

John Donohue

johnohue@Uwat ...

ENTANGLEMENT

↳ What's a q. state?

↳ What are entangled states?

↳ Why do QI folks care?

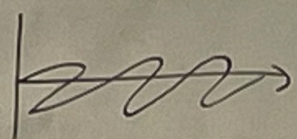
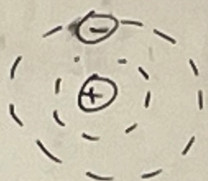
↳ How do we make entanglement?

↳ Why should anyone else care?

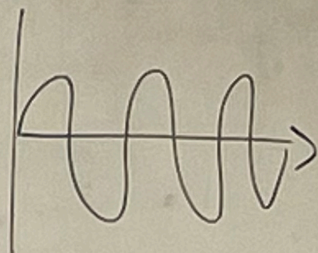
Quantum State



The e^- is in the ground state



The photon is in the $|0\rangle$ state



$$\equiv |0\rangle$$

$$\equiv |1\rangle$$

$|0\rangle, |1\rangle,$

$$c_0 |0\rangle + c_1 |1\rangle$$

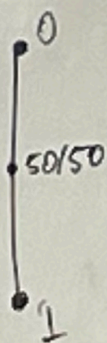
$$|c_0|^2 \quad |c_1|^2$$

$$|+\rangle = \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle)$$

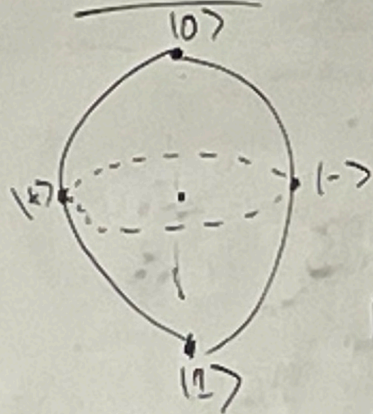
$$|-\rangle = \frac{1}{\sqrt{2}} (|0\rangle - |1\rangle)$$

$$\frac{1}{\sqrt{2}} (|0\rangle + i|1\rangle)$$

Classical



Quantum



Entangled States

Diagram showing two particles, each with a plus sign, representing the state $|0\rangle \otimes |0\rangle = |00\rangle$.

Diagram showing two particles, one with a plus sign and one with a minus sign, representing the state $|0\rangle \otimes |1\rangle = |01\rangle$.

$$|10\rangle$$

$$|11\rangle$$

$$x^2 + x^2$$

Entangled States

$$c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$$

3

$$c_{000}|000\rangle + c_{001}|001\rangle + c_{010}|010\rangle + \dots + c_{111}|111\rangle$$

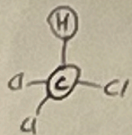
7

$$2^n - 1$$

⊗
entangled

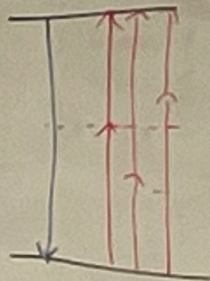
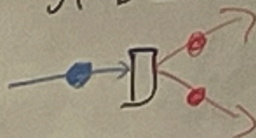
Entanglement
via Interaction

J-coupling



Entanglement
via Conservation Relations

SP DC



How do we use entanglement?

2. Computing -

H T CNOT

Quantum Error Correction

$$0_L = 000$$

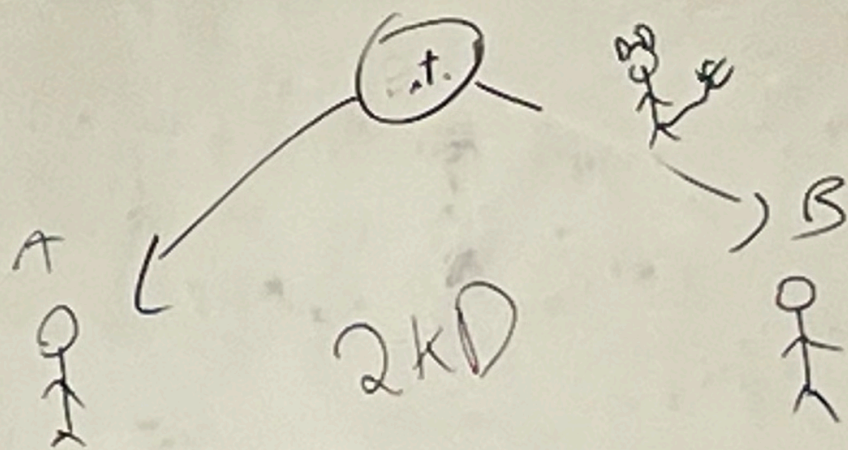
$$1_L = 111$$

ment?

Star Code

$$|0_L\rangle = \frac{1}{\sqrt{2}} (|1000\rangle + |1111\rangle) (|1000\rangle + |1111\rangle) + (|0000\rangle + |1111\rangle)$$

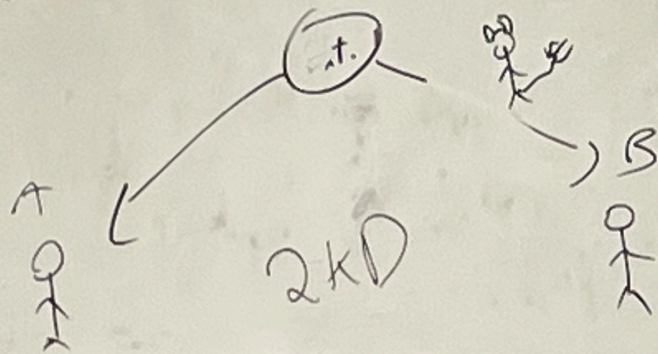
2. Communication



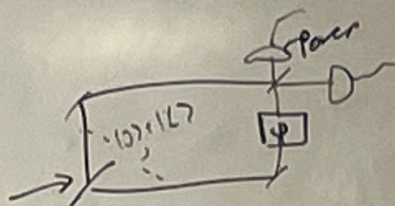
Short Code

$$|0_L\rangle = \frac{1}{\sqrt{2}} (|000\rangle + |111\rangle) (|000\rangle + |111\rangle) + (|000\rangle - |111\rangle)$$

2. Communication



Interferometer



$$\cos^2 \phi = \cos^2 \left(2\pi \frac{d}{\lambda} \right)$$

$$2 \text{ qubit: } \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle) \rightarrow \frac{1}{\sqrt{2}} (|0\rangle + e^{i\phi} |1\rangle)$$

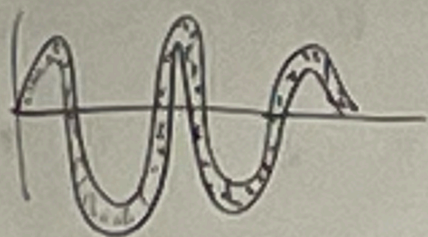
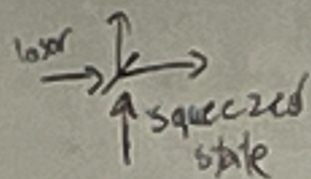
$$\frac{1}{\sqrt{2}} (|000\rangle + |111\rangle) \rightarrow \frac{1}{\sqrt{2}} (|000\rangle + e^{i3\phi} |111\rangle)$$

$$\delta_{\text{ent}} \sim \frac{1}{\sqrt{M}}$$

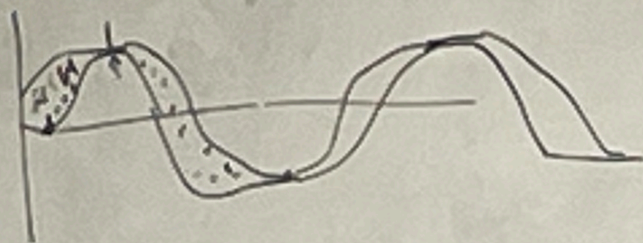
$$\delta_{\text{ent}} \sim \frac{1}{M}$$

NOON

Squeezed State



Amp. Squeezed



Phase Squeezes

