Vorlesung 8

Physik II

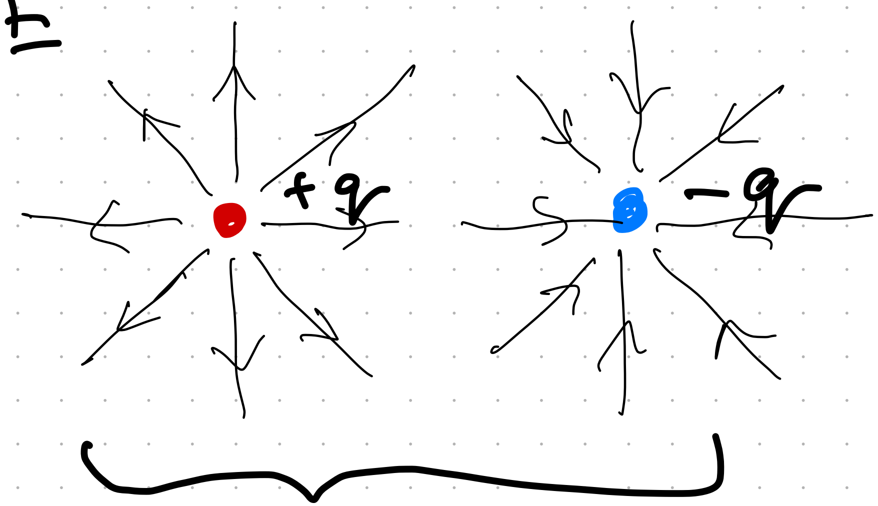
A. Ustinov

SS 2020

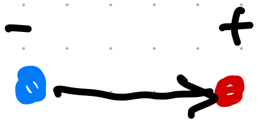
Elektrische vs magnetische Feld

Elemente (Bausteine)

$\vec{E}$



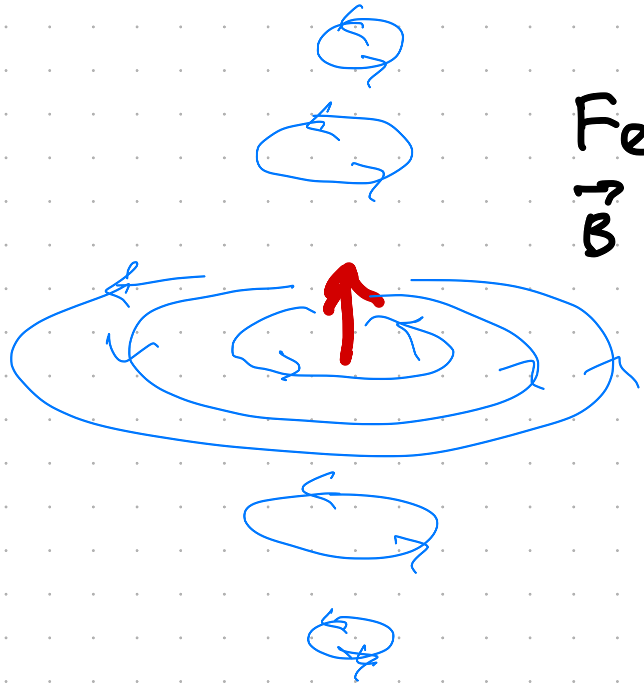
$\pm$ Ladungen



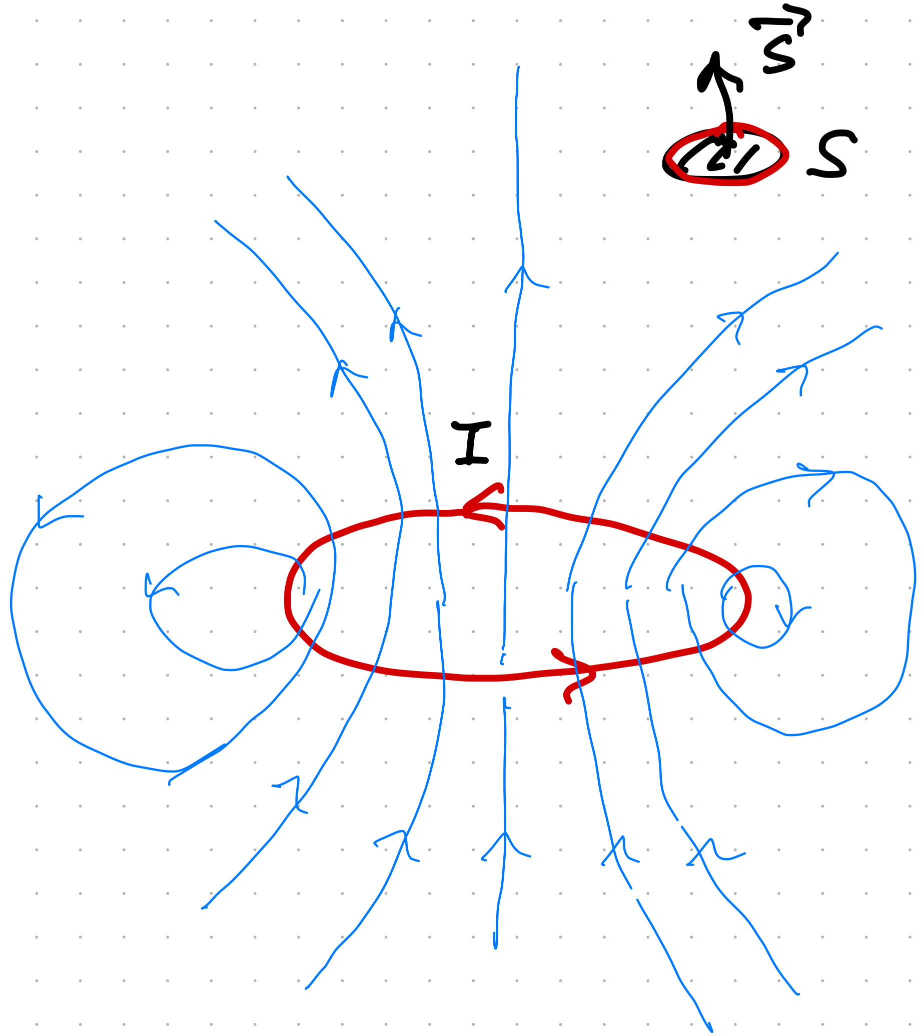
el. Dipol

$\vec{B}$

! keine magnet. Ladungen
(keine Monopole)



Feldlinien $\vec{B}$ enden auf sich oder ∞.



magnetische Dipolmoment

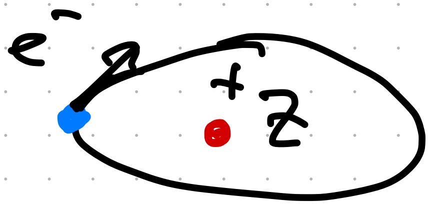
$$\vec{p}_m = I\vec{S} \; ; \; |\vec{S}| = \pi R^2$$

$$\vec{B} = \frac{3(\vec{p}_m\vec{r})\vec{r}}{r^5} - \frac{\vec{p}_m}{r^3} \; ;$$

wie elektrische Dipolmoment

$$\vec{E} = \frac{3(\vec{p}\,\vec{r})\vec{r}}{r^5} - \frac{\vec{p}}{r^3} \; ; \quad \vec{p} \; +$$

Atome, Moleküle

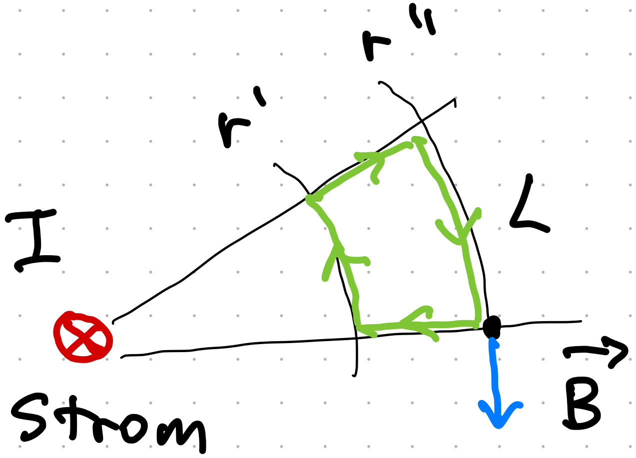


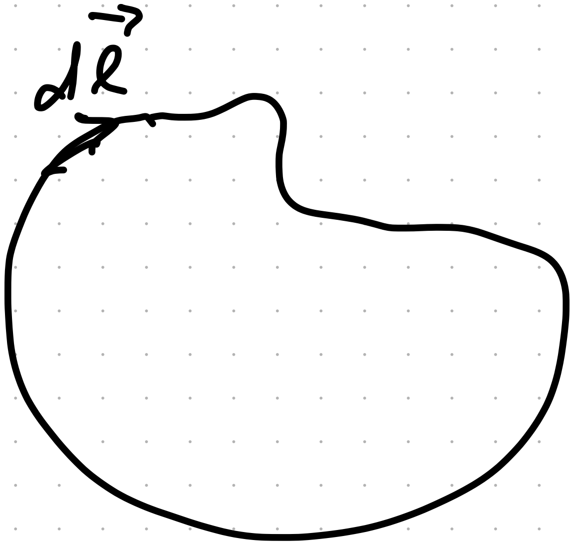
↳ Orbitalmoment, Spin

Zirkulation

: $\oint_L (\vec{B} \, d\vec{\ell}) = \, ?$

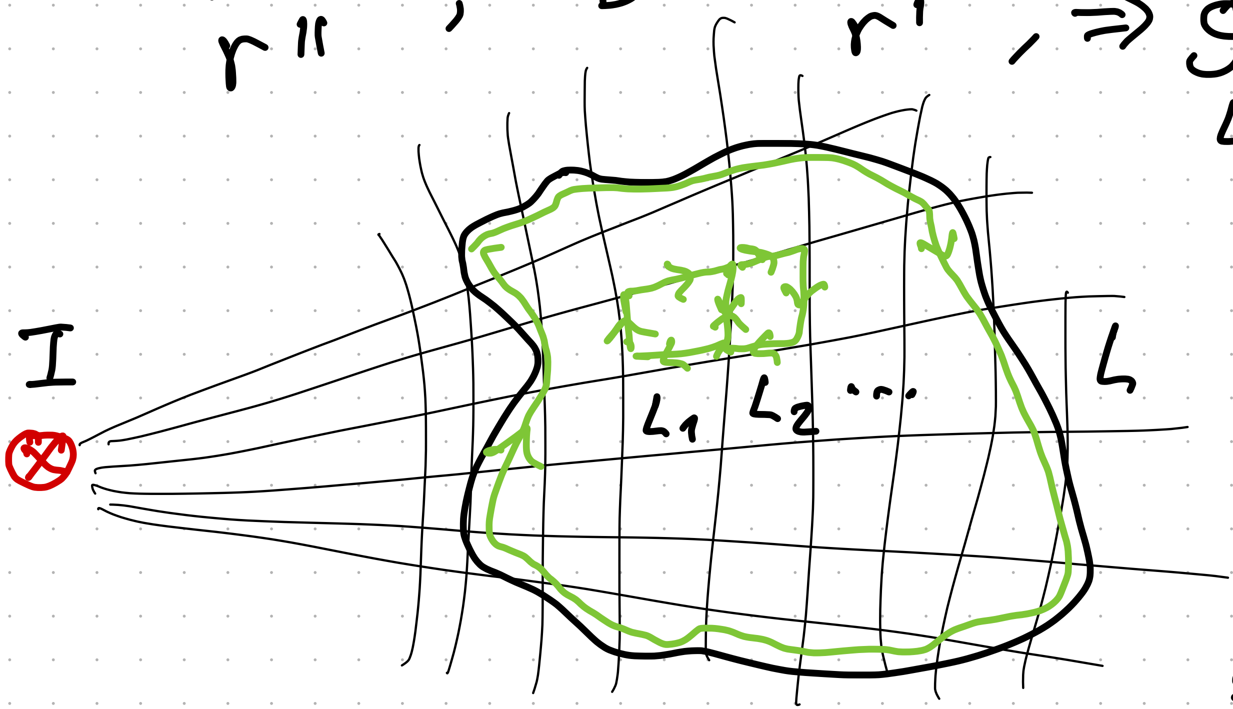
a)





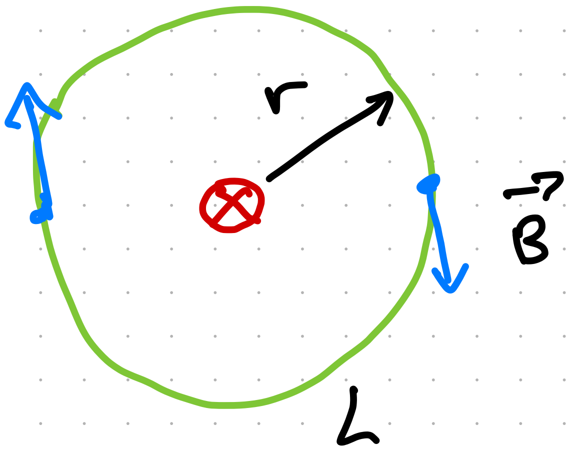
$B'' \sim \frac{1}{r''}$; $B' \sim \frac{1}{r'}$; $\Rightarrow \oint_L (\vec{B} \, d\vec{\ell}) = 0$

b)



$$\oint_L (\vec{B} \, d\vec{\ell}) = \sum_i \int_{L_i} (\vec{B} \, d\vec{\ell}) = 0.$$

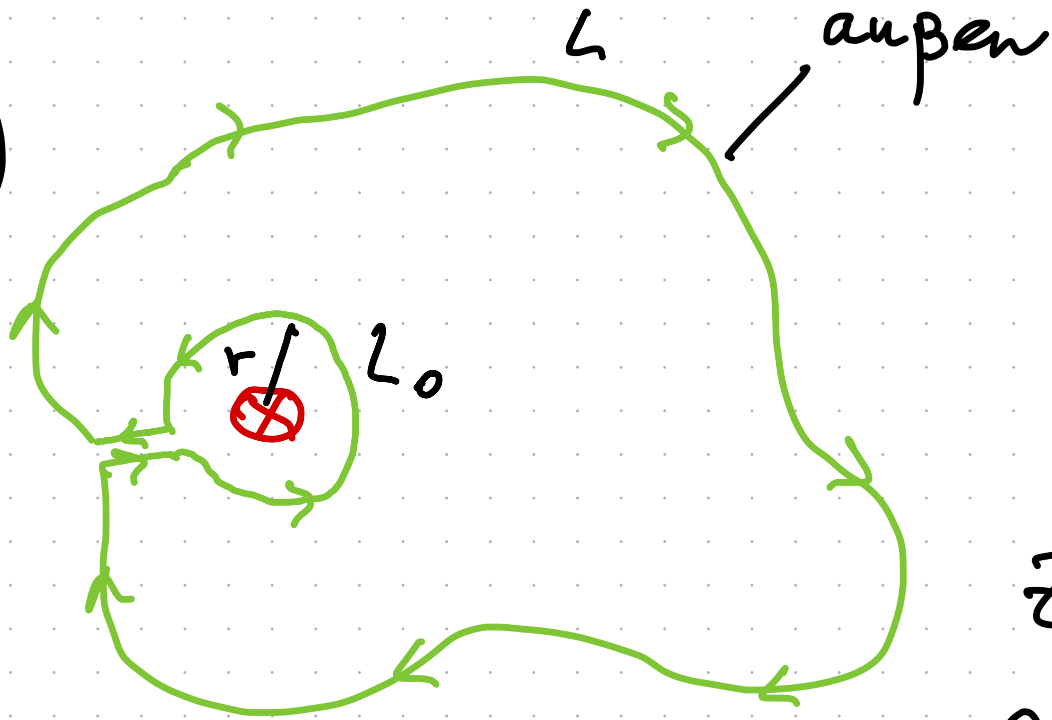
c)



$$\oint_L \left(\vec{B}\, d\vec{\ell}\right) = 2\pi\cancel{r}\,\frac{2I}{c\cancel{r}} = \frac{4\pi I}{c}\,;$$

! NB

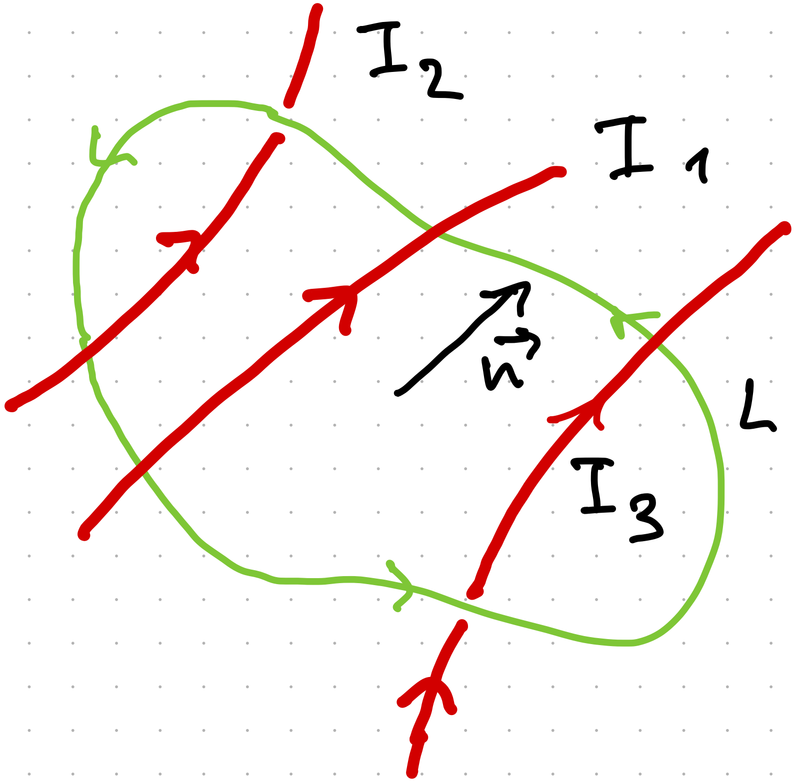
d)



$$\oint_L = \underbrace{\oint_L + \oint_{L_0 \circlearrowleft}}_{=0\ (\text{außen})} + \oint_{L_0 \circlearrowright}$$

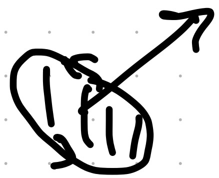
Zirkulation!

$$\oint_L \left(\vec{B}\, d\vec{\ell}\right) = \frac{4\pi I}{c}\,;$$



$$\oint_L (\vec{B}\, d\vec{\ell}) = \frac{4\pi}{c}(I_2 - I_3)$$

Rechtschraube-Regel



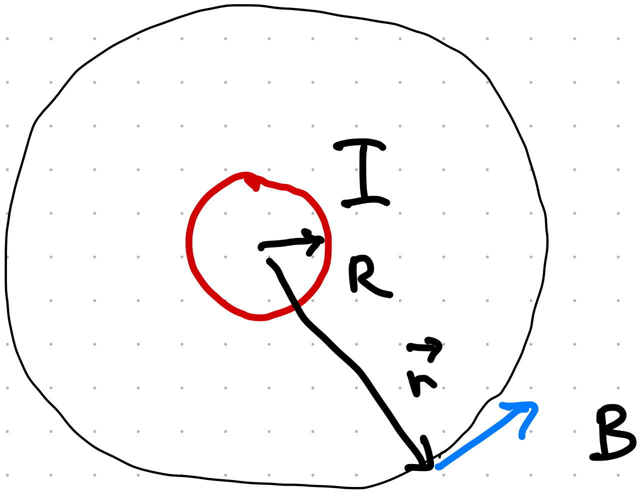
Elektro- und Magnetostatik

$$\oint_S (\vec{E}\cdot d\vec{s}) = 4\pi q \qquad \oint_S (\vec{B}\cdot d\vec{s}) = 0$$

$$\oint_L (\vec{E}\cdot d\vec{\ell}) = 0 \qquad \oint_L (\vec{B}\, d\vec{\ell}) = \frac{4\pi}{c} I$$

Beispiele für Zirkulationssatz:

a) Hohlrohr mit Strom

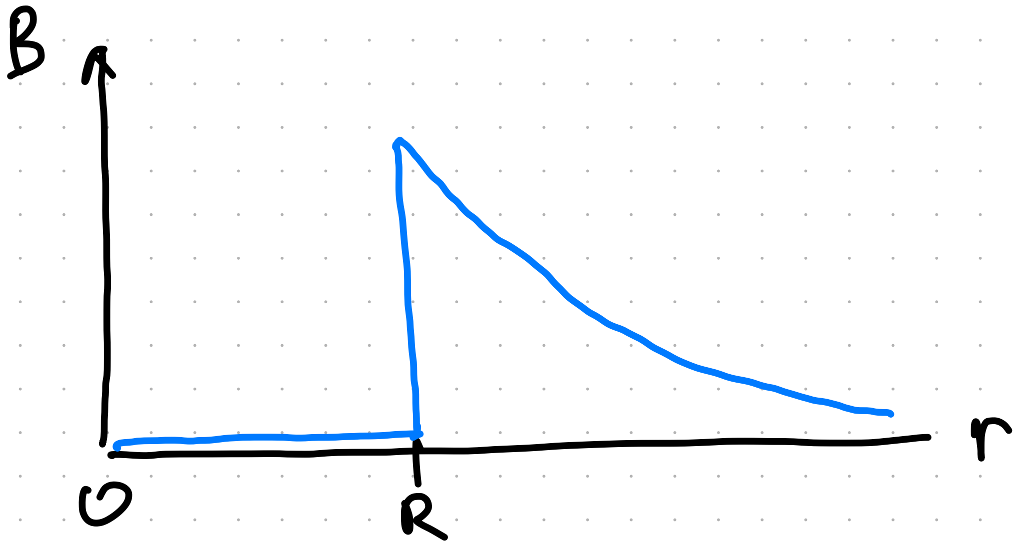


$r \geq R$;

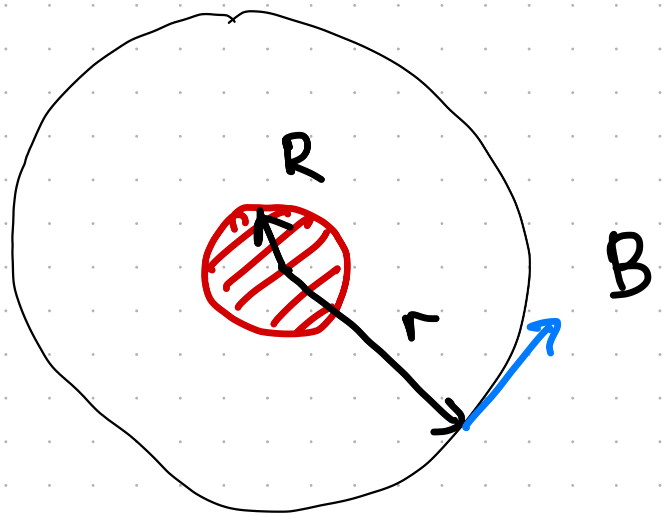
$2\pi r B = \frac{4\pi}{c} I$; $B = \frac{2I}{cr}$;

$r < R$;

$2\pi r B = 0$, $\Rightarrow$ $B = 0$



b) Stab mit Strom

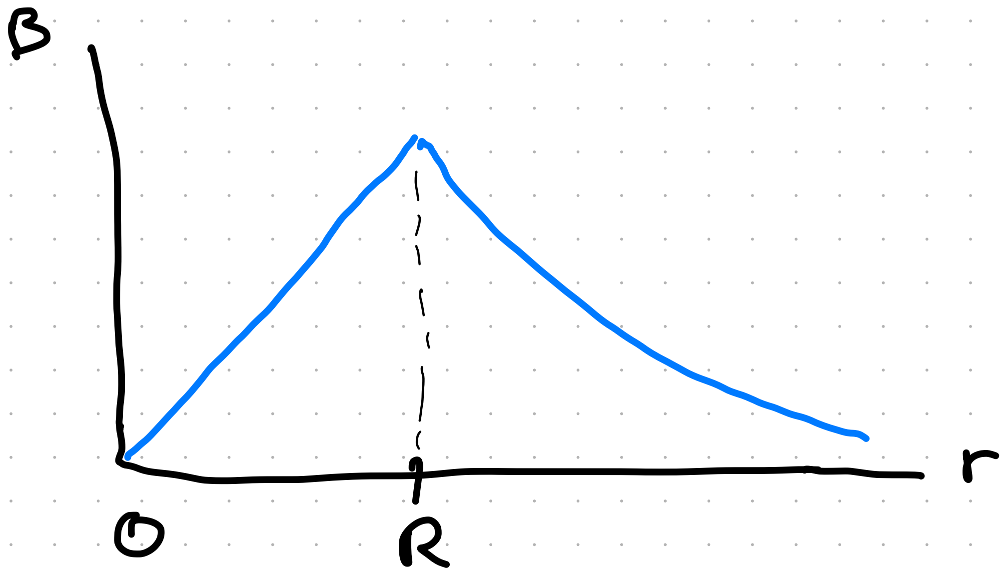


$r \geq R \;, \Rightarrow \quad B = \frac{2\,I}{c\,r}\;;$

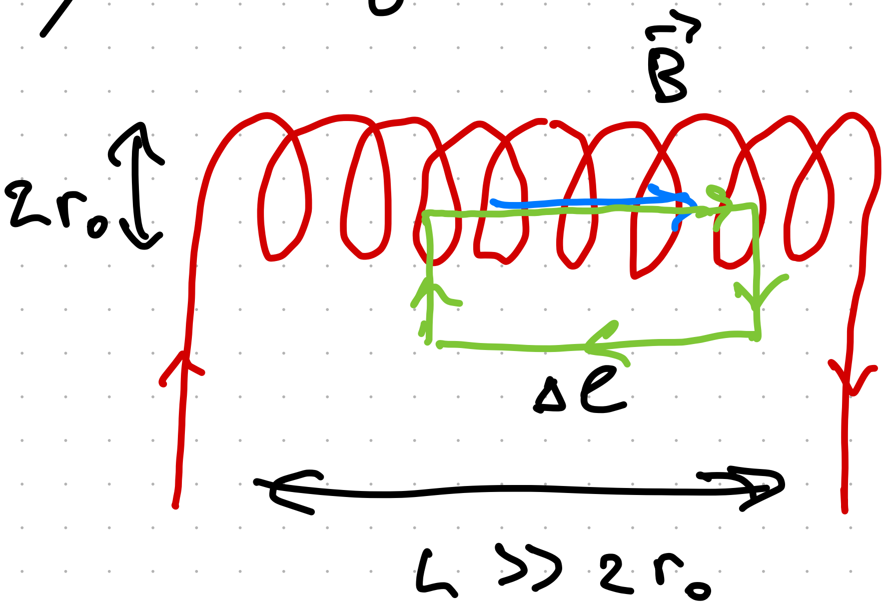
$r < R\;;$

$$2\pi r B = \frac{4\pi}{c} I \frac{r^2}{R^2}\;;$$

$$\Rightarrow \quad B = \frac{2}{c}\frac{r}{R^2} I\;;$$



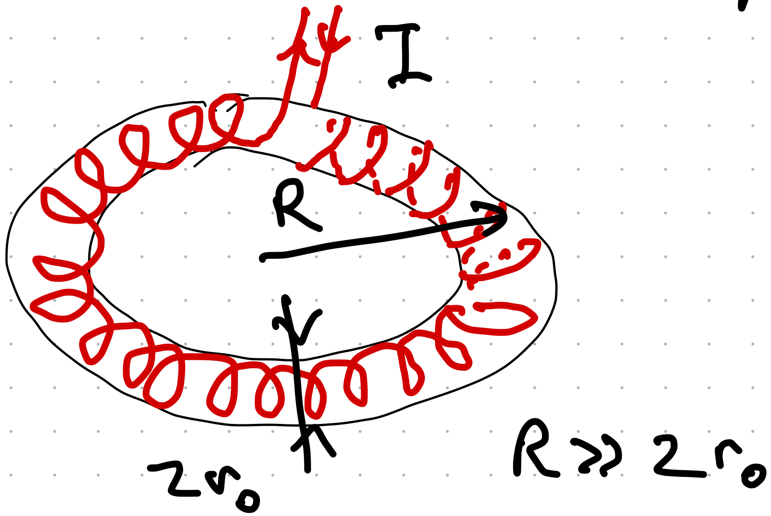
c) lange Spule



$$\cancel{\Delta l}\, B = \frac{4\pi}{c} n_w I \cancel{\Delta l}$$

$$B = \frac{4\pi}{c} n_w I;$$

d) Toroidale Spule:

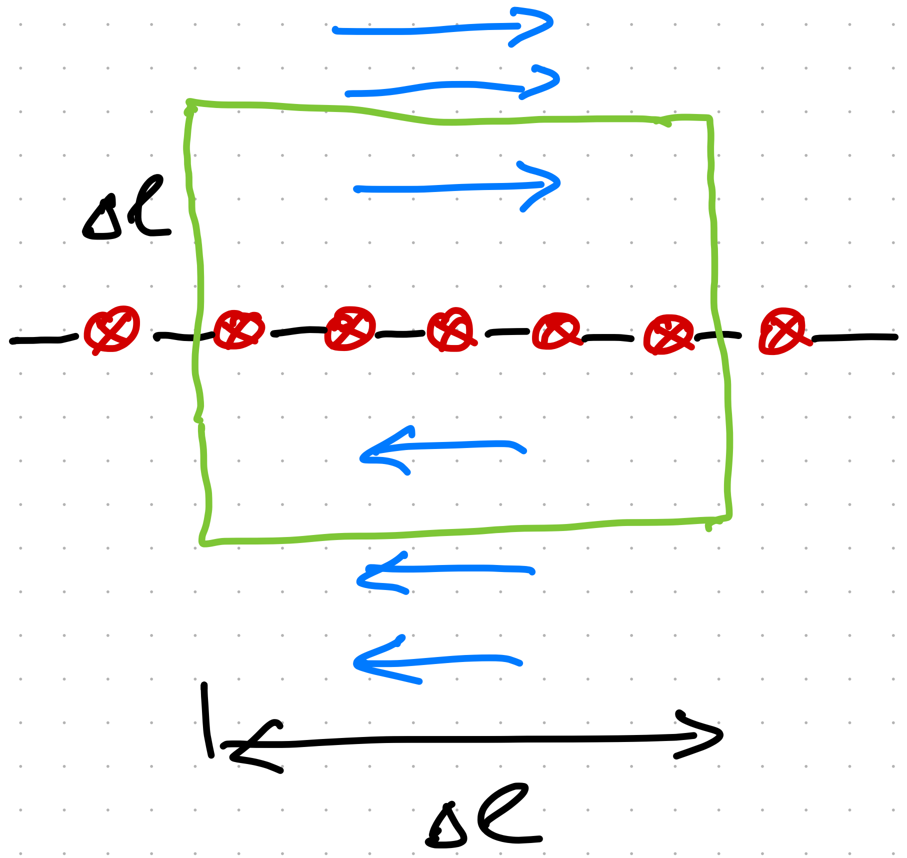


n_w – Windungen pro 1 cm

$$\cancel{2\pi R}\, B = \frac{4\pi}{c} n_w I \cancel{2\pi R}$$

$$B = \frac{4\pi}{c} n_w I;$$

e) 2D Oberfläche mit homogene Stromverteilung



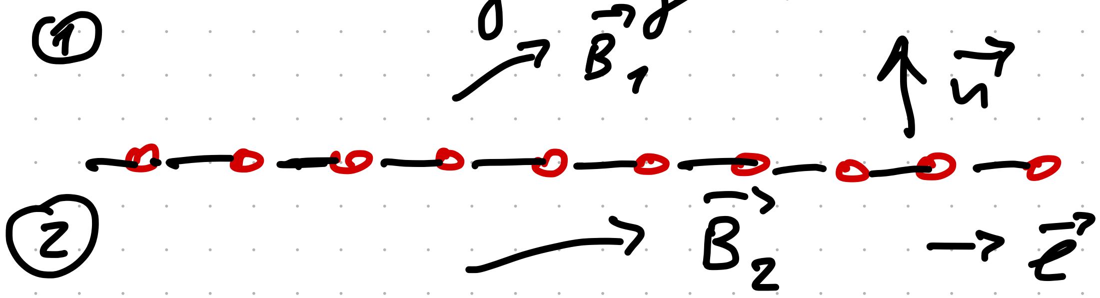
$i = I$ pro 1 cm

Stromdichte

$$B\,\Delta l + B\,\Delta l = \frac{4\pi}{c}\underbrace{i\,\Delta l}_{I}$$

$$B = \frac{4\pi}{2c}\,i = \frac{2\pi}{c}\,i\,;$$

Randbedingungen auf 2D Oberfläche:

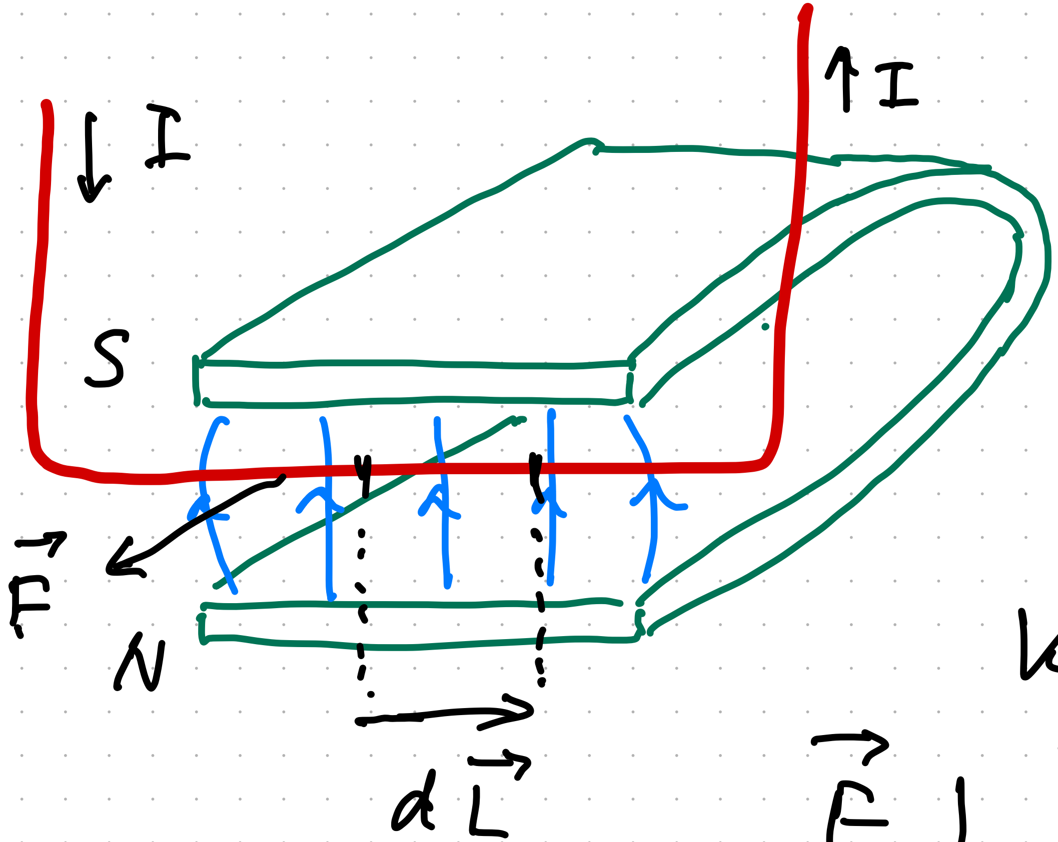


$$B_{1n} = B_{2n}$$

$$B_{1e} = B_{2e} = \frac{4\pi}{c}\,i$$

3.3 Lorentzsches Kraftgesetz

$$\vec{F}_L = \frac{q}{c}\left[\vec{v}\,\vec{B}\right]; \leftarrow \text{Lorentzkraft [cgs]}$$

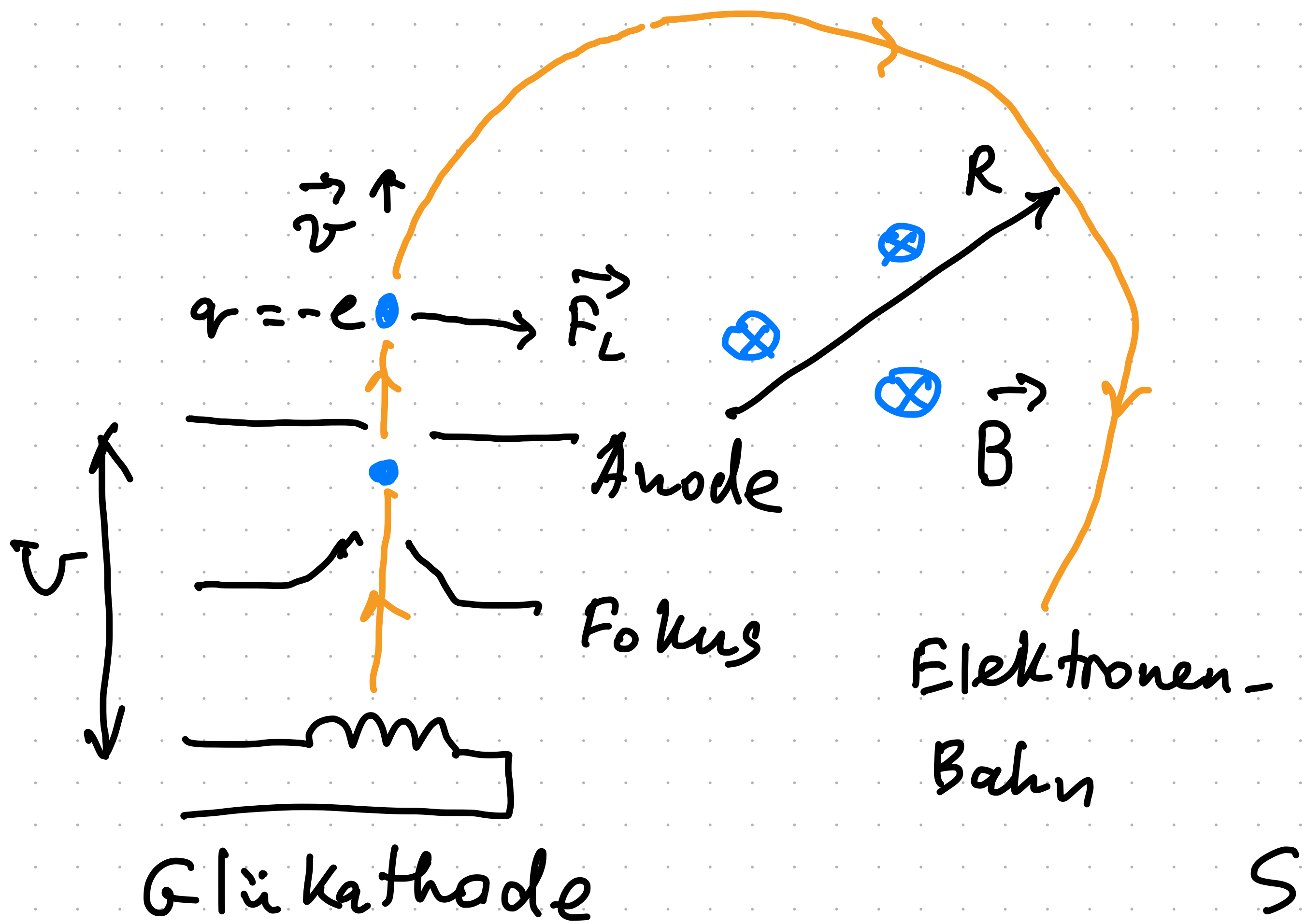


auf einen stromdurchflossenen Leiter im Magnetfeld $\vec{B}$ wirkt die Kraft $\vec{F}$;

$$\vec{F} \perp \vec{I}\ ; \quad \vec{F} \perp \vec{B}\ ;$$

$$[SI]:\ d\vec{F} = I \cdot \left[d\vec{L}\,\vec{B}\right];$$

3.4. Zyklotronbewegung, Hall-Effekt



Fadenstrahlrohr

Elektronenstrahl in eine Kathodenstrahlröhre im Magnetfeld $\vec{B}$.

$$F_L = q[\vec{v}\,\vec{B}]; [SI]$$

Spannung U;

$$\frac{mv^2}{2} = eU;$$

$$\Rightarrow \quad v = \sqrt{\frac{2eU}{m}};$$

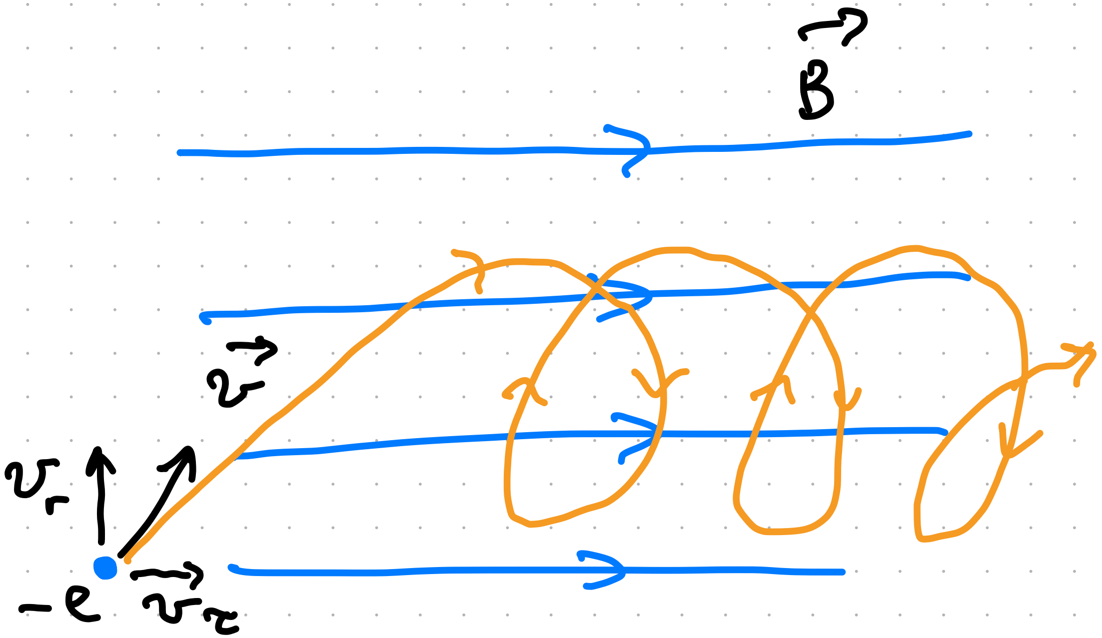
Zentripetalkraft:

$$[SI] \Rightarrow \quad e v B = \frac{m v^2}{R}; \quad \Rightarrow \quad R = \frac{1}{B}\sqrt{\frac{2mU}{e}};$$

Zyklotronbewegung;

$$\boxed{f_z = \frac{eB}{2\pi m}} \leftarrow \text{Zyklotronfrequenz}$$

z.B. Protonen: $\quad B = 1\,T \quad \Rightarrow \quad f_z \sim 15\,MHz$



Spiralbahn von Elektronen; $v_z = \text{const}$

$\Downarrow$

Fokusierung $\Rightarrow$ Elektronen-Optik.