

# Quantum Hardware

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# Requirements for a Quantum Computer

- ▶ We have considered qubits to be electrons where the 0 state is spin up and the 1 state is spin down
  - ▶ Some quantum computers work like this but there are other options
- ▶ Requirements for quantum computer:
  - ▶ Two-level system to represent the qubits
  - ▶ Must be able to control and change the level of the system

# Superconducting Quantum Computers

- ▶ Largest and most popular form of creating quantum computers
  - ▶ Many modern QPUs are superconducting quantum computers
  - ▶ IBM, Google, Intel, among others
- ▶ What does superconducting mean?
  - ▶ Most materials have a resistance no matter how low the temperature is
  - ▶ Superconductors have a critical temperature below which there is no resistance in the material
  - ▶ Magnetic fields are not produced by superconductors below the critical temperature

# Josephson Junctions

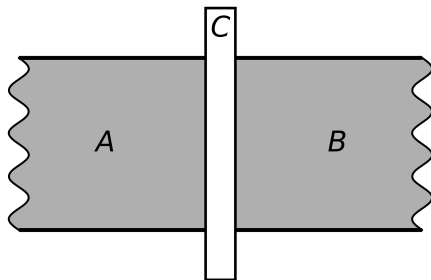


Figure 1: Josephson Junction

# Cooper Pair

- ▶ Pair of electrons bound together at a low temperature
  - ▶ At low temperatures the electrons will be attracted to each other even though they have the same charge

# Transmon (Transmission Line Shunted Plasma Oscillation) Qubits

- ▶ The most popular type of superconducting qubit
- ▶ Two level system is created using a Cooper Pair
  - ▶ Two levels are encoding in the charge of the pair as it moves across the Josephson junction
  - ▶ Frequency of charge oscillations
- ▶ Should have reduced sensitivity to noise

# Magnetic Flux Qubits

- ▶ Background: Changing magnetic fields can cause current to flow through a loop of wire
- ▶ Utilize the magnetic flux in through a loop of superconducting wire
- ▶ Loop is micrometer sized and has a number of Josephson junctions throughout
- ▶ Magnetic fields are applied such that the current flow is clockwise or counterclockwise (two level system)
  - ▶ Possible to put it in a superposition between clockwise and counterclockwise current

# Quantum Dot (Semiconductor Nanocrystals)

- ▶ Very small semiconductor particles whose properties are different from larger systems because of quantum mechanics
  - ▶ Semiconductor: Somewhere between an insulator and a conductor
- ▶ Produce light when excited/de-excited and can tune the exact wavelength of light produced
  - ▶ Valence and Conduction Bands
- ▶ Artificial atoms



# Quantum Dot (Spin Qubit/Silicon Spin) Quantum Computers

- ▶ Utilize trapped semiconductor atoms (such as silicon)
- ▶ The qubits are electrons or multi-electron systems
  - ▶ Quantum dot electrons
- ▶ The two level system is encoded into either the spin or the charge of the electrons
- ▶ System is controlled with microwaves, voltage changes, or magnetic fields
- ▶ Typically made of silicon
  - ▶ Gallium arsenide, silicon carbide, diamond
- ▶ Can operate at “hot” temperatures (several Kelvin) so may be advantageous for scaling

# Linear Optical Quantum Computer

- ▶ Qubits are photons, controlled by linear optical elements and voltages
  - ▶ Mirrors, waveplates, interferometers
- ▶ Options for the two-level system
  - ▶ Path the photon takes through the chip
  - ▶ Number of photons in a path
- ▶ Combine multiple qubits by creating an integrated photonics chip

# Trapped Ion Quantum Computer

- ▶ Qubits are charged (ionized) atoms trapped in a electromagnetic field
- ▶ Two level system are two energy levels of the atoms
- ▶ Controlled with microwaves or laser beams
- ▶ Implementation can be difficult, high decoherence and short lifetime of entangled states

# Less Used Architectures

- ▶ Color Center Quantum Computers
  - ▶ Atom are embedded in a gap in a material such as diamond
  - ▶ Two level system is the spin of the atom
  - ▶ Controlled with microwaves and lasers
- ▶ Optical Lattice Quantum Computers
  - ▶ Qubits are cold, neutral atoms which are trapped in an optical lattice
    - ▶ Criss-crossed laser beams which form energy wells that the atoms become trapped in
  - ▶ Two level system are the energy levels of the atoms
  - ▶ Controlled with lasers