Vorlesung 7

Physik II

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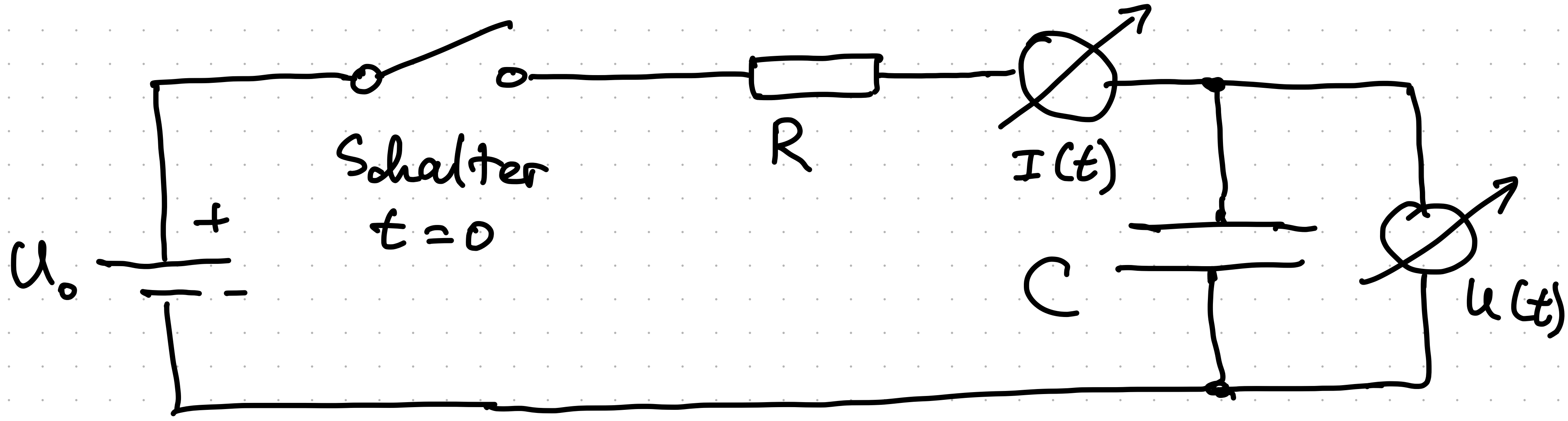
SS 2020

Aufladung eines Kondensators



$$t = 0 \; ; \quad U(0) = 0 \; ; \quad Q(t) = C \cdot U(t) \; ;$$

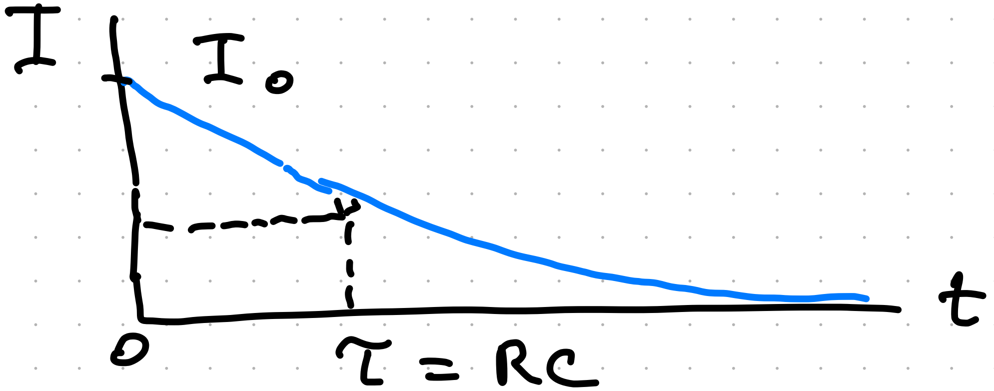
$$I(t) = \frac{U_0 - U(t)}{R} = \frac{U_0}{R} - \frac{Q(t)}{RC} \; ;$$

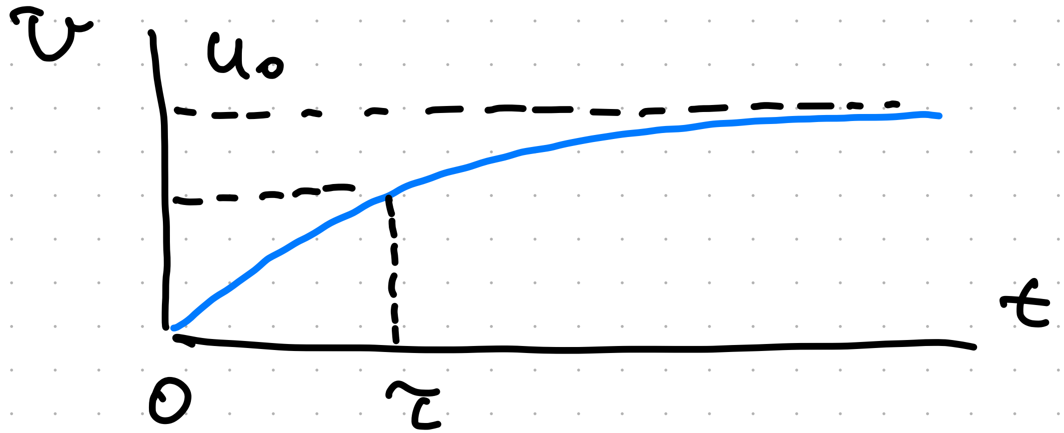
$$I(t) = \frac{dQ(t)}{dt} \; ;$$

Differentiation:

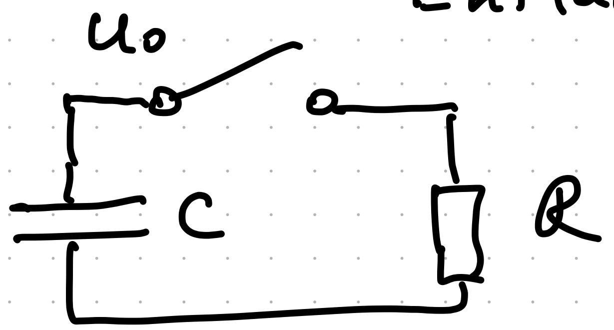
$$\frac{dI}{dt} = -\frac{1}{RC}\, I(t) \;; \qquad I(0) = I_0$$

$$\Rightarrow \quad I(t) = I_0 \cdot e^{-t/RC} \;; \qquad U(t) = U_0\left(1 - e^{-t/RC}\right);$$



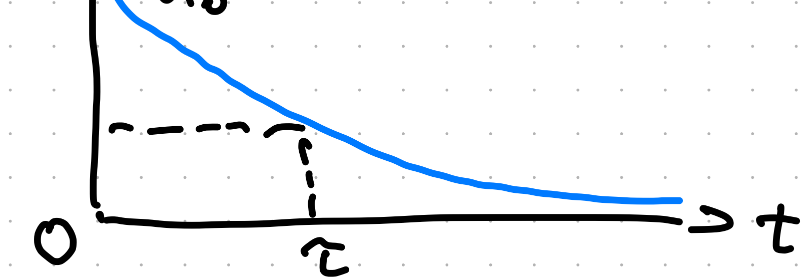


Kondensator-Entladung



$$Q_0 = Q(0) \;; \; U_0 = U(t)$$

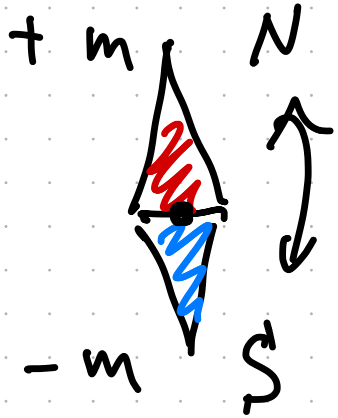
$$U(t) = U_0\, e^{-t/RC}$$



3. Statische Magnetfelder

3.1. Magnetfeld Stationären Strömungen

1785 Coulomb → Elektrostatik



Hypothese ?

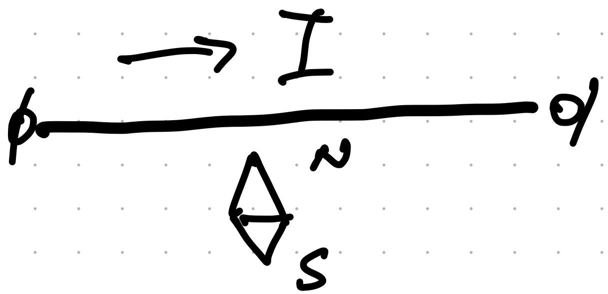
Theorien von magnetischen Ladungen

Magnetostatik: $F \sim \dfrac{m_1 m_2}{r^2}$;

Magnetisches Feld (Feldstärke): $\vec{H} = \dfrac{\vec{F}}{m}$;

1820 Oersted – Versuch (DK)

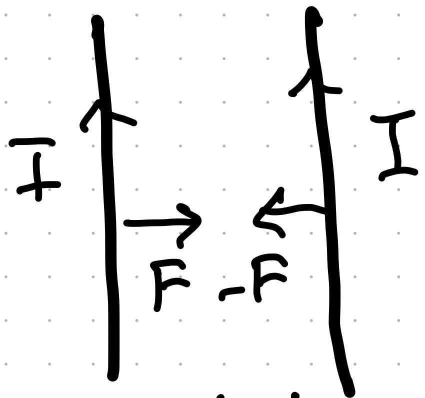
(Ørsted)



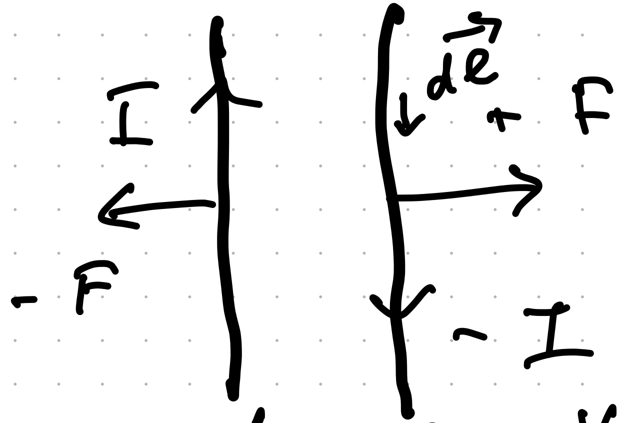
Magnetfelder stationärer Ströme

$[H] \rightarrow 1\,\mathrm{Oe}$; [cgs]

1820 Ampère (F) Versuche



parallel



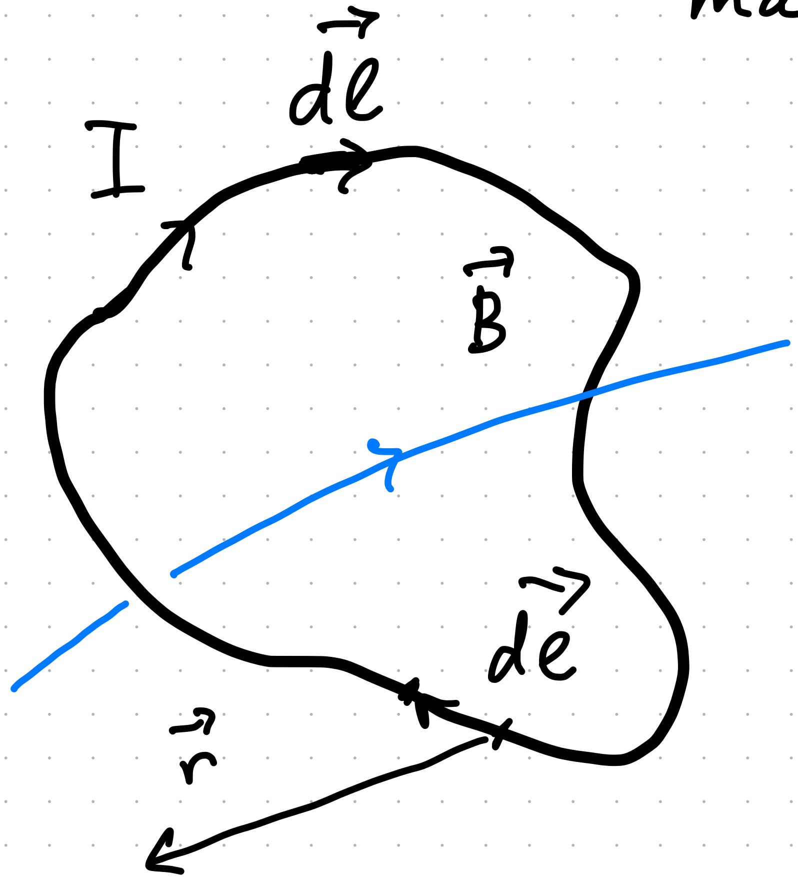
anti-parallel

Idee: perman. Magnete

neu: Vektor $\underbrace{\vec{B}}_{\text{Feldstärke (magn. Induktion)}}$ und Stromelement $I d\vec{l}$

Feldstärke (magn. Induktion)

magnetische Kraftflußdichte.



Ampersche Gesetz:

$$(1) \quad d\vec{F} = k_1 I \underbrace{[d\vec{l}\,\vec{B}]}_{\text{Vektorprodukt: } d\vec{l} \times \vec{B}};$$

Vektorprodukt: $d\vec{l} \times \vec{B}$

auch als Definition für $\vec{B}$!

Biot-Savart Gesetz:

$$(2)\quad d\vec{B} = k_2 I \frac{[d\vec{\ell}\ \vec{r}]}{r^3} \quad ; \quad dB \sim \frac{1}{r^2} \ ;$$

Mit $k_1 = k_2 = 1$, $\Rightarrow$ [cgs M];

nicht mehr benutzt!

$$[\text{cgs E}] + [\text{cgs M}] = [\text{Gauß}] \ ;$$

$Q, I, \Delta\varphi, R \qquad B, H, L, M$

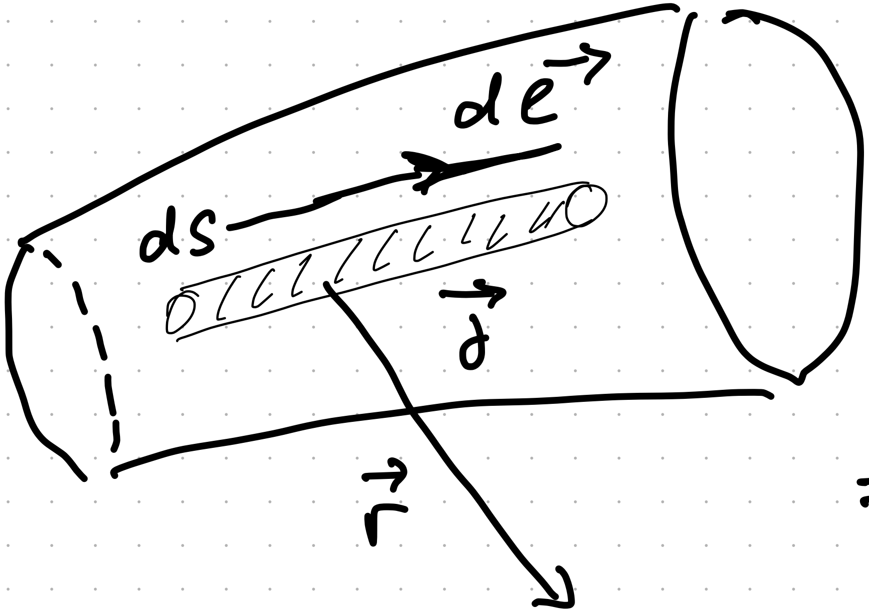
$$I_{[\text{cgs M}]} = \frac{1}{c} I_{[\text{cgs E}]} \quad ; \quad c = 3 \cdot 10^{10} \frac{cm}{s} \ ;$$

Elektrodynamische Konstante

$$[E]_{[\text{cgsE}]} = [B]_{[\text{cgsE}]} \ ; \quad [B] \to \text{cgs} \to 1\,G \text{ Gauß}$$

$$\boxed{1\,T = 10^4\,G} \qquad [B] \to SI \to 1 \text{ Tesla}$$

Superpositionsprinzip: $\vec{B} = \sum_i \vec{B}_i$;



$\vec{j} = \rho_{el} \cdot \vec{v}$; $\rho_{el} = n q$;

$I = j\, ds$; $I d\vec{l} \parallel \vec{j}$;

$$\Rightarrow d\vec{F} = \frac{ds \cdot dl}{c} [\vec{j}\, \vec{B}];$$

$$d\vec{F} = \frac{dV \rho_{el}}{c} [\vec{v}\, \vec{B}];$$

Lorentzkraft!

(1 Ladung) (3)

$$\boxed{\vec{F}_L = \frac{q}{c} [\vec{v}\, \vec{B}]}$$

anβ (1)

auch als Definition für $\vec{B}$ nutzen.

Gleichung (2):

$$d\vec{B} = \frac{dS \cdot dl}{c} [\vec{j}\,\vec{r}] \frac{1}{r^3} = \frac{dV \overbrace{nq}^{Sel}}{c} \frac{[\vec{v}\,\vec{r}]}{r^3};$$

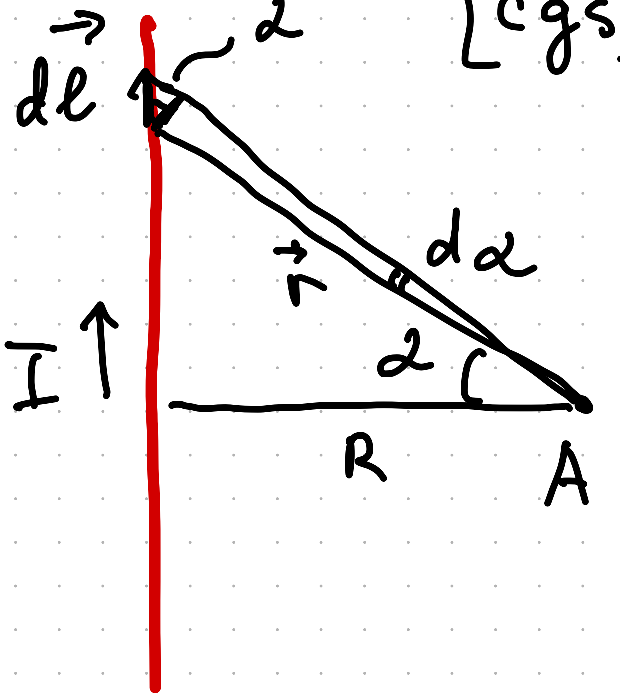
1 Ladung: $\vec{B} = \frac{q}{c} \frac{[\vec{v}\,\vec{r}]}{r^3}$; $\Rightarrow (4)$ $\boxed{\vec{B} = \frac{1}{c}[\vec{v}\,\vec{E}]}$

cgs E:

$$\underbrace{\vec{dF} = \frac{1}{c} I [\vec{dl}\,\vec{B}]}_{\text{Ampere}}\,; \quad \underbrace{\vec{dB} = \frac{1}{c} I \frac{[\vec{dl}\,\vec{r}]}{r^3}}_{\text{Biot-Savart}}$$

3.2. Gesetz von Biot-Savart

Magnetfeld eines geraden Leiters



[cgs]

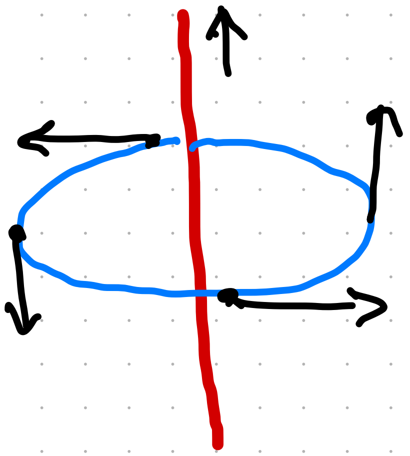
$$dB = \frac{I}{c}\,\frac{dl\,r\cos\alpha}{r^3};$$

$$dl\cdot\cos\alpha = r\,d\alpha; \Rightarrow$$

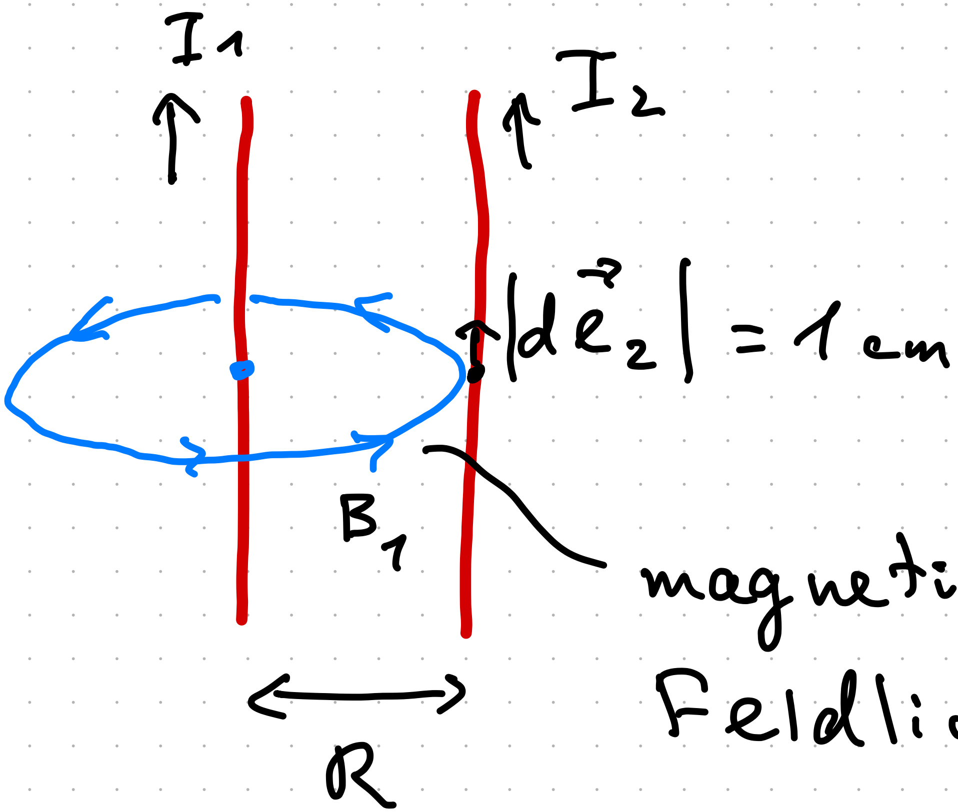
$$dB = \frac{I}{c}\,\frac{r^2\,d\alpha}{r^3} = \frac{I\,d\alpha}{c\,r};$$

$$dB = \frac{I\cos\alpha\cdot d\alpha}{c\,R};$$

$$\Rightarrow \quad B = \int_{-\pi/2}^{\pi/2} \frac{I\cos\alpha\,d\alpha}{c\,R} = \frac{2I}{c\,R}; \quad (5)$$



Rechtsschraube! $\vec{B} \sim [\vec{dl}\,\vec{r}]$;



$$B_1 = \frac{2 I_1}{c R} \; ;$$

$$F_{1,2} = \frac{2 I_1 I_2}{c^2 R} \; ;$$

[cgs]

[SI] :

$$\boxed{F_{1,2} = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{R}}$$

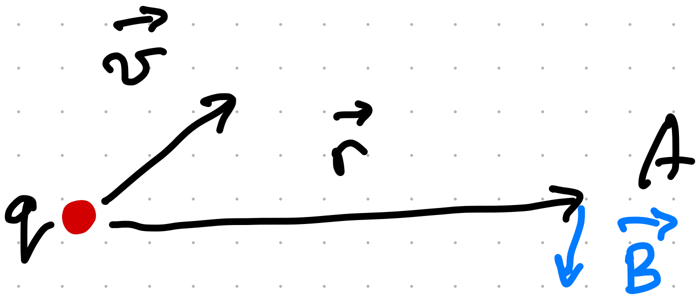
$$\mu_0 = 4\pi \cdot 10^{-7} \frac{H}{m} \; ;$$

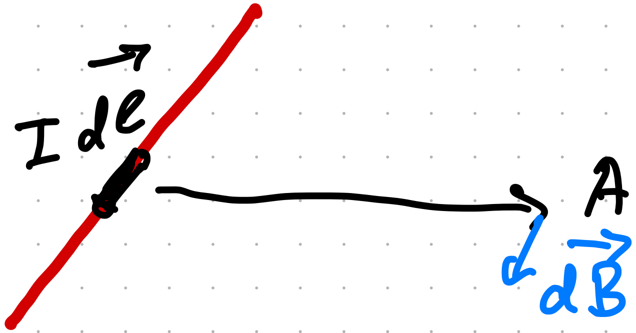
$\downarrow$

Definition von $[I] = 1 A$.

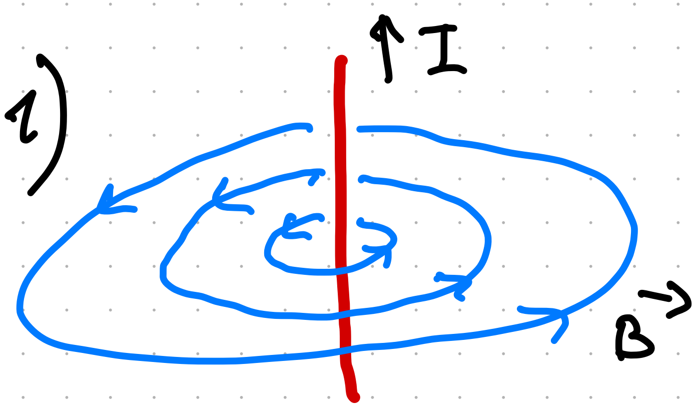
Statische Magnetfelder: Zusammenfas

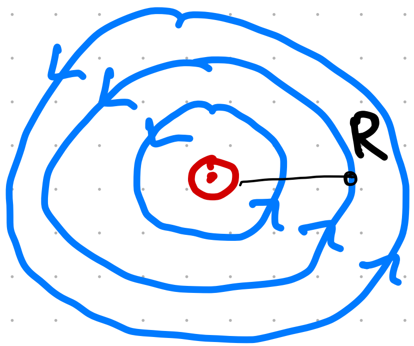
[cgsE]	[SI]
$\vec{B} = \frac{q}{cr^3}[\vec{v}\,\vec{r}]$;	$\vec{B} = \frac{\mu_0 q}{r^3}[\vec{v}\,\vec{r}]$;
$d\vec{B} = \frac{I}{cr^3}[d\vec{l}\,\vec{r}]$;	$d\vec{B} = \frac{\mu_0}{4\pi r^3} I [d\vec{l}\,\vec{r}]$;
oder	oder
$d\vec{B} = \frac{dV}{cr^3}[\vec{j}\,\vec{r}]$;	$d\vec{B} = \frac{\mu_0}{4\pi r^3} dV [\vec{j}\,\vec{r}]$





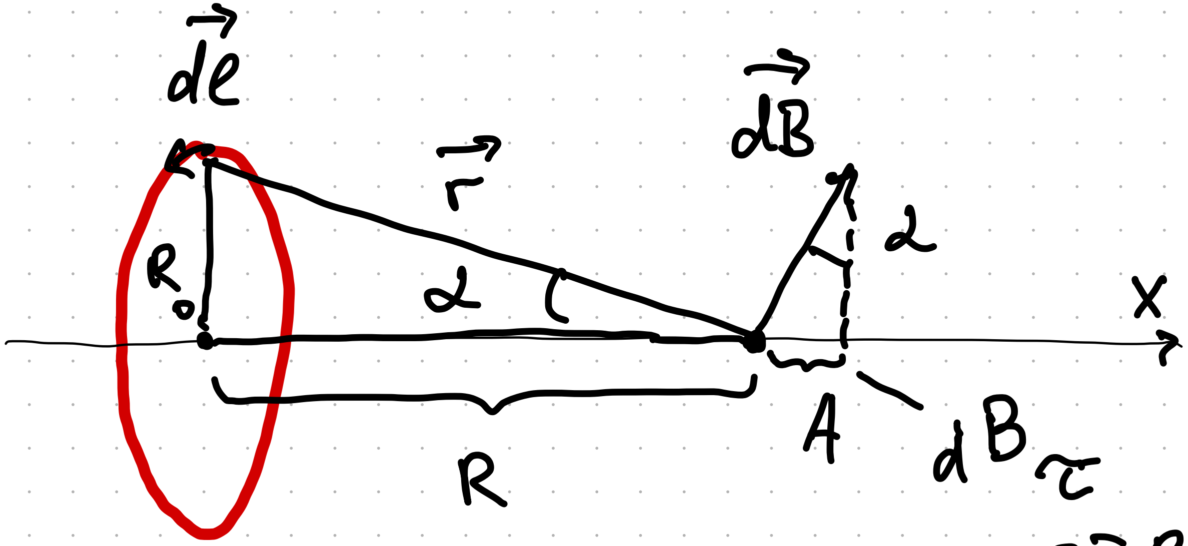
1)





$$B = \frac{2I}{cR}; \quad B = \frac{\mu_0 I}{2\pi R};$$

2) Magnetfeld einer kreisförmigen Stromschleife



$$\sin\alpha = \frac{R_0}{r};$$

$$dB_\tau = \frac{I}{c}\,\frac{dl\, r \sin\alpha}{r^3}$$

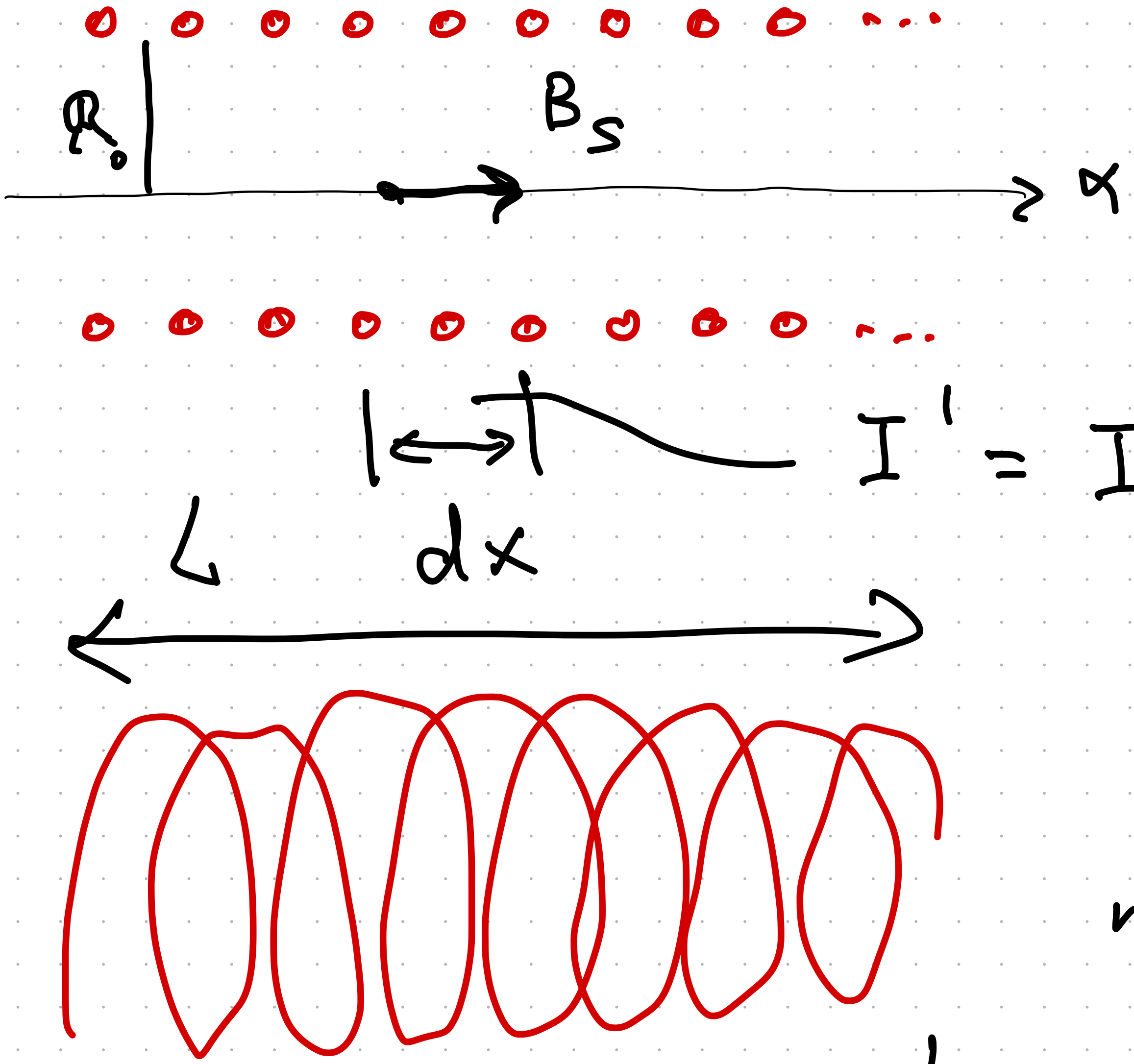
$$B_\tau = \frac{I \sin\alpha}{c\, r^2}\int_0^{2\pi R_0} dl = \frac{I R_0 \cdot 2\pi R_0}{c\, r^3};$$

$$(6)\quad B_\tau = \frac{2\pi R_0^2 I}{c\left(R_0^2 + R^2\right)^{3/2}};$$

für $R = 0$

$$B_{\tau_0} = \frac{2\pi I}{c R_0};$$

3) Magnetfeld einer Zylinderspule.



n_w — Windungen pro cm [cgs]
(Windungsdichte)

$I' = I\, n_w \cdot dx$; (*)

Gl. (6) mit

$R = x$

nach Integrierung:

$$B_s = \frac{4\pi}{c}\, n_w I \; ; \; [\text{cgs}]$$

$$B_s = \mu_0 n_w I \; . \; [\text{SI}]$$

für $L \gg R_0$!