Qubit

In quantum computing, a **qubit** or **quantum bit** (sometimes **qbit**) is the basic unit of quantum information—the quantum version of the classical binary bit physically realized with a two-state device.

## **Bit versus qubit**

A binary digit, characterized as 0 and 1, is used to represent information in classical computers. There are two possible outcomes for the measurement of a qubit—usually taken to have the value "0" and "1", like a bit or binary digit. However, whereas the state of a bit can only be either 0 or 1, the general state of a qubit according to quantum mechanics can be a coherent superposition of both. Moreover, whereas a measurement of a classical bit would not disturb its state, a measurement of a qubit would destroy its coherence and irrevocably disturb the superposition state. It is possible to fully encode one bit in one qubit. However, a qubit can hold more information, e.g. up to two bits using superdense coding.

## **Standard representation**

In quantum mechanics, the general quantum state of a qubit can be represented by a linear superposition of its two orthonormal basis states (or basis vectors). These vectors are usually denoted as {\displaystyle |0\rangle ={\bigl [}{\begin{smallmatrix}1\\0\end{smallmatrix}}{\bigr ]}}|0> =[1 0] and {\displaystyle |1\rangle ={\bigl [}{\begin{smallmatrix}0\\1\end{smallmatrix}}{\bigr ]}}|1> = [0 1]. They are written in the conventional Dirac—or "bra–ket"—notation; the |0> {\displaystyle |0\rangle }|0> |and |1> {\displaystyle |1\rangle }||are pronounced "ket 0" and "ket 1", respectively.

Qubit basis states can also be combined to form product basis states. For example, two qubits could be represented in a four-dimensional linear vector space spanned by the following product basis states: {\displaystyle |00\rangle ={\biggl [}{\begin{smallmatrix}1\\0\\0\\0\end{smallmatrix}}{\biggr ]}}|00> = [1 0 0 0], |01> = [0 1 0 0], |10> = [0 0 1 0] and |11> = [0 0 0 1].

In general, n qubits are represented by a superposition state vector in 2n dimensional Hilbert space.

## **Qubit States**

A pure qubit state is a coherent superposition of the basis states. This means that a single qubit can be described by a linear combination of |0> {\displaystyle |0\rangle }and |1> :

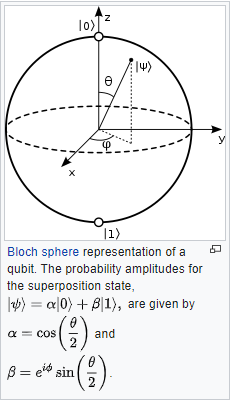
|phy> = α  |0> + β  |1>

where α and β are probability amplitudes and can in general both be complex numbers. When we measure this qubit in the standard basis, according to the Born rule, the probability of outcome |0> with value "0" is | α |2 and the probability of outcome |1> with value "1" is | β  |2 .Because the absolute squares of the amplitudes equate to probabilities, it follows that α{\displaystyle \alpha } and β must be constrained by the equation

| α |2 + | β |2 =1

Note that a qubit in this superposition state does not have a value in between "0" and "1"; rather, when measured, the qubit has a probability | α |2{\displaystyle |\alpha |^{2}} of the value “0” and a probability {\displaystyle |\beta |^{2}}| β |2 of the value "1". In other words, superposition means that there is no way, even in principle, to tell which of the two possible states forming the superposition state actually pertains. Furthermore, the probability amplitudes α and β  encode more than just the probabilities of the outcomes of a measurement; the relative phase of α and β  is responsible for quantum interference, e.g., as seen in the two-slit experiment.

### Bloch sphere representation



The possible quantum states for a single qubit can be visualized using a Bloch sphere (see diagram). Represented on such a 2-sphere, a classical bit could only be at the "North Pole" or the "South Pole", in the locations where |0> |0> and |1> are respectively. This particular choice of the polar axis is arbitrary, however. The rest of the surface of the Bloch sphere is inaccessible to a classical bit, but a pure qubit state can be represented by any point on the surface. For example, the pure qubit state ((|0> + i |1>) / 2)would lie on the equator of the sphere at the positive y-axis. In the classical limit, a qubit, which can have quantum states anywhere on the Bloch sphere, reduces to the classical bit, which can be found only at either poles.