

Ferromagnetisme. Magnetisk hysteres.

Fra i høst:

Vekselvirkende magnetiske dipoler \Rightarrow ferromagnetisk ordning: $\uparrow\uparrow\uparrow\uparrow$
 minimal potensiell energi U med alle dipolmoment \vec{m}_i parallelle
 (evt. antiferromagnet: $\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow$)

Økt temp. $T \Rightarrow$ termisk uorden

\Rightarrow paramagnet for $T > T_c =$ kritisk temp. } Faseovergang
 ferromagnet for $T < T_c$ } ved $T = T_c$

	T_c (K)
Fe	1043
Co	1388
Ni	627

} ferromagn. ved romtemp. ($\approx 300\text{K}$)

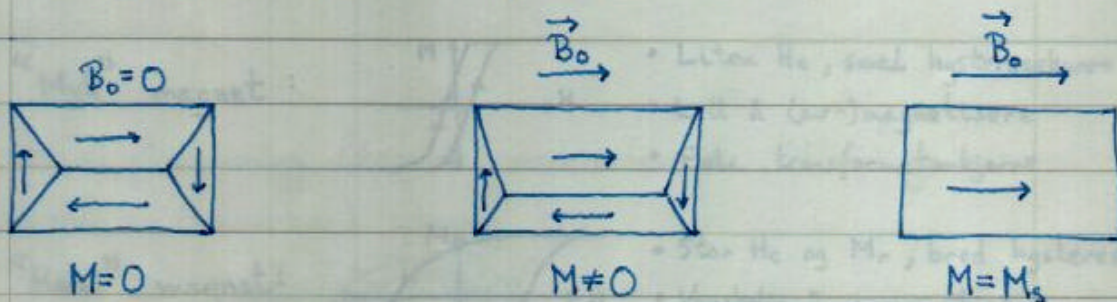
Domener: områder med alle \vec{m}_i parallelle, $\sim 10^{15} - 10^{20}$ atomer

Magnetisering: $\vec{M}_d = \frac{1}{V_d} \sum_i \vec{m}_i \neq 0$ ($V_d =$ domenevolum)

Stort antall domener med ulike \vec{M}_d

$\Rightarrow \vec{M}_{\text{tot}} = \sum_d \vec{M}_d \approx 0$ for unmagnetisk ferromagnet

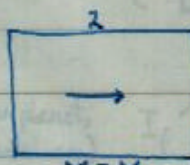
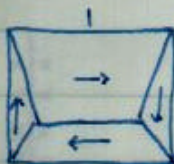
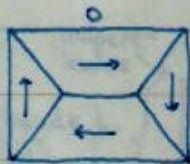
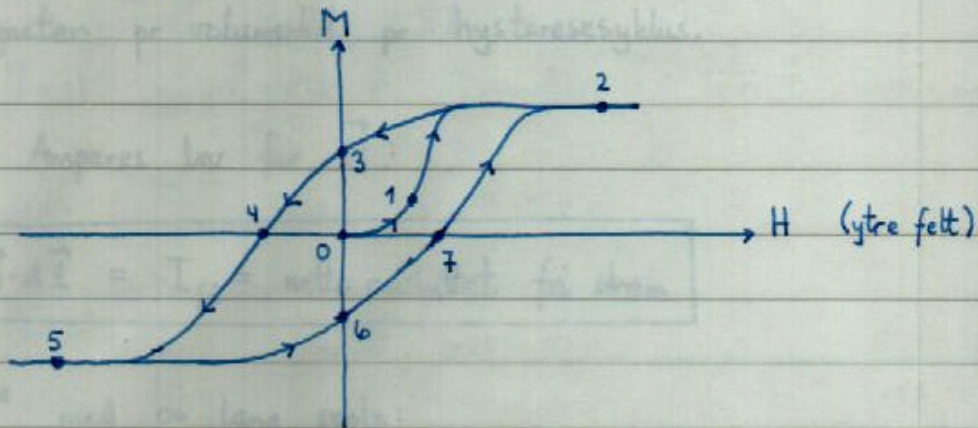
Med ytre felt \vec{B}_0 ($= \mu_0 \vec{H}$):



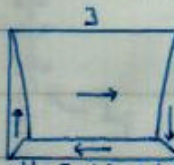
(vekst av domener med gunstig retning på \vec{M})

(maksimal magnetisering M_s)

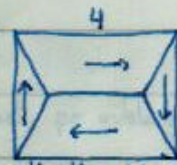
Magnetisk hysteresese:



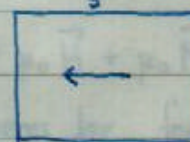
$M = M_s$



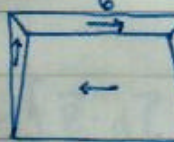
$H = 0, M = M_r$



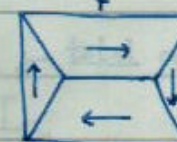
$H = H_c, M = 0$



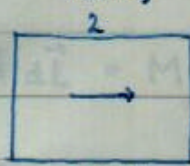
$M = M_s$



$H = 0, M = M_r$

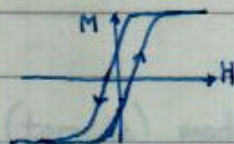


$H = H_c, M = 0$



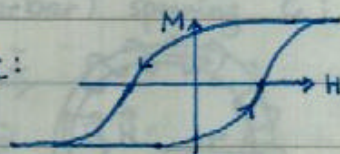
$M = M_s$

"Myk" magnet:



- Liten H_c , smal hysteresekurve
- Lett å (av-)magnetisere
- F.eks. transformator-kjerne

"Hard" magnet:



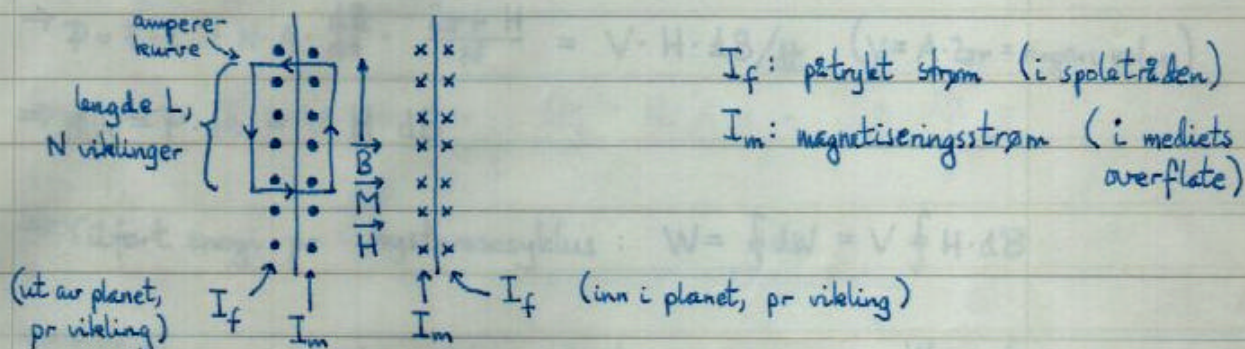
- Stor H_c og M_r , bred hysteresekurve
- Vanskelig å avmagnetisere
- Permanentmagneter (magnetbånd, disketter etc.)

Skal vise at areal innenfor hysteresekurven = tapt energi i ferromagneten pr volumenhett pr hysteresesyklus.

Trønger Amperes lov for \vec{H} :

$$\oint \vec{H} \cdot d\vec{l} = I_{\text{fri}} = \text{netto omsluttet fri strøm}$$

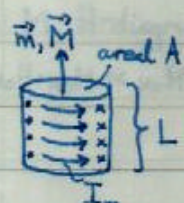
"Bevis" med ∞ lang spole:



$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$$

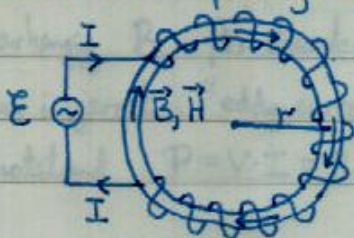
Amperes lov for \vec{B} : $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{in}}$ (total omsluttet strøm)

$$\oint \vec{M} \cdot d\vec{l} = M \cdot L = \frac{m}{V} \cdot L = \frac{N \cdot I_m \cdot A}{A \cdot L} \cdot L = N I_m$$



$$\Rightarrow \oint \vec{H} \cdot d\vec{l} = \oint \left(\frac{\vec{B}}{\mu_0} - \vec{M} \right) d\vec{l} = N(I_f + I_m) - N I_m = N I_f = I_{\text{fri}} \quad (\text{qed})$$

Ser nå på jernring (toroide) med radius r, N viklinger, strøm I drevet av (varierbar) spenning \mathcal{E} :



anta $r \gg \sqrt{A}$, $A = \text{areal av ringens tverrsnitt}$

(\Rightarrow tilnærmet konstant r for hele ringen)

Amperekurve : sirkel med radius r inne i ringen

$$\Rightarrow \oint \vec{H} \cdot d\vec{l} = H \cdot 2\pi r = NI$$

fordi $\vec{H} = H\hat{\phi}$ og $d\vec{l} = r d\phi \hat{\phi}$. Dermed: $\vec{H} = \frac{NI}{2\pi r} \hat{\phi}$ (inne i ringen)

Tilført effekt fra spenningskilden: $P = \mathcal{E} \cdot I$

der \mathcal{E} = induert motspenning i spolen

$$= \frac{d\Phi_m}{dt} \quad (\text{Faradays lov})$$

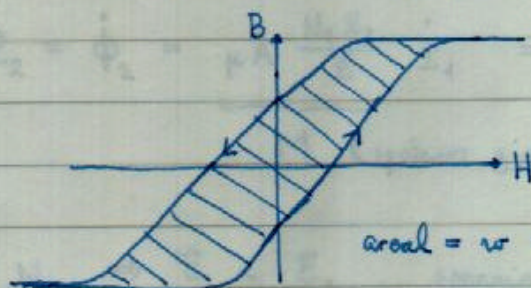
$$= N \cdot A \cdot \frac{dB}{dt}$$

$$\Rightarrow P = \mathcal{E} \cdot I = N \cdot A \cdot \frac{dB}{dt} \cdot \frac{2\pi r H}{N} = V \cdot H \cdot \frac{dB}{dt} \quad (V = A \cdot 2\pi r = \text{ringens volum})$$

$$\Rightarrow dW = P \cdot dt = V H dB$$

$$\Rightarrow \text{Tilført energi pr hysteresesyklus: } W = \oint dW = V \oint H \cdot dB$$

$$\Rightarrow \text{Tilført energi pr volumenhet pr hysteresesyklus: } w = \frac{W}{V} = \oint H \cdot dB$$



(Omtrent som M-H-diagram dersom $B = \mu_0 H + \mu_0 M \approx \mu_0 M$)

$$\text{areal} = w = \oint H dB$$

↑ integral rundt én syklus

Transformator som "opererer" ved 50 Hz må ha smal hysteresekurve for å unngå stort energitap (og dermed varmeutvikling) i jernkjernen.

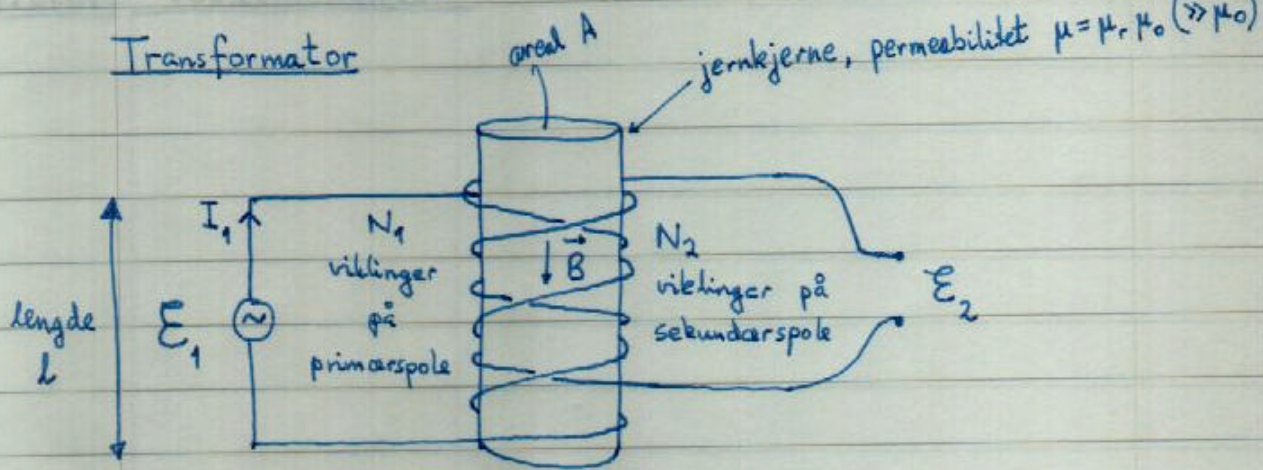
lit 21.1.04

(Med tidsavhengig B , fås dessuten induert elektrisk felt i jernet \Rightarrow elektrisk strøm i jernet, "eddy currents", \Rightarrow også energitap på grunn av motstand: $P = V \cdot I = R \cdot I^2$)

(Tatt som svingsoppgave)

14

Transformator



$$B = \mu n_1 I_1 = \mu \frac{N_1}{l} I_1$$

$$\text{Fluks omsluttet av primærspole: } \Phi_1 = N_1 A B = \mu A \frac{N_1^2}{l} I_1$$

$$\Rightarrow \mathcal{E}_1 = \dot{\Phi}_1 = \underbrace{\mu A \frac{N_1^2}{l}}_L \dot{I}_1$$

L (primærspolens selvinduktans)

$$\text{Fluks omsluttet av sekundærspole: } \Phi_2 = N_2 A B = \mu A \frac{N_1 N_2}{l} I_1$$

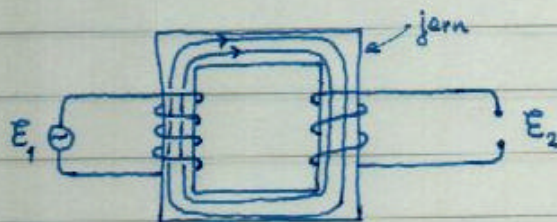
$$\Rightarrow \mathcal{E}_2 = \dot{\Phi}_2 = \underbrace{\mu A \frac{N_1 N_2}{l}}_M \dot{I}_1 = \frac{N_2}{N_1} \mathcal{E}_1$$

M (spolenes gjensidige induktans)

$$N_2 < N_1 \Rightarrow \mathcal{E}_2 < \mathcal{E}_1, \text{ spenningen transformeres ned}$$

$$N_2 > N_1 \Rightarrow \mathcal{E}_2 > \mathcal{E}_1, \text{ ———— " ———— opp}$$

Vanlig utforming:



Feltlinjene holdes inne i jernet

\Rightarrow omtrent samme feltstyrke B i begge spoler