

Exercises for Introduction to Quantum Computing (physics7514) Wise 2025

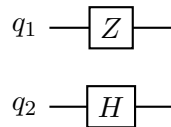
L. Funcke, A. Bulgarelli and N. Dichter

1 Installation of Qiskit

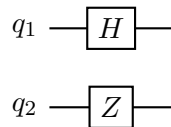
Please install and get familiar with the `qiskit` and `qiskit_aer` python packages. See the accompanying Jupyter Notebook `qiskit_introduction` for an example (*0 points*).

2 Quantum Gates

Derive the matrix representation for the two-qubit system (*2 points*)



and (*2 points*)



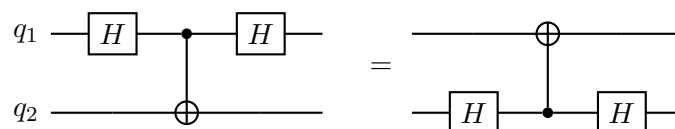
Note that the standard computational basis is

$$\begin{pmatrix} \alpha \\ \beta \\ \gamma \\ \delta \end{pmatrix} = \alpha |00\rangle + \beta |01\rangle + \gamma |10\rangle + \delta |11\rangle$$

and the top qubit in the quantum circuits corresponds to the leftmost qubit in $|q_1q_2\rangle$. Note that this notation follows the lecture and the book by Nielsen and Chuang, while the *Qiskit* python package for simulating quantum circuits adopts a different notation, $|q_2q_1\rangle$.

3 Quantum Circuits

Prove the following identity (*2 points*)



4 No-Cloning Theorem

In general, it is impossible to copy a qubit, i.e., there is no unitary operator that transforms the state $|\psi\rangle|0\rangle$ into $|\psi\rangle|\psi\rangle$ for arbitrary $|\psi\rangle$. However, certain qubit states can be copied.

- Find a quantum circuit that copies the states $|0\rangle$ and $|1\rangle$ into a target qubit, where the latter is initialized in the state $|0\rangle$ (*2 points*).
- Find a quantum circuit that copies the states $|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$ and $|-\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$ into a target qubit, where the latter is initialized in the state $|0\rangle$ (*2 points*).