

# How To Make A Qubit

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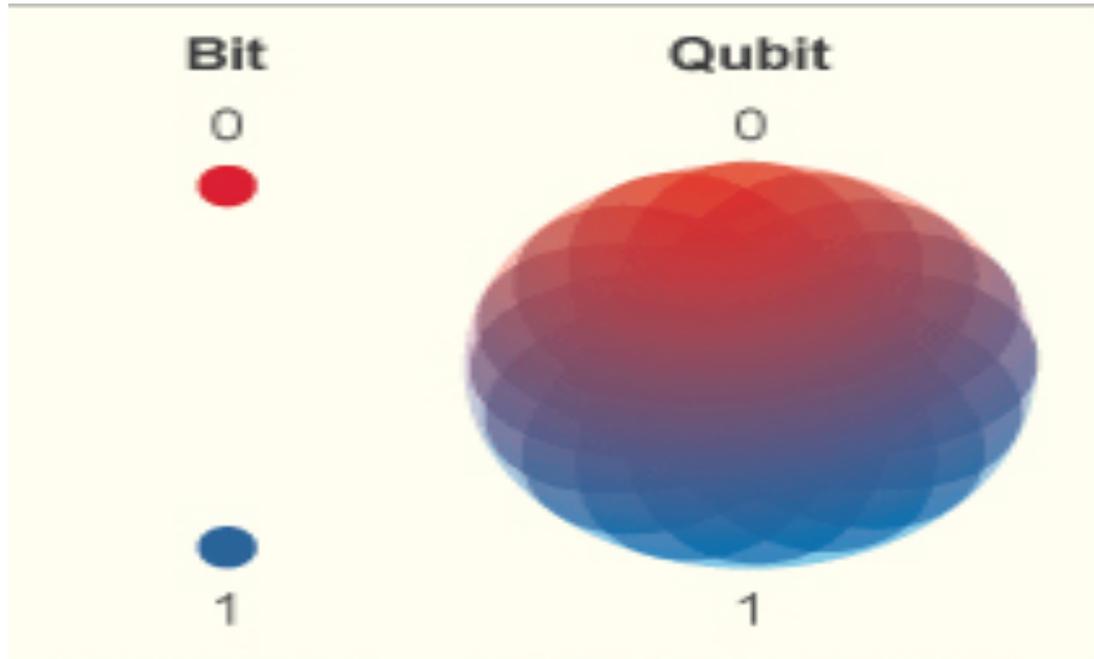
# What is a Qubit?

- A qubit (quantum bit) is a memory element like a bit; a unit of information in a quantum computer.
- a qubit is a two-state quantum mechanical system, these two states are vertical and horizontal polarization.
- Qubits represent atoms, ions, photons or electrons and their respective control devices that are working together to act as computer memory and a processor.

# Superposition

- upon measurement the state of a qubit can be zero or one, just like a bit, however due to quantum mechanics a qubit can also be a superposition of zero AND one at the same time (fundamental property of quantum computing).
- Therefore in quantum memory, all possible combinations of zeros and ones can exist simultaneously (mathematically expressed as a linear combination between zero and one in bra-ket notation).

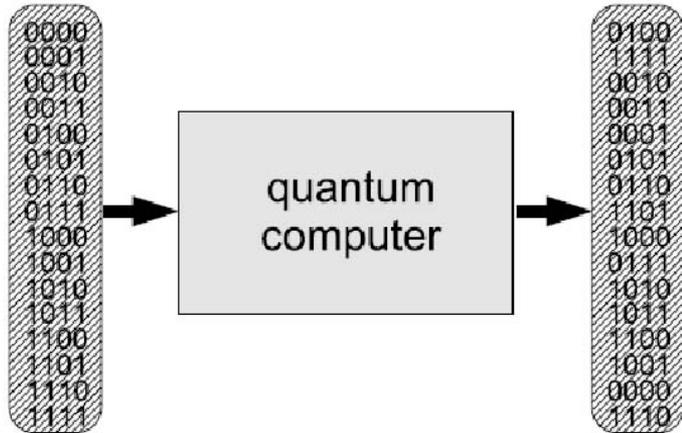
# Classical Bit vs Qubit



A bit can only be a 0 or 1

Superposition can be represented anywhere on a sphere.

# classical bit vs Qubit

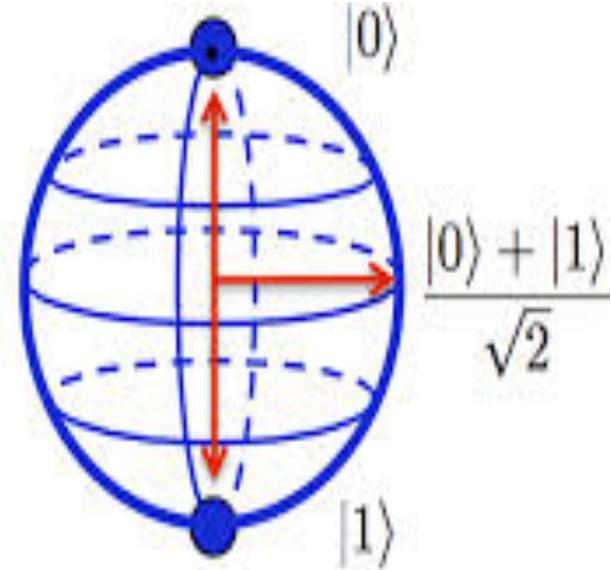


0



1

**Classical Bit**



**Qubit**

# What's so great about the superposition of Qubits?

- the superposition of qubits gives quantum computers their parallelism which allows quantum computers to work on a million computations at once. They are fast due to this massive parallel processing that the superposition of Qubits gives them
- quantum computers can take advantage of this superposition to reduce the number of steps to compute a computation.
- According to physicist **David Deutsch**, this parallelism allows a quantum computer to work on a million computations at once, while your desktop PC works on one.

# Entanglement

- two qubit systems allow *entanglement*- which is the power behind quantum computers.
- One problem with the idea of quantum computers is that if you try to look at the subatomic particles, you could bump them, and cause them to change their value.
- Also, if you look at a qubit in superposition to determine its value, the qubit will assume the value of either 0 or 1, but not both. To make a practical quantum computer, scientists have to devise ways of making measurements indirectly to preserve the system's integrity.

# What's so great about the entanglement of Qubits?

- **Entanglement** provides a potential answer. In quantum physics, if you apply an outside force to two atoms, it can cause them to become entangled, and the second atom can take on the properties of the first atom. So if left alone, an atom will spin in all directions. The instant it is disturbed it chooses one spin, or one value; and at the same time, the second entangled atom will choose an opposite spin, or value.
- This allows scientists to know the value of the qubits without actually looking at them.

# How to Make a Qubit

Quantum systems are difficult to make because qubits being affected by noise and other environmental factors which diminish performance. Prospective quantum circuits must preserve qubits from outside interference for as long as the quantum calculation proceeds.

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# Different Implementations:

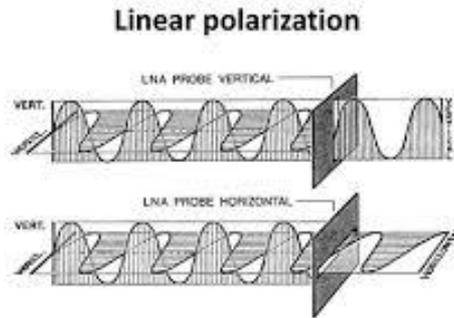
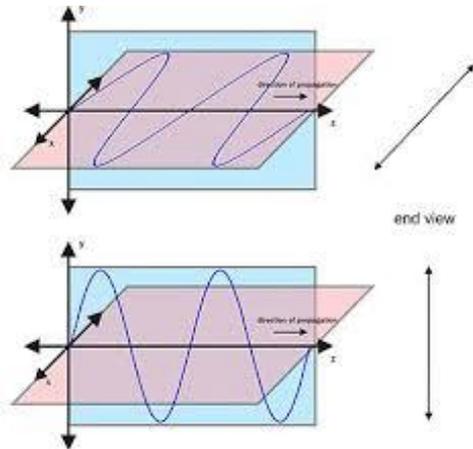
Computer scientists control the microscopic particles that act as qubits in quantum computers by using **control devices**:

1. **linear optics through polarization** – use light waves to trap and control particles.
2. **ion traps** – use optical or magnetic fields (or a combination of both) to trap ions.
3. **NMR systems** – encodes qubits as global spin states of many molecules in some fluid - uses spin states of molecules as qubits.
4. **quantum dots** – are made of semiconductor material and are used to contain and manipulate electrons.
5. **superconductors** – allow electrons to flow with almost no resistance at very low temperatures.

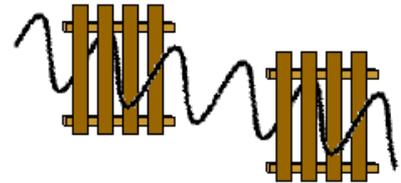
# Linear Optics through Polarization

Building a quantum machine out of light

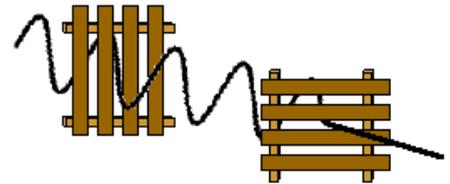
**Photons** are created through **polarization**: a beam of light passes through a polarization filter and the result is a coherent beam of light i.e., an electromagnetic wave that vibrates along a specific plane



The Picket Fence Analogy



When the pickets of both fences are aligned in the vertical direction, a vertical vibration can make it through both fences.

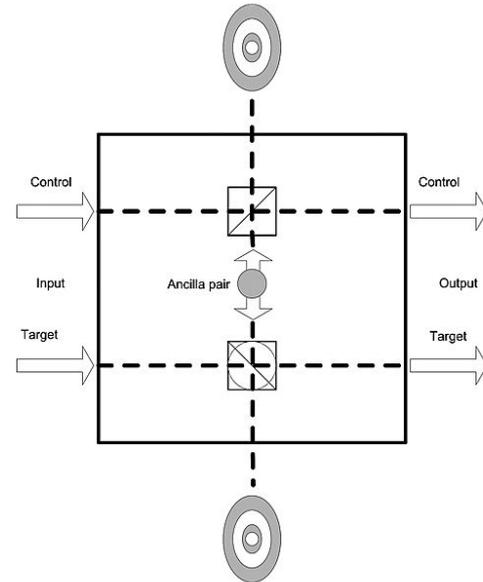
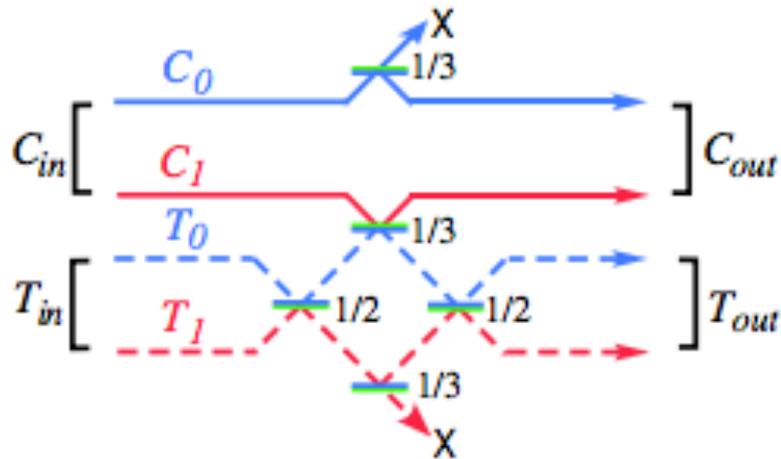


When the pickets of the second fence are horizontal, vertical vibrations which make it through the first fence will be blocked.

# Linear Optics through Polarization

## CNOT Gate

Measurement of the final output uses a combination of polarization filters and single-photon detectors



# Linear Optics Video Clip:

<https://www.youtube.com/watch?v=fM4GYnMgGcQ>

# Ion traps

- An ion is an electrically charged atom (cations, anions)
- Ionized atoms can be acted upon by means of an electromagnetic field and they are electrically charged.
- We can confine our ionized atom in an ion trap.
- The qubits are encoded using the atom in an excited state or in a ground state and from there we use optical pumping.
- Then, we manipulate the register using single-qubit rotation and two-qubit gates
- The last step is measurement to detect the photons and see where the qubit is

## NMR systems- (Nuclear Magnetic Resonance) :

- encodes qubits as **global spin states** of many molecules in some fluid.
- these molecules float in a cup, which is placed in an NMR machine (like the devices used in hospitals for magnetic resonance imaging.)
- this large ensemble of molecules has plenty of built in redundancy, which allows us to maintain coherence for a relatively long time span (several seconds).
- However, this implementation is ineffective since later studies show they don't actually possess quantum entanglement, rather nmr experiments were a classical simulation of a quantum computer.

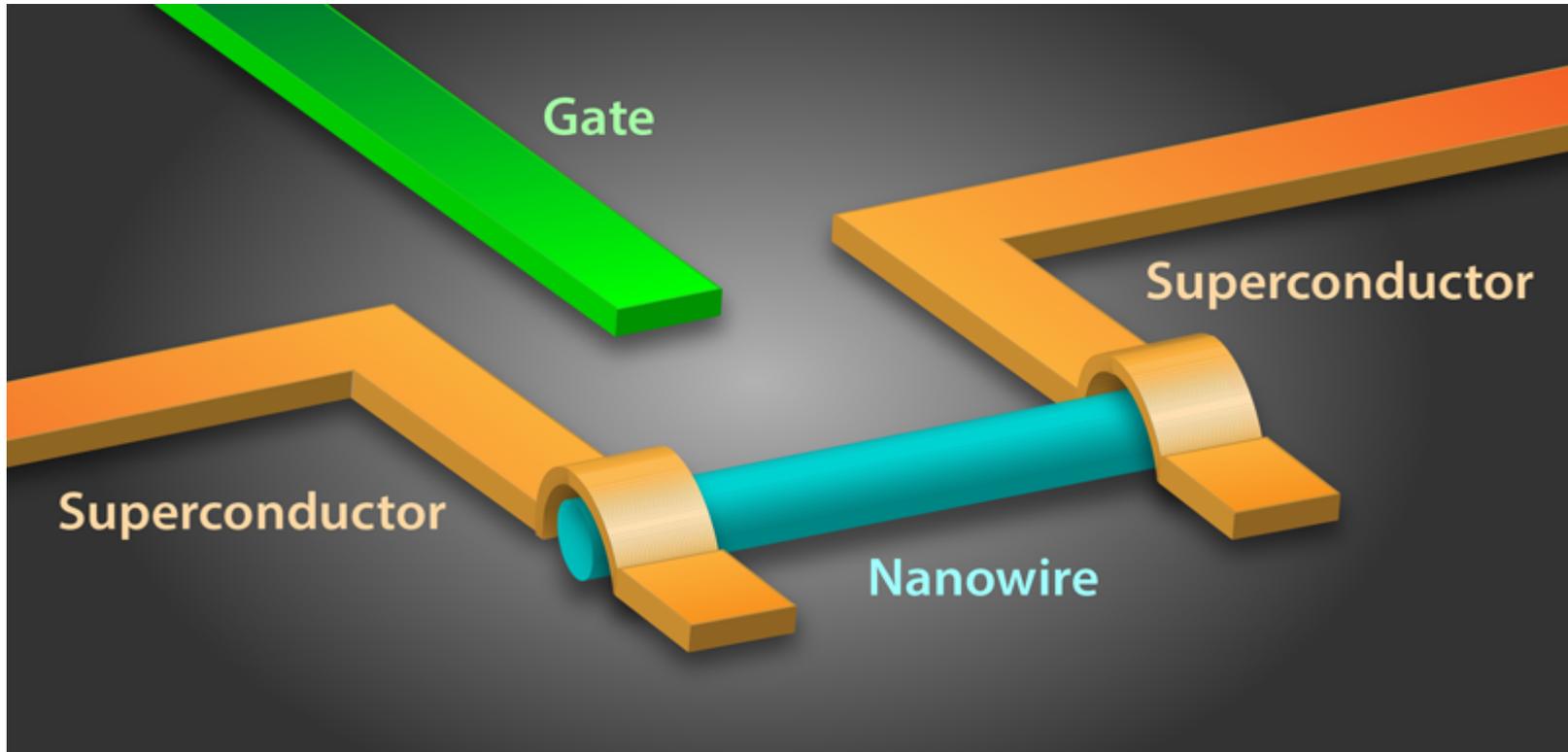
# Quantum Dots

- A quantum dot is a semiconductor
- These use electrons confined into a “box” where they stop behaving like electrons in bulk and instead behave like electrons as individual atoms.
- This causes the electrons to occupy discrete energy levels and allows the electrons to be forced into the ground state of the dot.
- That spin of the electron stored in a quantum dot couples weakly to its environment, making it a promising candidate for a qubit (-:

# Superconductors

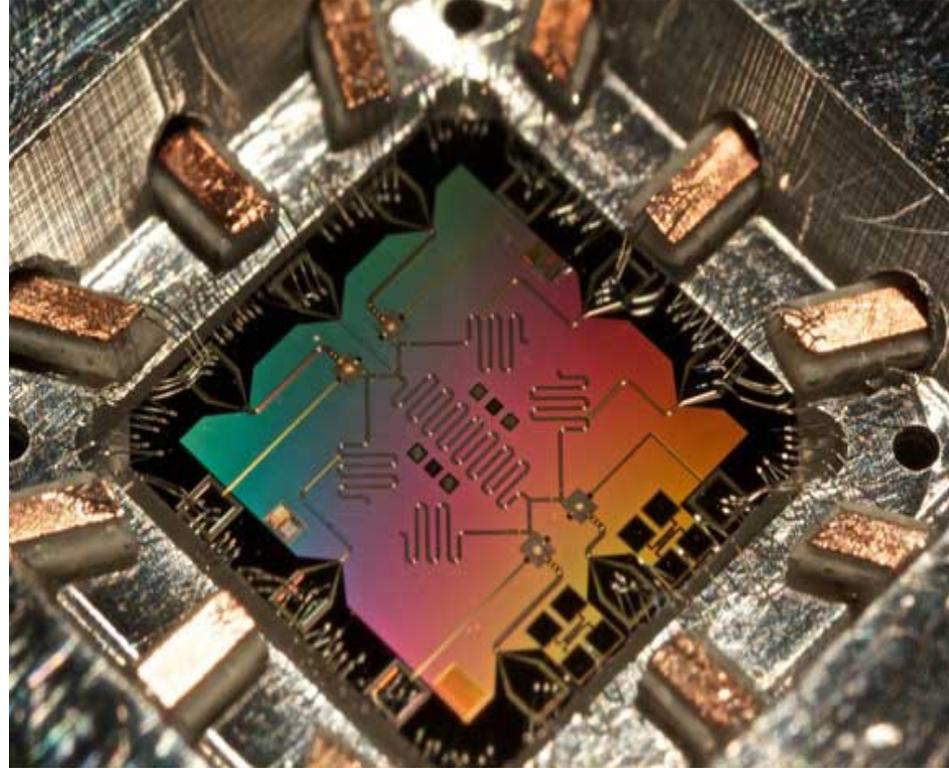
- a **superconductor** is matter at very low temperature, exhibiting so-called superconductivity properties.
- superconducting qubits are solid state electrical circuits based on the Josephson tunnel junction, the only non-dissipative, strongly non-linear circuit element available at **low temperature**.
- they use superconductors through **Joseph-junctions**- thin layers of nonconducting material sandwiched between two pieces of superconducting metal. At very low temperatures, electrons within a superconductor pair up to form a “superfluid” flowing with no resistance and traveling through the medium as a wave pattern. Qubits are then implemented through the **Josephson junction qubit**, where the current flows back and forth. The 0 and 1 states are represented by the two lowest-frequency oscillations of the currents flowing through the junction.

**-nanowire based qubits,** A nanowire bridging two superconductors substitutes the insulating barrier used in conventional qubits to form a Josephson Junction. These hybrid semiconducting-superconducting schemes could help researchers design flexible quantum computing architectures that combine multiple types of qubits.



# Computer chip with four superconducting Qubits

cool video: <https://www.youtube.com/watch?v=zNzzGgr2mhk>



# Recent Research / Interesting Reads

- **Google and NASA are getting a new quantum computer**

<http://www.theverge.com/2015/9/28/9398807/google-nasa-quantum-computer-d-wave-2x>

- D-Wave quantum computers, the D-Wave 2X™ system - In addition to scaling beyond 1000 qubits, the new system incorporates other major technological and scientific advancements. These include an operating temperature below 15 millikelvin, near absolute zero and 180 times colder than interstellar space. With over 128,000 **Josephson tunnel junctions**, the new processors are believed to be the most complex superconductor integrated circuits ever successfully used in production systems.

<http://www.dwavesys.com/blog/2015/08/announcing-d-wave-2x-quantum-computer>

French Advances / My Doctor Fired Me / Love App-tually

# TIME

IT PROMISES TO SOLVE SOME OF HUMANITY'S  
MOST COMPLEX PROBLEMS. IT'S BACKED  
BY JEFF BEZOS, NASA AND THE CIA.  
EACH ONE COSTS \$10,000,000 AND OPERATES  
AT 459° BELOW ZERO. AND NOBODY KNOWS  
HOW IT ACTUALLY WORKS

## THE INFINITY MACHINE

BY LEV GROSSMAN



# Quantum computers

- The challenge is that a qubit must satisfy contradictory requirements: It must be isolated from its environment to preserve quantum coherence, but also retain enough coupling to the outside world to enable manipulation and measurement. One possible solution is to combine the advantages of several types of qubits in hybrid architectures.

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