# High-Speed Electronics in Practice

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# Recall for MM3

**Field**

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

**Medium constant**

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

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

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

# Recall for MM3

For technical formula of Ampere's law:

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.

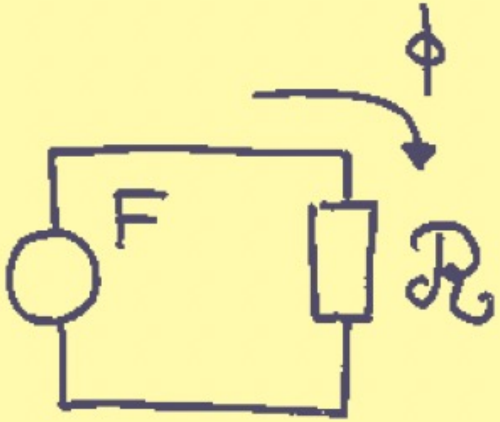
5. KSN is commonly used.

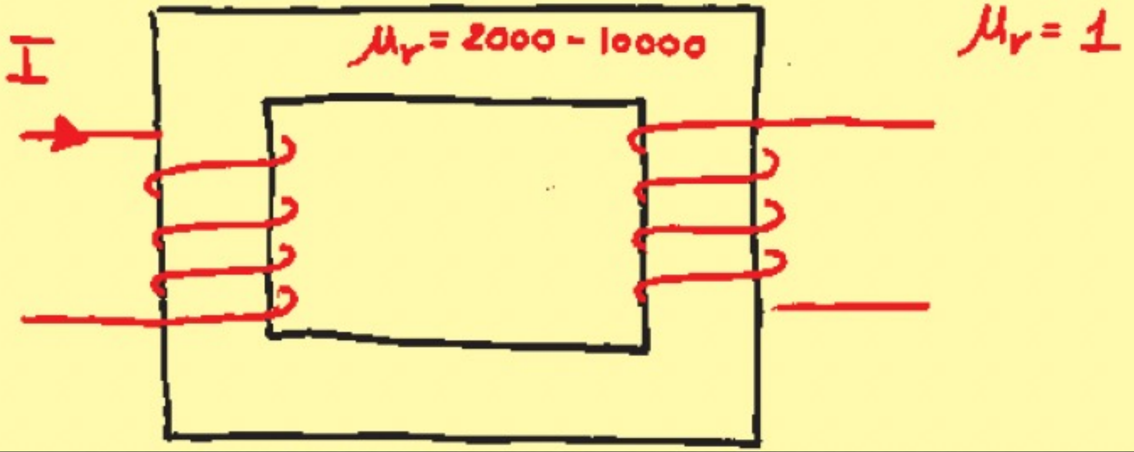
# Recall for MM3

$$F = mmf = NI = H \cdot l \quad [Av]$$

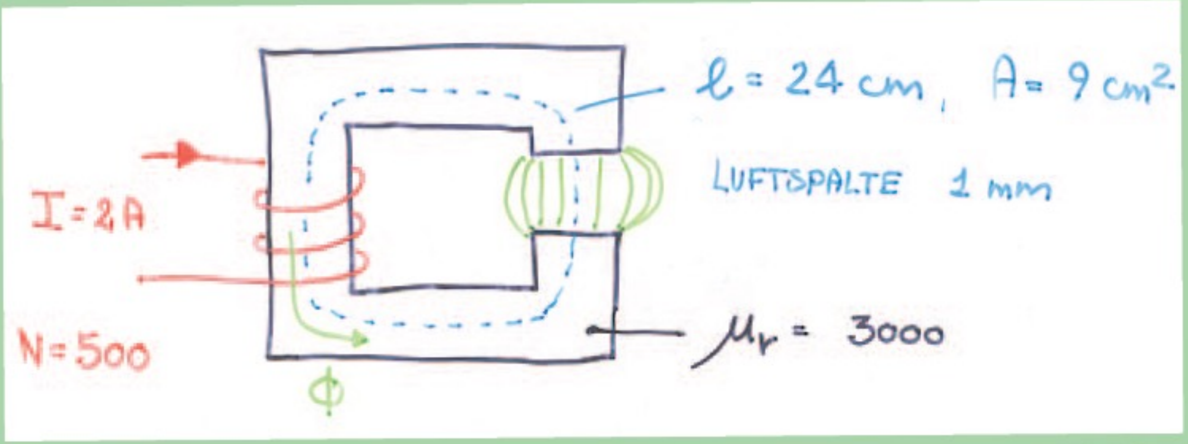
$$\phi = \frac{F}{\mathcal{R}} \quad [Wb]$$

$$\mathcal{R} = \frac{l}{\mu \cdot A} \quad \left[\frac{A}{Wb} = H^{-1}\right]$$



# Recall for MM3



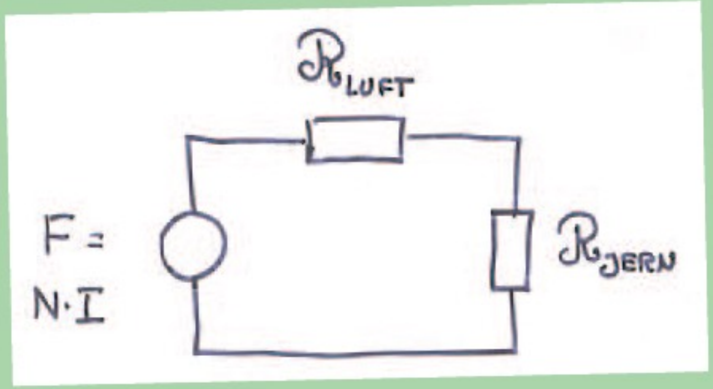

$$F = N \cdot I = 2 \cdot 500 = 1000 \text{ Av}$$

$$\mathcal{R}_{JERN} = \frac{\ell}{\mu \cdot A} = \frac{0{,}24}{4\pi \cdot 1E{-}7 \cdot 3000 \cdot 9E{-}4} = 71 \ k\frac{A}{Wb}$$

$$\mathcal{R}_{LUFT} = \frac{\ell}{\mu A} = \frac{0{,}001}{4\pi \cdot 1E{-}7 \cdot \underbrace{1{,}1}_{} \cdot 9E{-}4} = 804 \ k\frac{A}{Wb}$$

Arealforøgelse 10 %

$$\phi = \frac{F}{\mathcal{R}_{JERN} + \mathcal{R}_{LUFT}} = \frac{1000}{875\,K} = 1{,}14 \text{ mWb}$$



# High-Speed Electronics in Practice

## MM4. Induction and Magnetic Material

# INDUCTION AND MAGNETIC MATERIAL

Targets:

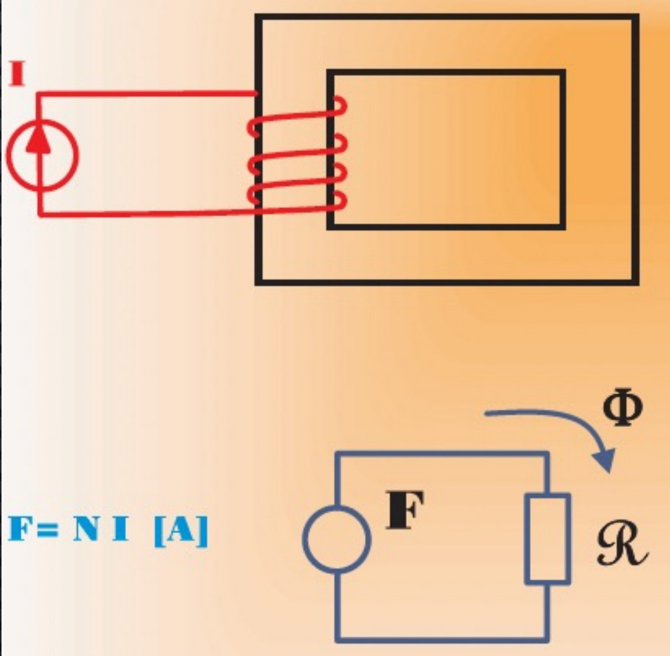
1. Read "Quasistatiske elektriske og magnetiske felter" (Page 76-110) (before or after the lecture)

2. Be able to calculate with self-induction and nonlinear magnetic material (lecture)

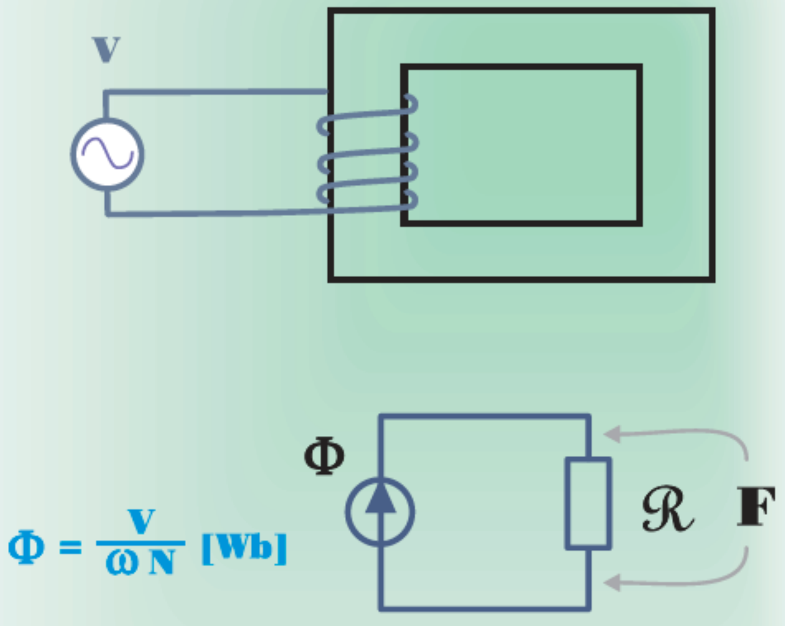
3. Finish the exercise (after the lecture)

# Ampere's Law and Faraday's Law

Blackboard (1)



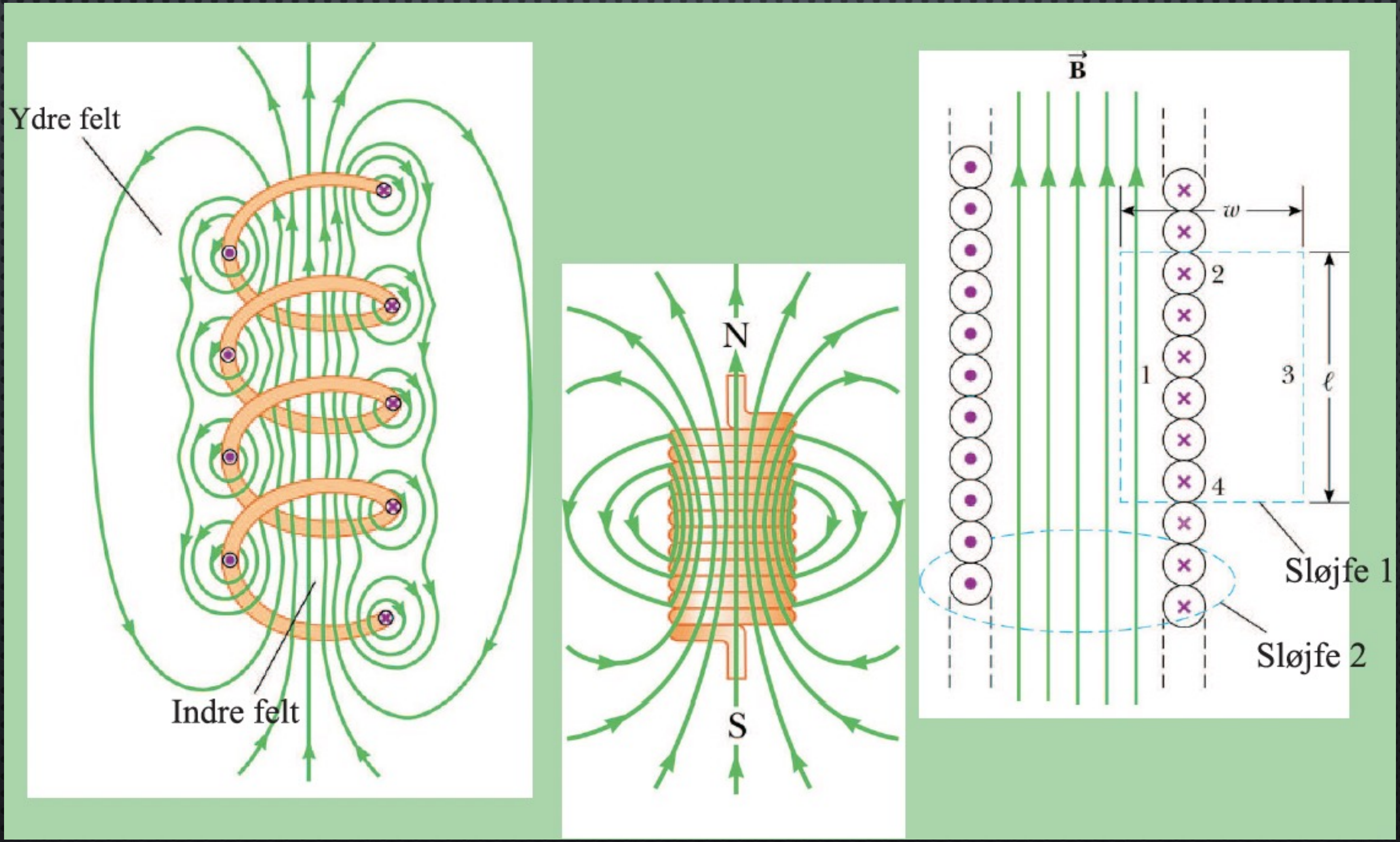

A electric current source gives a magnetic voltage source




A electric voltage source gives a magnetic current source

# Selfinduction

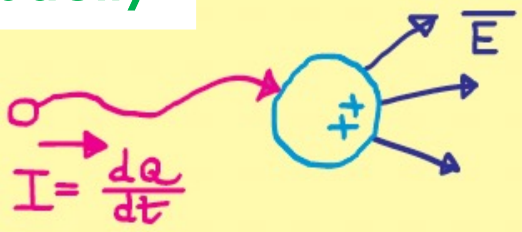
Blackboard (2)



# Selfinduction

L & C

## Capactiy




Electric field due to charge accumulation

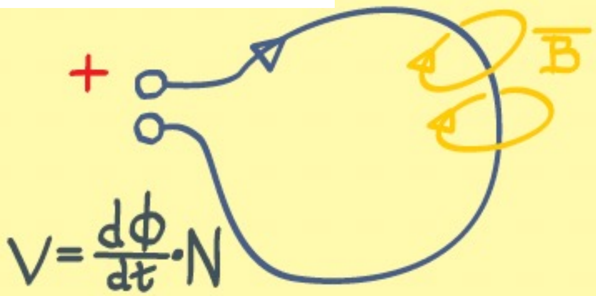
$$I = \frac{dQ}{dt} = \frac{dQ}{dV} \cdot \frac{dV}{dt} \quad [A]$$

$$C \triangleq \frac{dQ}{dV} \quad \left[\frac{C}{V} = \frac{A \cdot s}{V} = F\right]$$

KSN:

$$I = C \cdot j\omega V \quad [A]$$

## Selfinduction




Magnetic field due to currents

$$V = \frac{d\phi}{dt} \cdot N = \frac{d\phi}{dI} \cdot N \cdot \frac{dI}{dt} \quad [V]$$

$$L \triangleq \frac{d\phi}{dI} \cdot N \left[\frac{Wb}{A} = \frac{V \cdot s}{A} = H\right]$$

KSN:

$$V = L \cdot j\omega I \quad [V]$$

# Selfinduction

## L & C

**Fundamental formula**
**Time domain**

$$V_C = \frac{1}{C}\int I_C \, dt \quad [V]$$

$$I_C = C \cdot \frac{dV}{dt} \quad [A]$$

$$V_L = L \cdot \frac{dI}{dt} \quad [V]$$

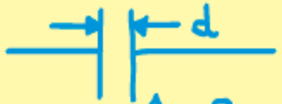
$$I_L = \frac{1}{L}\int V_L \, dt \quad [A]$$

**Energy**

$$U_C = \frac{1}{2} C V^2 \quad [J]$$

$$U_L = \frac{1}{2} L I^2 \quad [J]$$

**Plate capacitor**




$$C = \frac{A \cdot \varepsilon}{d} \quad [F]$$

**Air coil**


$$L = \frac{A \cdot \mu}{\ell} \cdot N^2 \quad [H]$$

**Time constant**

$$\tau = R \cdot C \quad \left[\frac{V}{A} \cdot \frac{A \cdot s}{V} = s\right]$$

$$\tau = G \cdot L \quad \left[\frac{A}{V} \cdot \frac{V \cdot s}{A} = s\right]$$

The time is corresponding to 63% of the final value.

## KSN

$$X_C = -\frac{1}{\omega C} \quad [\Omega]$$

$$X_L = \omega L \quad [\Omega]$$

**Reactance**

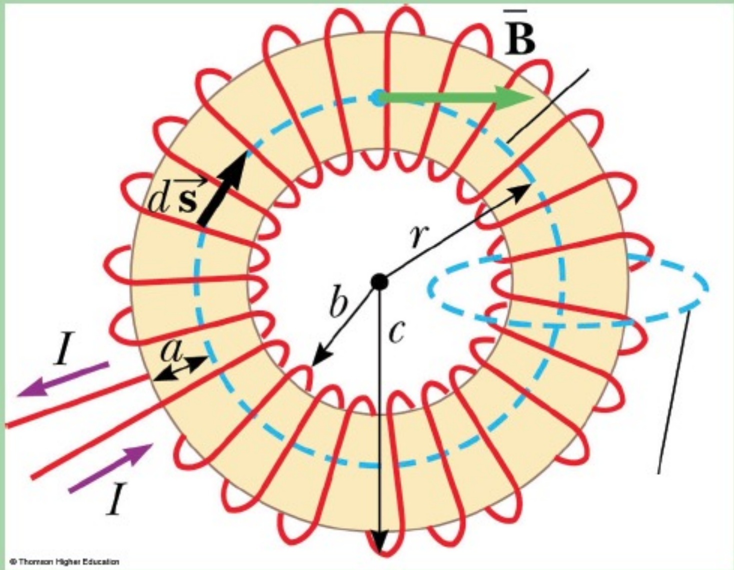
$$B_C = \omega C \quad [S]$$

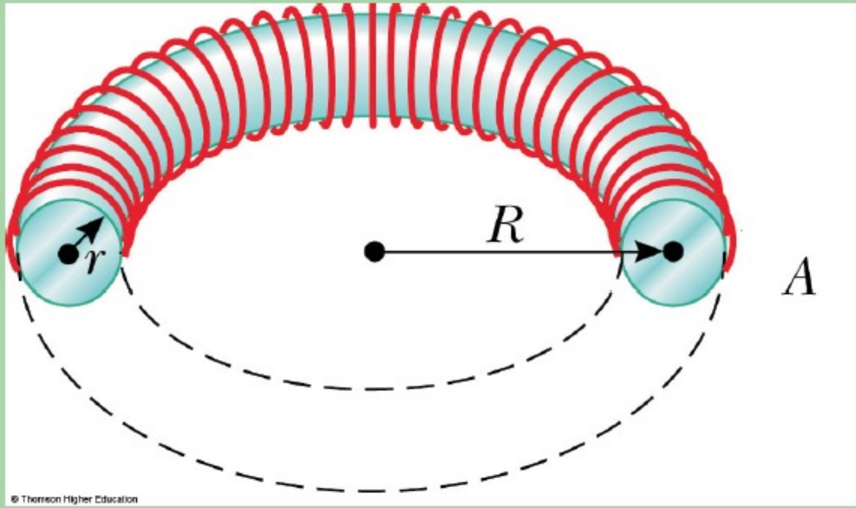
$$B_L = -\frac{1}{\omega L} \quad [S]$$

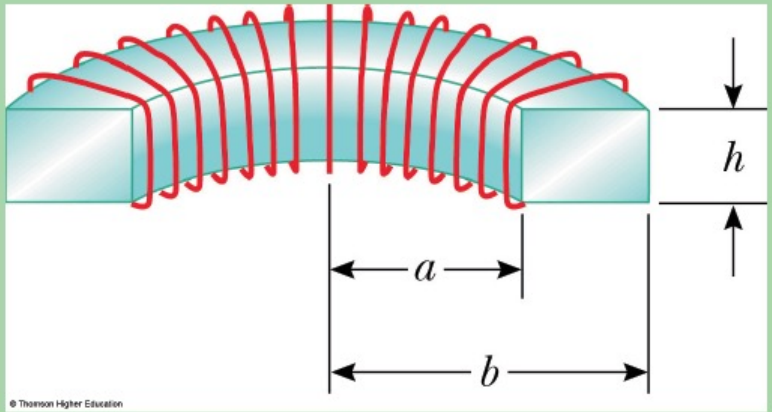
**Susceptance**

# Selfinduction

**Ring core inductor**

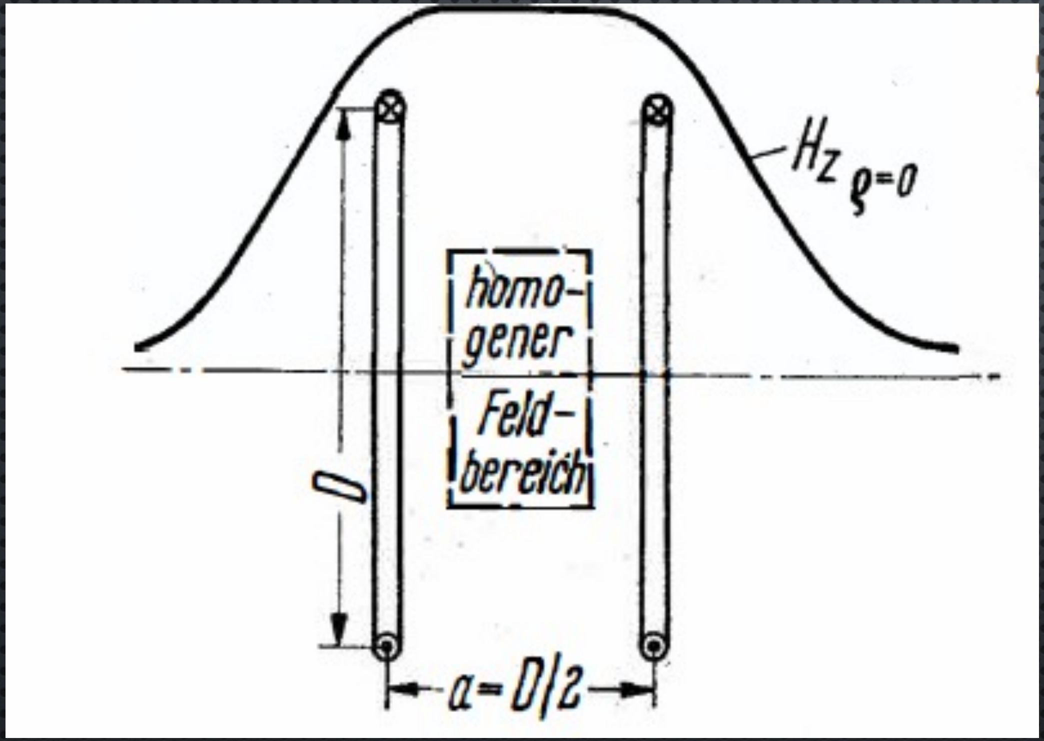


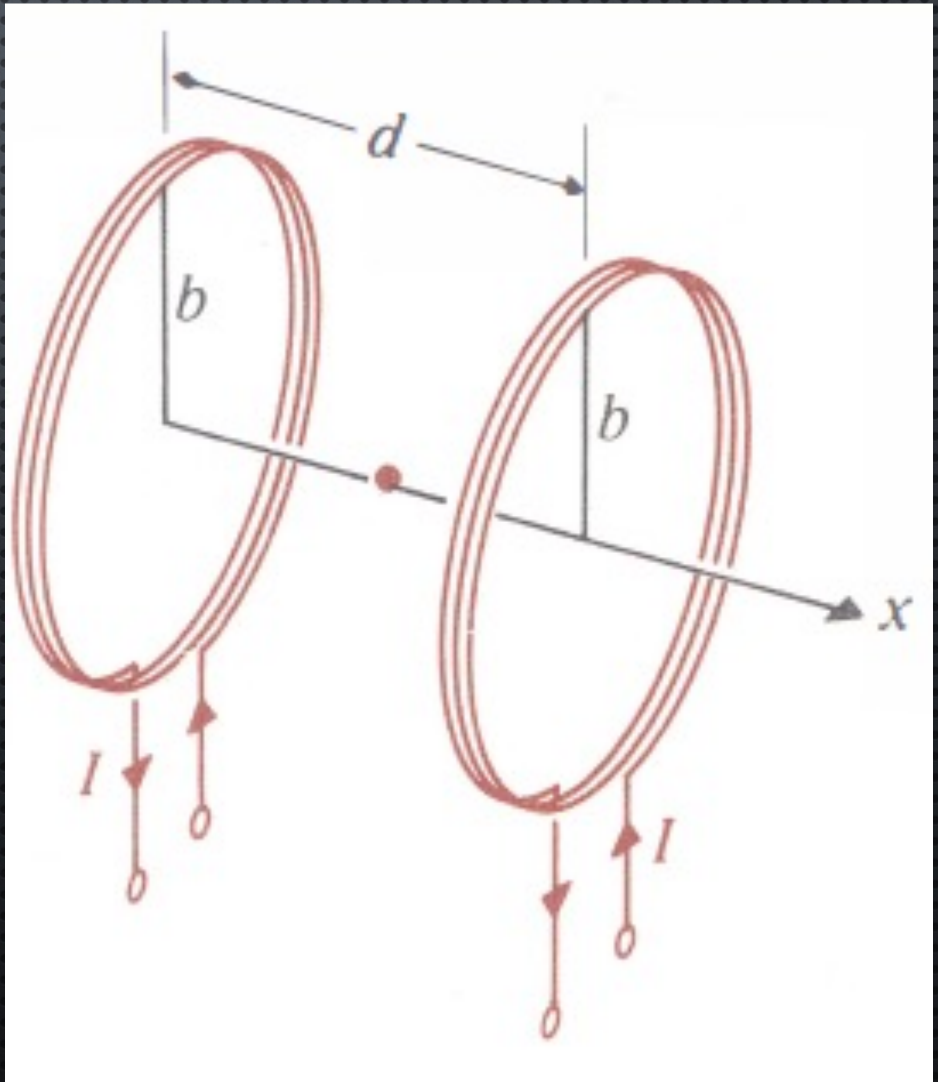



# Selfinduction

**Helmholtz coil**



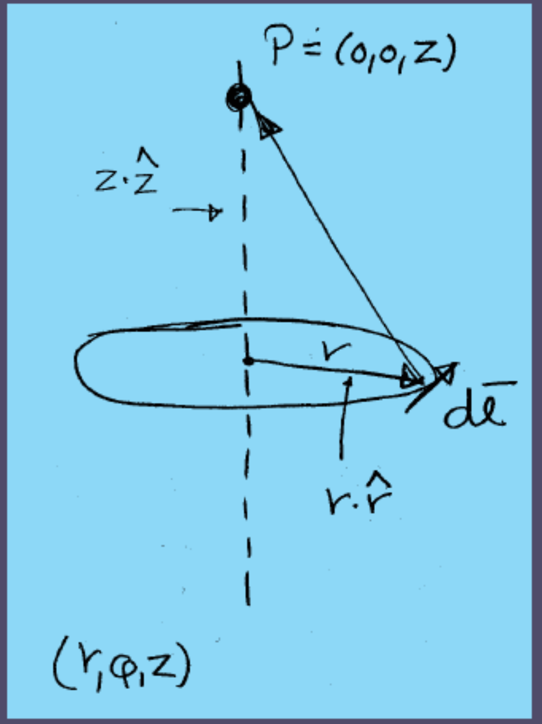

A homogeneous magnetic field can be achieved in a small area in the middle between the coils.

The distance between the coils must be equal to the radius to get a maximally flat field.

# Selfinduction

## **Helmholtz coil**

Biot-Savart's Law




$$\bar{dl} = r\,d\varphi \cdot \hat{\varphi}$$

$$\bar{d} = z\cdot\hat{z} - r\cdot\hat{r}$$

$$d = |\bar{d}| = \sqrt{z^2+r^2}$$

Beregning af: $\bar{dl} \times \bar{d}$:

$$\begin{vmatrix} \hat{r} & \hat{\varphi} & \hat{z} \\ 0 & r\,d\varphi & 0 \\ -r & 0 & z \end{vmatrix}$$

$$= z r\,d\varphi \cdot \hat{r} + r^2 d\varphi \cdot \hat{z}$$

$$B(P) = \frac{I\mu}{4\pi} \oint \frac{\bar{dl}\times\bar{d}}{d^3}$$

$$= \frac{I\mu}{4\pi} \oint \frac{1}{d^3} \cdot \begin{bmatrix} z\cdot r \\ 0 \\ r^2 \end{bmatrix} d\varphi$$

$$= \frac{I\mu}{4\pi} \int_0^{2\pi} \frac{r^2}{\sqrt{r^2+z^2}^{\,3}} \cdot \hat{z}\; d\varphi$$

$$= \frac{I\mu\, 2\pi}{4\pi} \cdot \frac{r^2}{\sqrt{r^2+z^2}^{\,3}} \cdot \hat{z}$$

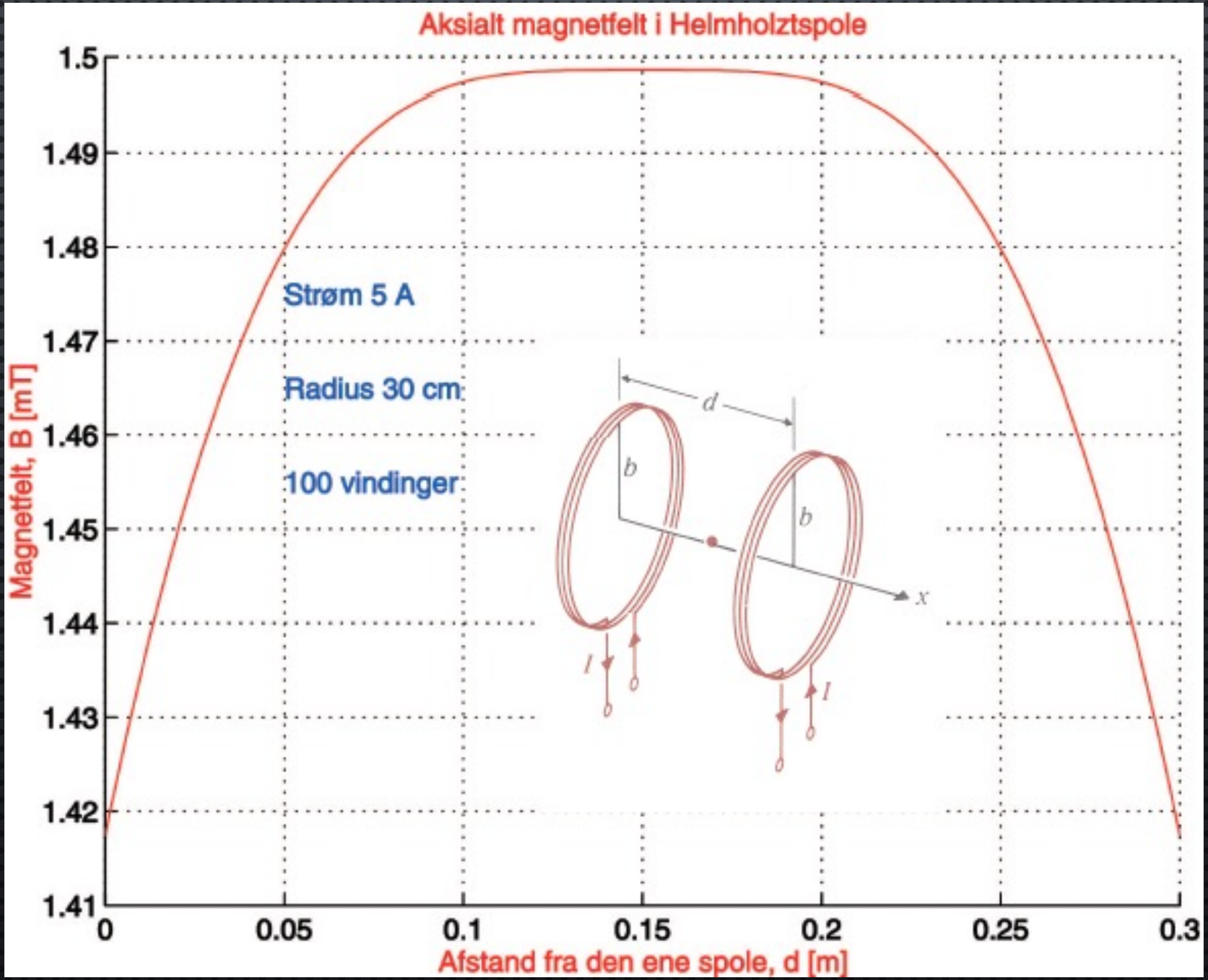
$$= \frac{\mu \cdot I \cdot r^2}{2\sqrt{r^2+z^2}^{\,3}} \cdot \hat{z}$$

Genvej:

$$\int_0^{2\pi} \frac{1}{d^3} \cdot z \cdot r \cdot \hat{r}\, d\varphi$$

bliver til 0, da bidragene udbalancerer hinanden.

# Selfinduction



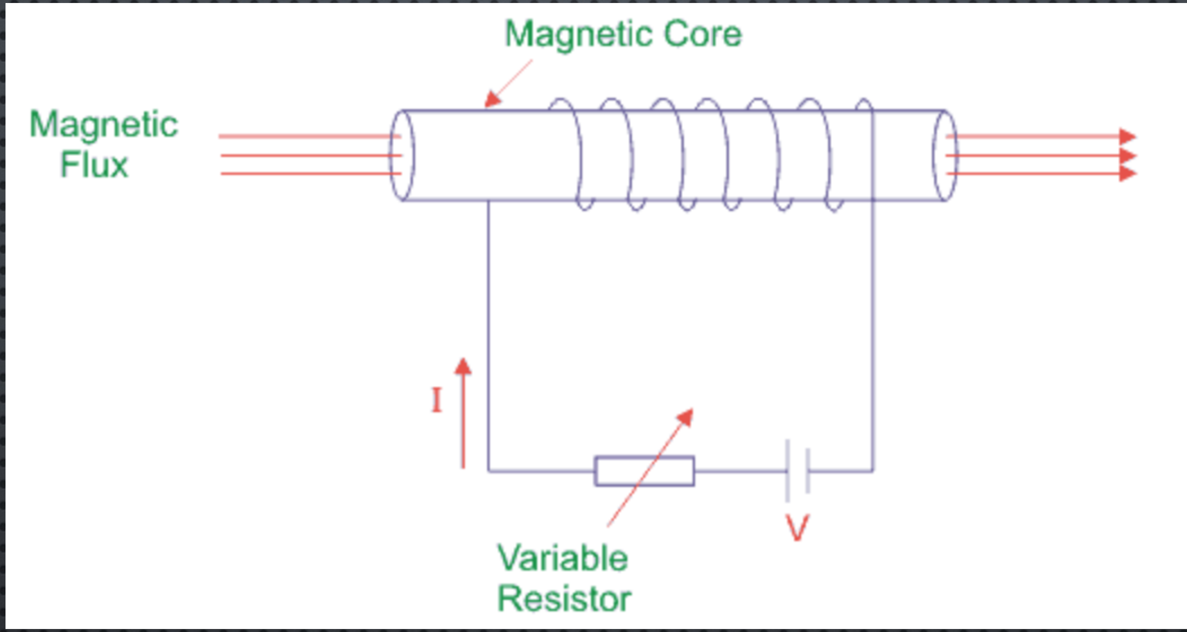
# Magnetic Materials

Blackboard (3)

## Magnetic classification of materials

| Type | Characteristics and example |
|---|---|
| Nonmagnetic | Vacuum |
| Diamagnetic | Weakly magnetic. Moment opposes applied **B**. Repelled by bar magnet. *Example:* Bismuth |
| Paramagnetic | Significant magnetism. Attracted to a bar magnet. *Example:* Aluminum. |
| Ferromagnetic | Strongly magnetic (atomic moments aligned). Attracted to a bar magnet. Has exchange coupling and domains. Becomes paramagnetic above Curie temperature. *Examples:* Iron, nickel cobalt |
| Antiferromagnetic | Nonmagnetic even in presence of applied field. Moments of adjacent atoms align in opposite directions. *Example:* Manganese oxide ($MnO_2$) |
| Ferrimagnetic | Less magnetic than ferromagnetic materials. *Example:* Iron ferrite |
| Ferrites | Ferrimagnetic material with low electrical conductivity. Useful as inductor cores for ac applications. |
| Superparamagnetic | Ferromagnetic materials suspended in dielectric matrix. Used in audio and video tapes. |

# Hysteresis Loop




The coils are connected to a DC supply through a variable resistor to vary the current "I". We know that current I is directly proportional to the value of magnetizing force (H) as

$$H = \frac{NI}{l}$$

Where N = number of turns of coil and l is the effective length of the coil. The magnetic flux density of this core is B which is directly proportional to magnetizing force H.

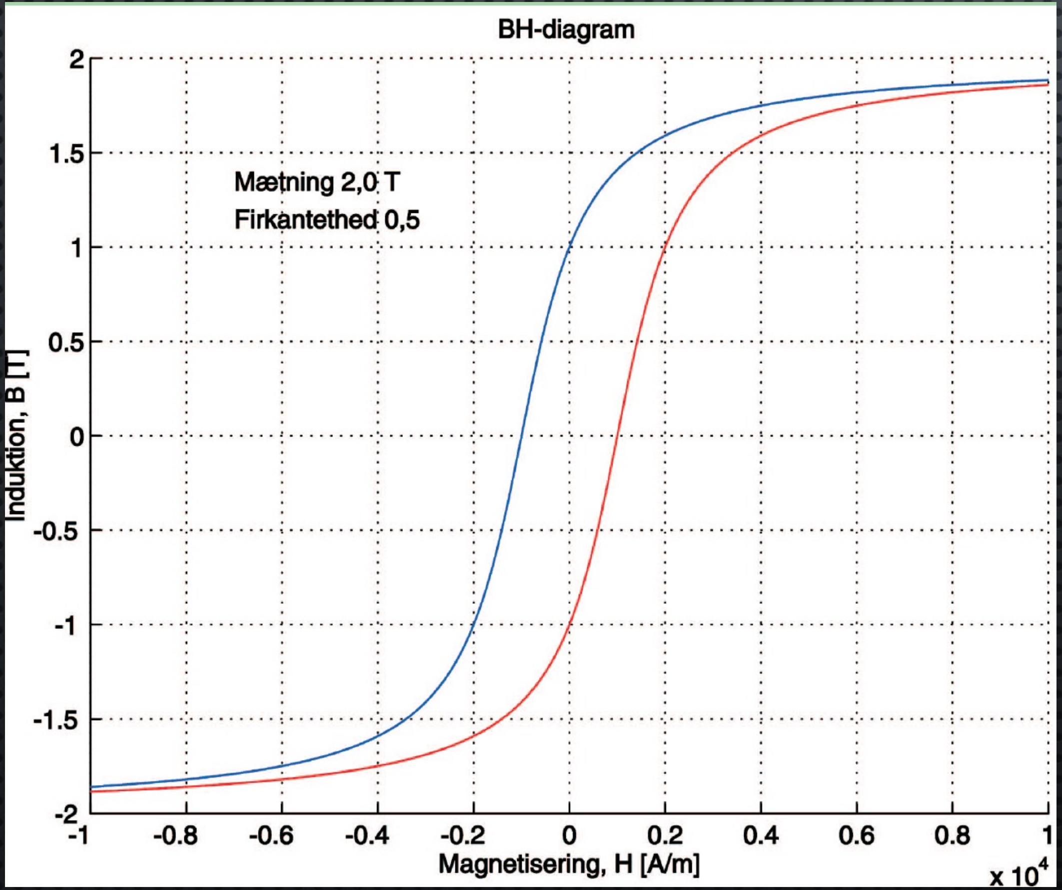


Blackboard (4)

# Hysteresis Loop

**Formula**

$$B = B_s \cdot \frac{2}{\pi} \cdot \operatorname{arctg}\left[\frac{H - H_c}{H_c} \cdot \operatorname{tg}(\pi \cdot \frac{s}{2})\right] \qquad \left[\frac{\mathrm{Wb}}{\mathrm{m}^2}\right]$$

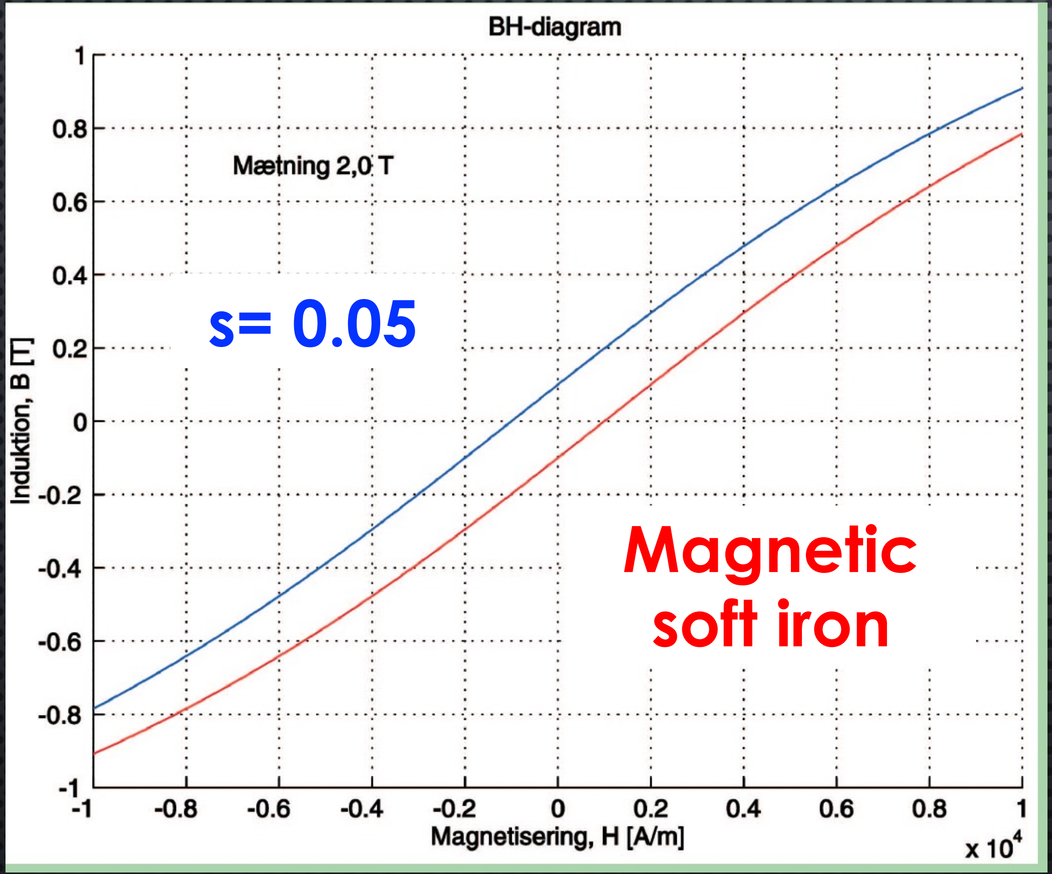


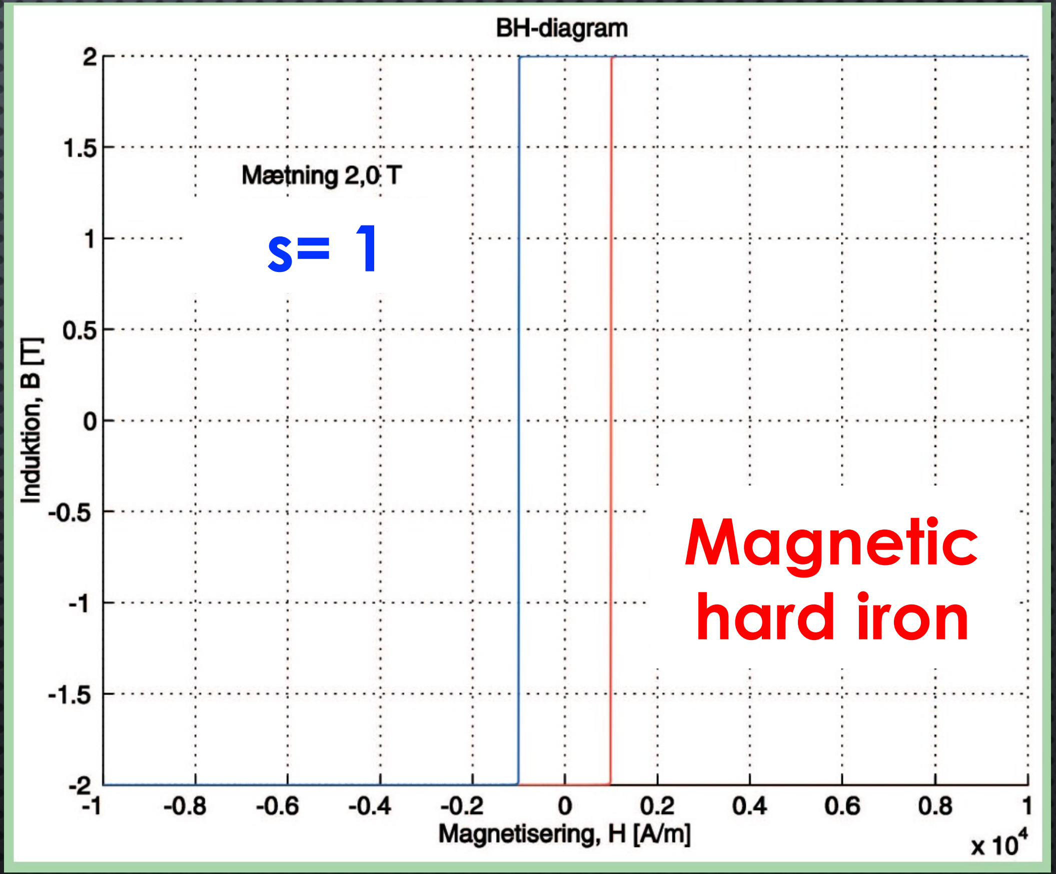

**Br: Residual magnetism**
**Bs: Saturation flux**
**s: Squareness**

$$B_r = B_s \cdot s$$

# Hysteresis Loop

## Soft and hard magnetic materials

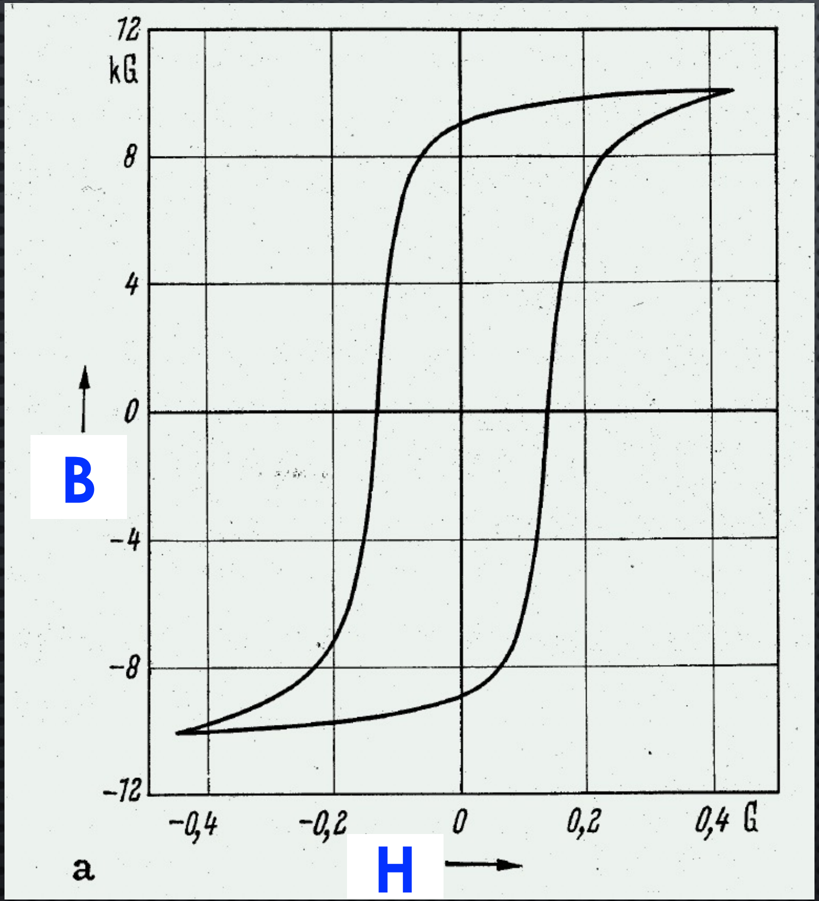


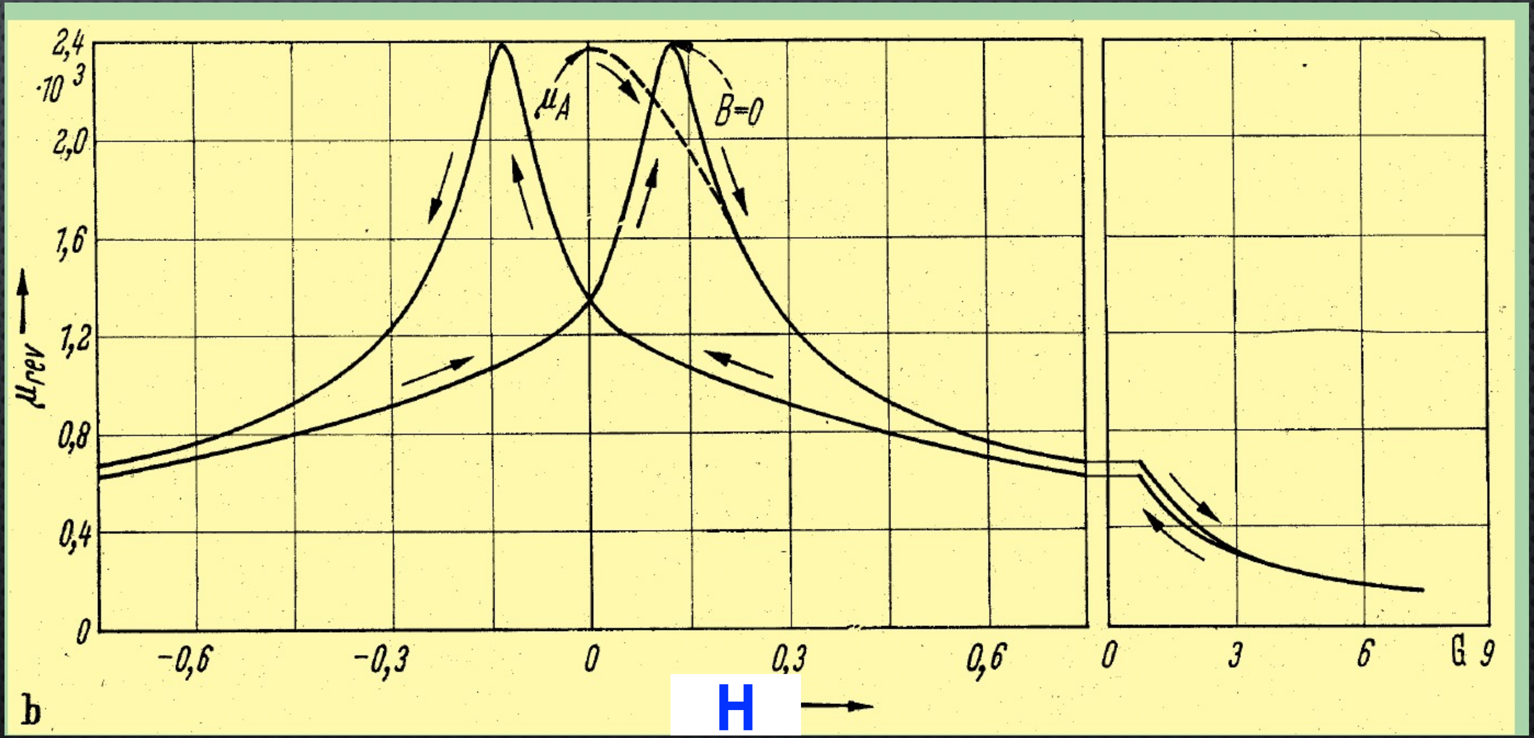




A soft magnetic material is easier to magnetize, while a hard one is more difficult to magnetize

# Hysteresis Loop

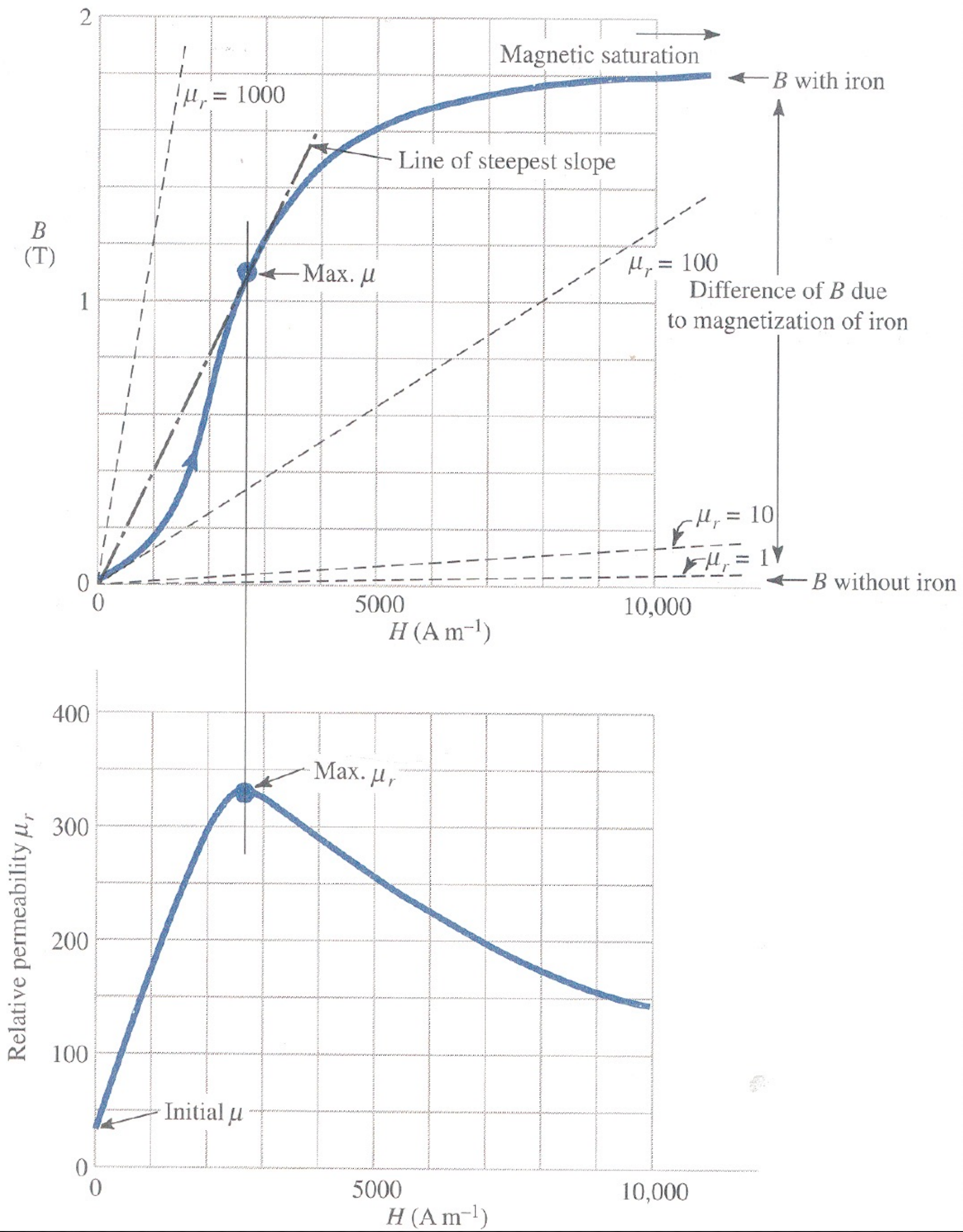
**Permeability**



# Hysteresis Loop

**Permeability**



# Hysteresis Loop

**Permeability**