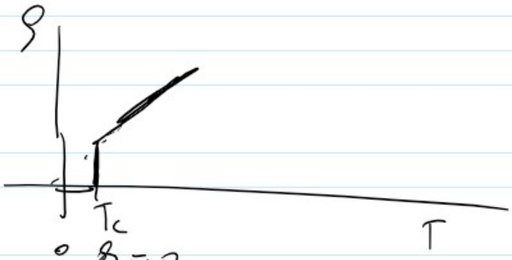
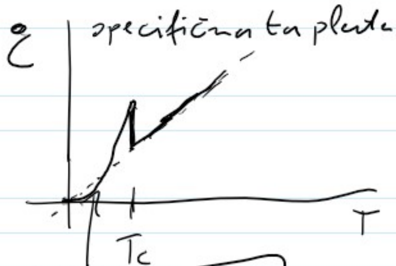
Nanofizika - SC

četrtek, 07. maj 2020 22:25

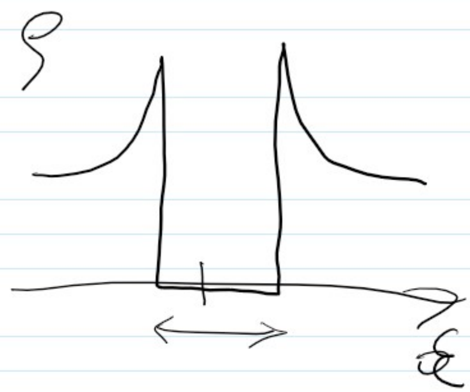
Coulombska blokada in superprevodnost



$\circ\ \varrho = 0$



$\boxed{c \sim e^{-\Delta/T}}$



mikroskopski izvor

$$|\psi_0\rangle = \prod_{k\sigma} c^+_{k\sigma} |0\rangle$$

$$|\psi_{BCS}\rangle_\varphi = \prod_k \left(u_k + v_k e^{i\varphi} c^+_{k\uparrow} c^+_{-k\downarrow} \right) |0\rangle$$

$$H = \sum_k \varepsilon_k n_k + \sum_{kk'\sigma\sigma'} U_{kk'\ldots}\, c^+_{k\sigma} c^+ c\, c$$

$$n_k = c^+_{k\uparrow} c_{k\uparrow} + c^+_{k\downarrow} c_{k\downarrow}$$

$$c_i^+ c_i \qquad c_j^+ c_j$$

$$\underbrace{\langle c_i^+ c_i \rangle}_{n_i} c_j^+ c_j$$

$$\langle \psi | c^+ c^+ | \psi \rangle = \begin{cases} 0; & \text{ni superprev.} \end{cases}$$

$$H_{BdG} = \sum_k \varepsilon_k n_k + \sum_k \Delta e^{i\varphi} c^+_{k\uparrow} c^+_{-k\downarrow} + h.c.$$

$$H_{BdG} = \sum_k \varepsilon_k n_k + \left(\sum_k \Delta e^{i\varphi} c_{k\uparrow}^+ c_{-k\downarrow}^+ + h.c. \right)$$

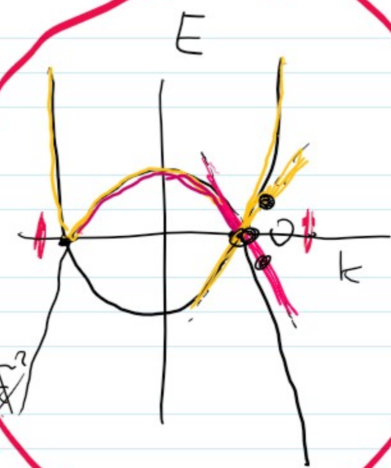
$$c_{-k\downarrow}^+ = \tilde{d}_{k\uparrow} \qquad \underbrace{U\langle c_{k\uparrow}^+ c_{-k\downarrow}^+\rangle}_{\Delta}$$

$$c_{-k\downarrow} = d_{k\uparrow}^+$$

BdG

$$\begin{pmatrix} \hat{H} & \Delta e^{i\varphi} \\ \Delta e^{-i\varphi} & -\hat{H}^* \end{pmatrix} \begin{pmatrix} \psi_e(\vec r) \\ \psi_h(\vec r) \end{pmatrix} = E \begin{pmatrix} \psi_e(\vec r) \\ \psi_h(\vec r) \end{pmatrix}$$

$$\hat{H} = -\frac{\hbar^2}{2m} \nabla^2 + V(r) - E_F$$



$\Delta = 0$

$$\psi_e(\vec r) = e^{i\vec k \cdot \vec r}$$

$$\psi_h(\vec r) = e^{i\vec k \cdot \vec r}$$

$$\hat{H} : \quad \tilde{E} = \frac{k^2 \hbar^2}{2m} = \frac{\hbar^2 k_F^2}{2m} + \frac{\hbar^2 k_F \tilde{k}}{m} + \cancel{\tilde{k}^2}$$

$$k = k_F + \tilde{k} \qquad v_F = \frac{\hbar k_F}{m}$$

$$= \underline{E_F + \hbar v_F \tilde{k}}$$

$\Delta = 0$ $\qquad \boxed{E = \pm \hbar v_F \tilde{k}}$

$\Delta > 0$

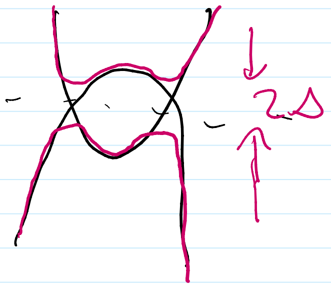
$$\begin{pmatrix} \tilde{E} & \Delta e^{i\varphi} \\ \Delta e^{-i\varphi} & -\tilde{E} \end{pmatrix} \begin{pmatrix} \psi_e^0 \\ \psi_h^0 \end{pmatrix} = E \begin{pmatrix} \psi_e^0 \\ \psi_h^0 \end{pmatrix} \qquad \begin{aligned} \psi_e &= e^{i(k_F + \tilde{k})x} \psi_e^0 \\ \psi_h &= e^{i(k_F + \tilde{k})x} \psi_h^0 \end{aligned}$$

$$\tilde{E} = \hbar v_F \tilde{k}$$

$$\begin{vmatrix} \tilde{E} - E & \Delta e^{i\varphi} \\ \Delta e^{-i\varphi} & -\tilde{E} - E \end{vmatrix} = 0$$

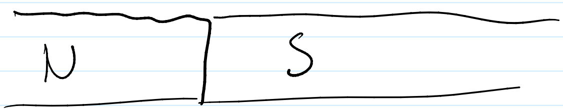
$$E^2 - \tilde{E}^2 - \Delta^2 = 0$$

$$E^2 = \tilde{E}^2 + \Delta^2 \qquad E = \pm\sqrt{\tilde{E}^2 + \Delta^2}$$

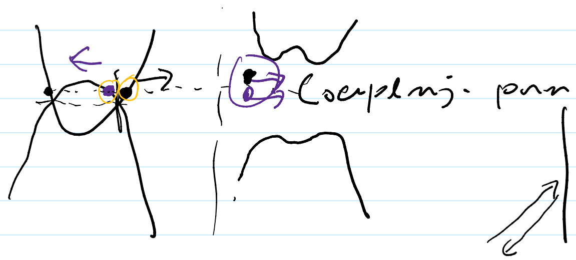


REŽA, ENOEL. EKSITACIJ PRI TEJ ENERGIJI.

Andreeva tuneliranje



$x<0$ $x>0$



$$\psi_e = e^{ik_F x}\tilde{\psi}_e(x)$$

$$\left(\frac{-\hbar^2\nabla^2}{2m}\right)\psi_e(x) = e^{ik_F x}\left(\frac{\hbar^2 k_F^2}{2m} + \frac{-\hbar^2 i k_F \nabla}{\cancel{2}m} + \frac{-\hbar^2}{2m}\nabla^2\right)\tilde{\psi}_e(x)$$

$$\begin{pmatrix} -i\hbar v_F \nabla & \Delta e^{i\varphi} \\ \Delta e^{-i\varphi} & i\hbar v_F \nabla \end{pmatrix}\begin{pmatrix}\tilde{\psi}_e(x)\\ \tilde{\psi}_h(x)\end{pmatrix} = E\begin{pmatrix}\tilde{\psi}_e(x)\\ \tilde{\psi}_h(x)\end{pmatrix}$$

$$\tilde{\psi} = C\begin{pmatrix} e^{i\tilde{k}x} \\ r\, e^{-i\tilde{k}x}\end{pmatrix}$$

$$E = \tilde{E} = \hbar v_F \tilde{k}$$

na S:

$$\tilde{\psi} = C\begin{pmatrix}\tilde{\psi}_e^0\\ \tilde{\psi}_h^0\end{pmatrix} e^{-Kx}$$

$$\begin{pmatrix} +i\hbar v_F K - E & \Delta e^{i\varphi} \\ \Delta e^{-i\varphi} & -i\hbar v_F K - E\end{pmatrix}\begin{pmatrix}\tilde{\psi}_e^0\\ \tilde{\psi}_h^0\end{pmatrix} = 0$$

$$K = \frac{\sqrt{\Delta^2 - E^2}}{\hbar v_F}$$

$$(K^2\hbar^2 v_F^2 - \Delta^2) = -E^2$$

$$E^2 = \Delta^2 - \hbar^2 v_F^2 K^2$$

$$(i\hbar v_F K - E)\tilde{\psi}_e^0 + \Delta\tilde{\psi}_h^0 e^{i\varphi} = 0$$

$$\tilde{\psi}_h^0 = \frac{\left(E/\Delta - i\sqrt{1-(E/\Delta)^2}\right)\tilde{\psi}_e^0}{e^{i\varphi}} = \frac{(\cos\alpha - i\sin\alpha)\tilde{\psi}_e^0}{e^{i\varphi}}$$

$$E/\Delta = \cos\alpha$$

$$\frac{\tilde{\psi}_h^0}{\tilde{\psi}_e^0} = e^{-i\ell} e^{-i\alpha} = e^{i\chi_e}$$

$$\psi(0^-) = \psi(0^+)$$

$$\begin{pmatrix}\tilde{\psi}_e \\ \tilde{\psi}_h\end{pmatrix} = \begin{pmatrix} e^{i\tilde{k}x} \\ r e^{-i\tilde{k}x}\end{pmatrix}\Bigg|_{0^-} = \begin{pmatrix}1 \\ r\end{pmatrix} =$$

$$\tilde{\psi}_h / \tilde{\psi}_e = r = e^{i\chi_e} \qquad \chi_e = -\ell - \alpha$$

$$r_e = e^{i\chi_e} \qquad R_A = |r|^2 = 1$$

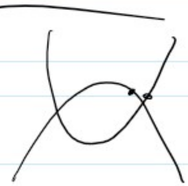
D.N 1:

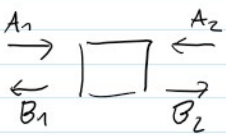
$$r_h = e^{i\ell} e^{-i\alpha} = e^{i\chi_h}$$

DN. 2:

$$E > \Delta \qquad r_A = e^{-i\ell}\left(E/\Delta - \left(\sqrt{E^2-\Delta^2}\right)/\Delta\right)$$

Prevodnost Andreeva





$$\begin{pmatrix}B_1 \\ B_2\end{pmatrix} = S\begin{pmatrix}A_1 \\ A_2\end{pmatrix} \qquad S_e = \begin{pmatrix} r_e & t_e' \\ t_e & r_e'\end{pmatrix} = \begin{bmatrix} r & t \\ t & r'\end{bmatrix}$$

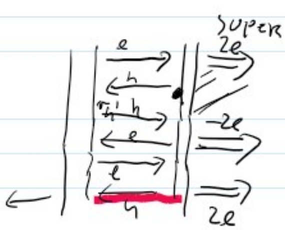
$$S_e = S_e(E) = S(E_F + E) \doteq S(E_F)$$

$$S_h = S^*(E_F - E) \doteq S^*(E_F) \qquad S_h = \begin{pmatrix} r_h & t_h' \\ t_h & r_h'\end{pmatrix} = \begin{bmatrix} r^* & t^* \\ t^* & r'^*\end{bmatrix}$$

$$r_A = t_e e^{i\chi_e} t_h' + t_e \left(e^{i\chi_e} r_h' e^{i\chi_h} r_e'\right) e^{i\chi_e} t_h'$$

$$+ t_e \left(\qquad \right)^2 e^{i\chi_e} t_h'$$

$$+ \quad \dots$$



$$r_A = \frac{t_e e^{i\chi_e} t_h}{1 - e^{i(\chi_e + \chi_h)} r_h' r_e'} = \frac{|t|^2 e^{i\chi_e}}{1 - (-1)|r'|^2}$$

$$e^{i\chi_e} = e^{-i\ell} e^{-i\alpha} \qquad \alpha = \arccos E/\Delta \qquad |t|^2 = T$$

$$e^{i\chi_e} = e^{-i\varphi} e^{-i\alpha} \qquad \alpha = \arccos E/\Delta$$

$$e^{i\chi_h} = e^{i\varphi} e^{-i\alpha} \qquad E \ll \Delta$$

$$e^{i(\chi_e+\chi_h)} = e^{-2i\alpha} \qquad \alpha \doteq \pi/2$$

$$\doteq e^{-i\pi} = -1$$

$$|t|^2 = T$$

$$|r'|^2 = |r|^2 = 1-T$$

$$r_A = e^{i\chi_e} \frac{T}{2-T}$$

$$R_A = |r_A|^2 = \frac{T^2}{(2-T)^2}$$

$$\boxed{G = \frac{2e^2}{h} \cdot 2 R_A = 2 G_0 R_A}$$

$T \sim 1 \qquad G = 2G_0$

T mali $\qquad G = 2G_0 \frac{T^2}{4}$

navadna

$G = G_0$

$G = G_0 T$

Andreeva vezana stanja

$$\underline{B}^e = \begin{pmatrix} B_1^e \\ B_2^e \end{pmatrix} = S \begin{pmatrix} A_1^e \\ A_2^e \end{pmatrix} = S \underline{A}^e \qquad \begin{pmatrix} B_1^h \\ B_2^h \end{pmatrix} = S^* \begin{pmatrix} A_1^h \\ A_2^h \end{pmatrix} = S^* \underline{A}^h$$

$$\begin{pmatrix} \underline{B}^e \\ \underline{B}^h \end{pmatrix} = \underbrace{\begin{bmatrix} S & 0 \\ 0 & S^* \end{bmatrix}_{4\times4}}_{S_{4\times4}} \begin{pmatrix} \underline{A}^e \\ \underline{A}^h \end{pmatrix}$$

$$\begin{pmatrix} A_1^e \\ A_1^h \end{pmatrix} = \begin{pmatrix} 0 & e^{i\chi_h^L} \\ e^{i\chi_e^L} & 0 \end{pmatrix} \begin{pmatrix} B_1^e \\ B_1^h \end{pmatrix} \qquad \begin{pmatrix} A_2^e \\ A_2^h \end{pmatrix} = \begin{pmatrix} 0 & e^{i\chi_h^0} \\ e^{i\chi_e^0} & 0 \end{pmatrix} \begin{pmatrix} B_2^e \\ B_2^h \end{pmatrix}$$

$$\begin{pmatrix} A_1^e \\ A_2^e \end{pmatrix} = \underbrace{\begin{pmatrix} e^{i\chi_h^L} & \\ & e^{i\chi_h^0} \end{pmatrix}}_{S_S} \begin{pmatrix} B_1^h \\ B_2^h \end{pmatrix}$$

$$\begin{pmatrix} A_1^h \\ A_2^h \end{pmatrix} = \underbrace{\begin{pmatrix} e^{i\chi_e^L} & \\ & e^{i\chi_e^0} \end{pmatrix}}_{\tilde{S}_S} \begin{pmatrix} B_1^e \\ B_2^e \end{pmatrix}$$

$$\begin{pmatrix} \underline{A}^e \\ \underline{A}^h \end{pmatrix} = \underbrace{\begin{pmatrix} & S_S \\ \tilde{S}_S & \end{pmatrix}_{4\times4}}_{S_{S\,4\times4}} \begin{pmatrix} \underline{B}^e \\ \underline{B}^h \end{pmatrix}$$

$$\boxed{\underline{A} = S_{S\,4\times4} \cdot S_{4\times4}\, \underline{A}}$$

$$\det \left(S_{S\,4\times4} \cdot S_{4\times4} - 1 \right) = 0$$

$e^{i\chi} = e^{-i\alpha} e^{-i\varphi}$ $\quad \cos\alpha = E/\Delta$

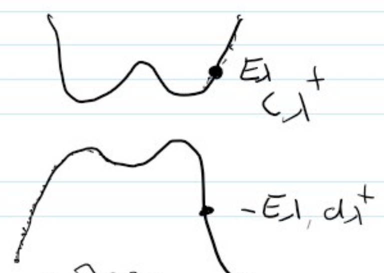
energija vez. stanja

$$\boxed{E = \Delta \sqrt{1 - T \sin^2\left(\frac{\varphi_2 - \varphi_0}{2}\right)}}$$

Josephsonov stik/efekt

$I, \quad V, \quad \varphi, \quad E(\varphi)$

$\varphi_2 \; S_1 \qquad S_2 \; \varphi_0 \qquad \varphi = \varphi_0 - \varphi_2$



$|\Psi_0\rangle =$

$$|\Psi_0\rangle = \prod_{E_\lambda > 0} c_\lambda \, d_\lambda^+ \qquad |\tilde{\Psi}_0\rangle = \begin{cases} 0 \\ \alpha |\Psi\rangle \end{cases}$$

$$E_0 = \sum_{\lambda; E_\lambda < 0} E_\lambda = -\sum_{\lambda; E_\lambda > 0} E_\lambda$$

$$E_0(\varphi) = -\sum_{\lambda'} E_{\lambda'} = -\Delta \sum_n \sqrt{1 - T_n \sin^2(\varphi/2)} = -\Delta \sum_n 1 - \frac{T_n \sin^2 \varphi/2}{2}$$

λ' Andreeva vezana st.

$$= \text{const} + \frac{\Delta T_n}{4}(-\cos\varphi)$$

$$\boxed{E_0(\varphi) = E_J(-\cos\varphi)}$$

$V_2 \; S \; \varphi_2 \qquad S \; \varphi_0 \; V_0$

$V_2 \qquad V_0$

$\xrightarrow{I}$

$V = V_2 - V_0$

$P = VI$

$$\frac{dE}{dt} = VI$$

$$\frac{dE}{d\varphi} = +\Delta \sum_n \frac{T_n \sin\varphi/2 \cos\varphi/2 \; \frac{1}{2}}{\sqrt{} \; -} \quad \Bigg| \; \frac{dE}{d\varphi} \frac{d\varphi}{dt} = VI \qquad i\partial_t \Psi = H\Psi = eV,$$

$$\frac{dE}{d\varphi} = +\Delta\sum_n \frac{T_n \sin\frac{\varphi}{2}\cos\frac{\varphi}{2}}{\sqrt{1-T_n\sin^2\frac{\varphi}{2}}}\,\frac{1}{2}$$

$$\frac{dE}{d\varphi}\,\frac{d\varphi}{dt} = VI$$

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi = eV_L$$

$$-\frac{\Delta}{4}\sum_n \frac{T_n\sin\varphi}{\sqrt{1-\cancel{T_n}\sin^2\frac{\varphi}{2}}}$$

$$i\hbar\,\frac{d\,e^{i\varphi_L}}{dt} = 2e\,V_L\,e^{i\varphi_L}$$

$$-\hbar\,\frac{d\varphi_L}{dt} = 2e\,V_L$$

$$\boxed{\frac{\Delta}{4}\sum_n \frac{T_n\sin\varphi}{\sqrt{\;}}\cdot\frac{2e}{\hbar}\cancel{V} = \cancel{V}I}$$

$$\dot\varphi_L = -\frac{2e}{\hbar}V_L\,, \quad \dot\varphi_D = -\frac{2e}{\hbar}V_D$$

$$\varphi = \varphi_D - \varphi_L$$

$$\boxed{\dot\varphi = \frac{2e}{\hbar}\cdot V} \qquad V = V_L - V_D$$

T_n mali

$$\boxed{I = \underbrace{-\frac{\Delta|e|}{2\hbar}\sum_n T_n}_{I_c}\sin\varphi} =$$

$$\boxed{I = -I_c\sin\varphi}$$

konst. nap.

$$\varphi = \frac{2e}{\hbar}Vt$$

$$I = -I_c\sin\varphi$$

$$= -\frac{\Delta\pi}{2|e|}\frac{(2|e|)^2}{2\pi\hbar}\sum_n T_n\sin\varphi$$

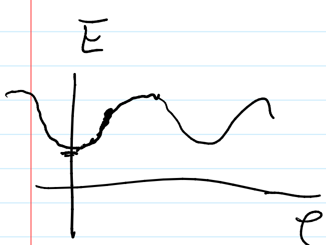
$$I = -\frac{\Delta\pi}{2|e|}\,G\,\sin\varphi$$

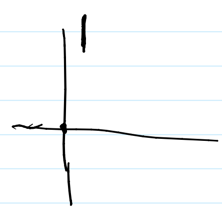
izmenični Josephsonov pojav

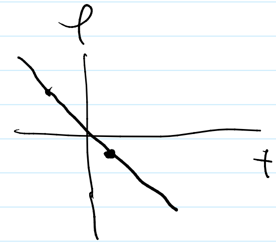
$$E(\varphi) = -E_J\cos\varphi$$

$$I = -E_J\frac{2|e|}{\hbar}\sin\varphi = -I_c\sin\varphi$$

$$I_c = E_J\frac{2|e|}{\hbar}$$



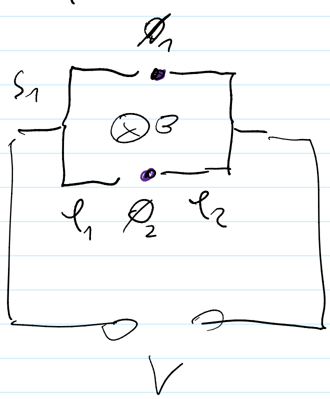




istosmjerni J. pojav

$V = 0$; $\varphi = \text{konst}$; $I = -I_c\sin\varphi$

SQUID



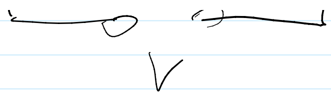
$$I = -I_c(\sin\phi_1 + \sin\phi_2)$$

$$\phi_m = \int \vec{A}\,\frac{2e}{\hbar}\,d\vec{s} = \int \vec{B}\cdot d\vec{S}\,\frac{2e}{\hbar} = 2\,\frac{2\pi\Phi}{\Phi_0}$$

$$\Phi_0 = h/e$$

$$\phi_1 = \overbrace{\varphi_2 - \varphi_1}^{\varphi} + \phi_m/2$$

$$\phi_2 = \underbrace{\varphi_2 - \varphi_1}_{\varphi} - \phi_m/2$$



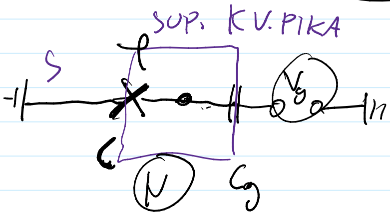
$$\varphi_2 = \underbrace{\varphi_2 - \varphi_1}_{\varphi} - \Phi_m/2$$

$$I = -I_c\left(\sin(\varphi + \Phi_m/2) + \sin(\varphi - \Phi_m/2)\right)$$

$$\boxed{I = -2I_c \cos\frac{\Phi_m}{2}\,\sin\varphi}$$

$$\Phi_0 = 10^{-15}\,\mathrm{Tm}^2$$

Coopernjeva škatla



$$E = \frac{1}{2(C+C_g)}(eN - q)^2 + (-E_J)\cos\varphi$$

$$q = C_g V_g \qquad \cos\varphi \to 1 - \varphi^2/2$$

$$V_g = 0$$

$$E = \frac{1}{2\tilde{C}}(eN)^2 + E_J\left(\varphi^2/2 + c\right)$$

$$E = E_c N^2/2 + E_J \varphi^2/2$$

$$I = -I_c \sin\varphi$$

$$e\dot{N} = -I_c \sin\varphi$$

KVANTIZACIJA OPISA

$$\psi_{BCS}(\varphi) = \prod_k \left(u_k + v_k e^{-i\varphi} c^+_{k\uparrow} c^+_{-k\downarrow}\right)|0\rangle$$

$$|N\rangle = \int \psi_{BCS}(\varphi)\, e^{-iN\varphi/2}\, d\varphi \qquad \int_0^{2\pi} e^{iM\varphi - N\varphi/2}\, d\varphi = \begin{cases} 2\pi; & M = N/2 \\ 0; & \text{sicer} \end{cases}$$

$\hat{N}, \hat{\varphi}$ ... kanonični količini p, x

$$H = E_c \frac{\hat{N}^2}{2} + E_J \frac{\hat{\varphi}^2}{2}$$

$\hat{\varphi}$ ... koordinata

$\hat{N}$ ... gib. količina

$$[\hat{N}, \hat{\varphi}] = -2i$$

$$I = -I_c \sin\varphi$$

$$i\hbar \dot{\hat{N}} = [N, H]$$

$[N,\varphi] = -2i$

$i\hbar\dot{\hat N} = [N,H]$

$I = -I_c \sin\varphi$

$I = e\dot N = -I_c\sin\varphi = -I_c\varphi$

$\dot I = -I_c\dot\varphi = -I_c\left(-\frac{2eV}{\hbar}\right) = +I_c\frac{2e^2N}{C\hbar}$ $\quad E_c = \frac{e^2}{C}$

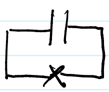
$V = \frac{eN}{C}$ $\quad = +I_c\frac{E_c\cancel{4}N}{\hbar}$ 2

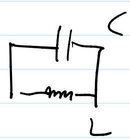
E

$H = \frac{k\hat x^2}{2} + \frac{\hat p^2}{2m}$

$$\boxed{\dot N = -\frac{I_c}{e}\varphi \qquad \dot\varphi = -E_c\frac{\cancel{4}N}{\hbar}}$$ 2

$I = \left(\frac{1}{L}\right)V$ $\quad$ φ mala $\quad$ X ...





$I_c = \frac{2eE_J}{\hbar}$

$$\boxed{\dot N = \frac{2E_J}{\hbar}\varphi \qquad \dot\varphi = E_c\frac{\cancel{4}N}{\hbar}}$$ −2

$[\hat N,\cancel{x}\ \varphi] = +2i$

torej $\boxed{\dot N = \frac{2E_J}{\hbar}\varphi \qquad \dot\varphi = -\frac{2E_cN}{\hbar}}$

na piki $\quad$ na izviru

Tu je vseskozi φ označeval $\varphi = \varphi_p - \varphi_s$

V literaturi se uporablja obratna def.

$\varphi_s \quad \varphi_p$

$\varphi = \varphi_s - \varphi_p$; če $\varphi_s = 0$ $\quad \varphi = -\varphi_p$

potem imamo $[\hat N,\hat\varphi] = -2i$. To je predpostavljena spodaj.

$\langle\varphi|N\rangle = e^{i\varphi N/2}$ $\qquad \langle x|k\rangle = e^{ikx}$

$\hat N = -2i\partial_\varphi$

$\hat H$ v fazni repr.

$$\boxed{H = \frac{E_c}{2}(-2i\partial_\varphi)^2 + \frac{E_J}{2}(\varphi^2) = \frac{E_c}{2}(-2i\partial_\varphi)^2 + E_J(-\cos\varphi)}$$

$H = -\frac{\hbar^2}{2m}\partial^2/\partial x^2 + x^2\ldots$

$\hat H$ v nab. reprezentaciji

popravki!

$\hat{H}$ v nab. reprezentaciji

$$H = \frac{E_c}{2} N^2 \qquad \cos\varphi = \frac{e^{i\varphi} + e^{-i\varphi}}{2}$$

$$e^{i\varphi} e^{i\varphi N/2} = e^{i\varphi (N+2)/2}$$

$$2\cos\hat{\varphi}\,|N\rangle = |N+2\rangle + |N-2\rangle$$

$$\boxed{H = \frac{E_c}{2} N^2 + E_J \sum_N |N+2\rangle\langle N| + |N-2\rangle\langle N|}$$

Kvantna računalništva

N

$\hat{q}$ o o o o o o

0,1

stanje $\qquad 2^N$ različnih stanj

$|\psi\rangle = \sum_n c_n |n\rangle \qquad |0\rangle = |00001\ldots0\rangle$

... v različnih stanjih

$$|\psi\rangle = \sum_n c_n |n\rangle \qquad |0\rangle = |0000\ldots0\rangle,\quad |1\rangle = |0\ldots1\rangle,\quad |2\rangle = |000\ldots10\rangle$$

c_n 10 bitov

$10 \cdot 2^N$ bitov za zapis kvantnega stanja

Enota kv. informacije kubit
dvonivojski kv. sistem

$\uparrow, \downarrow$

$$|\psi\rangle = a|\uparrow\rangle + b|\downarrow\rangle = \cos\frac{\vartheta}{2}|\uparrow\rangle + \sin\frac{\vartheta}{2}\, e^{i\varphi}|\downarrow\rangle$$

$$\langle\psi|\vec{\sigma}|\psi\rangle = \begin{pmatrix}\cos\varphi \sin\vartheta \\ \sin\varphi \sin\vartheta \\ \cos\vartheta\end{pmatrix} = \begin{pmatrix}\langle\sigma_x\rangle \\ \langle\sigma_y\rangle \\ \langle\sigma_z\rangle\end{pmatrix}$$

(1) $$|\psi\rangle = \hat{R}_z(\varphi)\hat{R}_y(\vartheta)|\uparrow\rangle$$

$$\hat{R}_{\hat{n}}(\alpha) = e^{-i\frac{\hat{n}\cdot\vec{\sigma}}{2}\alpha} = \cos\frac{\alpha}{2}\,\hat{1} - i\,\hat{n}\cdot\vec{\sigma}\,\sin\frac{\alpha}{2}$$

D.N. pokaži zvezo (1).

Izrek o nekloniranju (NO-CLONING TH.)

$|\psi\rangle$ ..... $|\psi\rangle|\psi\rangle|\psi\rangle\ldots$

$|e\rangle$ .. znano zač. stanje

Ali $\exists\, U$?

$$U|\psi\rangle|e\rangle = |\psi\rangle|\psi\rangle$$

$$|\psi\rangle = a|\uparrow\rangle + b|\downarrow\rangle$$

$$U(a|\uparrow\rangle + b|\downarrow\rangle)|e\rangle = (a|\uparrow\rangle + b|\downarrow\rangle)(a|\uparrow\rangle + b|\downarrow\rangle)$$

$$\| $$

$$Ua|\uparrow\rangle|e\rangle + Ub|\downarrow\rangle|e\rangle = a|\uparrow\rangle|\uparrow\rangle + b|\downarrow\rangle|\downarrow\rangle$$

$b = 0 \quad a = 1$

Operacije na kubitih

- enokubitne operacije

$U|\psi\rangle$ ... elek. potencial V

$$H = \hat{1}\, eV + \mu_B \vec{B}\cdot\vec{\sigma}$$

$$U = e^{iHt}$$

$H = (1\ eV) + \mu_B B \cdot \sigma$

$U = e^{iHt}$

$\boxed{\begin{pmatrix} & 1 \\ 1 & \end{pmatrix} \quad \ldots \quad SWAP = e^{+i\pi/2} R_{\hat{x}}(\pi)}$

2x matrika $\quad \begin{pmatrix} & 1 \\ 1 & \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$