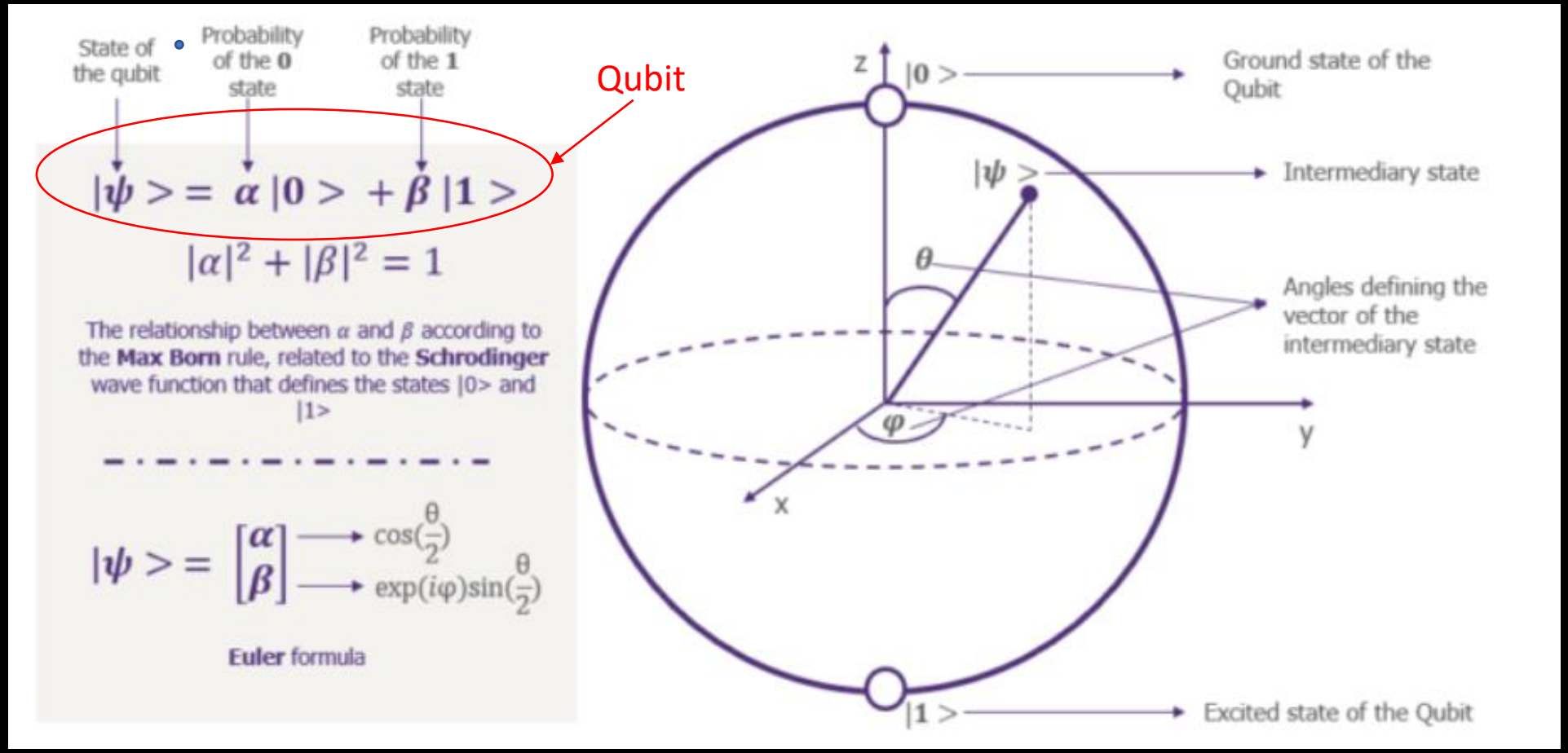
Lecture 4 (supplemental materials) + Parag Lala Chapter 6: Superposition and Entanglement

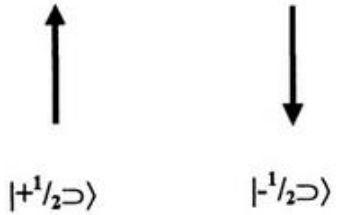
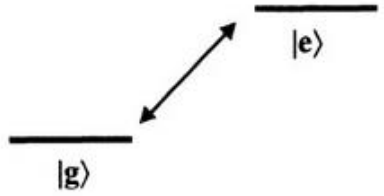
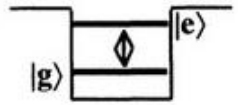
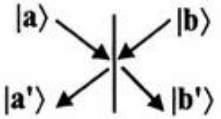
CS 518

2/8/23

Mathematical Model of Qubit

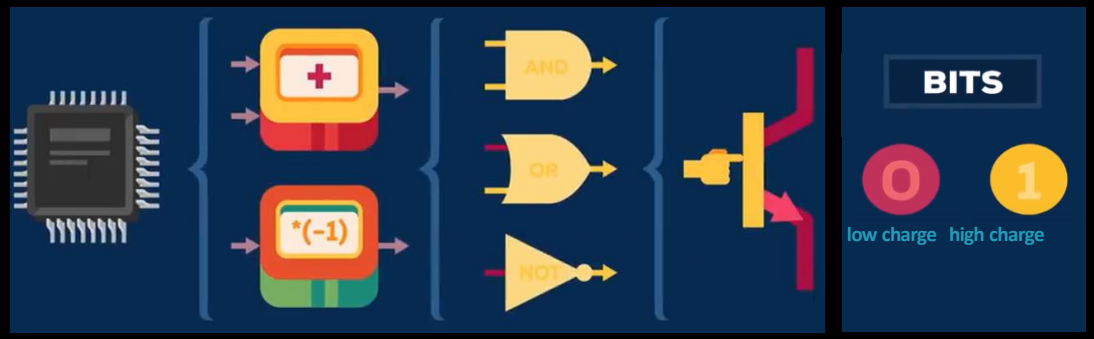


Physical Realizations of Qubits

'0'	'1'	Qubit
		Photon: linear polarization
		Photon: circular polarization
		Electron, Neutron: Spin
		Atom: Energy levels
		Quantum Dot
		Particles: beam splitter modes

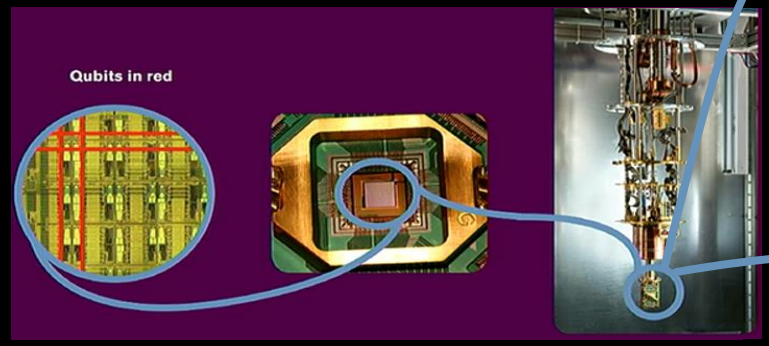
Classical vs. Quantum Computers Basics

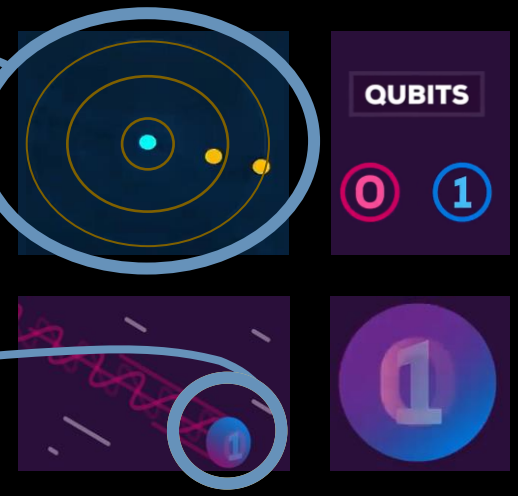
Classical Computer



IC Circuit Module Logic gates Transistor

Quantum Computer



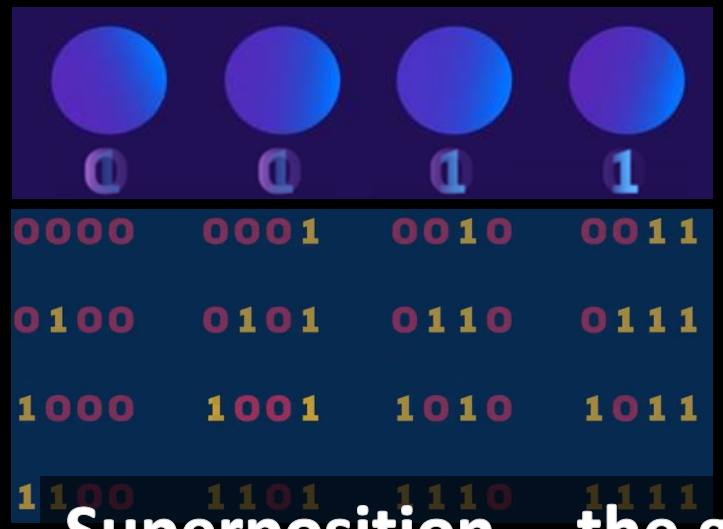


Quantum Circuit Q-Chamber

4-bit Classical Register

- One number from 0 to 15 one at a time

4-qubit Register

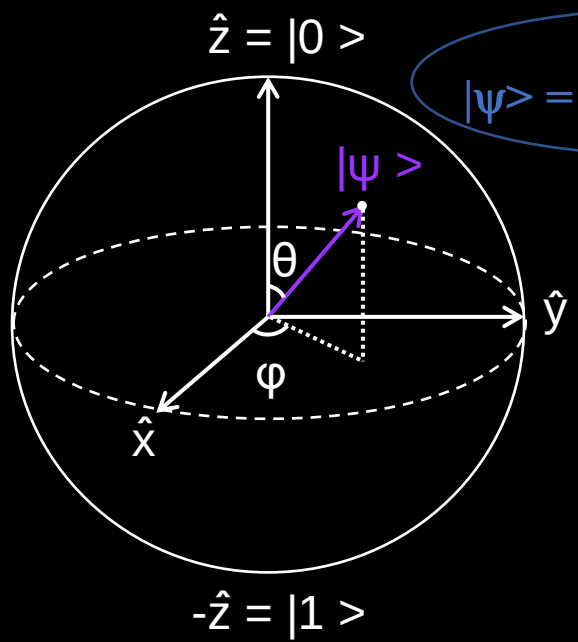


- All 16 numbers in a superposition allowing truly parallel computation
- Exponential growth with addition of each qubit:

$2^{20} = 1{,}048{,}576$

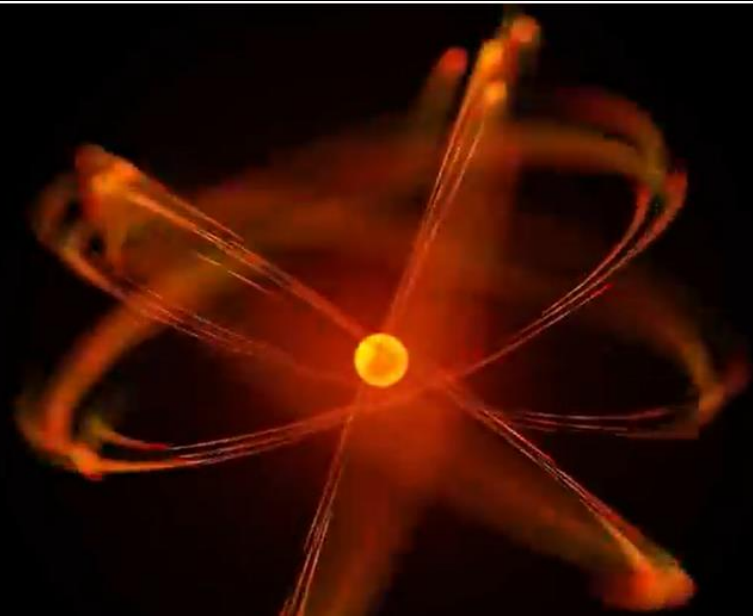
Superposition -- the game changer

Superposition of Qubit



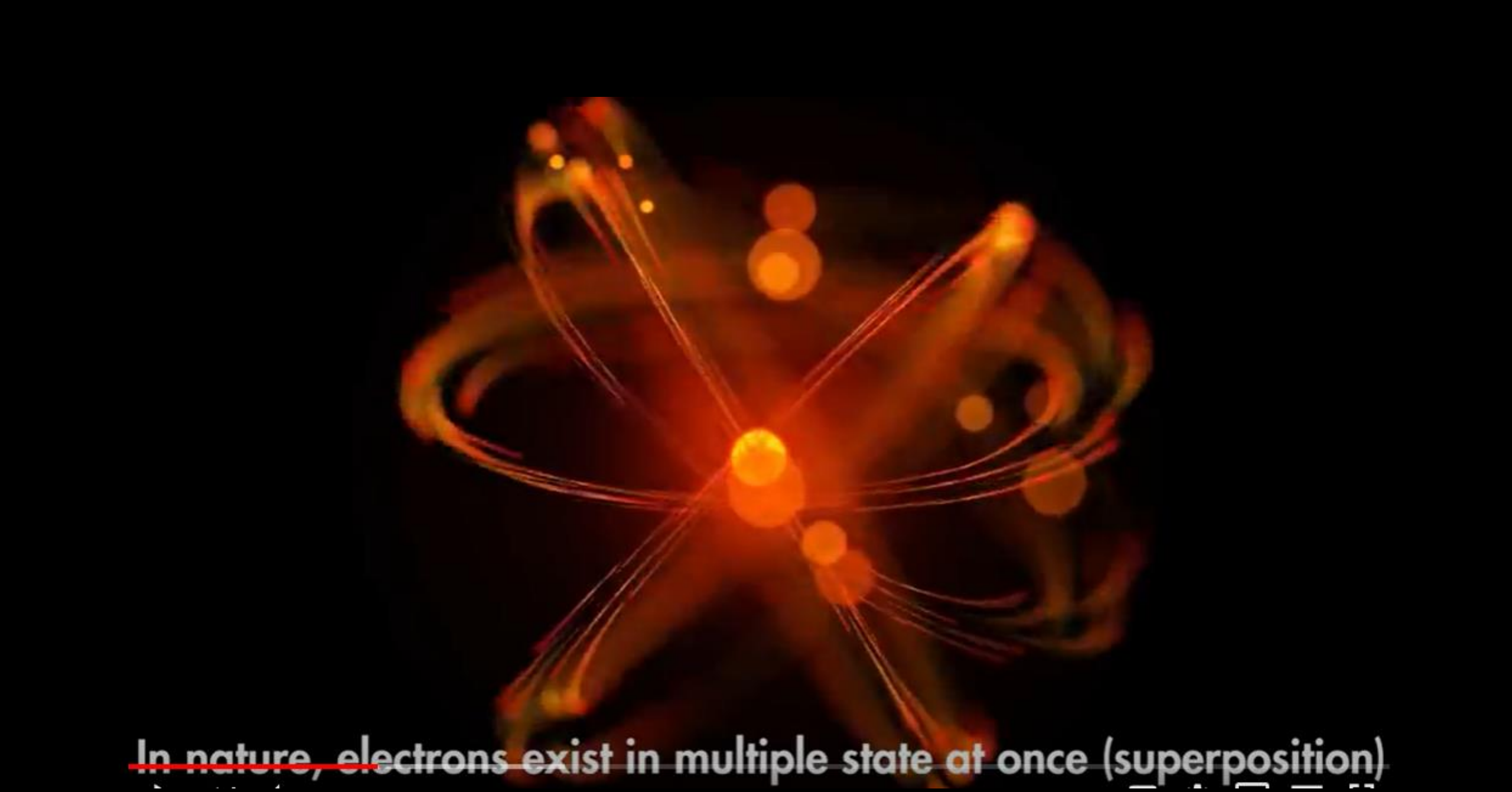
$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$

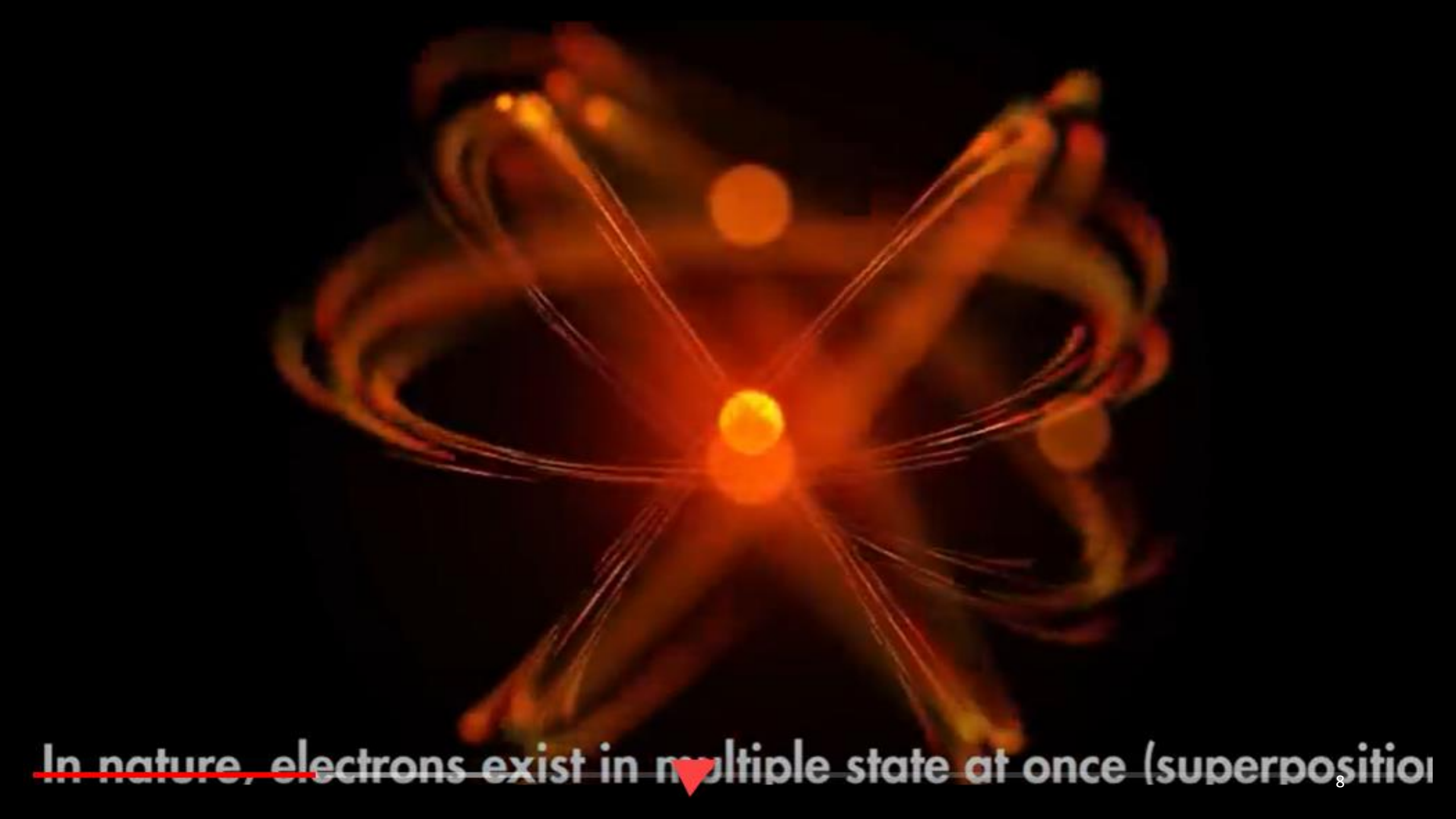
A single qubit (like electron) in a superposition of two states 0 and 1 simultaneously



In nature, electrons exist in multiple state at once (superposition)

In general, the electron is a quantum system


In nature, electrons exist in multiple state at once (superposition)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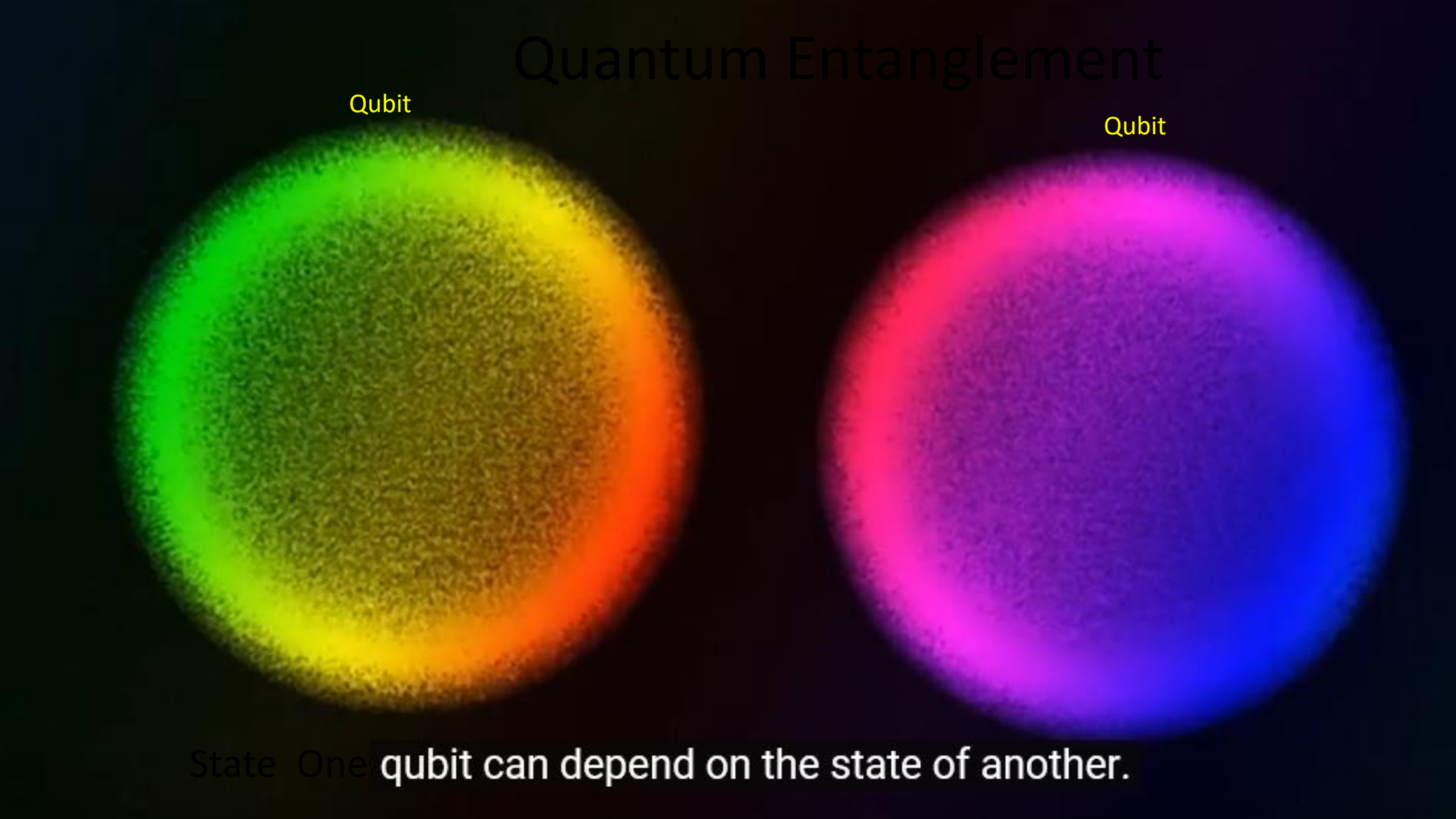
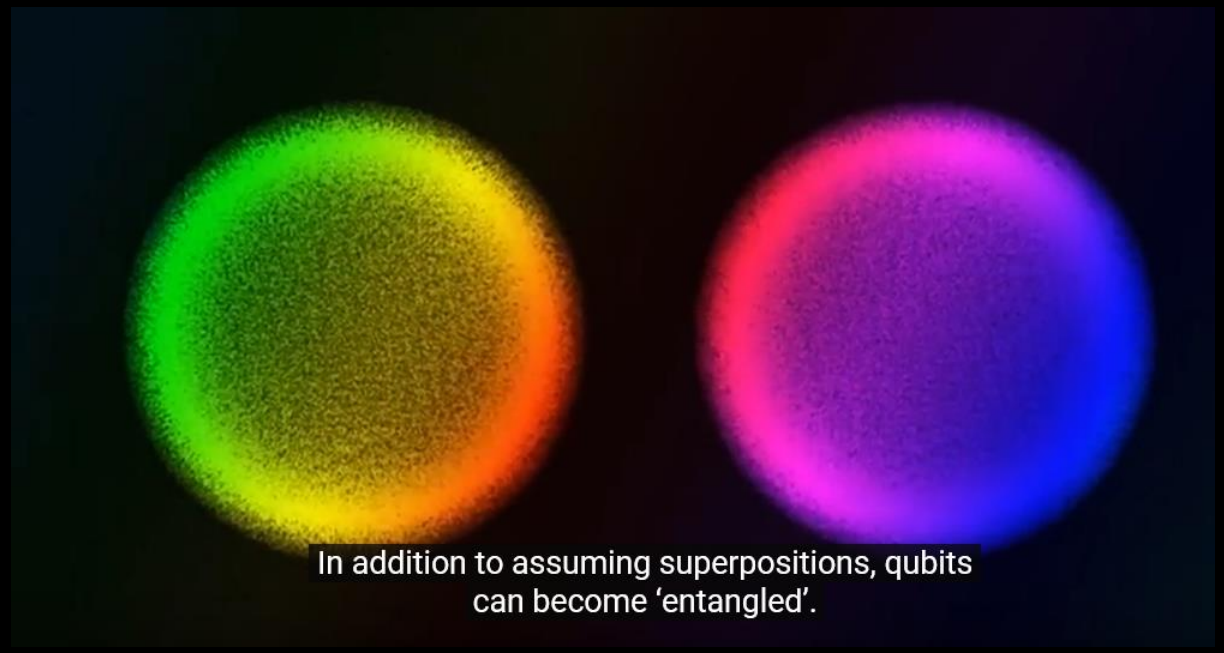
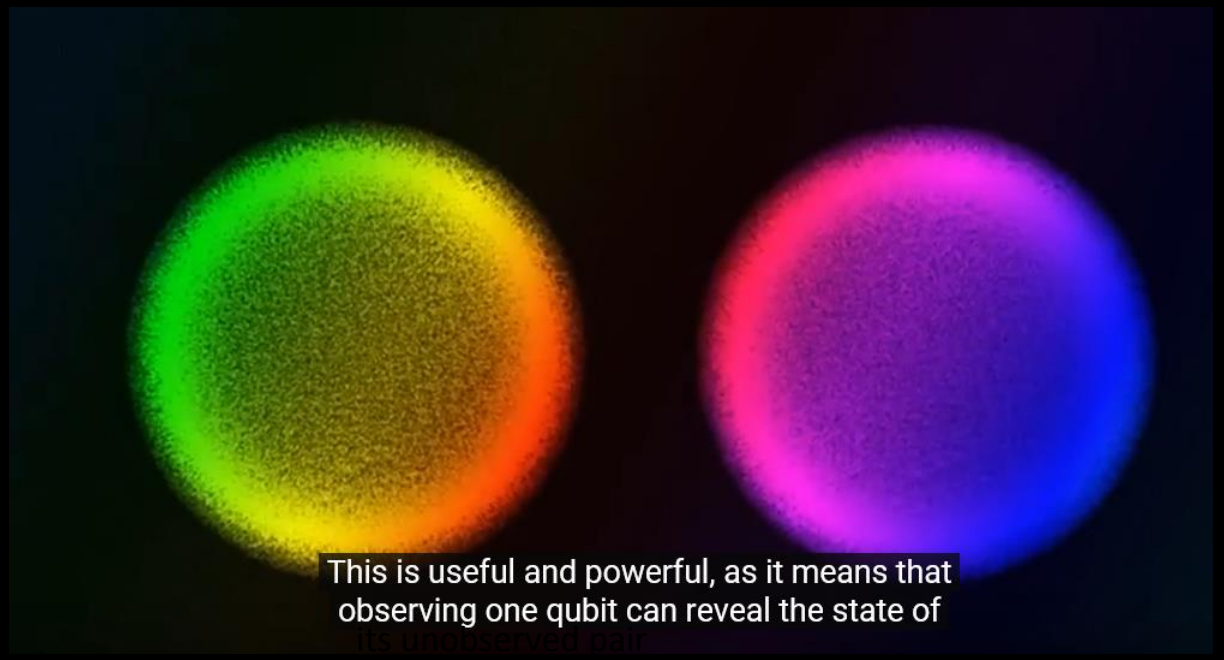
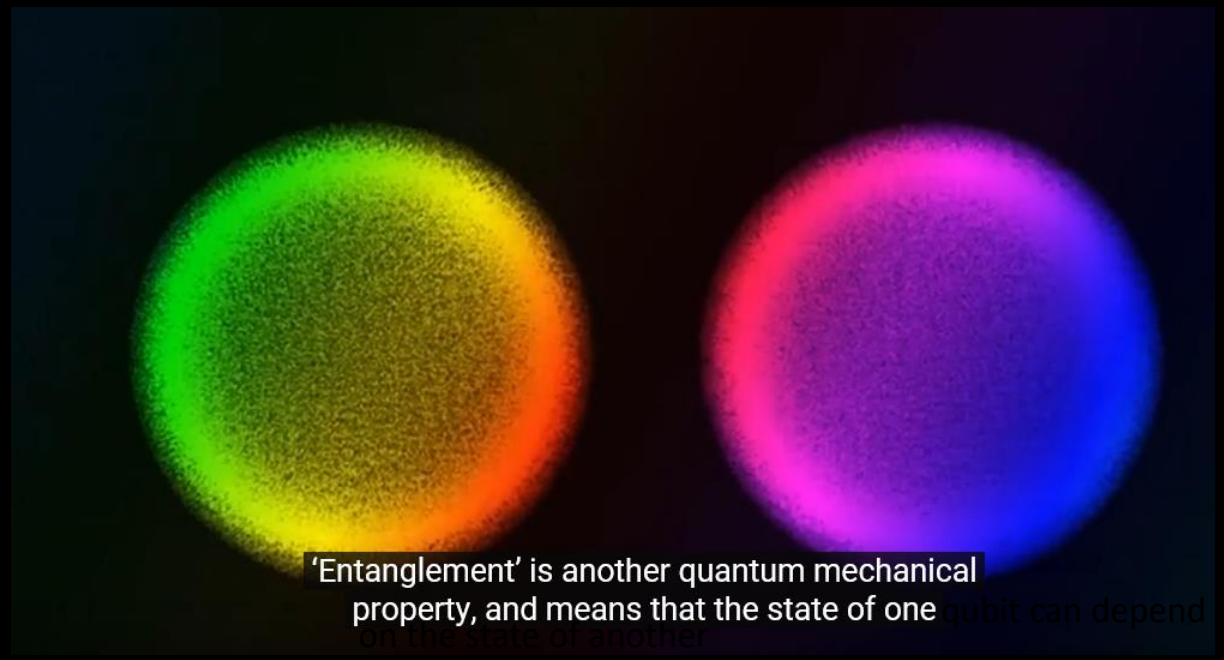
Quantum Entanglement

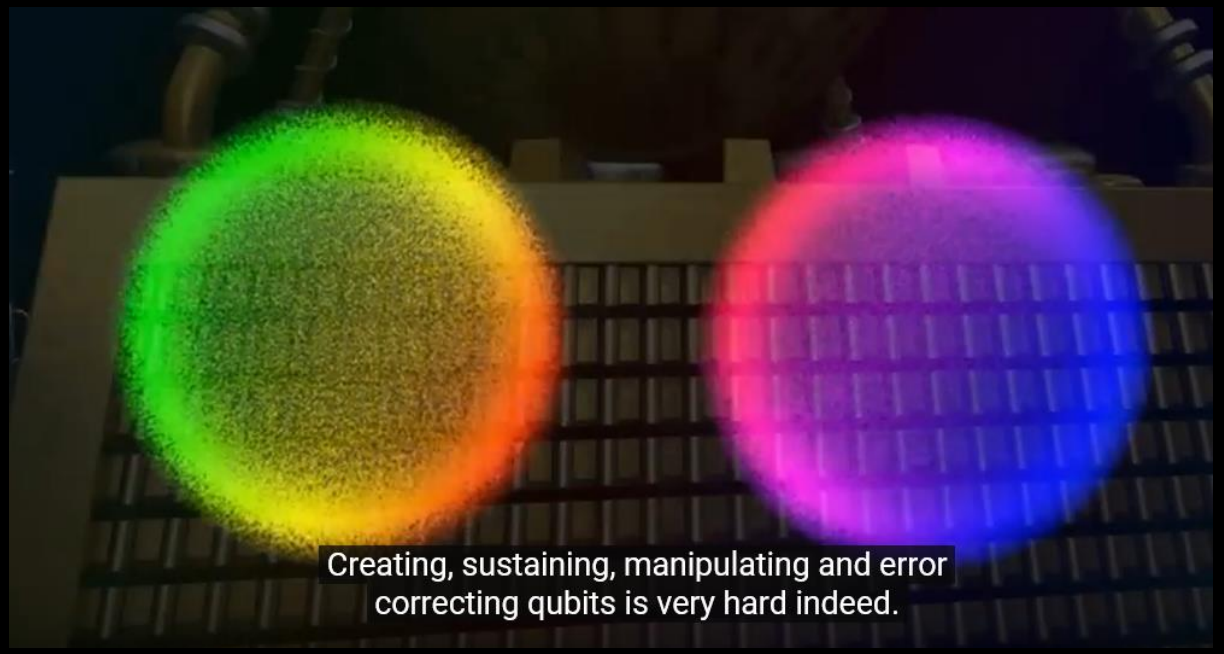


State One qubit can depend on the state of another.


In addition to assuming superpositions, qubits
can become ‘entangled’.


This is useful and powerful, as it means that
observing one qubit can reveal the state of
its unobserved pair


‘Entanglement’ is another quantum mechanical
property, and means that the state of one qubit can depend
on the state of another


Creating, sustaining, manipulating and error
correcting qubits is very hard indeed.

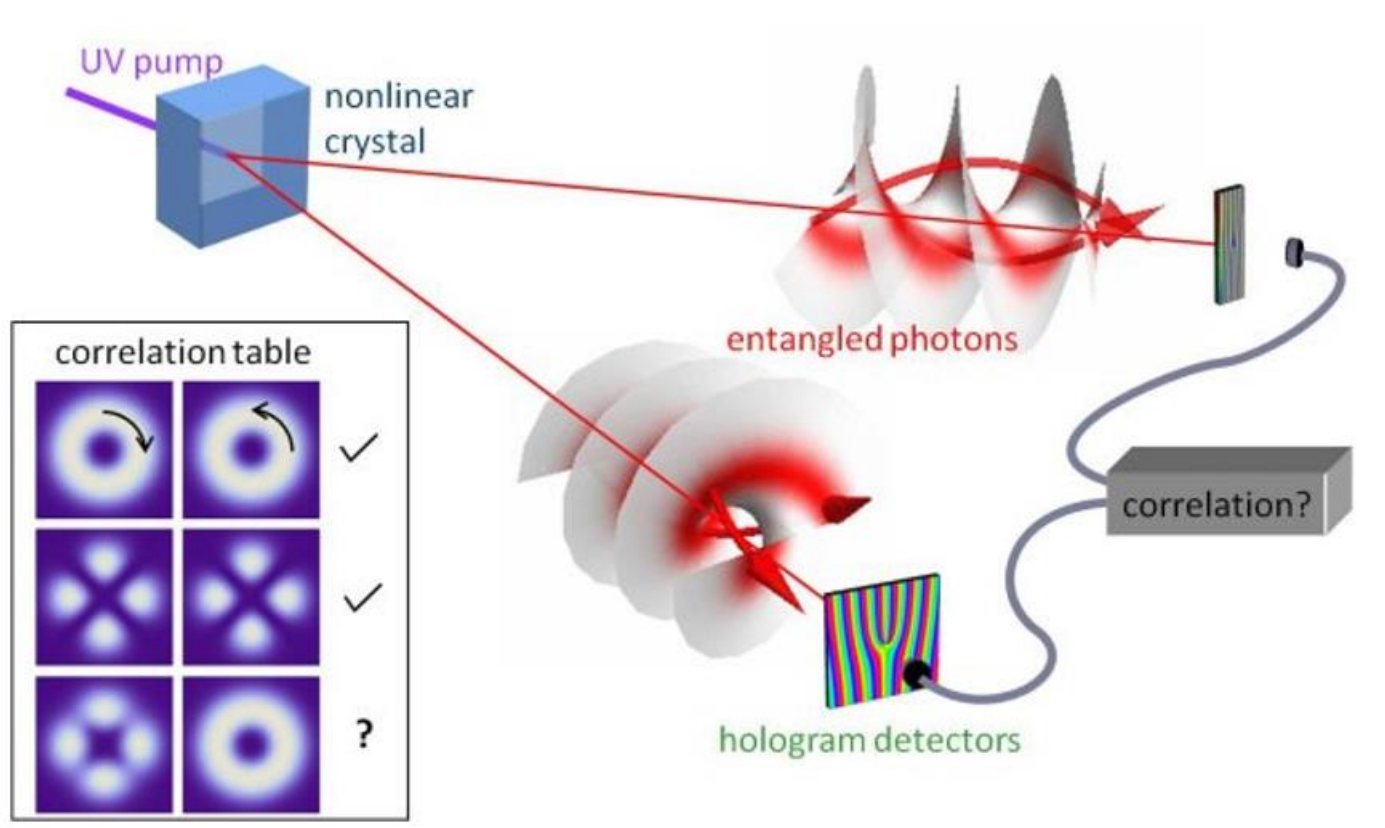
Non-Locality and Entanglement

Imagine we have created a pair of entangled qubits.

Non-Locality and Entanglement

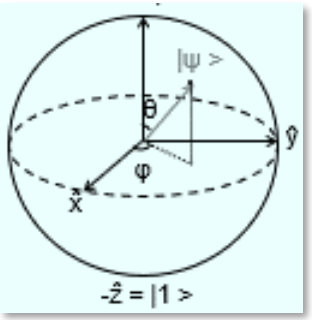
- Even if we move one qubit to the Moon, the global state of the two qubits cannot be described solely in terms of the individual state of each of them!
- In particular, if we measure one of the qubits, this apparently instantaneously affects the other one.

Entanglement Creation



- To create entangled photons, we use a special type of crystal to split one photon into an entangled pair of photons
- A single incoming beam (typically blue or ultraviolet) can thus conjure up two beams (typically red)
- This process occurs particle by particle: each blue photon splits into two red ones

Quantum Computing Ĉ Quantum Informatics



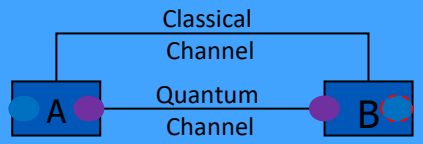
Quantum Networking

Teleportation

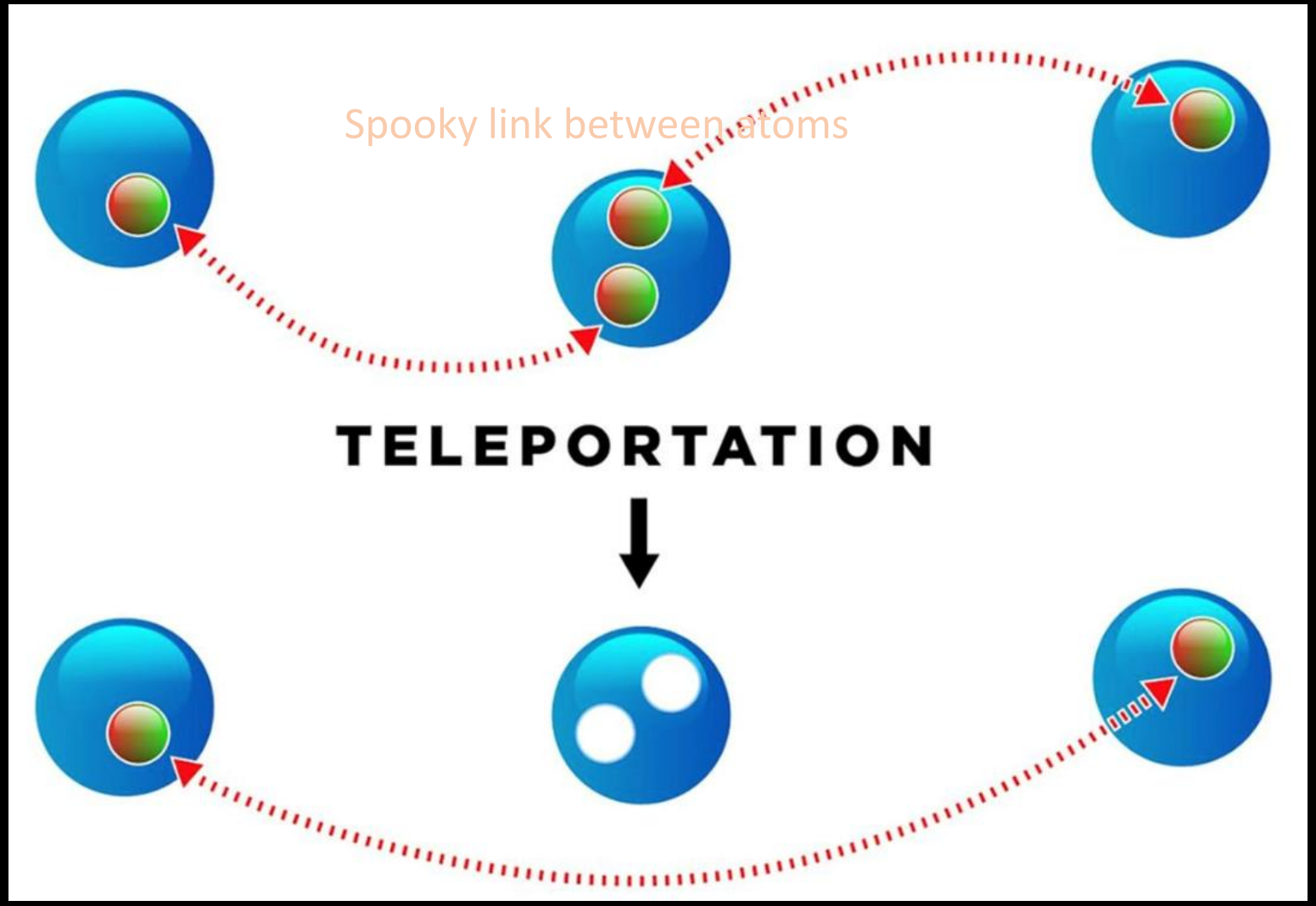
Quantum Processor
Quantum Channel

Classical Channel

Quantum Internet

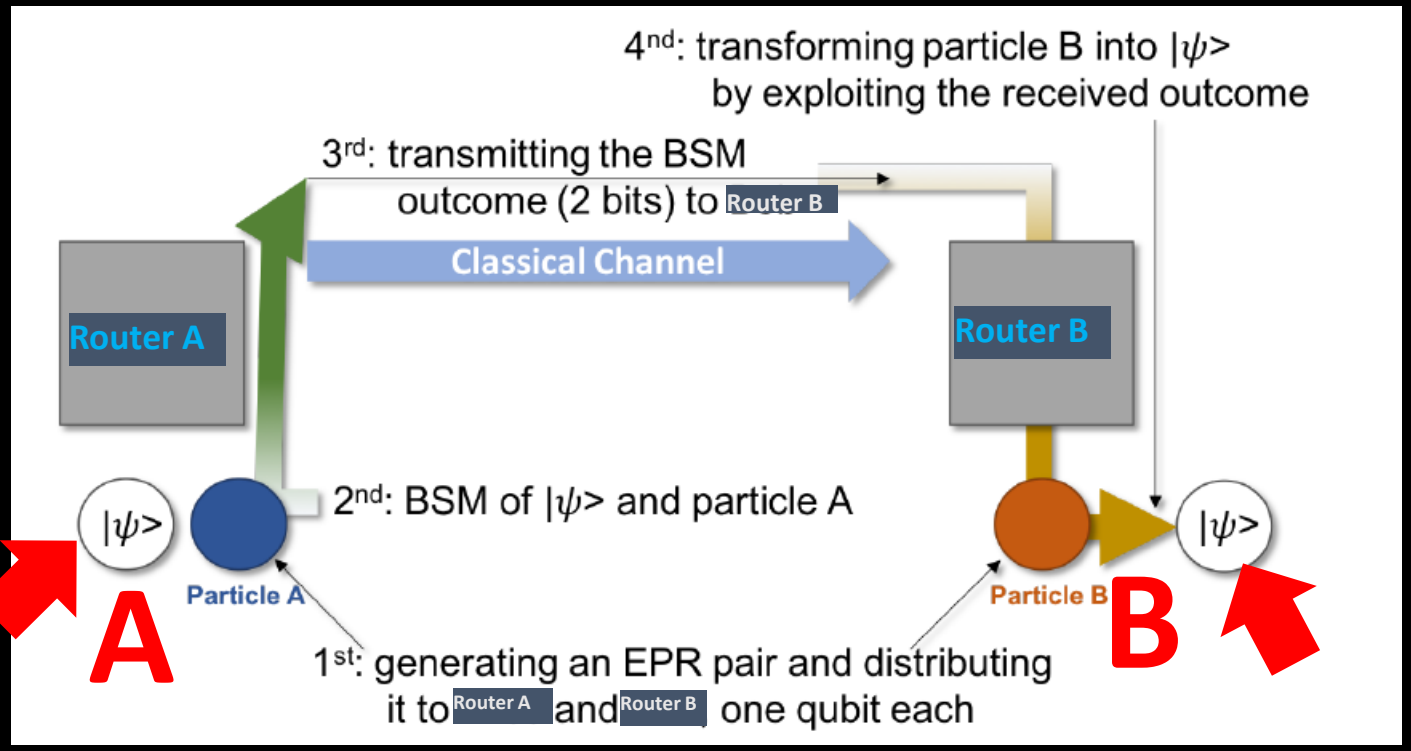


Teleportation



- A qubit transmitted from one location to another
- Related to entanglement of quantum systems.
- Defined as a process by which a qubit (the basic unit of quantum information) can be transmitted from one location to another,
- **without the qubit actually being transmitted through space.**

Teleportation



1. Two entangled qubits, forming an EPR pair, are generated and distributed so that one qubit (particle A) is stored by Router A and another qubit (particle B) is stored by Router B

2. Router A performs a BSM upon the two qubits at its side, i.e., the qubit to be transmitted and particle A

3. Then, Router A sends the measurement outcome, i.e., 2 classical bits, to Router B with a classical channel

4. By processing particle B according to the measurement outcome, Router B finally obtains the qubit by applying appropriate unitary transformation