Introduction to quantum gates

Small operations on amplitudes become the building blocks of a circuit.

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By the end, you'll be able to

- Trace the order of operations in a circuit.
- Distinguish a gate's effect on amplitudes from its effect on measurement probabilities.

An operation, not an assignment

An ideal quantum gate applies a unitary matrix to a state. X exchanges amplitudes. Z changes the sign of the 1 component. H mixes components so they can reinforce or cancel.

If H is applied first and Z second, the resulting state is $ZH|\psi\rangle$. The rightmost matrix acts first. Circuit diagrams here read left to right, so follow the physical order when translating to algebra.

A small gate dictionary

Gate	Action on a one-qubit state $(\alpha, \beta)^T$
X	$(\beta, \alpha)^T$
Z	$(\alpha, -\beta)^T$
H	$(\alpha + \beta, \alpha - \beta)^T/\sqrt{2}$
S	$(\alpha, i\beta)^T$
T	$(\alpha, e^{i\pi/4}\beta)^T$

Predict, then build

Apply H to q0 and CX from q0 to q1. Predict which two basis outcomes survive. Use Undo to check the circuit one step at a time.

L02 · INTERACTIVE LAB

Runs on your device

Quantum gate playground

Gates act on amplitudes. Build a small circuit one operation at a time and compare its exact predictions with repeated measurements.



MODEL · Ideal pure-state vector, complex double precision ORDER · q0 is the leftmost bit

Prediction: Apply H to q0, then CX from q0 to q1. Which two outcomes should disappear? Challenge: Create the Bell state, then undo the gates in reverse order. Where did the randomness go? Open the live experiment studio.

Order can matter

On $|0\rangle$, H followed by Z gives $|-\rangle$. Z followed by H gives $|+\rangle$. Their Z probabilities match, so add a final H to reveal the difference.

Do not infer that two circuits are equivalent merely because they give the same counts for one input in one basis. A gate is a transformation with a contract over its allowed inputs.

Challenge: find two gates in the table that square to I. Then explain why S is not one of them.

Reference: IBM Quantum — Bits, gates, and circuits.