Quantum Club

Assignment 7

QUANTUM NONLOCALITY.

- Study Sec. 2.3 of the textbook and solve the exercises therein.

Problem 1. Test the Bell inequality using the IBM quantum computer. Prepare the state $|\Psi^-\rangle$ and measure it in the four bases corresponding to the two different settings of each of the parties' apparatus. You will need to construct a separate circuit for each measurement. Run the quantum computer, collect the measurement result statistics, and check if it violates the Bell inequality.

Problem 2. Problem 4.1 from
`https://www.dropbox.com/s/19r15ug1co4whdo/homework4.pdf?dl=0`.

Problem 3. Test the Greenberger-Horne-Zeilinger nonlocality using the IBM quantum computer.

MEASUREMENTS. INTERPRETATIONS OF QUANTUM MECHANICS

- Study Sec. 2.4 of the textbook and solve the exercises therein, as well as Ex. 2.64. Section 2.4.4 can be skipped.
- These topics are largely philosophical and do not require practice exercises.

QUANTUM TELEPORTATION.

- Study Sec. 2.6 of the textbook and solve the exercises therein.

Problem 4. End-of-chapter problem 2.17.

Problem 5. Design and test a quantum circuit that implements quantum teleportation of qubit $q0$ onto $q2$.
Hint: You already realized two key elements of this circuit: the preparation of a Bell state and a measurement in the Bell basis. There is, however, a problem with the third element: the transformation of Bob's qubit $q2$ dependent on the result of the Bell measurement (Table 2.3 in the book). To my knowledge, Quantum Composer does not allow such conditional operations. There are two ways to circumvent this problem. One is to use *Qiskit* — IBM's open source SDK for working with their quantum computers, which can be downloaded as a Python package and permits constructing sophisticated and fully customized quantum circuits. You are welcome to explore this on your own.

The other approach is to still use Composer, but implement the required transformations of Bob's qubit as *quantum* conditional operations. Notice that the c-phase and c-not gates can be interpreted, respectively, as the $\hat{\sigma}_z$ and $\hat{\sigma}_x$ operators applied to the target qubit that take place when the control qubit is in the state $|1\rangle$. You can use this property after you transform $q0 \otimes q1$ from the Bell basis into the canonical basis according to

$$\begin{aligned}
\left|\Psi^-\right\rangle &\to |00\rangle\,; \\
\left|\Psi^+\right\rangle &\to |10\rangle\,; \\
\left|\Phi^-\right\rangle &\to |01\rangle\,; \\
\left|\Phi^+\right\rangle &\to |11\rangle\,.
\end{aligned} \tag{1}$$

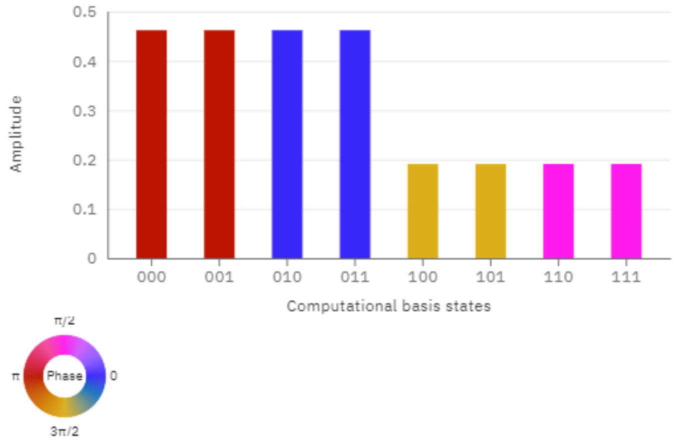

Figure 1: Output *Statevector* appearance after teleportation. The input state is $\hat{U}(\pi/4, \pi/2)\,|0\rangle$.

If you construct your circuit correctly, the Statevector should appear as shown in Fig. 2. That is, no entanglement is present among the three qubits. The states of the $q0 \otimes q1$ is $-\,|+\rangle \otimes |-\rangle$, respectively, whereas the state of $q2$ is equal to the initially prepared state of $q0$. Please explain why this is the case as a part of your solution to this problem.

- If you are interested to learn more about quantum computing, you can study IBM's tutorial (marked by G in Fig. 1) and try implementing some of the classic quantum computing algorithms, such as Deutsch-Jozsa, Grover, phase estimation and Shor. If you follow this path, you should procure the book *Quantum Computation and Quantum Information* by Nielsen and Chuang, which has been the "bible" of this field for many years.