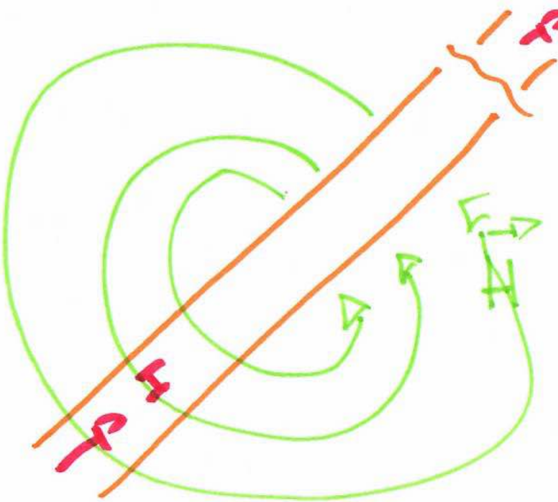
16.11.18 Electric Machinery

①

Basics of magnetic field

- Each current has a magnetic field AND each magnetic field has a current, also PM (Permanent magn.)
- The magnetic field of a straight wire



3D-picture

$\vec{H}$: magnetic field strength

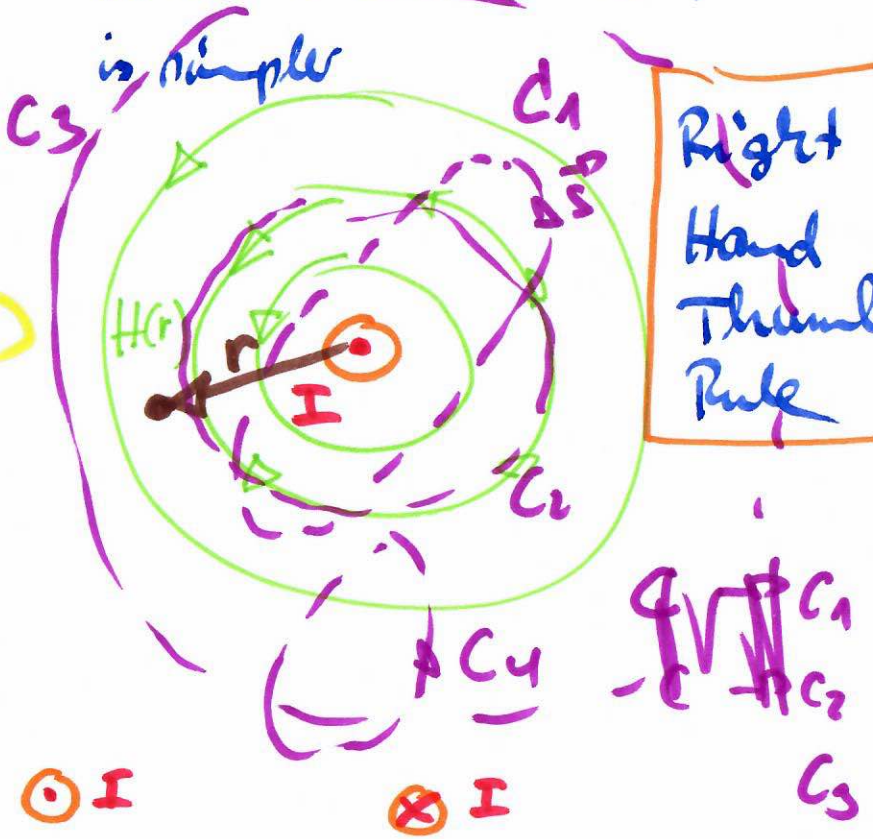
$\vec{H}$ is a vector

$[H] = A/m$

②

$\vec{H} = \vec{H}(x, y, z, t)$: Complicat

Only in some special cases we can handle it "by hand". in this case a 2D-picture is simpler



Right Hand Thumb Rule

⊙ I

Current goes to the top

⊗ I

current goes into the paper

$$H(r) = \frac{I}{2\pi r}$$

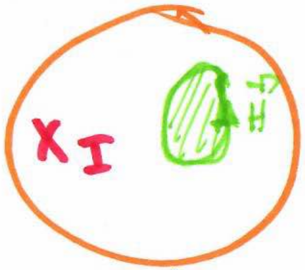
- From where does it come?

The law of Oersted

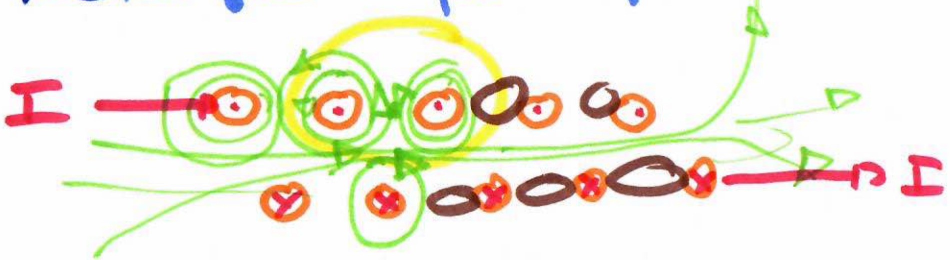
$$\oint_C \vec{H}\, d\vec{s} = I = \iint_A \vec{J}\, d\vec{A}$$

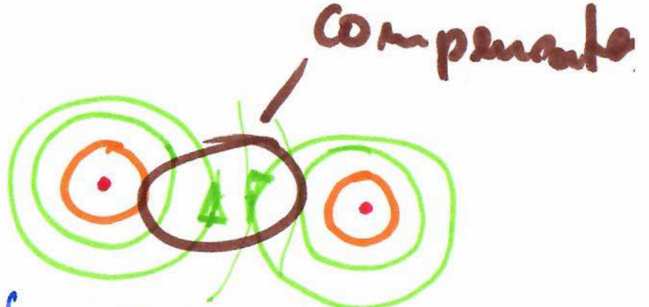
general Law → One of Maxwell Laws

Also:



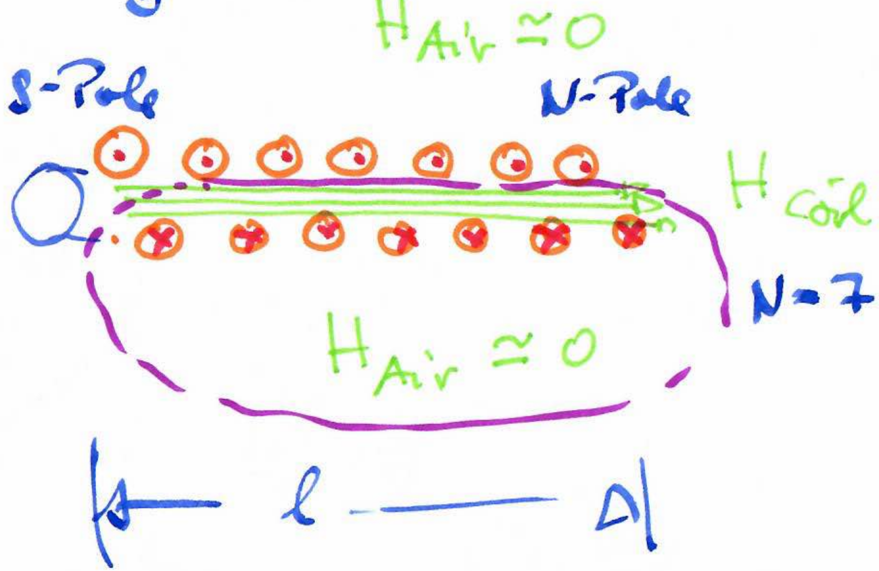
- The magnetic field of a coil (cylinder)





- copy fig. 4.4

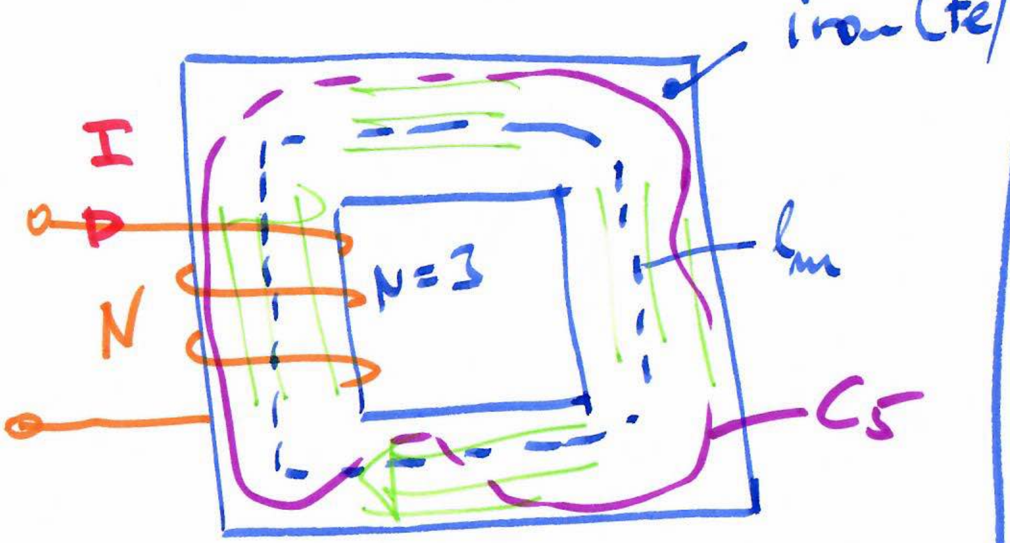
is



$$\oint \vec{H}\, d\vec{s} = H_{coil} \cdot l = NI = 7I$$

$$H_{coil} = \frac{N I}{l} \quad \text{in } \frac{A}{m}$$

• Iron core with a coil



- magn. : field lines like to go to iron and not to the air (as a current likes to go to metal conductor and not through plastic / wood conductors)

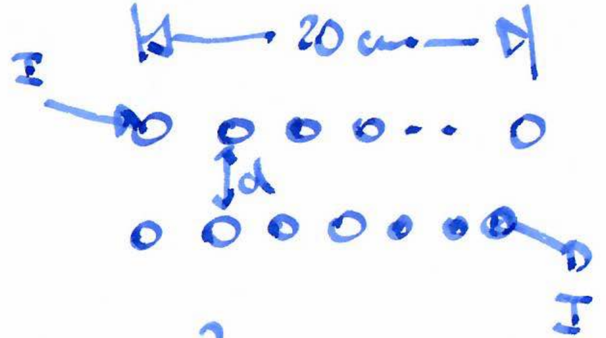
l_m : middle field strength length

$$\oint_{C5} \vec{H}\, d\vec{s} = NI \approx H \cdot l_m$$

$$H = H_{iron} = \frac{NI}{l_m}$$ → only a "long" coil

• Motor / drive of the magn. field is the current (I, $N \cdot I$)

<u>Examples:</u>

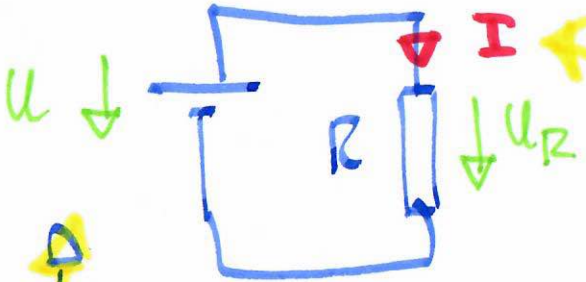


$l = 20\text{ cm}$
$I = 5\text{A}$
$d = 4\text{ cm}$ ($\ll 20\text{ cm}$)
$N = 200$

$$H = \frac{200 \cdot 5\text{A}}{0.2\text{m}} = 5000\,\frac{\text{A}}{\text{m}}$$

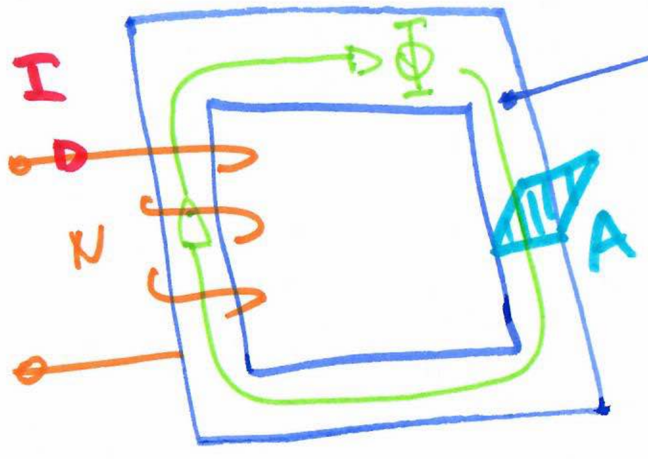
(7)

- magnetic flux, magnetic flux density



U, I are two different physical values

in magnetic circuits we have also two different physical values



μ : permeability

(A)

$N \cdot I$ and Φ

magnetic voltage, magnetic drive | magnetic flux

(8)

Permeability : "similar / magnetic conductivity"

: $\mu = \mu_0 \cdot \mu_r$ → relative permeab...

→ absolute permeability $= 4\pi \cdot 10^{-7} \frac{Vs}{Am}$

: $\mu_r = 1$ in air, water, plastic, wood..

$\mu_r >> 1$ in iron, ... (4)

⇒ it is not usual to handle with flux, we handle with flux density

$$B = \frac{\Phi}{A}$$

$$\Phi = \iint_A \vec{B}\, d\vec{A}$$

correct

flux density, magn. induction

H in $\frac{A}{m}$

μ in $\frac{Vs}{Am}$

Φ in $Vs = Wb$

B in $\frac{Vs}{m^2} = T$

σ in $\frac{S}{m}$ conduct.

ρ in $\Omega \cdot m$ spec. resistance

$\rho = 1/\sigma$

(9)

$T = \frac{kg}{s^2\,A}$

$= \frac{N \cdot s^2 \; Ws}{m^2\, s^2\, A \; VA}$

$= \frac{Vs}{m^2}$

Seven base units

mol, ~~V~~, A, s, m

kg, K, cd

!

$1\,Ws = 1\,Nm$

$= 1\,J$

$1N =$

$(\vec{F} = m\,\vec{a})$

↓ N ↓ kg ↓ $\frac{m}{s^2}$

(10)

Def $\vec{a} = \frac{d\vec{v}}{dt}$; $\vec{v} = \frac{d\vec{s}}{dt}$

↓ acceleration ↓ velocity, = speed

(W: work ; P: Power, ..)

$N = kg \cdot \frac{m}{s^2}$; $kg = \frac{N \cdot s^2}{m}$

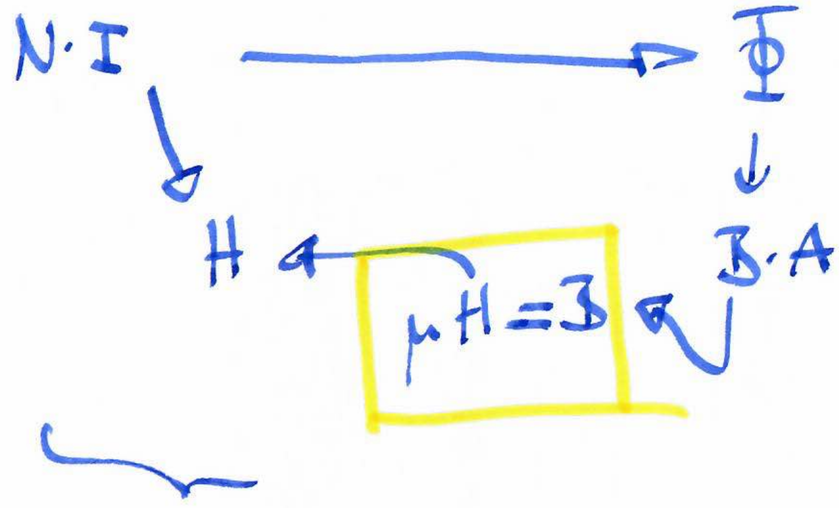
$N = \frac{Ws}{m}$

Examination question: show that $\frac{kg \cdot m^2}{s^2 A} = Vs$

~~$\vec{\sigma}$ $\vec{E}$~~ σ in $\frac{S}{m}$

$E = m\,c^2$

see above: (A)



$$\Rightarrow \Phi = B A = \mu \cdot H \cdot A$$

$$\Phi = \mu_0 \mu_r H \cdot A = \mu_0 \mu_r \cdot A \cdot \frac{IN}{l_m}$$

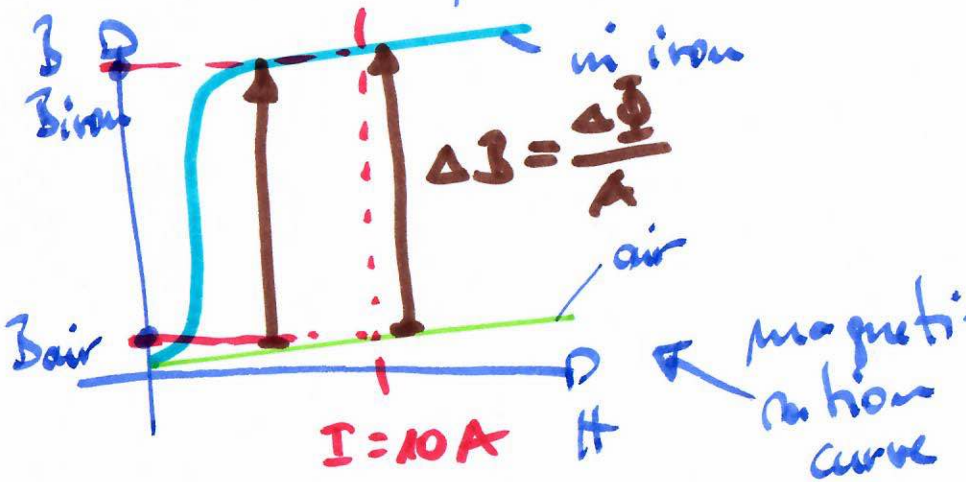
inside $B = \mu_0 \mu_r H$

μ_r: material constant as σ, ρ

But $B = f(H)$ → problem

↳ not linear

$$B = \mu H \; ; \; \mu = \frac{B}{H} = f(H)$$

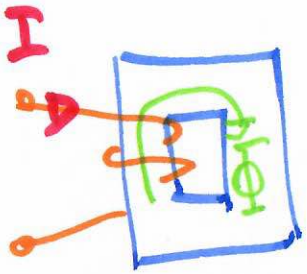


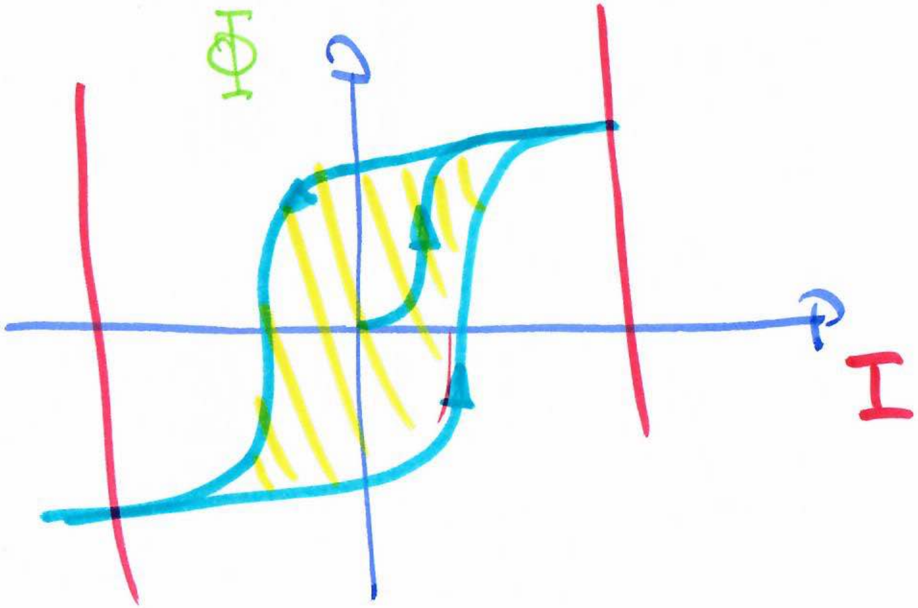
ΔB: Benefit of the iron. This is the reason why electric machines are always iron inside: motors, gener., magnets, ...

(13)

• Hysteresis Curve | Loop

- same construction as at the top ↗ (A)





|||| Area of the curve:

$$\left[\int \Phi \, dI\right] = Vs \cdot A = Ws$$

↳ Work, Energy

(14)

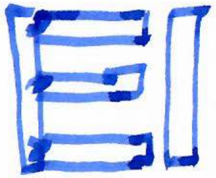
50 times/s this area ≡ energy is needed ⇒

$$P_{L.H} \sim f \sim$$ 

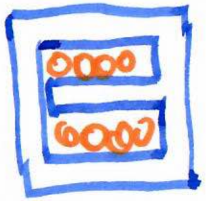
L ↓ loss, H ↓ Hysteresis

18.12.18, El. Modelling

- Iron Core with air gap
  - See iron cores in the internet as:



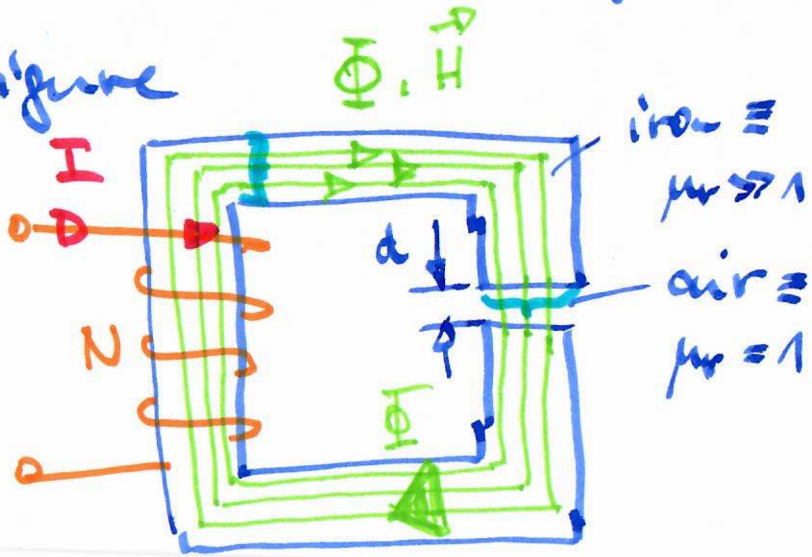
E-I-core



M-core

  - no solid core, it consists of thin iron leaves as in ET 22, Fig 20a, 20b

  - Figure



? all magnetic flux lines are closed ?

} homogene

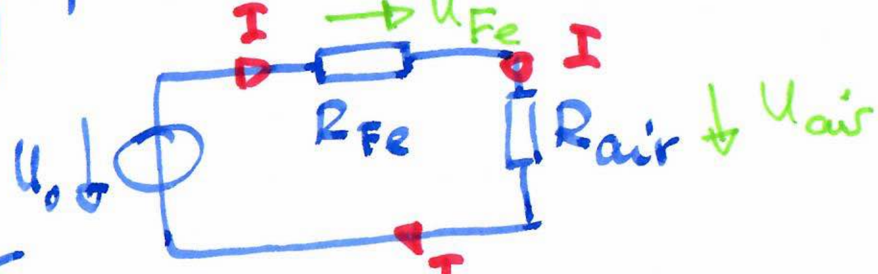
We run $\oint \vec{H} \, d\vec{s} = N \cdot I$

Area A is similar at all points of the core and in the air gap.

$\Phi = const = B \cdot A = \mu_0 \mu_r \cdot H \cdot A$

l_{Fe}, $l_{air} = d$

equivalent electric circuit:



③

$\rightarrow H_{Fe} \cdot l_{Fe} + H_{air} \cdot d = N I$ ✓

$\frac{B_{Fe}}{\mu_0 \mu_r}$ $(B = \mu_0 \mu_r H)$ $= B$ $\qquad \frac{B_{air}}{\mu_0}$ $= B$

$$\frac{\Phi = \Phi_{air} = \Phi_{Fe}}{A} = B = B_{air} = B_{Fe}$$

$$\frac{B}{\mu_0 \mu_r} \cdot l_{Fe} + \frac{B}{\mu_0} \cdot d = N \cdot I$$

$$B \left(\frac{l_{Fe}}{\mu_0 \mu_r} + \frac{d}{\mu_0} \right) = N \cdot I \, \mu_0$$

④

$$B = \frac{N I \mu_0}{\frac{l_{Fe}}{\mu_r} + d}$$

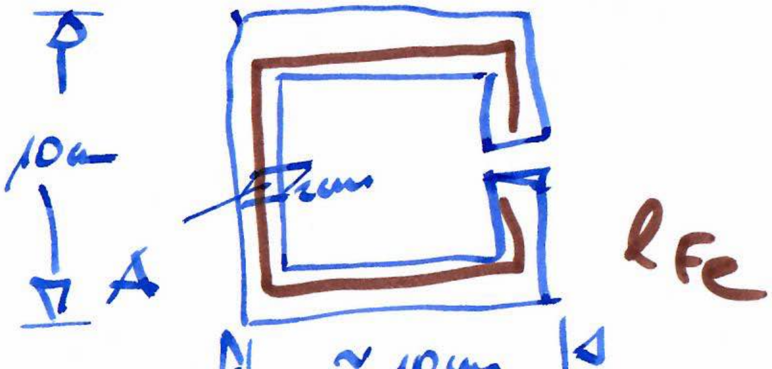
$$\Phi = \mu_0 \frac{N I A}{\frac{l_{Fe}}{\mu_r} + d}$$

Exaple: $\mu_r = 200$; $l_{Fe} = 40$ cm

$d = 1$ mm; $N = 500$

$I = 5A$; $\mu_0 = 4\pi \cdot 10^{-7} \frac{Vs}{Am}$

$A = 4 \text{ cm}^2$

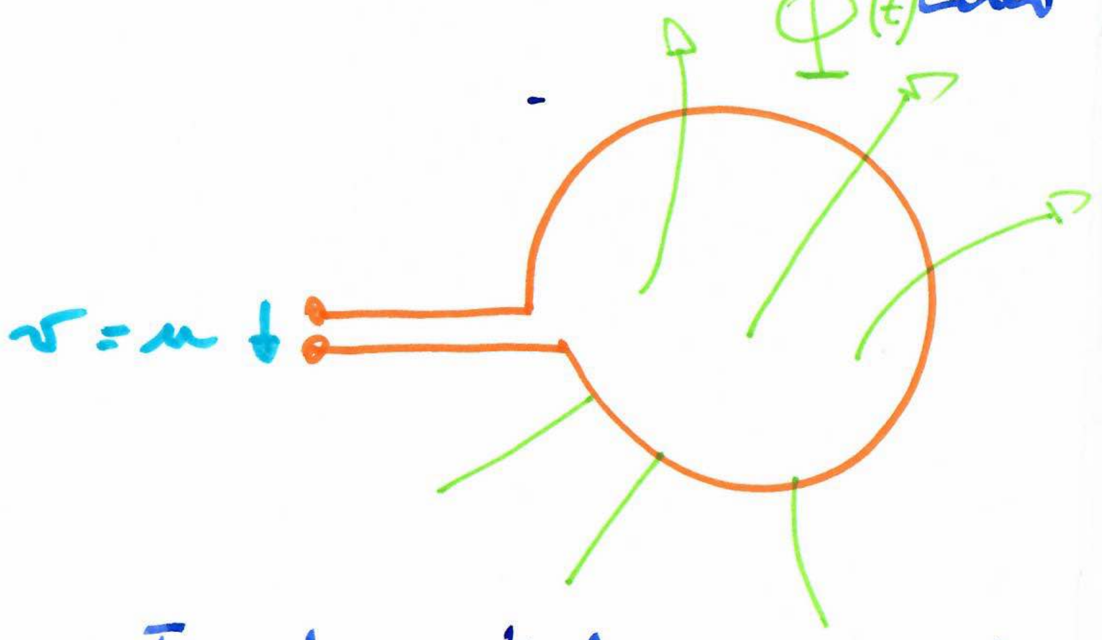


⑤

⇒ the air gap needs a lot of "magnetic voltage" = NI

So general the air gap should be small / short.

- Faraday Law / Induction Law



Faraday observed: if the

⑥

magn. flux Φ is changing, a voltage v appears

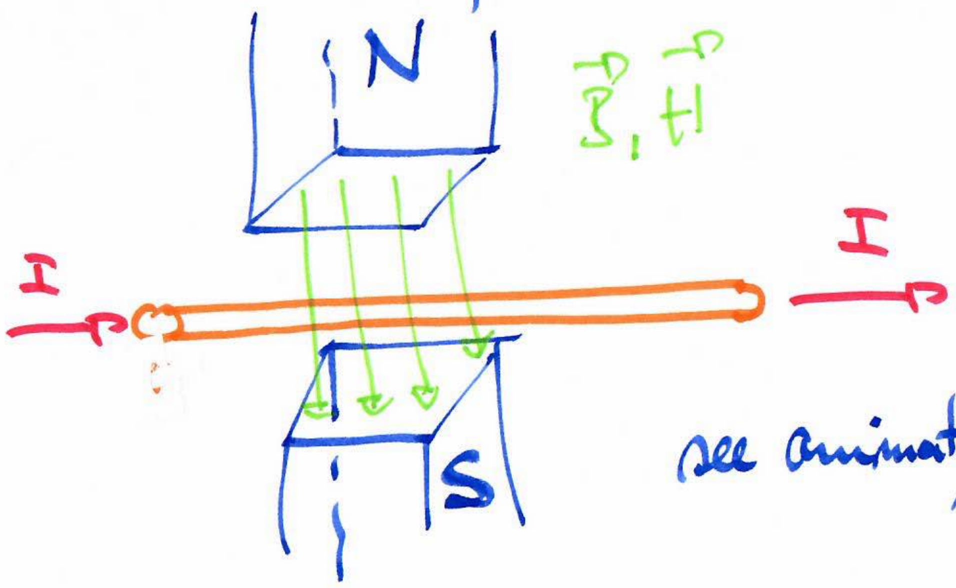
Induction law

$$u = N \frac{d\Phi}{dt}$$

! important

N : no. of windings

- Force on a wire in a magnetic field



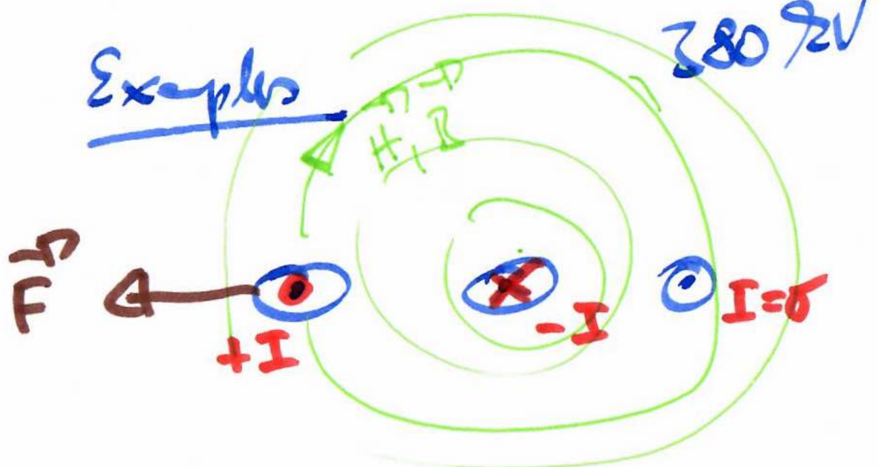
see animation

7

- direction of the force

rule: If the magn. field lines points into the inner of the open hand and the thumb shows to the direction of the current, then the other fingers shows in to the direction of the force.

Examples



8

I : short circuit current
for ex. 10^4 ... 10^6 A

• Lenz Rule

see: skript ET14A or/and Wikipedia

○ Inductance, a parameter of a coil, characteristic of a coil

we discussed :

$$I \rightarrow \vec{H} \rightarrow \vec{B} \rightarrow \Phi$$

but to measure the flux

is not so simple ? (9)

People in History did calculate this. Magn. flux – what is it?

We need it in elektr. circuit,...

It can be find ∫

$I \longrightarrow \Phi$

$I \sim \Phi$: ($Cost_{car} \sim mass$) → proportionality

$I = \alpha \, \Phi$

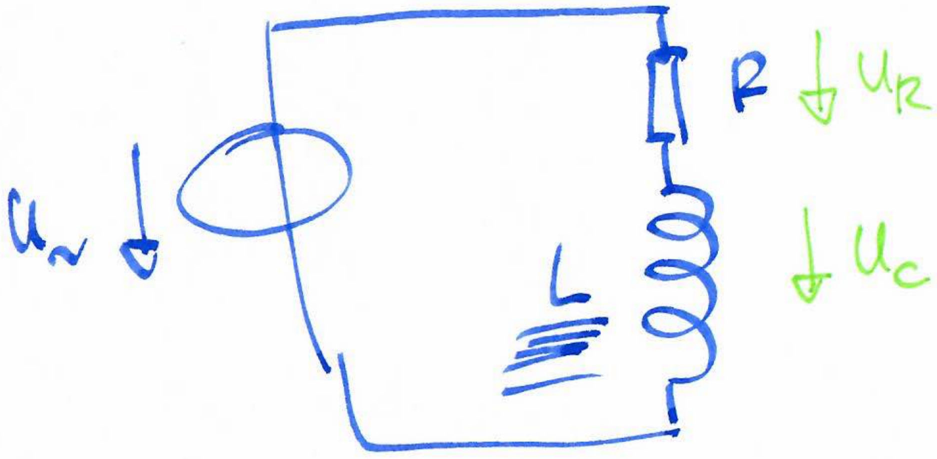
only another form

$\Phi = L \cdot I$ or $L = \frac{\Phi}{I}$ Inductance in $H = \frac{Vs}{A}$

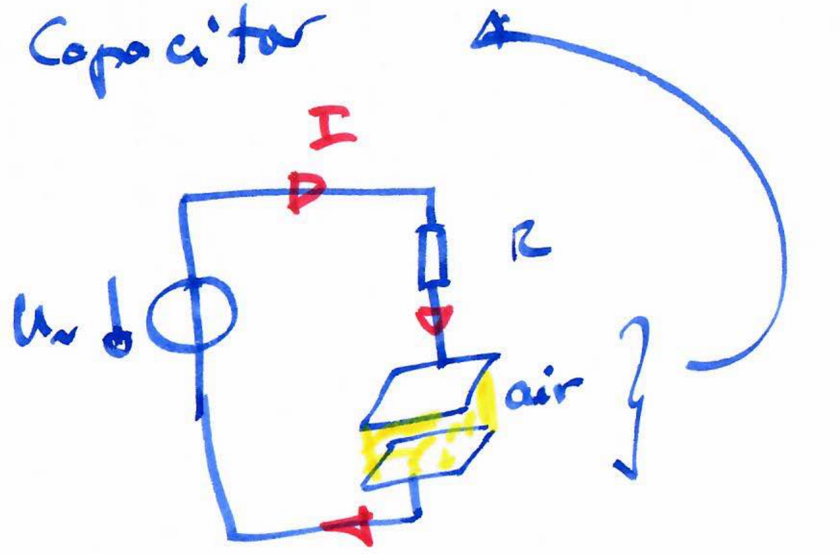
(10)

Inductances

example:



∘ Capacitor

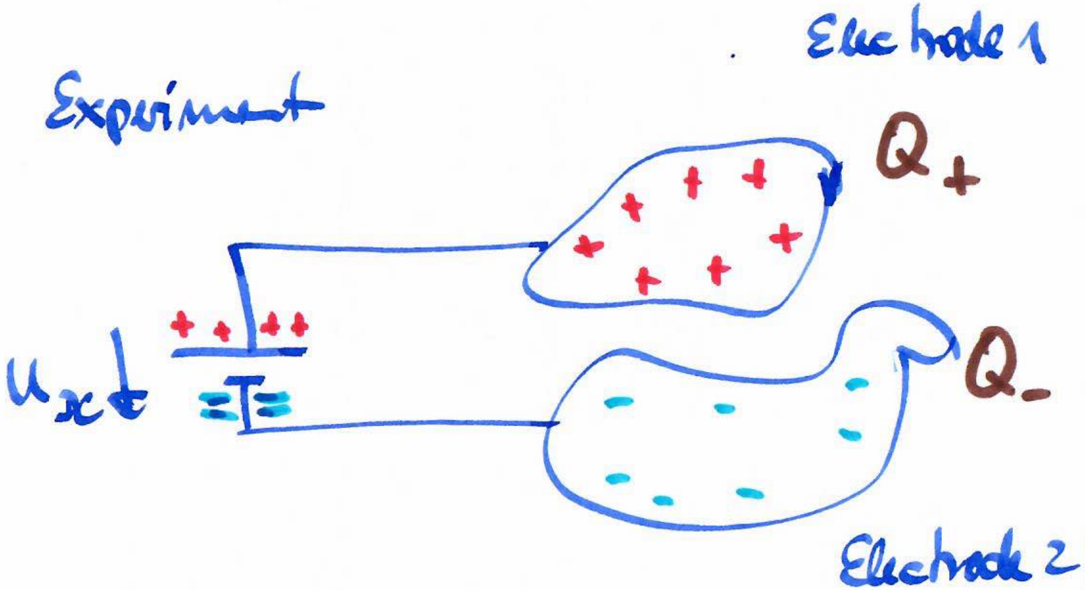


$$I = \frac{dQ}{dt}$$

Def. of current

1st semester

Experiment



$U_{DC} \longrightarrow Q_+$

$U_{DC}\uparrow \longrightarrow Q_+\uparrow$

$U_{DC}\uparrow\uparrow \longrightarrow Q_+\uparrow\uparrow$

$U_{DC} = U \longrightarrow Q_+ = Q$

$Q \sim U$

$Q = C \cdot U$

$$C = \frac{Q}{U}$$ in $\frac{As}{V} = F$ → Farad

as

$$L = \frac{\Phi}{I}$$ in $\frac{Vs}{A} = H$ → Henry

it follows $u = L\frac{di}{dt}$

$i = C\frac{du}{dt}$