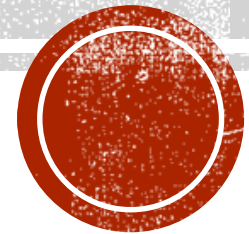# INTRODUCTION TO SUPERCONDUCTING QUBITS

A QHardware Tutorial Series

Part-3

SUPERCONDUCTOR

- A superconductor is a material that achieves superconductivity, which is a state of matter that has no electrical resistance and does not allow magnetic fields to penetrate.

- An electric current in a superconductor can persist indefinitely.

- Superconductivity can only typically be achieved at very cold temperatures.

- Prominent examples of superconductors include aluminium, niobium, magnesium diboride, cuprates such as yttrium barium copper oxide and iron pnictides.

- These materials only become superconducting at temperatures below a certain value, known as the critical temperature.

SUPERCONDUCTING QUBIT

- Superconducting circuits are macroscopic in size but have generic quantum properties such as quantized energy levels, superposition of states, and entanglement, all of which are more commonly associated with atoms.

- Superconducting quantum bits (qubits) form the key component of these circuits.

- Their quantum state is manipulated by using electromagnetic pulses to control the magnetic flux, the electric charge or the phase difference across a Josephson junction (a device with nonlinear inductance and no energy dissipation).

- As such, superconducting qubits are not only of considerable fundamental interest but also might ultimately form the primitive building blocks of quantum computers.

HAMILTONIAN

- The Hamiltonian of a system specifies its total energy i.e., the sum of its kinetic energy (that of motion) and its potential energy (that of position) in terms of the Lagrangian function derived in earlier studies of dynamics and of the position and momentum of each of the particles.

$$H_{operator} = \frac{-\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)$$

Operator associated with kinetic energy   Potential energy

LAGRANGIAN MECHANICS

- The state of a physical system is described by a Lagrangian function, often known as a Lagrangian quantity. The Lagrangian function in mechanics is just the kinetic energy (motion energy) minus the potential energy (energy of position).

- A reformulation of classical mechanics is known as Lagrangian mechanics. Classical mechanics is reformulated in Hamiltonian mechanics, which is a mathematically sophisticated version of classical mechanics.

- The key difference between Lagrangian and Hamiltonian mechanics is that Lagrangian mechanics describes the difference between kinetic and potential energies, whereas Hamiltonian mechanics describes the sum of kinetic and potential energies.

DIFFERENCE BETWEEN A LAGRANGIAN AND A HAMILTONIAN

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HARMONIC OSCILLATOR

- In classical mechanics, a harmonic oscillator is a system that, when displaced from its equilibrium position, experiences a restoring force F proportional to the displacement x: where k is a positive constant.

- An anharmonic oscillator is one which deviates from the exact form of the harmonic oscillator.

- The dependence of the energy levels and the value of the matrix elements of the momentum and position operators of a quantum anharmonic oscillator are studied as functions of the quantum number and the strength of the anharmonic term. The principal technique employed is the construction of a canonical transformation.
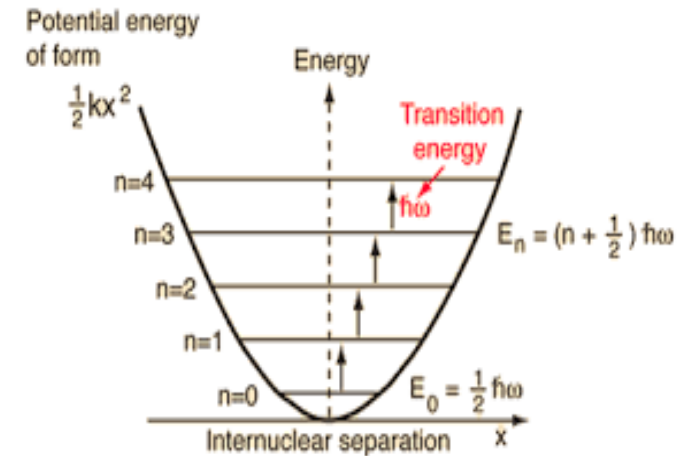
CIRCUIT QED

- Circuit QED allows the study and control of light-matter interaction at the quantum level in unprecedented detail. It also plays an essential role in all current approaches to quantum information processing with superconducting circuits.

- In addition, circuit QED enables the study of hybrid quantum systems interacting with microwave photons.

HOW HARDWARE QUBITS ARE MADE

- Several technologies are used to make hardware qubits for quantum computer.

- Numerous types of qubit technologies exist nowadays such as superconducting qubits, trapped ion qubits, photonic qubits, topological qubits, quantum dot qubits, nuclear magnetic resonance (NMR) qubits etc.

- Among these technologies, superconducting qubits are used mostly where IBM uses transmon qubit and Google has implemented sycamore superconducting qubit processor.

- Superconducting qubits are currently the most advanced qubit technology.

How Hardware Qubits Are Made

- Most existing quantum computers use superconducting qubits.

- They use metal-insulator-metal sandwiches called Josephson junctions.

- To turn these materials into superconductors – materials that electricity can run through with no loss – scientists lower them to extremely cold temperatures.

- The quantum computers you interact with in IBM Quantum use a physical type of qubit called a superconducting transmon qubit, which is made from superconducting materials such as niobium and aluminum, patterned on a silicon substrate.

- Besides, trapped ion quantum computer are also popular where ion trap is used to build quantum register.

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