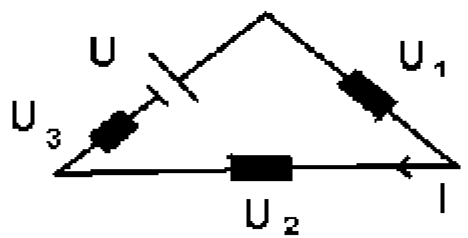
Comments to setups
Rules of Kirchhoff :

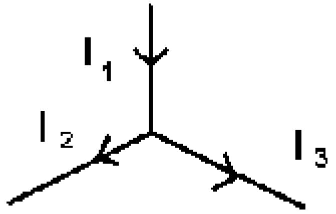
1: Node rule: $\sum_i I_i = 0$

Charge conservation

2: Mesh rule: $\sum_i U_i = 0$



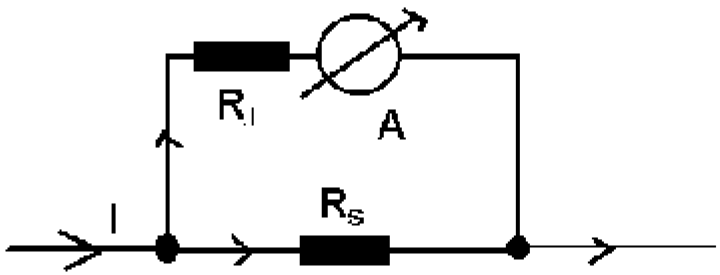
$$\sum_i U_i = U$$



Independence of path of potential difference

Application: Measurement device

e.g.: measurement of current

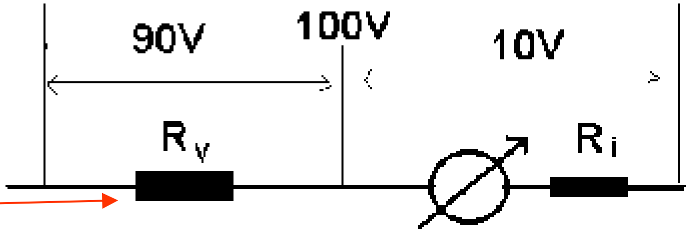


Increase of measurement range

$$\frac{R_s}{R_i} = \frac{\frac{1}{10}}{\frac{9}{10}} \Rightarrow R_s = \frac{1}{9} R_i$$

e.g.: Measurement of voltage
(most measurement of current)

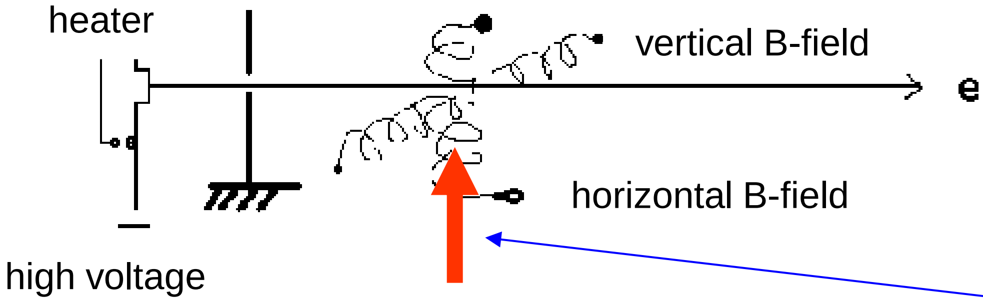
Series-resistor



Range of measurement $1R_V,$

9.5. Matter in a magnetic field

2. Tube of Braun



Horizontal B-Field → Vertical deflection

1. Step:

iron, ferrite

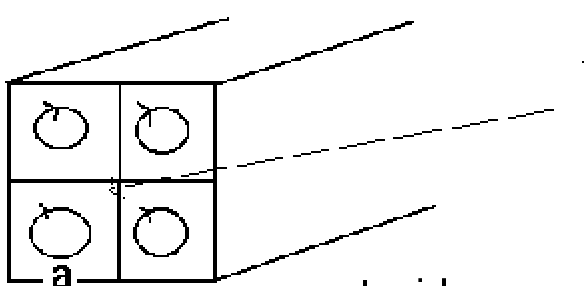
Permanent magnet

Matter in coil,
e.g.: Fe, Ferrite

amplification of deflection → amplification of magn. field

Model conception:

In iron/ Ferrite, are small magnetic dipoles, they get aligned due due the applied field amplify the field.



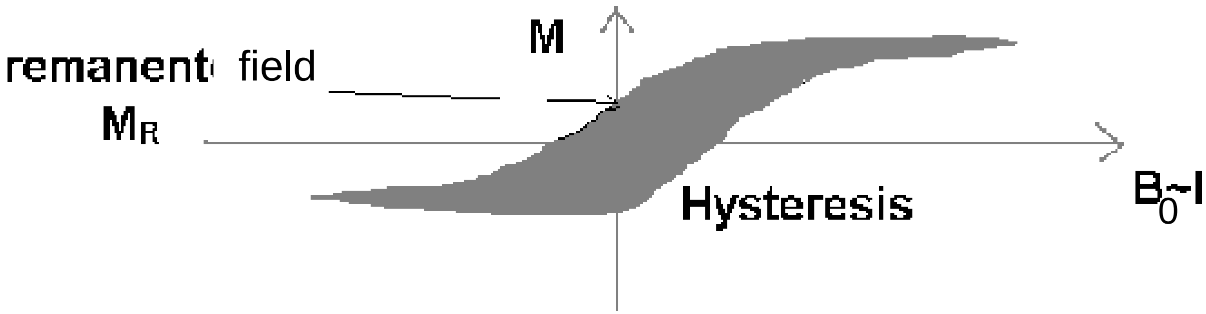
Inside currents cancel

outside: ring current I
crates I*a² :

Magnetic moment of the region

Magnetization: $\vec{M} = \frac{\text{magn.Moment}}{\text{Volume}}$ analog $\vec{P}$ for electrical case

conclusion: $\vec{B} = \vec{B}_0 + \mu_0 \vec{M}$ $\vec{B}_0$ magnetic field



„ time lag" of magnetization behind magnetic field

M_R ',large": magnetic hard $\rightarrow$ *permanent magnet*

M_R ',small": magnetic soft →Trafo

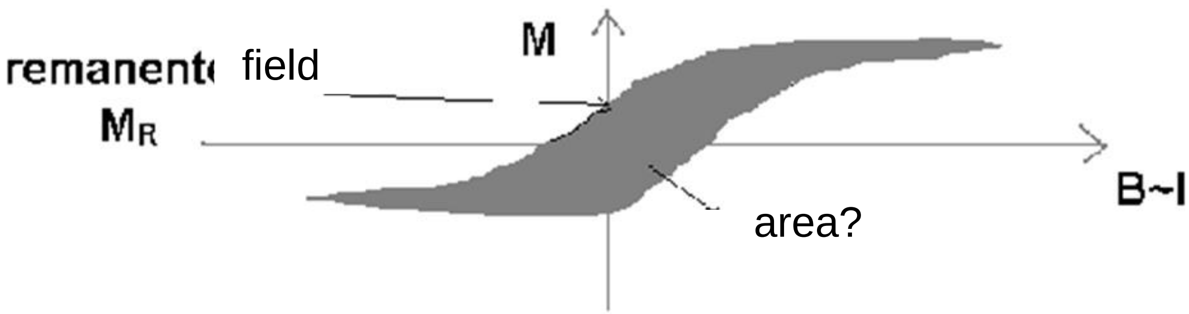
Relative permeability: $\vec{B} = \vec{B}_0 + \mu_0 \vec{M}$ conclusions:

$\mu_0 \vec{M} = \chi \vec{B}_0$ χ : Susceptibility and thus: $\vec{B} = \vec{B}_0 (1 + \chi)$

$1 + \chi = \mu$: degree orientation

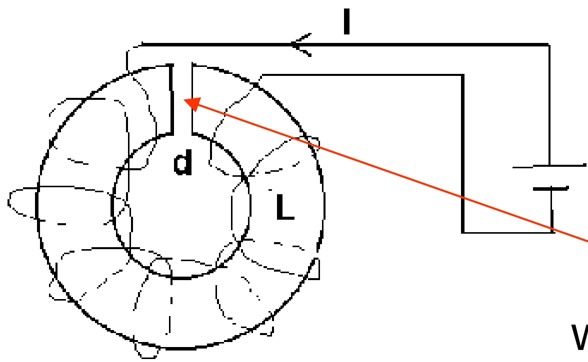
Ferromagnetic material:

$$\int M(B_0)dB_0 = \frac{\chi}{2\mu_0}B_0^2 = \frac{\mu-1}{2\mu_0}B_0^2$$



$\chi \gg 1$

Application: High magnetic fields



L: Path in iron, d: width of air gap
N: Number of turns

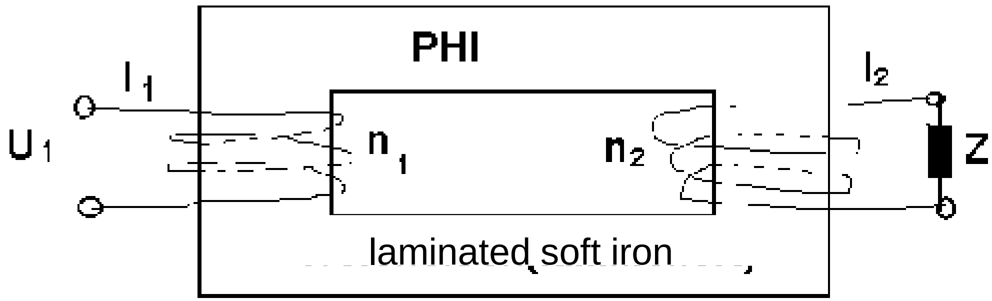
field strength of coil without iron:

$$B_0 = \mu_0 \frac{N}{L} I$$

with iron:

$$B = \mu \cdot B_0$$

Transformer:



Primary & secondary winding

Ideal Transformer

a) Ohmic resistance negligible (coils& supply lines)

b) No , hysteresis

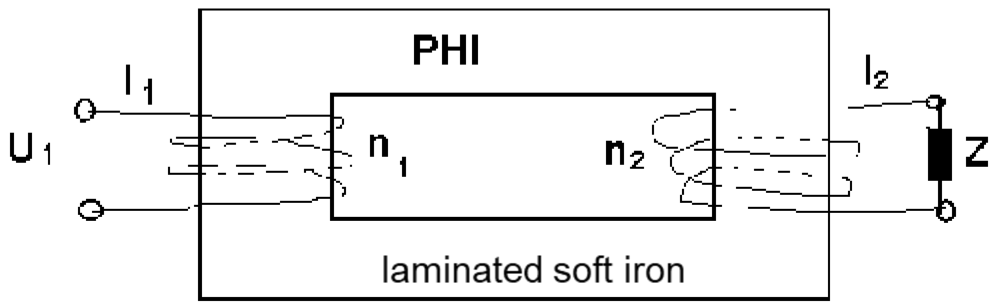
c) Φ in iron concentrated

$U_1 = -U_{ind}; U_1 = n_1 \cdot \dot{\Phi}$ secundary circuit: $\dot{\Phi}$ produces $U_2 = -n_2 \cdot \dot{\Phi}$

→Voltage transfer factor of transformer: $\frac{U_2}{U_1} = -\frac{n_2}{n_1}$

Special case : $I_2 = 0$ primary circuit: Open circuit voltage $I_{1,0} = \frac{U_1}{i\omega L_1}$

pure idle current



Z

in secondary circuit:

$$Z = R + i\omega L; I_2 = \frac{U_2}{Z}$$

$\dot{\Phi}$ compensates U_1, no extra change of Φ

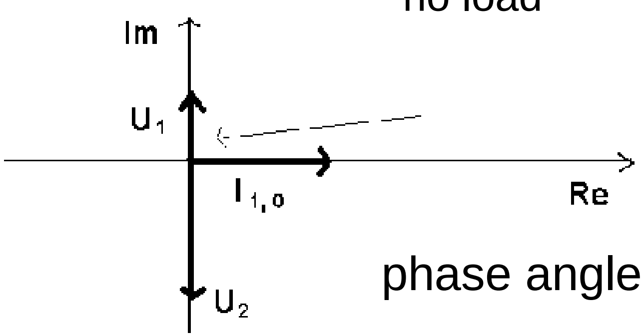
$n_2 \bullet I_2$ has to be compensated by I_1'

$$n_1 \bullet I_1' + n_2 \bullet I_2 = 0 \Rightarrow \frac{I_2}{I_1'} = -\frac{n_1}{n_2}$$

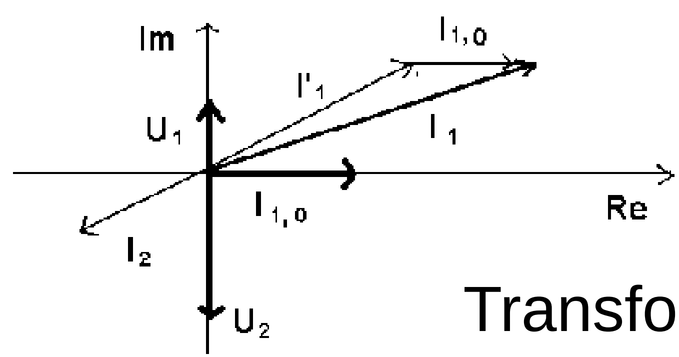
primary current:

$$I_1 = I_{1,0} - \frac{n_2}{n_1} I_2 = I_{1,0} - \frac{n_2}{n_1}\frac{U_2}{Z}$$

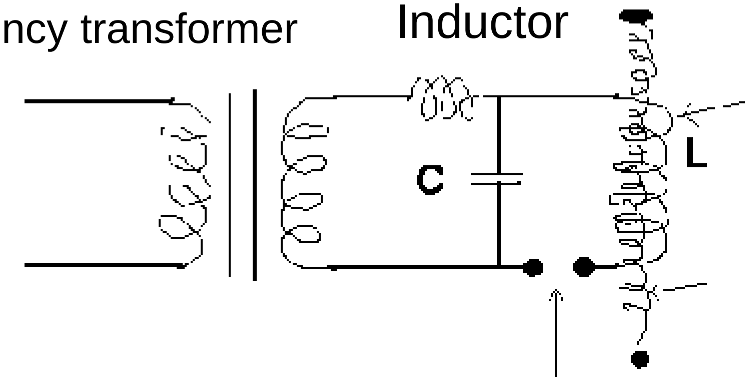
no load



phase angle



Transformer loaded



TESLA-Transformer

e.g.:C=$10^{-9}F, L = 1.25 \cdot 10^{-6}H \Rightarrow \nu = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} =$

$$\frac{1}{2\pi}\sqrt{\frac{1}{10^{-9}\cdot 1.25\cdot 10^{-6}}} = 4.5\times 10^{6}s^{-1}$$

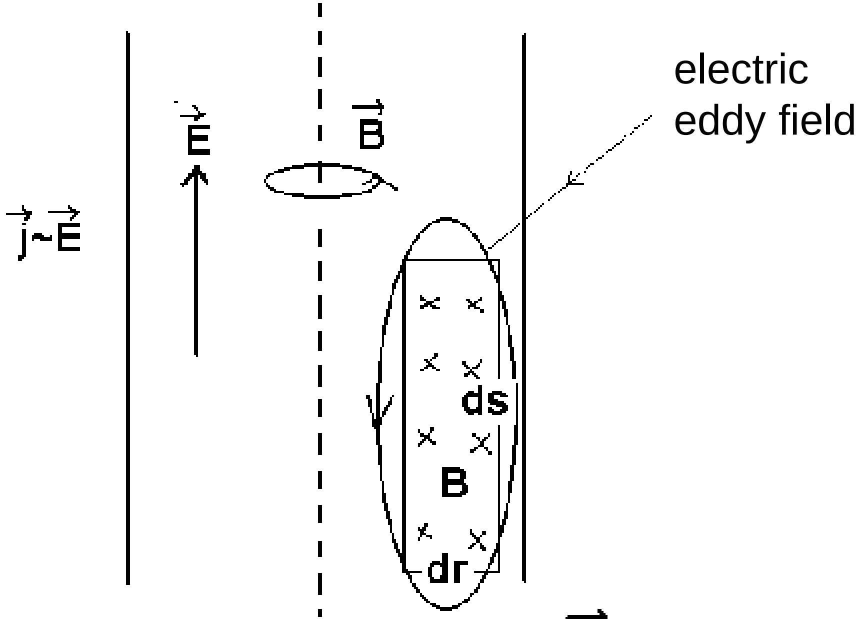
Damping due to resistance of coil and spark gap

very high voltages : a few $10^{5}V$

High rate of change of magnetic flux

Skin effect! Observation: High frequency

Current urges towards surface



E_{ind} via

$\dot{B} \cdot ds \cdot dr = \dot{\Phi}$

recall:

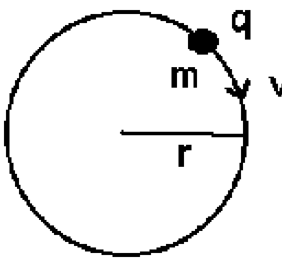
$$\oint \vec{E} \cdot d\vec{s} = -\dot{\Phi}$$

$\vec{E}_{ind}$ in wire opposite to $\vec{E}$

penetration depth for 100 Hz ca. few cm

for $10^{12} Hz$ ca. 0.1 μm

Other effects of matter in magnetic fields



On atomic level one has atomic magnetic moments:

$$angular\ momentum : L = m \cdot v \cdot r$$

Magnetic moment $m_m = I \cdot A = I \cdot \pi \cdot r^2$

Charge on orbit : $I = q \cdot v = \frac{q}{T} = \frac{q \cdot v}{2\pi r}$ With $T = \frac{2\pi r}{v}$

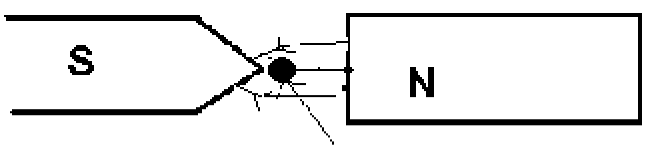
magnetic moment

$$m_m = I \cdot A = I \cdot \pi \cdot r^2 = \frac{q \cdot v}{2\pi r} \cdot \pi \cdot r^2 = \frac{1}{2} q \cdot v \cdot r$$

Paramagnetism: $\chi > 0$ e.g.: Al

χ Orientation of elementary magnets degree of orientation:

$$\vec{m}_m \cdot \frac{\vec{B}}{k \cdot T} = \frac{potential\ energy\ of\ dipoles\ a\ magnetic\ field}{thermal\ agitation}$$



pellet of matter

magnetic dipole in a inhomogene magnetic field:

gets pulled towards tip

force !

In case of a magn. dipole:

field gets stronger

with Pb, Bi and C one observes repulsion coming from tip!

All these elements do not have a permanent dipole momemt !

i.e.: $\chi < 0$ or the field gets weaker!

Diamagnetism

Cause (classical):

By bringing in matter the B-field induces „additional" loop currents , that means additional magnetic moments in atoms.

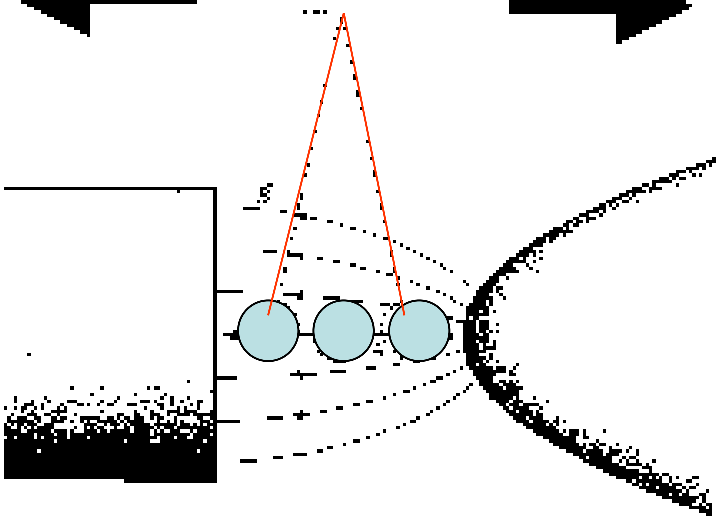
According to the rule of Lenz: Attenuation

All matter show diamagnetism!

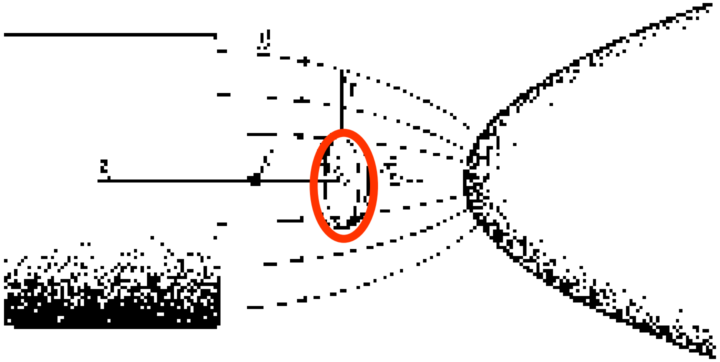
A few show in addition, but dominating, paramagnetism respectively, ferromagnetism

Diamagnetism

Paramagnetism



circuit currents by having diamagnetism



See Feynman Vol.II

„Now we would like to demonstrate that according to classical mechanics there can be no diamagnetism or paramagnetism at all“ !!!!!