Analytical view on tunnable quantum swap gate in tight-binding model

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Wannier qubit in the chain of coupled q-dots

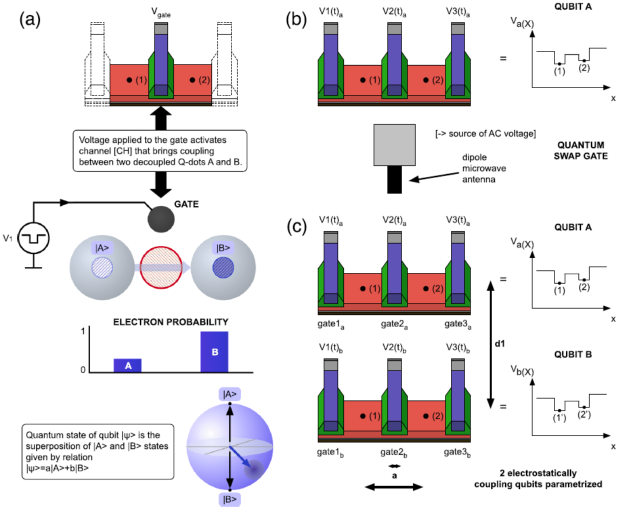


Figure: Basic concept of Wannier (position-based qubit) as from [Cryogenics 2020, Pomorski et al.].

Philosophy of anticorrelation in single electron devices

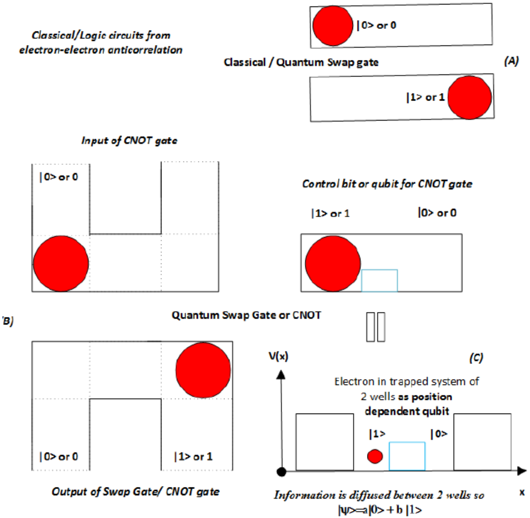
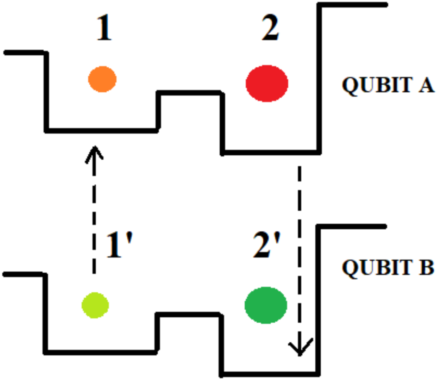


Figure: Principle of anticorrelation as by [Spie 2019, Pomorski et al.]

Oscillating charge in qubit A brings phase imprint on qubit B and reversely.

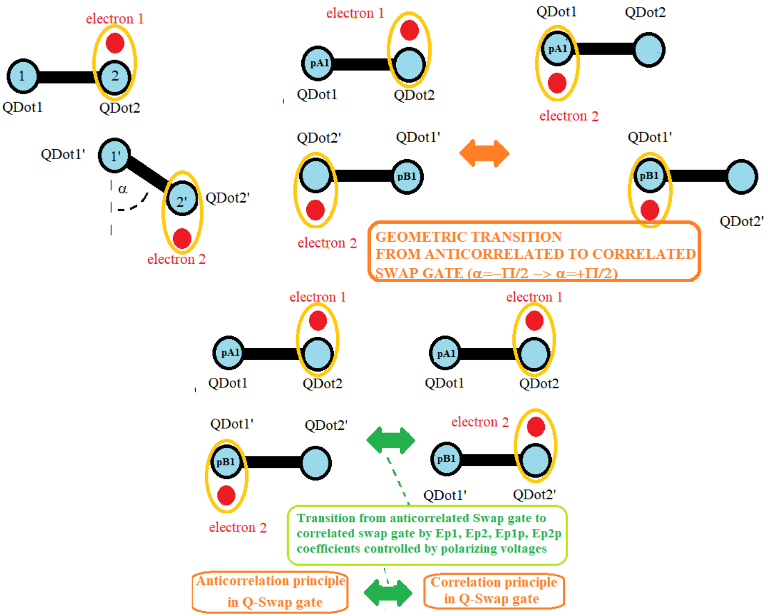


Qubit B deforms effective potential affecting qubit A and reversely !!! (->renormalization of hopping term and localization energy in self-consitent treatment).

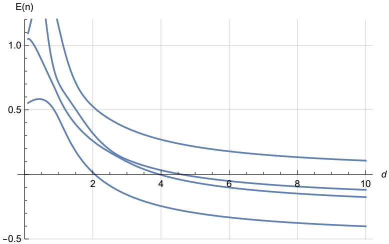
$$
\begin{aligned}
\hat{H} = (t_{s21}(t)\left|2\right\rangle\left\langle 1\right| + t_{s12}(t)\left|1\right\rangle\left\langle 2\right|)\hat{I}_b) + \\
+(\hat{I}_a(t_{s2'1'}(t)\left|2'\right\rangle\left\langle 1'\right| + t_{s1'2'}(t)\left|2'\right\rangle\left\langle 1'\right|) + \\
+(E_{p1}(t)\left|1\right\rangle\left\langle 1\right| + E_{p2}(t)\left|2\right\rangle\left\langle 2\right|)\hat{I}_b + \\
\hat{I}_a(E_{p1'}(t)\left|1'\right\rangle\left\langle 1'\right| + E_{p2'}(t)\left|2'\right\rangle\left\langle 2'\right|) + \\
+\frac{q^2}{d_{11'}}\left|1,1'\right\rangle\left\langle 1,1'\right| + \frac{q^2}{d_{22'}}\left|2,2'\right\rangle\left\langle 2,2'\right| + \\
\frac{q^2}{d_{12'}}\left|1,2'\right\rangle\left\langle 1,2'\right| + \frac{q^2}{d_{21'}}\left|2,1'\right\rangle\left\langle 2,1'\right| = \\
H_{kinetic1} + H_{pot1} + H_{kinetic2} + H_{pot2} + H_{A-B}
\end{aligned}
\tag{1}
$$

described by parameters $E_{p1}(t)$,$E_{p2}(t)$,$E_{p1'}(t)$,$E_{p2'}(t)$, $t_{s12}(t)$, $t_{s1'2'}(t)$ and distances between nodes k and l': $d_{11'}$,$d_{22'}$,$d_{21'}$,$d_{12'}$. In such case q-state of the system is given as

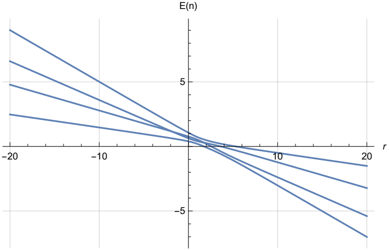
$$
\begin{aligned}
\left|\psi\right\rangle_t = \gamma_1(t)\left|1,0\right\rangle_U\left|1,0\right\rangle_L + \gamma_2(t)\left|1,0\right\rangle_U\left|0,1\right\rangle_L + \\
+\gamma_3(t)\left|0,1\right\rangle_U\left|1,0\right\rangle_L + \gamma_4(t)\left|0,1\right\rangle_U\left|0,1\right\rangle_L,
\end{aligned}
\tag{2}
$$


electron 1
1
2
QDot1
QDot2
QDot1'
1'
α
2'
QDot2'
electron 2
electron 1
pA1
QDot1
QDot2
QDot1
QDot2
pA1
electron 2
QDot2'
QDot1'
pB1
electron 2
QDot1'
pB1
QDot2'
GEOMETRIC TRANSITION
FROM ANTICORRELATED TO CORRELATED
SWAP GATE (α=–Π/2 –> α=+Π/2)
electron 1
pA1
QDot1
QDot2
electron 1
pA1
QDot1
QDot2
QDot1'
QDot2'
pB1
electron 2
electron 2
pB1
QDot1'
QDot2'
Transition from anticorrelated Swap gate to
correlated swap gate by Ep1, Ep2, Ep1p, Ep2p
coefficients controlled by polarizing voltages
Anticorrelation principle
in Q-Swap gate
Correlation principle
in Q-Swap gate

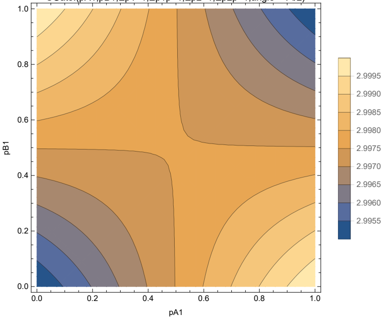
Swap gate,Ep1=0.1,Ep2=−0.1,Ep1p=−0.3,Ep2p=−0.2,angle=3Pi/4,ts=0.1

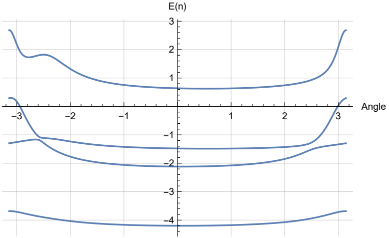


Ep1=0.1r,Ep2=−0.1r,Ep1p=−0.3r,Ep2p=−0.2r,angle=Pi/4,ts=0.1



SGate:(pA1,pB1,Ep1=1,Ep1p=1,Ep2=1,Ep2p=1,angle=−Pi/2)





Literature

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3. K.Pomorski, R.Staszewski, **Towards quantum internet and non-local communication in position-based qubits**, AIP Conference Proceeings 2241, 020030, 2020

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