

Probing Drexel's First Superconducting Artificial Atom

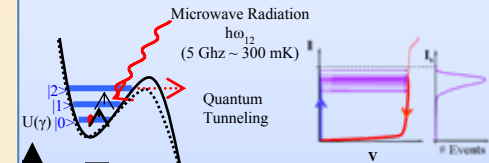
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Abstract

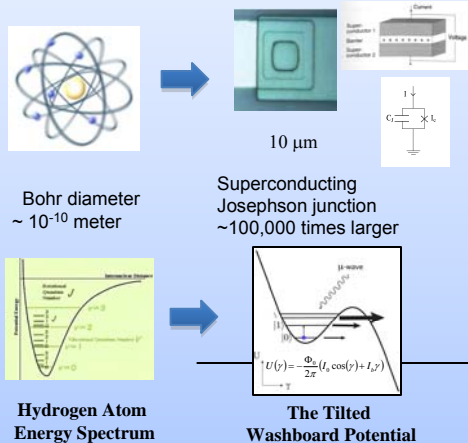
Real atoms demonstrate quantum-mechanical properties such as energy level quantization and superposition. In the rapidly evolving field of quantum state engineering, artificial, solid-state atoms are now being fabricated to exhibit these properties needed to implement basic quantum computing. In contrast to conventional computing which uses a classical two-state "bit" system (0,1), quantum computing uses quantum states $|0\rangle$, $|1\rangle$ and arbitrary superpositions of these to perform calculations. These basis states are physically realized through the quantum energy levels of these atoms. We report on the design, engineering and measurement of Drexel University's first solid state artificial atom, consisting of a superconducting Josephson junction. The "atom" is $\sim 100,000$ times bigger than the hydrogen atom - big enough to connect wires to it. We report on how we can control its quantum properties with macroscopic electrical currents and microwave excitation. We report energy level quantization data, demonstrating our atom's ground state $|0\rangle$ and first excited state $|1\rangle$, using microwave resonant activation techniques.

Microwave Spectroscopy



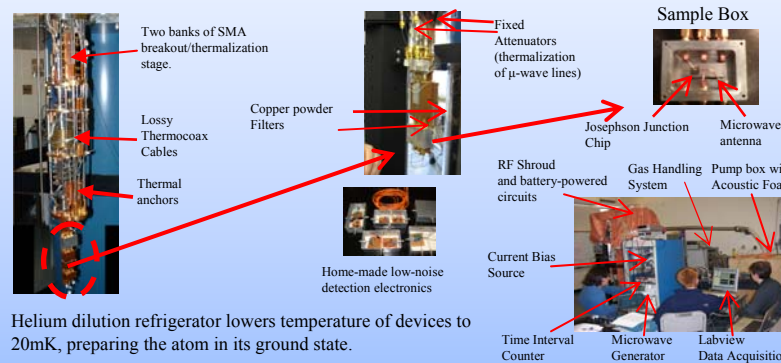
- We use microwaves to excite population from the ground state to higher energy states. This results in enhanced escape rates.
- Increasing the bias current lowers the barrier, so higher energy states will escape at lower bias currents.
- We ramp the bias current and record the current at which it switches to the finite voltage state
- The current at which the junction switches from superconducting to normal state depends on the quantum state ($|0\rangle$ or $|1\rangle$) of the atom.

What is an Artificial Atom?



- The energy levels are unequally spaced and tunable, which allows us to use these as quantum bits, or qubits.

Development of Apparatus



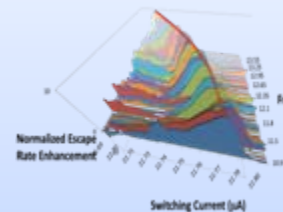
Our Results

Base Temperature ($T=20\text{mK}$)

Single Qubit

- We record histograms of statistically large number of switching events ($\sim 50,000$) for the case when microwaves are off and on
- Convert histograms to escape rates.
- A bump indicates transition from $|0\rangle \rightarrow |1\rangle$ states

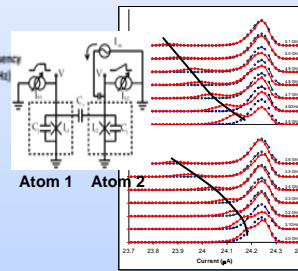
- We take the difference between RF on and RF Off Histograms and normalize to obtain the "Escape Rate Enhancement".



$$f = \left(\frac{I_0}{2\pi\Phi_0 C} \right)^{1/2} \left[1 - \left(\frac{I}{I_0} \right)^2 \right]^{1/4}$$

Repeat for different frequencies to obtain characteristic f vs I plot. We have performed high resolution scan of the $|0\rangle \rightarrow |1\rangle$ transition

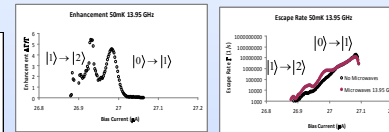
Coupled Qubits



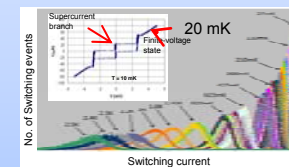
We have also performed experiments on two artificial atoms coupled electrically using a capacitor C_c . Possible quantum entanglement as seen as an avoided crossing in Energy Level Spectrum.

Elevated Temperatures

Single Qubit



At elevated temperatures, thermal energy populates the $|1\rangle$ state and microwaves pump to the $|2\rangle$ state.



Raising the temperature lowers the switching current

Summary

- Current biased solid-state Josephson junctions behave like macroscopic artificial atoms with discrete energy levels which are tunable.
- We have performed microwave spectroscopy experiments on Drexel's first artificial atoms, resolving multiple energy levels.
- Potential applications include quantum computing, performing tests of quantum mechanics using a giant, solid-state atom, and quantum-limited sensing.