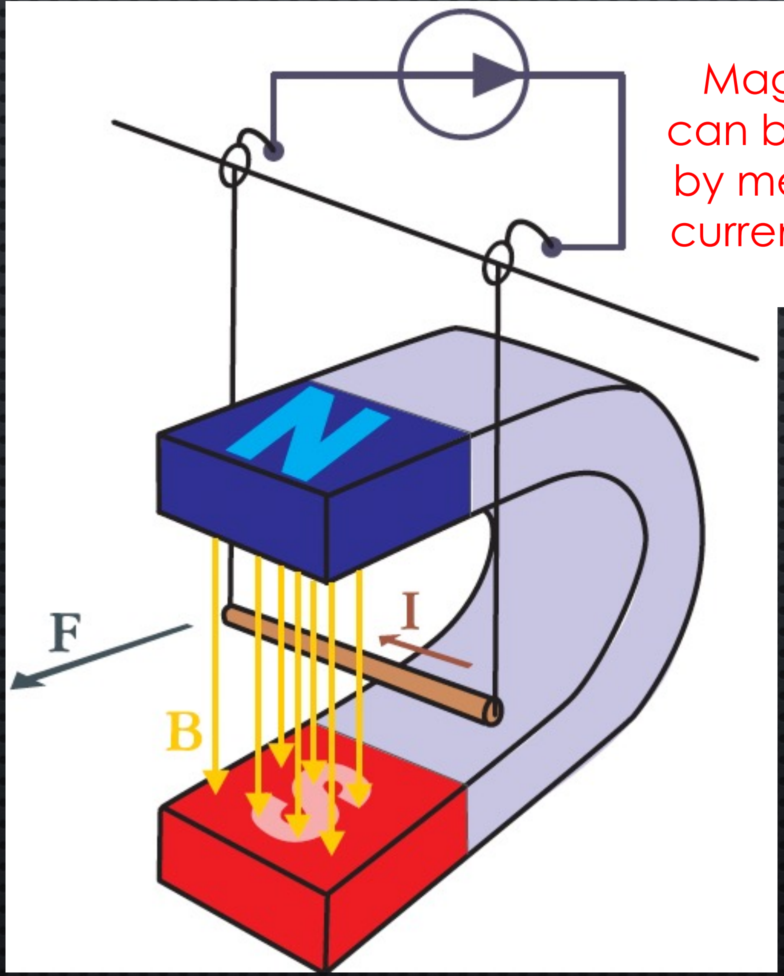
[4]For those who disagree, I quote A. Sommerfeld's *Electrodynamics* (New York: Academic Press, 1952), p. 45: "The unhappy term 'magnetic field' for **H** should be avoided as far as possible. It seems to us that this term has led into error none less than Maxwell himself . . ."

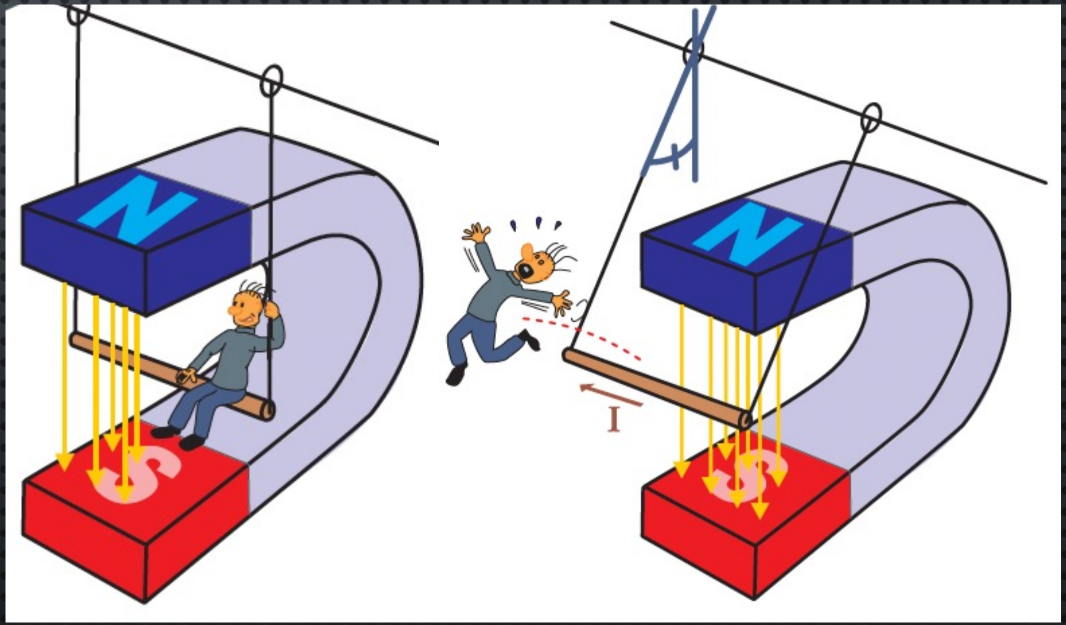
Laplace's Law

$$\overline{F} = \overline{I}\overline{L} \times \overline{B} \quad [N]$$

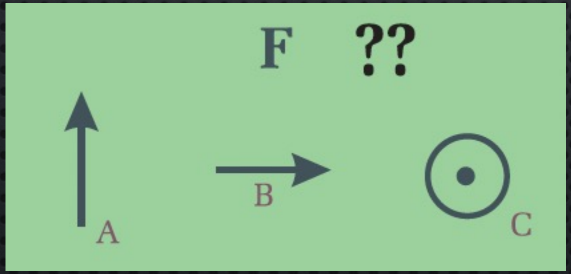
Magnetic field measurement

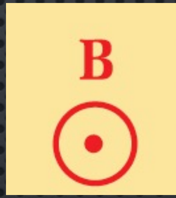


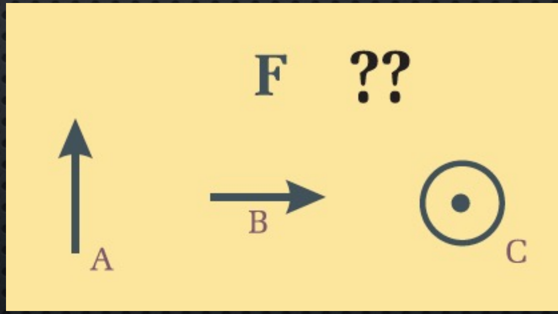
Magnetic field can be measured by measuring the current and force



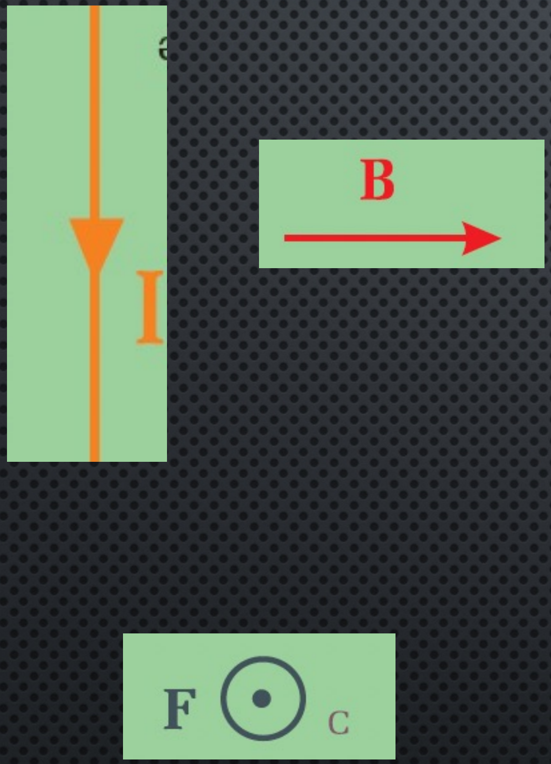
Laplace's Law

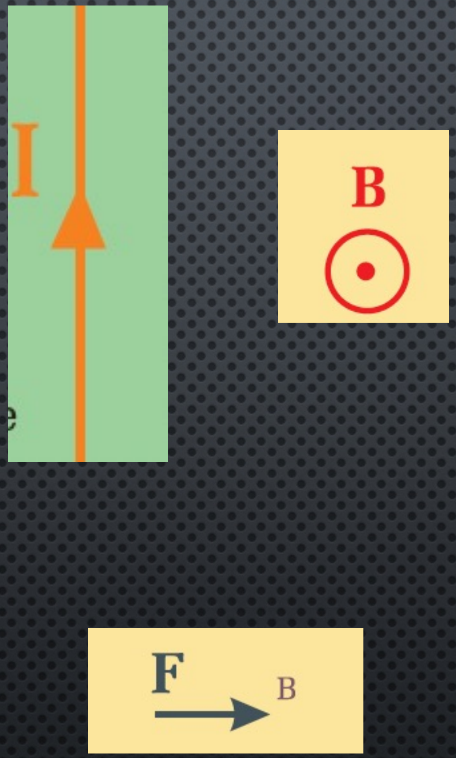


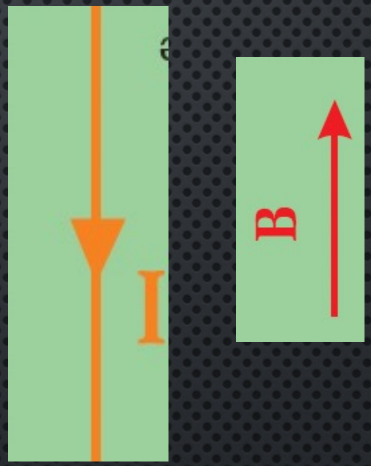




Laplace's Law





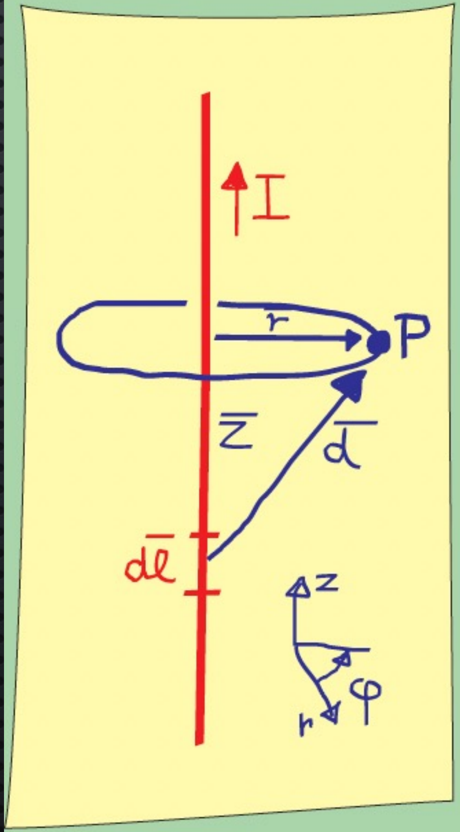


What is the force here?

Biot-Savart's Law

Blackboard (2)

Magnetic field on an infinite long conductor



$$\bar{B} = \frac{I\mu}{4\pi}\oint_C \frac{d\bar{l}\times\hat{d}}{d^2}$$

$$d\bar{l} = dz\cdot\hat{z}$$

$$\bar{d} = \bar{z}+\bar{r}$$

$$= z\cdot\hat{z} + r\cdot\hat{r}$$

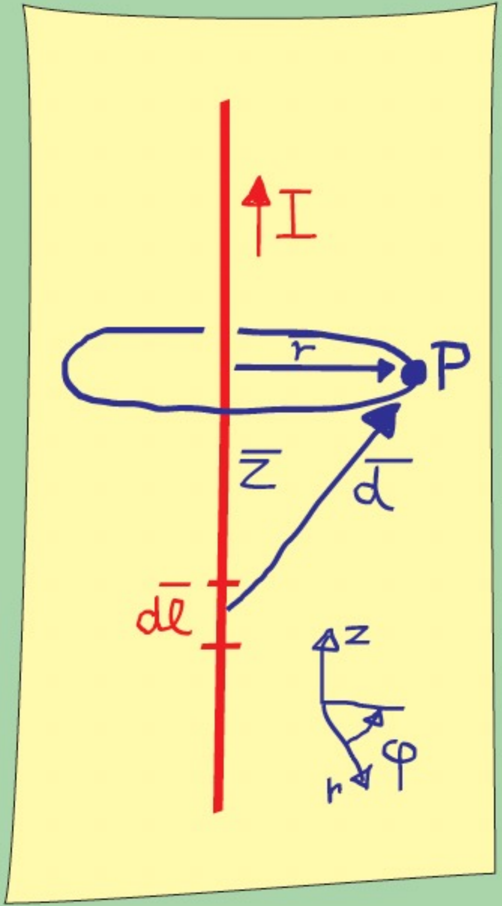
$$\hat{d} = \frac{z}{\sqrt{z^2+r^2}}\cdot\hat{z} + \frac{r}{\sqrt{z^2+r^2}}\cdot\hat{r}$$

$$d\bar{l}\times\hat{d} = \begin{vmatrix}\hat{r} & \hat{\varphi} & \hat{z}\\ 0 & 0 & dz\\ d_r & 0 & d_z\end{vmatrix}$$

$$= d_r\cdot dz\cdot\hat{\varphi}$$

$$= \frac{r\cdot dz}{\sqrt{z^2+r^2}}\cdot\hat{\varphi}$$

Biot-Savart's Law



$$\overline{B}(P) = \frac{I\mu}{4\pi}\int_{-\infty}^{\infty} \frac{r\,dz \cdot \hat{\varphi}}{\sqrt{z^2+r^2}\,(z^2+r^2)}$$

$$= \frac{I\mu}{4\pi}\left(\frac{2}{r}\right)\cdot\hat{\varphi} = \frac{I\mu}{2\pi r}\cdot\hat{\varphi}$$

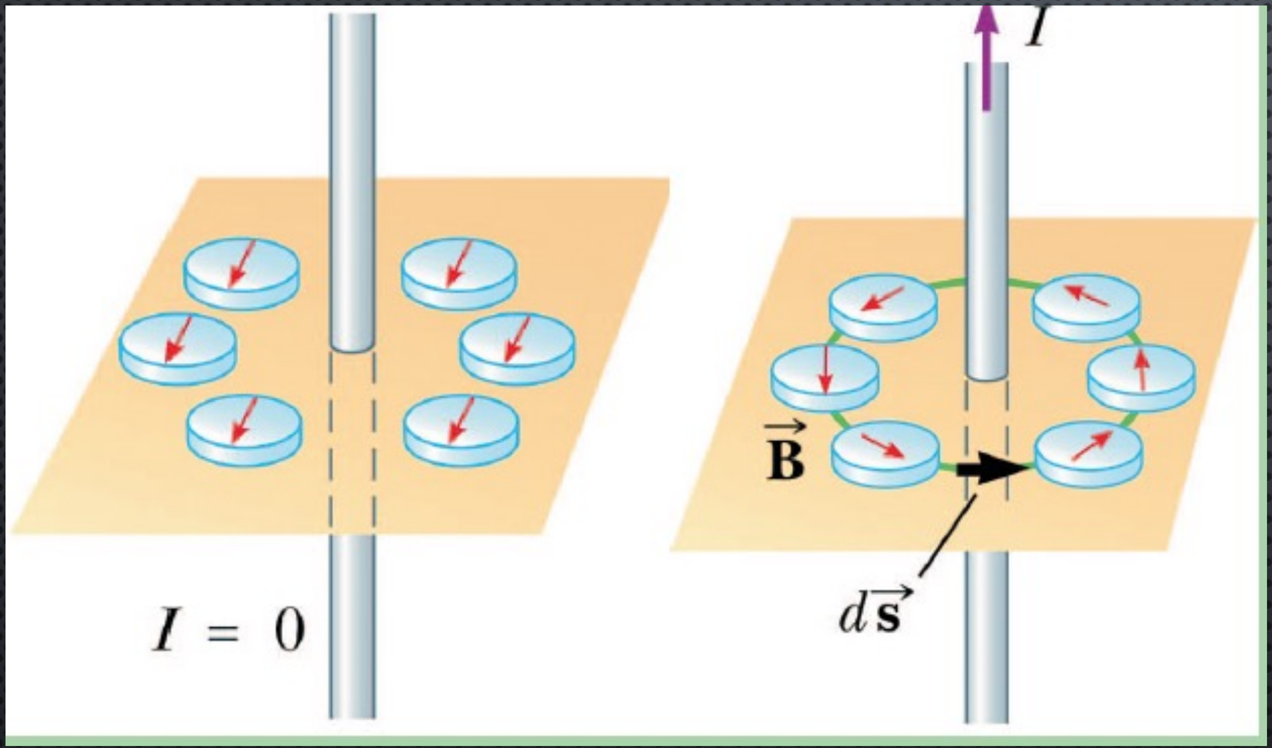
$$\overline{B} = B_\varphi \cdot \hat{\varphi} \qquad \left[\frac{Wb}{m^2}\right]$$

$$B_\varphi = \frac{I\mu}{2\pi r}$$

$$\overline{H} = \frac{1}{\mu}\overline{B} \qquad \left[\frac{A}{m}\right]$$

$$H_\varphi = \frac{I}{2\pi r}$$

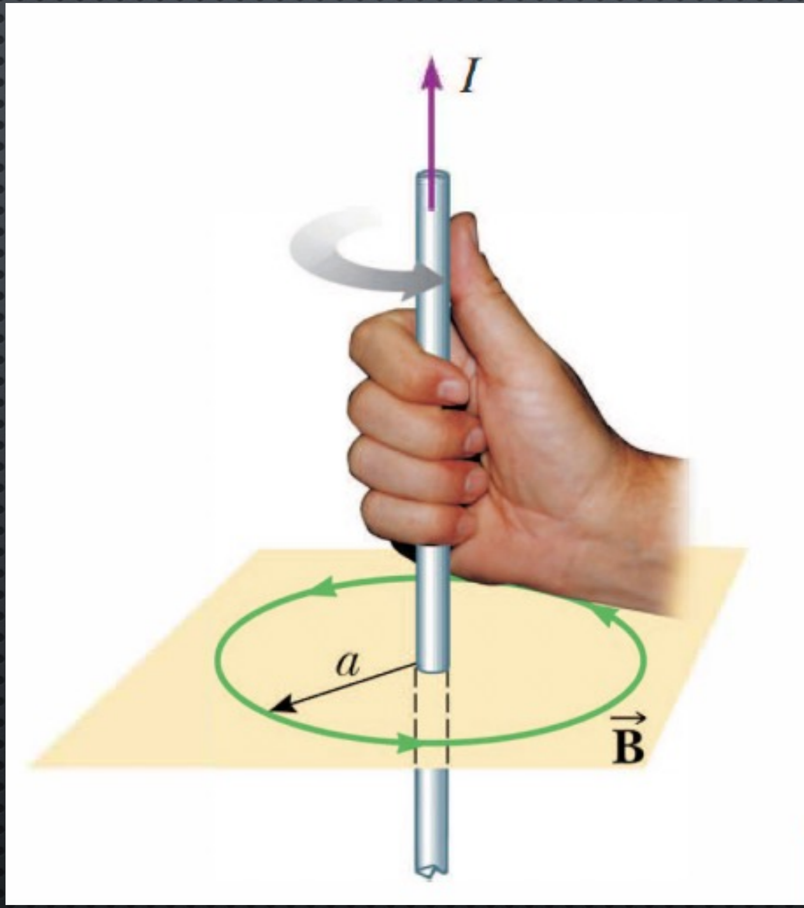
Biot-Savart's Law



The small compasses change according to the magnetic field.

Iron chips floating on oil turning according to the magnetic field.

Biot-Savart's Law

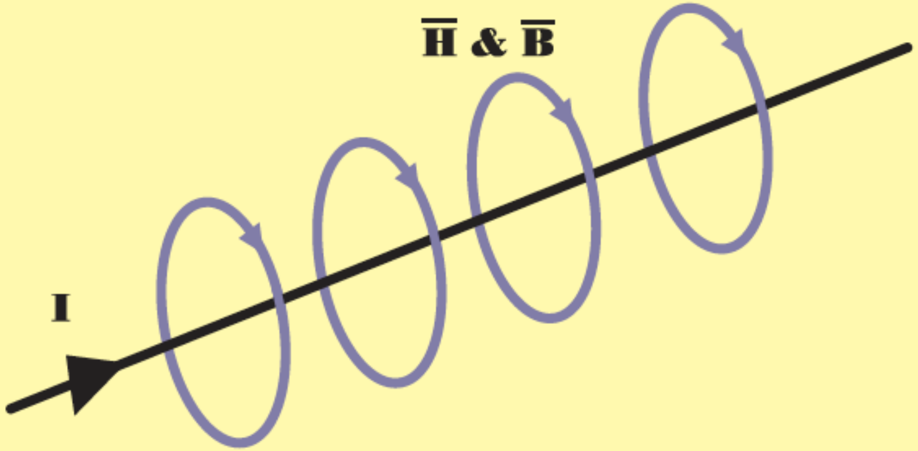


Right hand rules for biot-savart's law

Ampere's Law

Ampères lov (1820)

(H. C. Ørsted, Biot-Savart)



$$\oint_C \bar{H} \bullet d\bar{l} = I \qquad [A]$$

$$\nabla \times \bar{H} = \bar{J} \qquad \left[\frac{Wb}{m^2}\right]$$

$$I = \int_S \bar{J} \bullet d\bar{a}$$

Beregning af magnetfelt

$$H_\varphi \cdot 2\pi r = I \qquad [A]$$

$$H_\varphi = \frac{I}{2\pi r} \qquad \left[\frac{A}{m}\right]$$

Blackboard (3)

Ampere's Law

For technical formula:

1. All fields are equal and perpendicular to areas
2. Fields are parallel to integration paths.
3. Integration in spirals is replaced by N circles.
4. Surface integration of current density is replaced by N wires.
5. KSN is commonly used.

Magnetic Circuit

Fundamental parameters and analysis

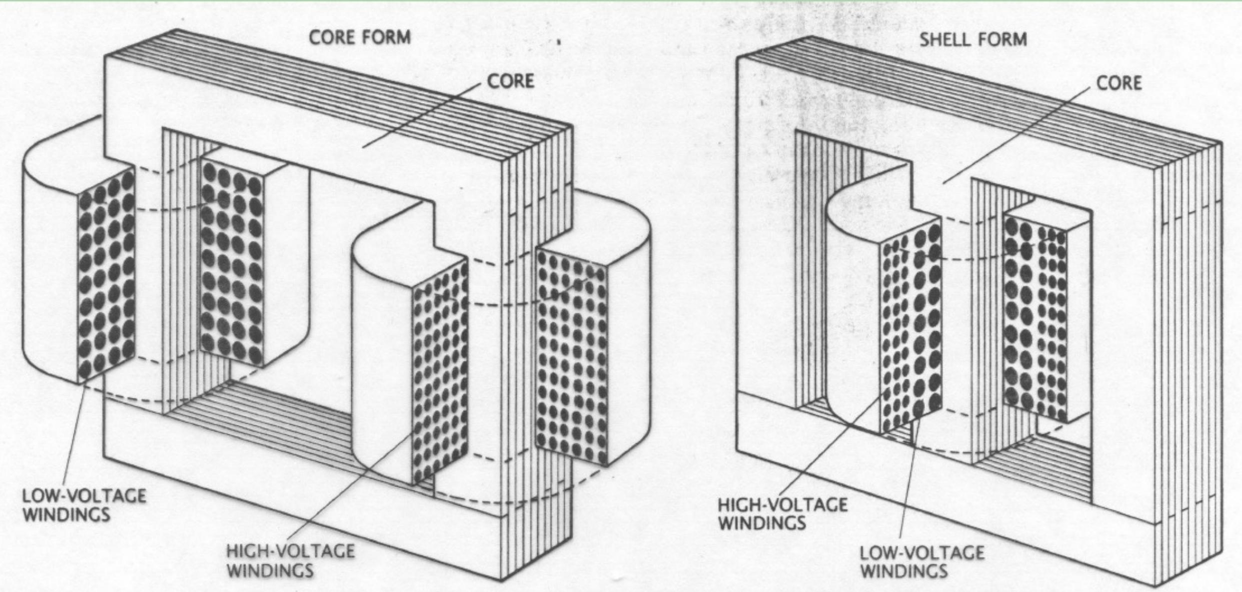
Blackboard (4)

Applications with magnetic circuit in transformer

A transformer can be used to for different purposes such as split currents, change impedance, transfer the power and so on.

For power transformer:

1. A fixed frequency
2. Frequency is low, 30-400 Hz
3. Loss in the transformer is substantial
4. Voltage and currents are strong, 1-1000 V, 1-100 A.



TWO TRANSFORMER DESIGNS illustrate different approaches to core structure and wiring. Both cores are made from stacked laminations stamped out of iron sheets. In the design at the left, called core form, the primary encloses one arm of the core and the secondary the other. The shell-form core at the right is made up of E-shaped stampings with the primary and secondary coils nested together on the middle bar. In three-phase transformers the coils are nested on all three bars (*see illustration on page 81*).

Quasi-Static Field

EQS/MQS

Electric quasi-static field

$$\nabla \times \bar{E} = \bar{0} \qquad \left[\frac{V}{m^2}\right]$$

$$\nabla \cdot \bar{D} = \rho \qquad \left[\frac{A \cdot s}{m^3}\right]$$

$$\nabla \cdot \bar{J} = -\frac{\partial}{\partial t}\rho \qquad \left[\frac{A}{m^3}\right]$$

$$\nabla \cdot \bar{J} = 0$$

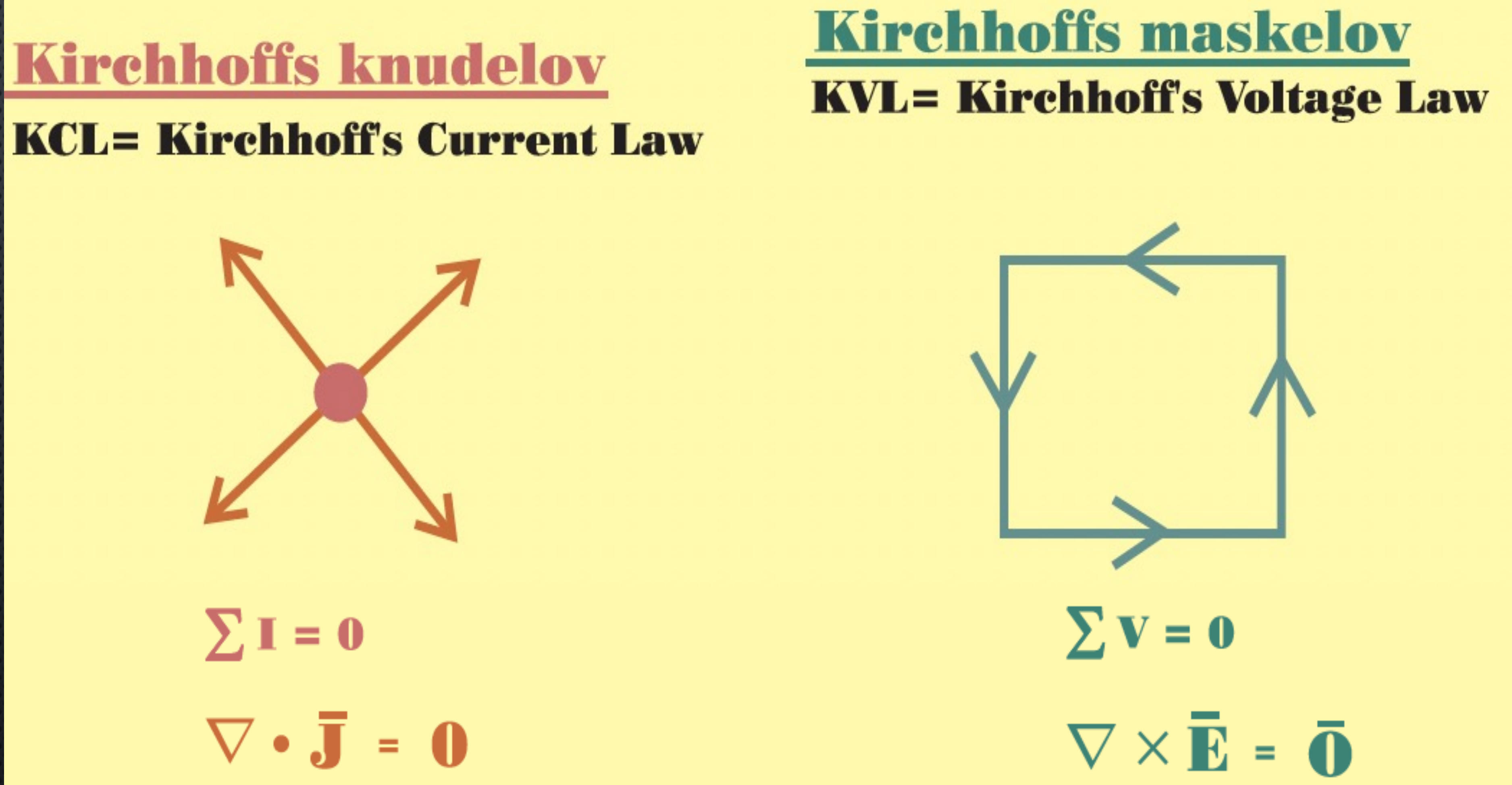
Static, low frequency, or in conductor

Magnetic quasi-static field

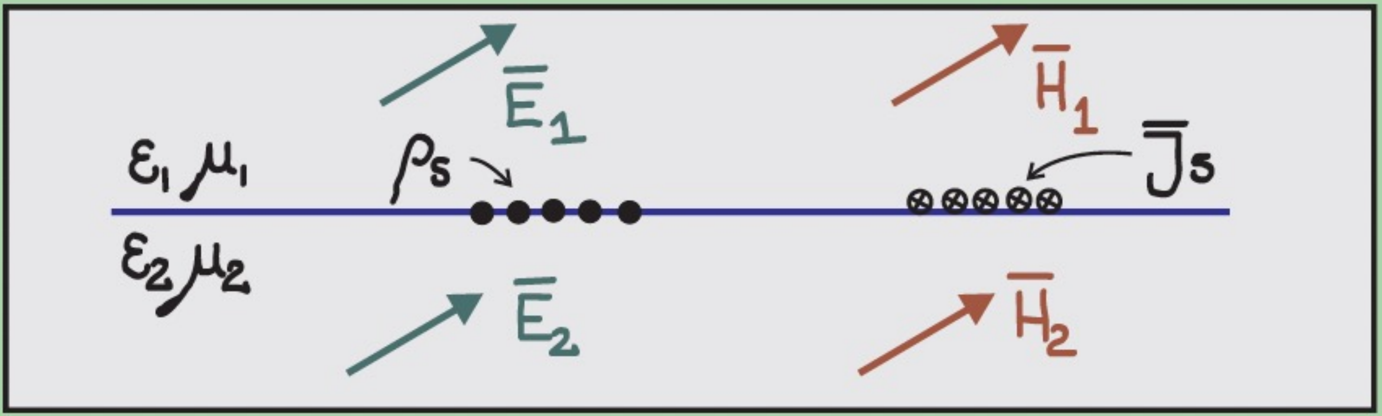
$$\nabla \times \bar{H} = \bar{J} \qquad \left[\frac{A}{m^2}\right]$$

$$\nabla \cdot \bar{B} = 0 \qquad \left[\frac{V \cdot s}{m^3}\right]$$

Quasi-Static Field



Boundary Conditions



Elektriske Felter

$$E_{t1} = E_{t2}$$

$$D_{n1} = D_{n2} + \rho_s$$

$$\varepsilon_1 E_{n1} = \varepsilon_2 E_{n2} + \rho_s$$

General case

Magnetfelter

$$H_{t1} = H_{t2} + J_s$$

$$B_{n1} = B_{n2}$$

$$\mu_1 H_{n1} = \mu_2 H_{n2}$$