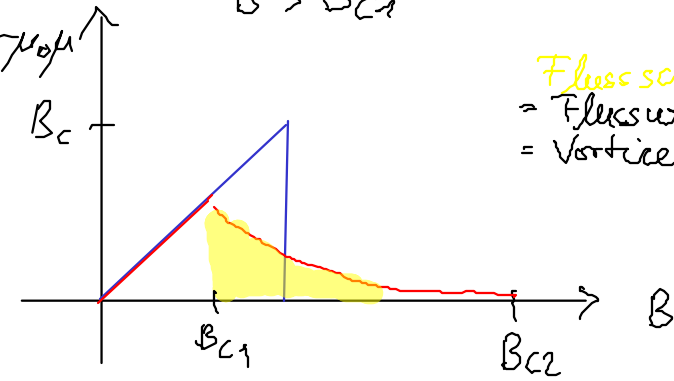


# Supraleitung

• Kohärenzlänge:  $\xi_0 \sim \frac{\hbar v_F}{2\Delta}$

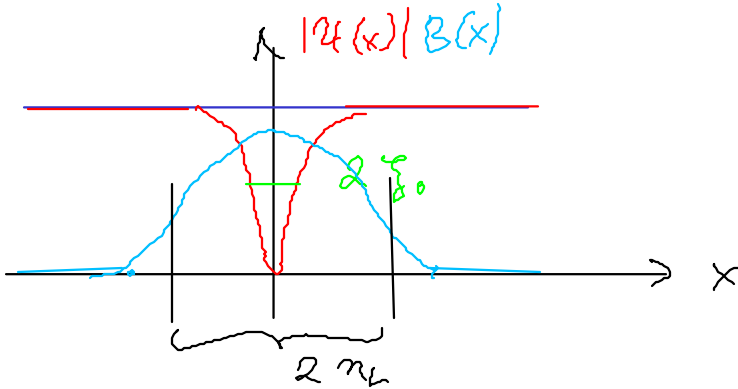
- Supraleiter 1. Art  $\xi_0 \gg \lambda_L$
- 2. Art  $\xi_0 \ll \lambda_L$

$B > B_{c1}$

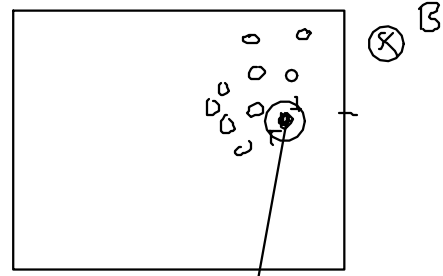


Flussschleife  
= Flusswirbel  
= Vortices

$\psi = |\psi| e^{i\theta(\mathbf{r})}$

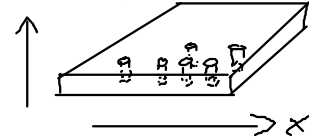


Probe

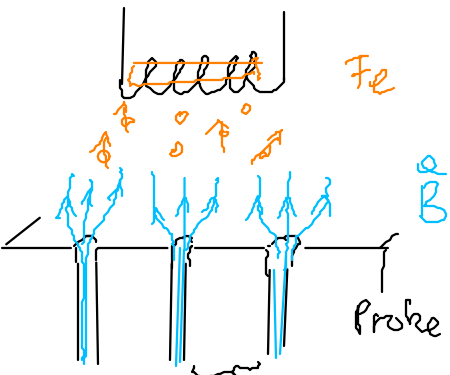


$\phi = \phi_0 = \frac{h}{2e} = 2,07 \cdot 10^{-15} \text{ Vs}$

Flusssquanten  $\phi$



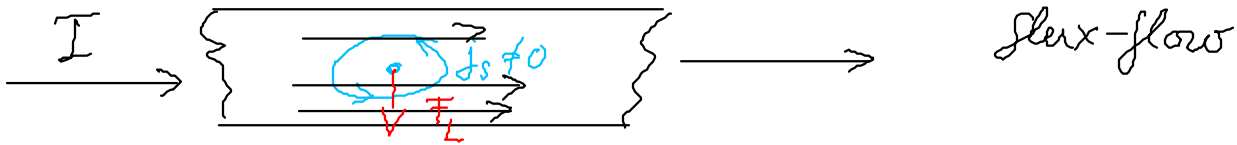
- Abrikosov vortex lattice
- Experiment <sup>Gossman (1967)</sup> / <sup>Trübels</sup>



- $B a^2 \sim \phi_0$
- für  $B \sim 1 \text{ mT} \Rightarrow a \sim \sqrt{\frac{\phi_0}{B}} \sim 3 \mu\text{m}$
- $\Rightarrow$  zur Beobachtung des Gitters  
selbste Probe notwendig

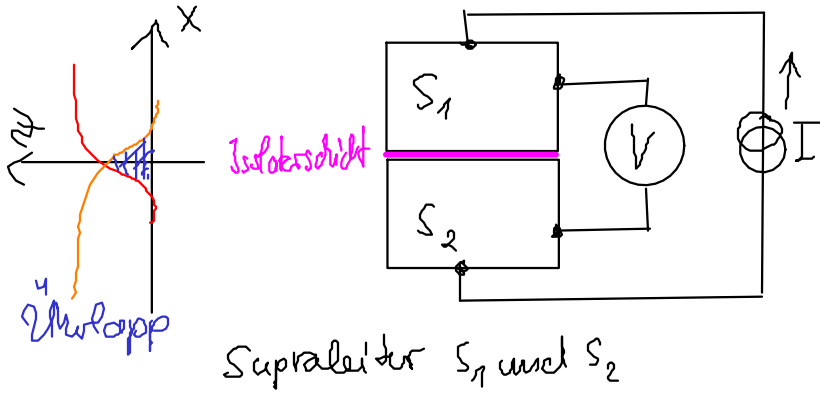
$a$  (vortex Gitterkonstante)

- Defekte im Material (nicht Supraleitend)
- $\Rightarrow$  Pinning
- Bewegung von vortices ist wichtig



- Lorentz kraft  $\neq F_L = \text{Magnus kraft}$

## Josephson Effekt (1962)



$$\psi_1 = |\psi_1| e^{i\theta_1}$$

$$\psi_2 = |\psi_2| e^{i\theta_2} \quad |\psi_1| = |\psi_2|$$

- Phasendifferenz  $\varphi = \theta_2 - \theta_1$

$$\left. \begin{array}{l} 1) I_s = 0, \varphi = 0 \\ 2) I_s(\varphi) = I_s(\varphi + 2\pi) \\ 3) I_s(-\varphi) = -I_s(\varphi) \end{array} \right\} \begin{array}{l} \text{Maximaler Strom durch S = kritischer Strom } I_c \\ \boxed{I_s = I_c \sin \varphi} \end{array} \quad \text{1. Josephson Gleichung}$$

## 2. Josephson Gleichung $V \neq 0$

- Schrödinger Gleichung  $i\hbar \frac{\partial}{\partial t} \psi_m = E_m \psi_m \quad m=1,2 \quad (\text{stationär})$

$$\rightarrow \hbar \frac{\partial}{\partial t} \theta_m = E_m$$

$$E_2 - E_1 = -\hbar \frac{\partial}{\partial t} \varphi = -2eV \quad \boxed{V = \frac{\hbar}{2e} \frac{\partial \varphi}{\partial t}} = \frac{\phi_0}{2\pi} \frac{\partial \varphi}{\partial t}$$

$$\varphi = \frac{2eV}{\hbar} t + \varphi_0$$

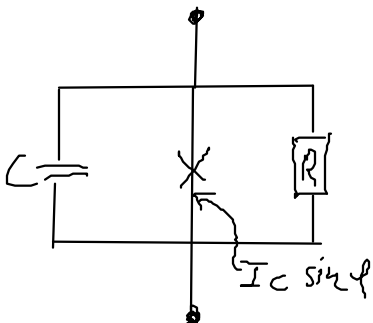
$$\Rightarrow I_s = I_c \cdot \sin(\omega_J t + \varphi_0) \quad \omega_J = \frac{2eV}{\hbar}$$

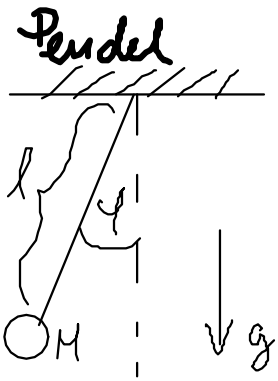
- $f_J = \frac{\omega_J}{2\pi} = \frac{V}{\phi_0} \quad 1\mu\text{V}(V) \Leftrightarrow 483,6 \text{ MHz } (f_J)$

## RC-Modell resistive-capacity-shunted-junction

$$I = I_c \sin \varphi + \frac{V}{R} + C \frac{dV}{dt} = I_c \sin \varphi + \frac{\hbar}{2eR} \frac{\partial \varphi}{\partial t} + \frac{\hbar C}{2e} \frac{d^2 \varphi}{dt^2}$$

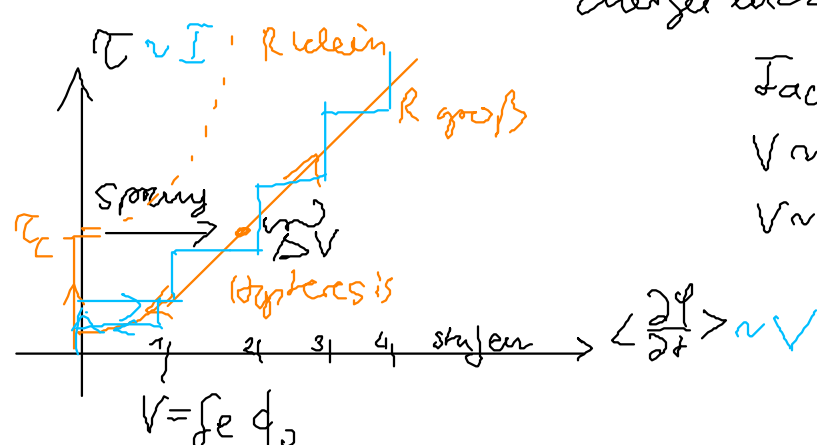
$\Rightarrow$  wie Pendelgleichung (Mechanik)





Josephson Kontakt  $\leftrightarrow$  Pendel  
 $I_C \leftrightarrow Mgl$  ( $F_G = Mgl \sin \phi$ )  
 $C \leftrightarrow Ml^2$  Trägheitsmoment  
 $I \leftrightarrow \tau$  Drehmoment

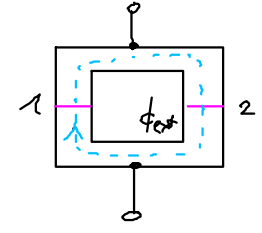
•  $f_0 = \frac{1}{2\pi} \sqrt{\frac{g}{l}}$   
 $f_P = \frac{1}{2\pi} \sqrt{\frac{2eI_C}{\hbar C}}$  Josephson Plasmafrequenz (kein Plasma)  
 $\Rightarrow$  Energie lücke zwischen  $f_0$  und  $f_P$



$I_{ac} = I_C \cos \omega_e t$ ,  $\omega_e = 2\pi f_e$   
 $V \sim 10V \Rightarrow 10^4$  Josephson Kontakte (seriell)  
 $V \sim 200\mu V \Rightarrow 1$  Josephson Kontakt bei  $100\text{GHz}$

• Magnetfeldmessung mit Josephson Kontakt

### SQUID Superconducting quantum interference device



- externer Fluss  $\phi_{ext}$  wird gemessen mit der Genauigkeit  $\delta\phi \sim 10^{-6} \phi_0$
- Phasendifferenzen an Kontakt 1 und 2

$I_{c1} = I_{c2} = I_C$   
 $I_S = I_C \sin \phi_1 + I_C \sin \phi_2 = I_C \sin \phi_1 + I_C \sin(\phi_1 + 2\pi \frac{\phi_{ext}}{\phi_0}) = 2I_C \cos(\frac{\pi \phi_{ext}}{\phi_0}) \sin(\phi_1 + \frac{\pi \phi_{ext}}{\phi_0})$   
 $\oint \vec{v} \cdot \vec{ds} = 2e \oint \vec{A} \cdot \vec{ds}$  (ein „Rundgang“ durch beide Kontakte)  
 $\hbar(\phi_2 - \phi_1) = 2e \frac{\phi_{ext}}{2\pi} \Rightarrow \phi_2 - \phi_1 = 2e \frac{\phi_{ext}}{\phi_0}$

$\Rightarrow \max I_S$   $B \sim 10^{-14} T$  messbar

