Understanding qubits

Meet the smallest quantum information system, with a sphere you can explore.

12 min read Dr. Charith Jayasekara

By the end, you'll be able to

- Describe a pure qubit using amplitudes and angles.
- Predict computational-basis measurement probabilities.
- Distinguish a mathematical state from one measured bit.

Two amplitudes, one state

A pure qubit lives in a two-dimensional complex vector space. After removing an unobservable global phase, we can write it as

$$|\psi\rangle = \cos(\theta/2)|0\rangle + e^{i\phi}\sin(\theta/2)|1\rangle.$$

The polar angle θ sets the Z-basis probabilities. The azimuth ϕ sets the relative phase. The explorer uses **degrees** for its controls; the formula uses radians.

Follow the sphere

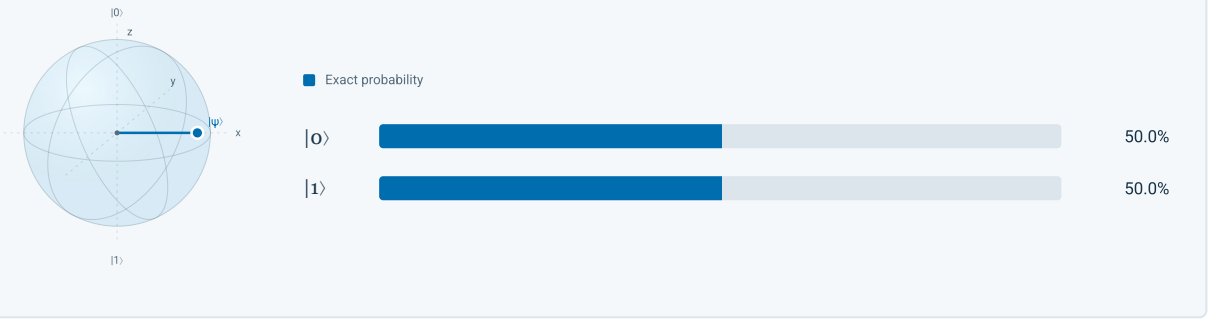
At $\theta = 0$, the state is $|0\rangle$. At $\theta = 180^\circ$, it is $|1\rangle$, up to a global phase. Along the equator, $\theta = 90^\circ$ and both Z outcomes have probability $1/2$.

L01 · INTERACTIVE LAB

Runs on your device

Qubit explorer

A pure qubit is a normalised pair of complex amplitudes. The sphere shows the state; the bars show measurement probabilities in the Z basis.



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

Prediction: Move the state to the equator. What will happen to the Z-basis probabilities when you change only the phase? Challenge: Create a state with a 75% probability of measuring 1. Can you find two different phases with the same probabilities? Open the live experiment studio.

Work one example

Choose $\theta = 120^\circ$ and $\phi = 90^\circ$. Then

$$|\psi\rangle = \frac{1}{2}|0\rangle + i\frac{\sqrt{3}}{2}|1\rangle.$$

Therefore $P(0) = 1/4$ and $P(1) = 3/4$. A 1,024-shot experiment has expected counts 256 and 768, but its observed counts fluctuate.

What the picture does and does not mean

The arrow is a geometric representation of an ideal pure state. It is not a tiny physical arrow inside every device. Mixed states belong inside the Bloch sphere; this particular explorer stays on the surface and does not model decoherence.

PAUSE & THINK

You change only φ while keeping θ fixed. What stays the same?

- ☐ The entire quantum state
- ☐ The Z-basis measurement probabilities
- ☐ All possible measurement results in every basis

Reference: Microsoft Learn — The qubit.