WEEK - 1

→ Quantum Mechanics

→ State: $|\psi\rangle$ → vector, n dimensional

→ Operators: $\hat{O}$ Ex: $\hat{H}$, $\hat{x}$.

$$\begin{bmatrix} x \\ y \end{bmatrix} \xrightarrow[2\times 2]{O} \begin{bmatrix} x' \\ y' \end{bmatrix}$$

$\hat{H}|\psi\rangle = E|\psi\rangle$

0, 1

→ Quantum Computing

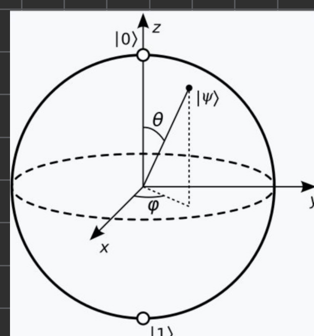
→ Qubits → quantum analog of classical bits

Single qubit: $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$; $|\alpha|^2 + |\beta|^2 = 1$

$|\psi_1\rangle \otimes |\psi_2\rangle$

→ Bloch sphere:

$|\psi\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\theta/2\right) e^{i\varphi} |1\rangle$



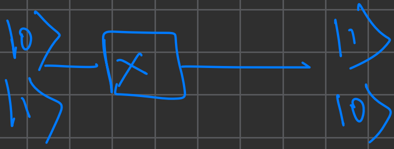
→ Superposition

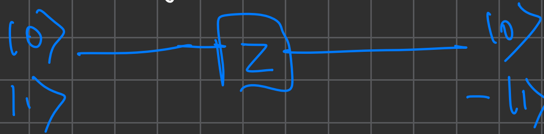
$|\psi_1\rangle|\psi_2\rangle = |0\rangle|1\rangle$
$= |01\rangle$

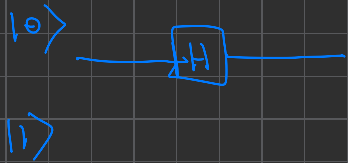
→ Entanglement: Ex: Bell state $|\phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$

$= |\psi_1\rangle \otimes |\psi_2\rangle$

→ Quantum gates : X gate, Hadamard gate, Z gate, CNOT gate

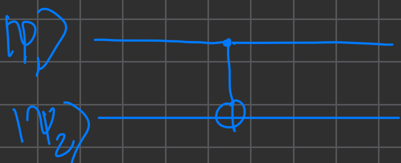






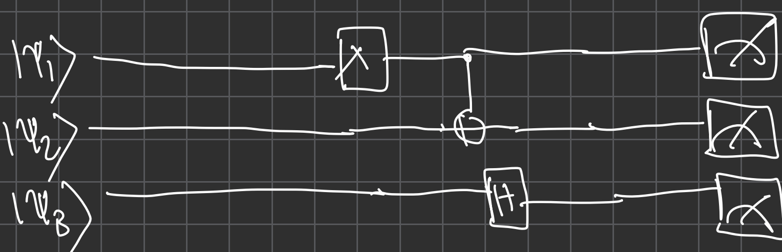
$$\frac{|0\rangle + |1\rangle}{\sqrt{2}} = |+\rangle$$

$$\frac{|0\rangle - |1\rangle}{\sqrt{2}} = |-\rangle$$



$\lvert\psi_1\rangle$	$\lvert\psi_2\rangle$	
$\lvert 0\rangle$	$\lvert 0\rangle$	$\lvert 00\rangle$
$\lvert 0\rangle$	$\lvert 1\rangle$	$\lvert 01\rangle$
$\lvert 1\rangle$	$\lvert 0\rangle$	$\lvert 11\rangle$
$\lvert 1\rangle$	$\lvert 1\rangle$	$\lvert 10\rangle$

Quantum Circuit



$|0\rangle, |1\rangle$

$|+\rangle, |-\rangle$

Z operator

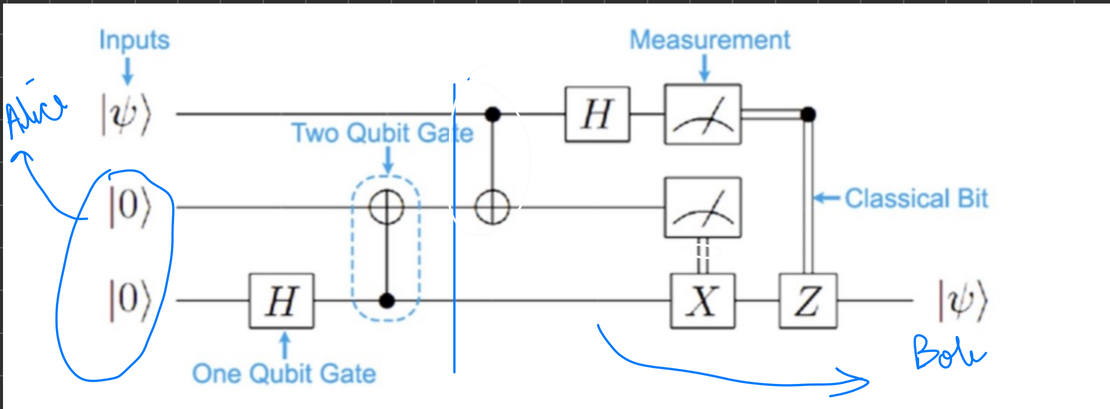
Pauli Matrices

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}, \quad Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}, \quad Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$Z|0\rangle = |0\rangle$$
$$Z|1\rangle = -|1\rangle$$

Quantum Teleportation



$$|00\rangle \rightarrow |0\rangle \otimes \left(\frac{|0\rangle + |1\rangle}{\sqrt{2}}\right) \xrightarrow{\text{CNOT}} \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|\phi\rangle = (\alpha|0\rangle + \beta|1\rangle) \otimes \left(\frac{|00\rangle + |11\rangle}{\sqrt{2}}\right)$$

$$= \frac{1}{\sqrt{2}}\left(\alpha|000\rangle + \alpha|011\rangle + \beta|100\rangle + \beta|111\rangle\right)$$

$$= \frac{1}{\sqrt{2}}\left(\alpha|000\rangle + \alpha|011\rangle + \beta|110\rangle + \beta|101\rangle\right)$$

Qiskit

→ open source python library for simulating quantum circuits

→ Key components - 1) Quantum Circuit ⇒ for creating circuits
2) Aer → simulator
3) IBMQ → for connecting to real QC
4) Visualization tools ⇒ draw, plot

Week 1 Assignment: Quantum Teleportation

Objective

Design and implement a quantum circuit to simulate quantum teleportation of the state 0.6|0>+ 0.8|1> . This assignment will introduce you to creating quantum circuits, running them on simulators and real quantum hardware, and analyzing the results.

Task Description

1. Circuit Design:
   - Design a quantum circuit to implement the quantum teleportation protocol.
   - Clearly annotate the circuit, showing all the steps: entanglement creation, Bell state measurement, and state reconstruction on the receiver's qubit.
2. Implementation:
   - Use Qiskit to simulate the quantum teleportation process.
   - Initialize the qubit in the state 0.6|0>+ 0.8|1> . Use Qiskit's state initialization methods to prepare this custom state.
3. Execution:
   - Execute the circuit on both:
   - The Aer simulator (local simulation).
   - A real IBM Quantum Computer (e.g., IBMQ backend).
   - Ensure you configure the backend and job submission correctly.
4. Analysis:
   - Measure the results after teleportation.
   - Plot and compare the histograms of results from the simulator and the real quantum hardware.
   - Analyze the results and provide an explanation for any observed discrepancies (e.g., noise in real quantum hardware).

Provide a clear and well-labeled quantum circuit diagram representing the quantum teleportation process. Submit the code used for the simulation and execution as a GitHub file. Include plots of the result histograms for both the Aer simulator and the IBMQ backend. Provide a brief explanation of the results, focusing on the correctness of the teleported state and the differences between simulated and hardware results.

General Guidelines

Make extensive use of the Qiskit documentation to thoroughly understand the functionality of each method. Avoid relying on AI tools such as ChatGPT for direct implementation, as the primary goal is to gain hands-on experience by independently exploring Qiskit’s features and capabilities. Ensure that all code, diagrams, and analysis are original and created by you.

Submission deadline- 11:59 pm, 15th December

Good luck with the assignment!