**Lab Manual 2: Exploring Entanglement in Quantum Computing**

**Step 1: Theoretical Background**

**Entanglement** is a quantum phenomenon where two or more qubits become linked, such that the state of one qubit directly affects the state of another, regardless of the distance between them. Key concepts include:

* **Entangled States:** For two qubits, the entangled states can be |00⟩, |01⟩, |10⟩, and |11⟩, but certain operations can create superpositions of these states.
* **Quantum Gates for Entanglement:**
  + **Hadamard Gate (H):** Creates a superposition.
  + **CNOT Gate (CX):** Creates entanglement by flipping the second qubit based on the state of the first qubit.

In this experiment, we will create and measure an entangled state using two qubits.

**Step 2: Implementation**

1. **Set Up Your Environment**
   * Ensure you have Python, Qiskit, and Matplotlib installed. If not, use:

bash

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pip install qiskit matplotlib

1. **Write the Code for Creating Entangled States**
   * Use the following code to create a Bell state, which is a specific type of entangled state:

python

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from qiskit import QuantumCircuit

from qiskit\_aer import AerSimulator

import matplotlib.pyplot as plt

# Create a Quantum Circuit with 2 qubits

qc = QuantumCircuit(2)

qc.h(0) # Apply Hadamard gate to the first qubit

qc.cx(0, 1) # Apply CNOT gate (control on qubit 0, target on qubit 1)

qc.measure\_all() # Measure both qubits

# Visualize the circuit

print("Quantum Circuit:")

print(qc.draw())

# Execute the circuit using the AerSimulator

simulator = AerSimulator()

result = simulator.run(qc).result()

counts = result.get\_counts()

# Plotting the results

plt.bar(counts.keys(), counts.values())

plt.title('Measurement Results for Entangled States')

plt.xlabel('State')

plt.ylabel('Counts')

plt.show()

1. **Run the Code**
   * Execute this script in your Python environment.

**Step 3: Test Results**

* **View the Quantum Circuit Diagram**  
  The line print(qc.draw()) will output a visual representation of the quantum circuit, showing the Hadamard gate on the first qubit followed by the CNOT gate.
* **Measurement Results**  
  After executing the circuit, you will see a bar plot displaying the measurement results for both qubits. The expected outcomes are:
  + You should primarily observe the states:
    - |00⟩ (both qubits in state 0)
    - |11⟩ (both qubits in state 1)

The states |01⟩ and |10⟩ should not appear if the circuit is functioning correctly, confirming the entangled nature of the state.

**Step 4: Analyze the Results**

* **Interpreting the Bar Plot**
  + The x-axis represents the possible states of the two qubits (e.g., |00⟩, |01⟩, |10⟩, |11⟩).
  + The y-axis represents the number of counts for each state.
  + You should find counts predominantly for |00⟩ and |11⟩, demonstrating the entanglement created by the quantum gates.

**Conclusion**

This lab manual demonstrates how to create and measure entangled states in a quantum circuit using Qiskit. By applying a Hadamard gate and a CNOT gate, we can observe the unique properties of entangled qubits. Understanding entanglement is fundamental for advancing in quantum algorithms and quantum information theory.

**Further Exploration**

1. **Modify the Circuit:** Try adding additional gates or changing the order of gates to see how it affects the results.
2. **Increase Qubits:** Explore entanglement with more than two qubits and analyze the results.
3. **Run Multiple Trials:** Execute the circuit multiple times to gather more data and analyze statistical variations.