Quantum Computing with Electrons on Helium

Physkiss-1

Sanskriti Chitransh

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Format of the talk

1. DiVincenzo criteria for realizing physical quantum computation
2. Experimental setup
3. Single qubit and multiple qubit arrangements
4. Decay, decoherence and relevant timescales
5. Quantum gates and readout

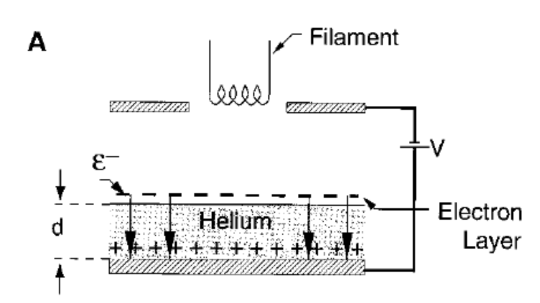
DiVincenzo Criteria

Experimental conditions necessary for quantum computation:

1. A scalable physical system with well characterized qubits
2. The ability to initialize the state of the qubits to a "ground state"
3. Long relevant decoherence times
4. A "universal" set of quantum gates
5. A qubit-specific measurement capability

Experimental setup

- Single electron trapped on a bulk liquid Helium film at $T < 0.1K$
- Image potential seen by electron is $\mathbf{V = \Lambda e^2/z}$



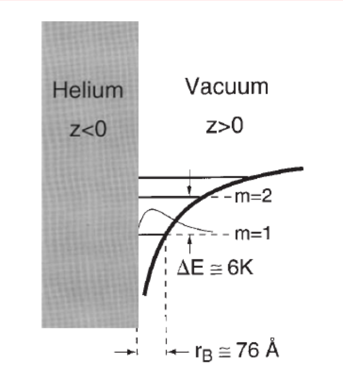
Qubit

- Electron z motion described by $1-D$ Hydrogenic potential:

$$\mathbf{E_m = -R/m^2}$$

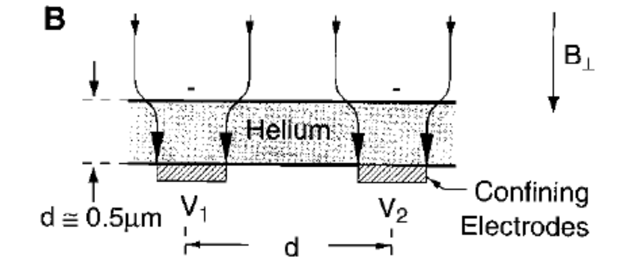
for the m'th state with Rydberg energy $R \cong 8K$.

- Rabi frequency $\sim GHz$



Multiple qubits

- Substrate with patterned electrodes for lateral "in-plane" confinement
- In-plane quantum energy levels created, harmonic oscillations at $\omega_{\parallel}/2\pi \approx \mathbf{10-20GHz}$ for $\mathcal{E}_{\perp} = 500V/cm$ and $h = 0.5\mu m$
- Qubit characterization $\equiv |\mathbf{i}, \mathbf{v}, \mathbf{m_v}\rangle$



Relaxation: Ripplons

- Ripplons are vibrations of the liquid He surface
- Electron-ripplon coupling takes the form:

$$\mathbf{H_i^{(1)}} = \sum_{\mathbf{q}} \xi_{\mathbf{q}} \mathbf{e}^{\mathbf{i(q\cdot r)}} \hat{\mathbf{V}}_{\mathbf{q}}$$

The quadratic term is:

$$\mathbf{H_i^{(2)}} = \sum_{\mathbf{q_1,q_2}} \xi_{\mathbf{q_1}} \xi_{\mathbf{q_2}} \mathbf{exp[i(q_1+q_2)r]} \hat{\mathbf{V}}_{\mathbf{q_1,q_2}}$$

Relaxation: One-ripplon processes

- Decay of $|2,0,0\rangle$ does not require transition to $|1,0,0\rangle$; $|2,0,0\rangle \to |1,v,m_v\rangle$ transitions are possible
- Energy conservation in a transition requires too large ripplon momentum for an electron to accommodate
- One-ripplon decay rate is calculated from the coupling Hamiltonian and is exponentially small for $\omega_{||} \sim 20GHz$
- Sufficiently suppressed by strong in-plane confinement

Relaxation: Two-ripplon processes

- Two ripplons with large wave vectors $\mathbf{q_1}, \mathbf{q_2}$ emitted
- Propagate in opposite directions at nearly the same frequencies
- For minimal electron energy change $\hbar\omega_{\|}$ ripplon frequencies $\sim \omega_{\|}$

Dephasing

Definition: diffusion of phase difference between $|2,0,0\rangle$ and $|1,0,0\rangle$ by quasielastic scattering of thermal excitations

- Primary source is coupling to ripplons
- Density of states for thermally excited ripplons is high even at low temperatures
- Dephasing rate depends on both frequency of singly coupled ripplons and $k_B T/\hbar$

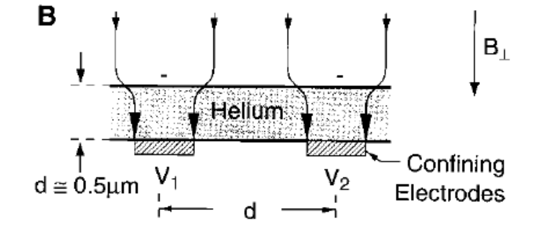
Single-qubit gates

- State changed by application of microwave frequencies

Two-qubit gates

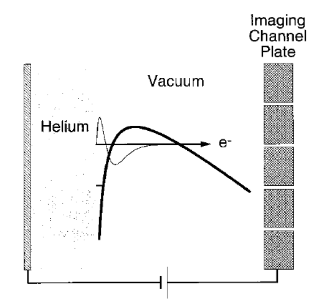
- Resonant frequencies controlled by patterned electrode voltage
- Electron-electron Coulomb interaction:

$$\mathbf{V_c(z_1, z_2) \cong \frac{e^2}{d^3}(z_1 z_2)}$$



Qubit readout

- Reverse field (just strong enough) applied to capacitor
- Electron sees potential as shown, tunnelling strength depends on strength of field
- Arrival time of electrons leaving the He surface strong function of **m**



References

Images from [1]; rest from [1] and [2].

[1] M. I. Dykman, P. M. Platzman, and P. Seddighrad. Qubits with electrons on liquid helium. *Phys. Rev. B*, 67:155402, Apr 2003.

[2] P. M. Platzman and M. I. Dykman. Quantum computing with electrons floating on liquid helium. *Science*, 284(5422):1967–1969, 1999.

Thank you!