# Quantum Bits

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Jun 5 2020

# what is a mug?


Large deep cup with straight sides and a handle, used for hot drinks

# if a mug was a quantum object...

if I throw it in a wall I get multiple mini mugs that do not hold any liquid

?


??

if I pour liquid sometimes the liquid disappears, sometimes it ends up in the floor

?

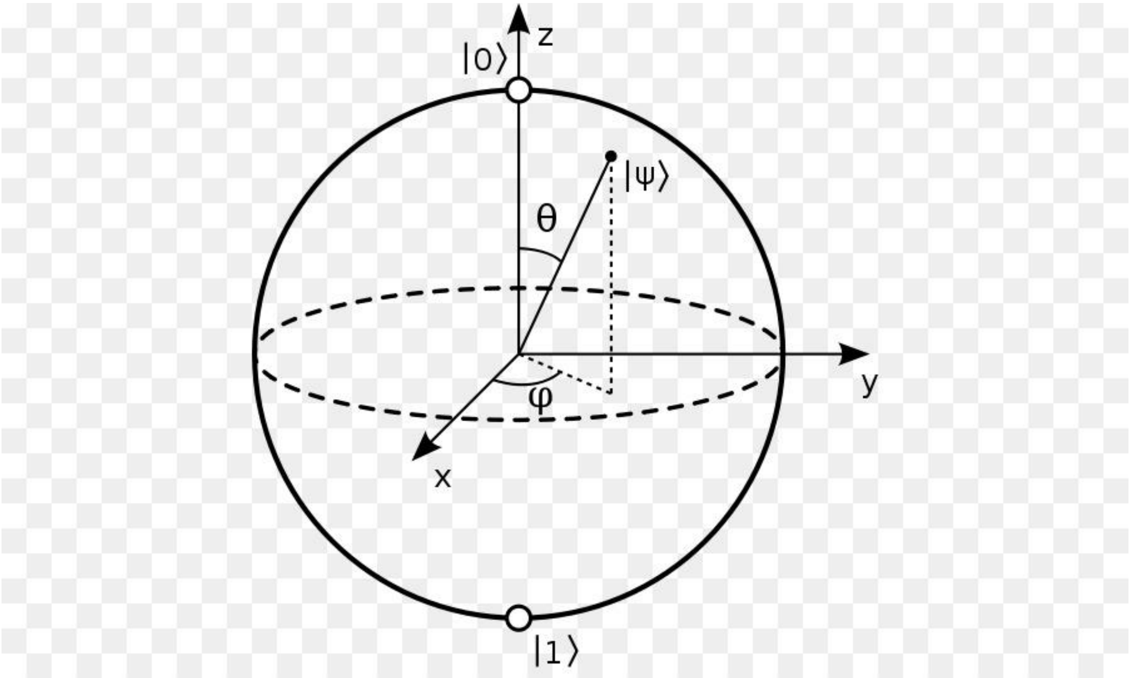
# A quantum bit as a mathematical object

| | | |
|---|---|---|
| **0** | **1** | classical |
| **\|0>** | **\|1>** | quantum |

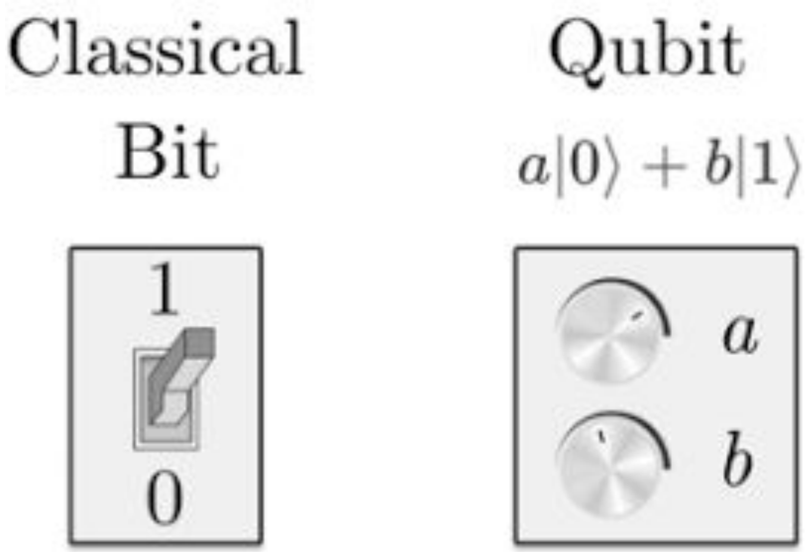
# state superposition

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

# graphical representation 1



# graphical representation 2



# But when you try to measure...

$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

**Always get 0 or 1**

...with a probability $\alpha^2$ and $\beta^2$ of getting 0 or 1.

If $\alpha$ is $(1/\sqrt{2})$, there is a 50% chance of getting 0 (and a 50% change of getting 1)

# measurement

How do I determine alpha and beta??

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

- Take infinite number of identical quantum bits
- Measure all
- Determine alpha and beta depending on the percentage of 0 and 1
- 😊😊😊

# Food for thought

- How does Nature do it?

- Does that suggest Nature has this hidden computing capabilities to know which state it should collapse to

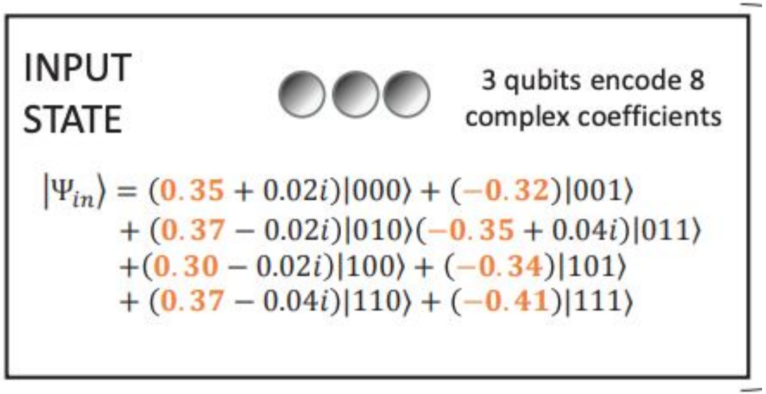
- Does it mean if we want to study quantum systems, like molecules for designing new drugs, only a quantum computer will do? (there is only so much we can make with a classical computer)

# What is the point?

| | | |
|---|---|---|
| 0 | 1 | 1 |

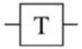
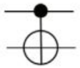
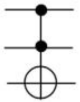
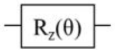
Needs 3 states to define

*States of the system*




$2^n$

# Logical Gates

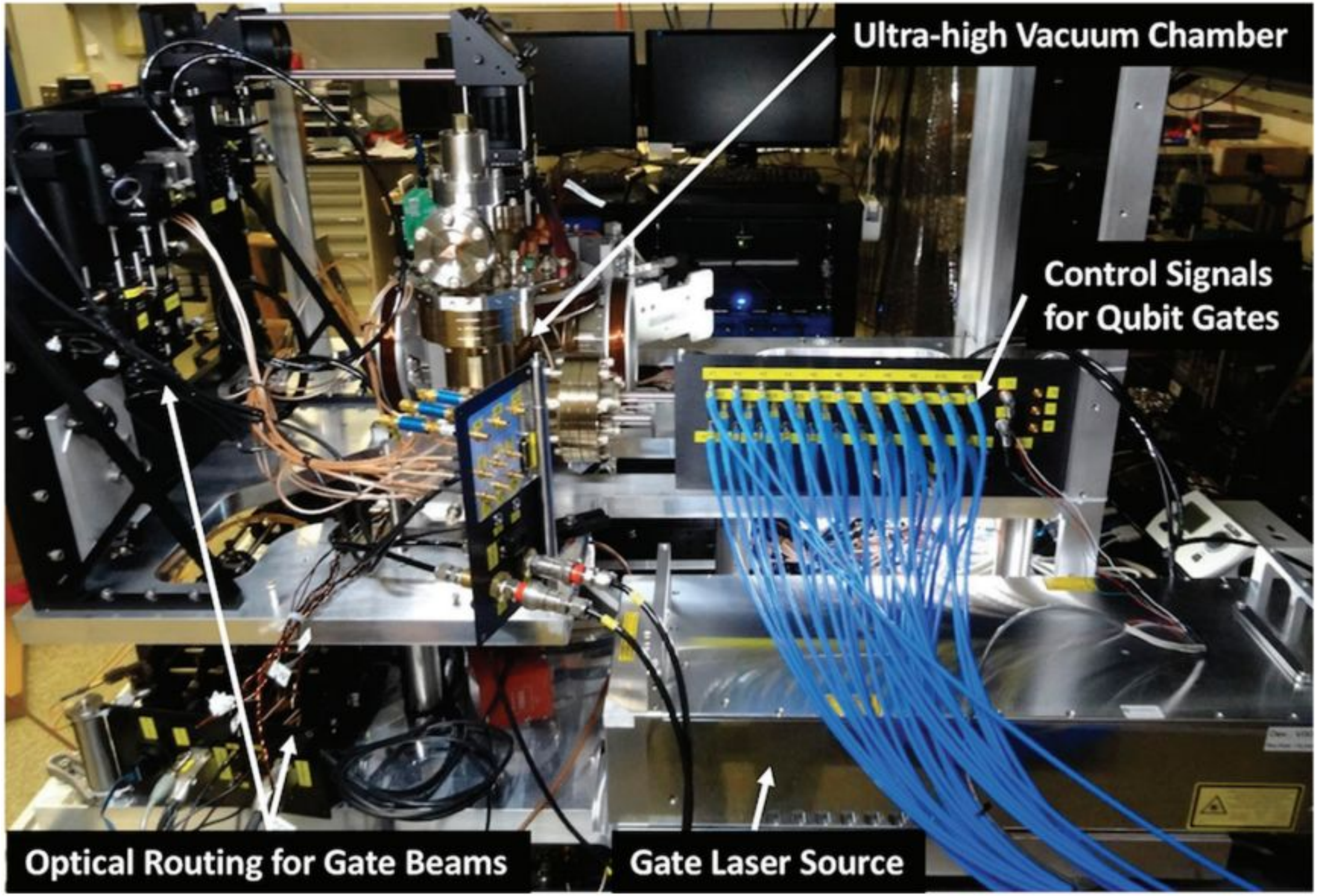
| Gate name | # Qubits | Circuit Symbol | Unitary Matrix | Description |
|---|---|---|---|---|
| Hadamard | 1 |  | $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$ | Transforms a basis state into an even superposition of the two basis states. |
| T | 1 |  | $\begin{bmatrix}1 & 0\\ 0 & e^{i\pi/4}\end{bmatrix}$ | Adds a relative phase shift of $\pi/4$ between contributing basis states. Sometimes called a $\pi/8$ gate, because diagonal elements can be written as $e^{-i\pi/8}$ and $e^{i\pi/8}$. |
| CNOT | 2 |  | $\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & 1 & 0\end{bmatrix}$ | Controlled-not; reversible analogue to classical XOR gate. The input connected to the solid dot is passed through to make the operation reversible. |
| Toffoli (CCNOT) | 3 |  | $\begin{bmatrix}1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&0&1\\0&0&0&0&0&0&1&0\end{bmatrix}$ | Controlled-controlled-not; a three-qubit gate that switches the third bit for states where the first two bits are 1 (that is, switches $\vert 110\rangle$ to $\vert 111\rangle$ and vice versa). |
| Pauli-Z | 1 |  | $\begin{bmatrix}1 & 0\\ 0 & -1\end{bmatrix}$ | Adds a relative phase shift of $\pi$ between contributing basis states. Maps $\vert 0\rangle$ to itself and $\vert 1\rangle$ to $-\vert 1\rangle$. Sometimes called a "phase flip." |
| Z-Rotation | 1 |  | $\begin{bmatrix}e^{-i\theta/2} & 0\\ 0 & e^{i\theta/2}\end{bmatrix}$ | Adds a relative phase shift of (or rotates state vector about z-axis by) $\theta$. |
| NOT | 1 |  | $\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}$ | Analogous to classical NOT gate; switches $\vert 0\rangle$ to $\vert 1\rangle$ and vice versa. |

# In real life

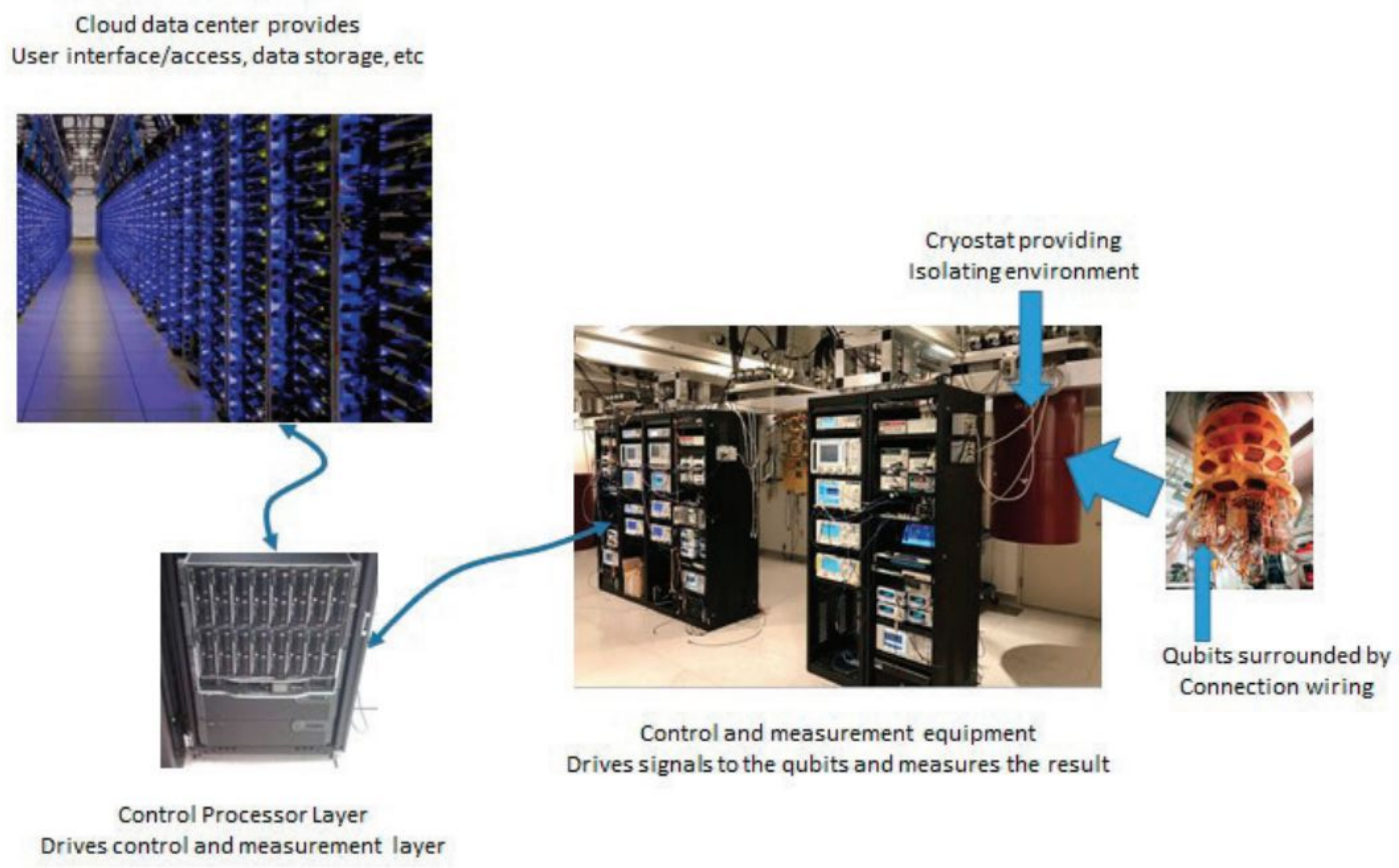
Which systems can be used?

- Nucleus spin
- Electron spin
- Polarization of photon

# In the lab


Ultra-high Vacuum Chamber
Control Signals for Qubit Gates
Optical Routing for Gate Beams
Gate Laser Source

# A quantum computer



# Thanks!!!