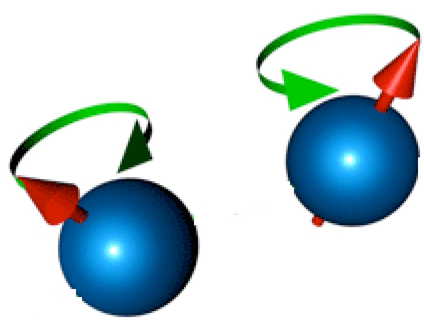
QUANTUM ENTANGLEMENT AND ITS ASPECTS

Dileep Dhakal
Masters of Science in Nanomolecular Sciences



Jacobs University Bremen
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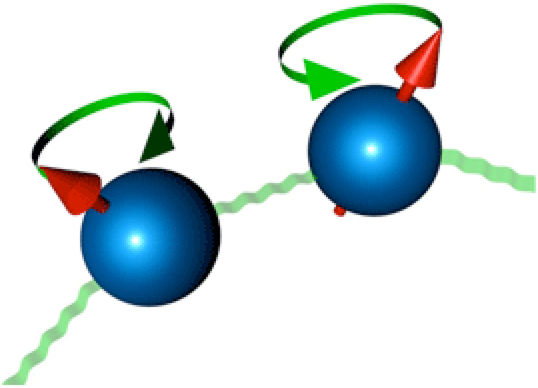
Classical vs. Quantum information

Classical: Exists in two states (binary digits), e.g
• A Switch on or logic ,‘1‘
•A Switch OFF or logic ,‘0‘
•All modern computer works on this two logic element.

Quantum : Exists any possible states between |0> and |1> (Qbits) e.g,
•Electon spin orientation with applied field (B)
  •Clockwise spin (+1/2 or |0> or |↑>)
  •Anticlockwise spin (-1/2 or |1> or |↓>)
  •Or any sates between them
•Polarization direction of photon
  •Horizontal polarization (|H> state)
  •Vertical polarization (|V> state)

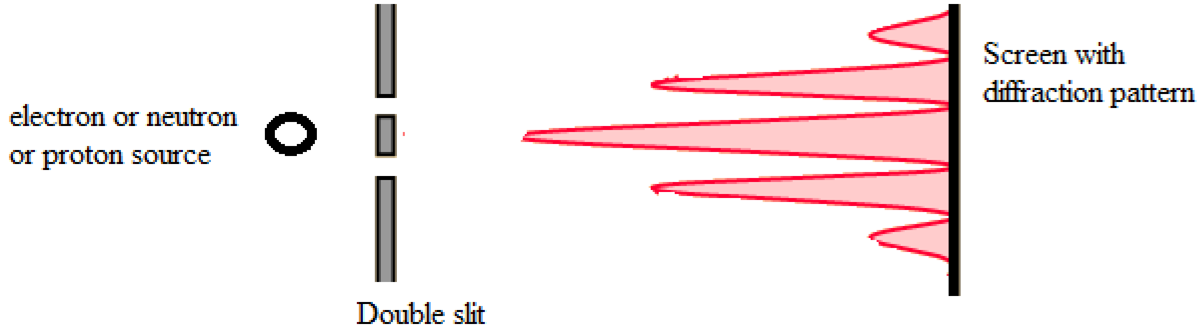


•Exhibits features like superposition and entanglement.

Picture: http://www.magnet.fsu.edu/inhouseresearch/condensedmatter/qubits.html

Quantum Superposition

- Two systems can be described separately
- Double slit experiment-basic of quantum mechanics



[http://forums.phys.unsw.edu.au]

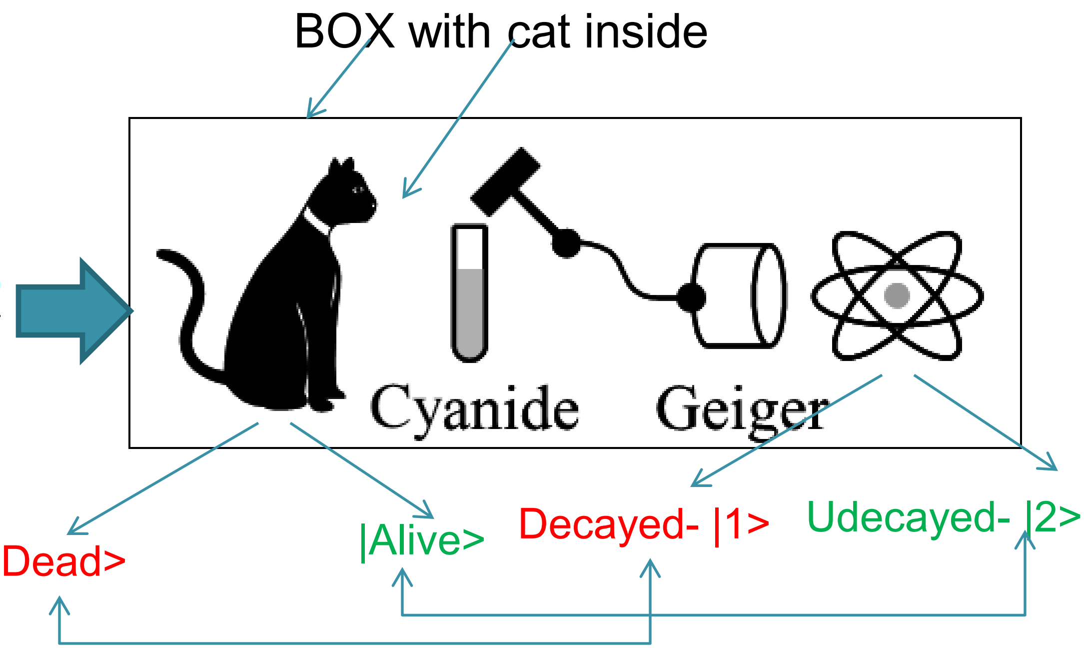
- Source can be unit source (single electrons or neutrons or proton at a time) or collection of particles
- Probability of going through any slit for a single particle is (50%).

$$|\psi>_{Doubleslit} = \frac{(|\psi_{slit\_a\_open}> + |\psi_{slit\_b\_open}>)}{\sqrt{2}}$$

Schrödinger’s Cat-entangled state

Systems cannot be described separately-entangled state.

$$|\psi>_{cat}=\frac{(|live,2>+|dead,1>)}{\sqrt{2}}$$



When radioactive particle decays, then Geiger counter counts, then it hits cyanide bottle.

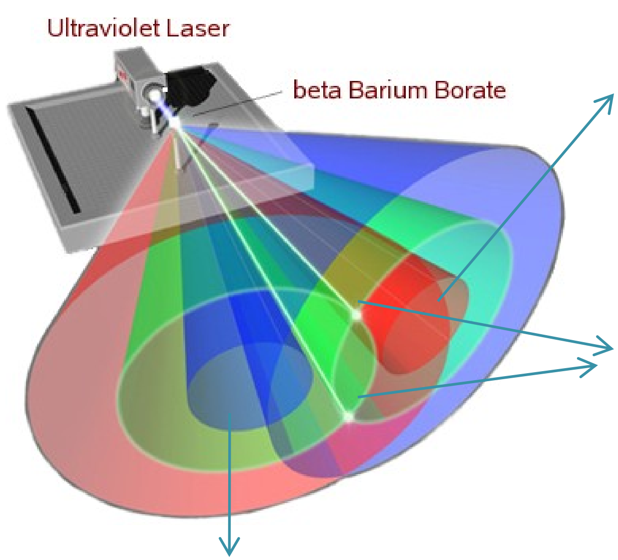
[Quantum Optics, Oxford University Press]

When two or more than stats are linked such that measurement on one directly effects the other states when separated by arbitary distance is an entangled states.

Entangled states

A. Photon entanglement

- Down conversion and phase matching process
- UV photon source striked β-barium borate crystal,
  - UV source is down converted to two red photons
  - Emerges cone of opposite polarization (horizontal-H and vertical-V)
  - Interference of double cone result in an entangled photon states- (if one is H then, other is V and vice versa).



H-polarized cone

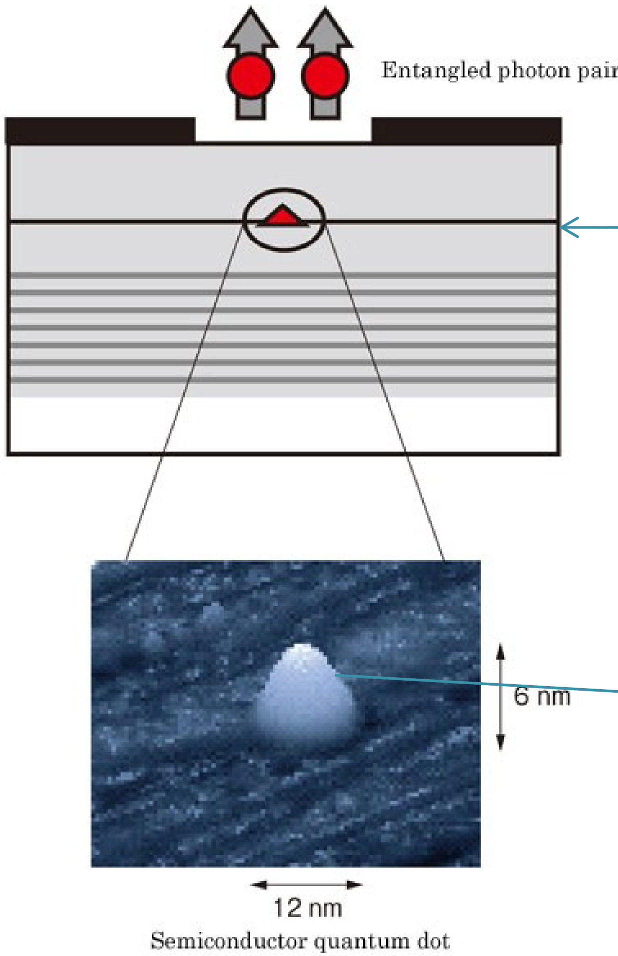
Entangled pair:

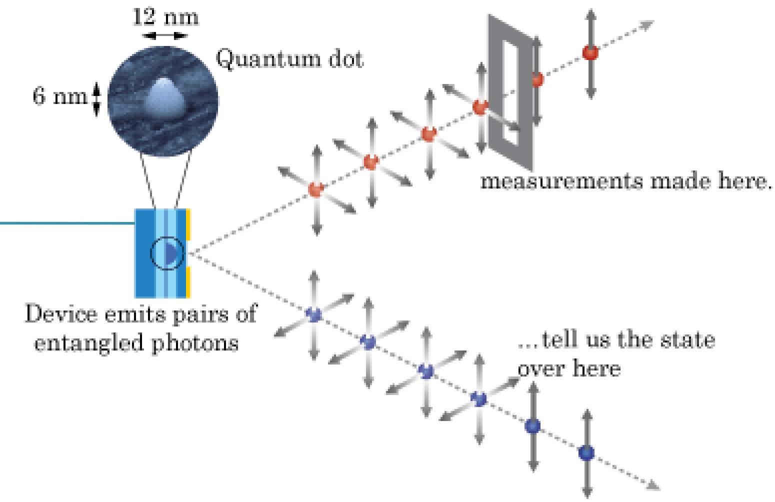
$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\leftrightarrow_1, \updownarrow_2\rangle + e^{i\phi}|\updownarrow_1, \leftrightarrow_2\rangle\right)$$

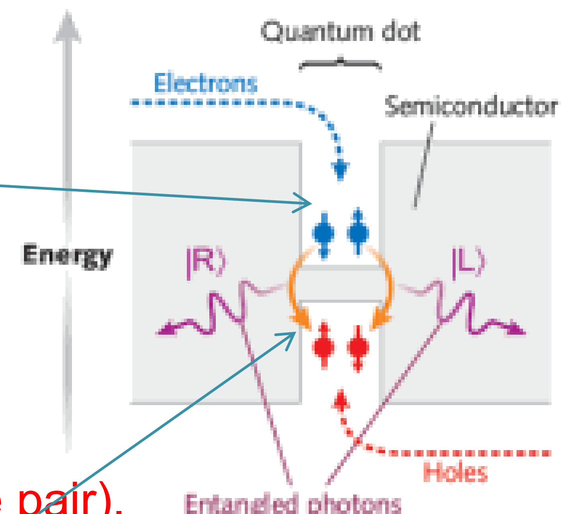
V-polarized cone

[Quantum Optics, Oxford University Press]

Entangled photon generation from Quantum Dots







Generation of biexiton (two electron and hole pair). Decay of biexciton result in entangled photon (right or left handed circularly polarized light).

Semiconductor Quantum Dot structure

[An entangled LED (Nature Volume: 465, Pages: 594–597, 2010)]

- B. Electron spin entangled state
  - Spin singlet state is an entangled state

$$|\psi>_{spin} = \frac{(|\uparrow\downarrow> - |\downarrow\uparrow>)}{\sqrt{2}}$$

  - Where, $|\uparrow>, |\downarrow>$ represents the eigen state of the spin operator along cretain direction.

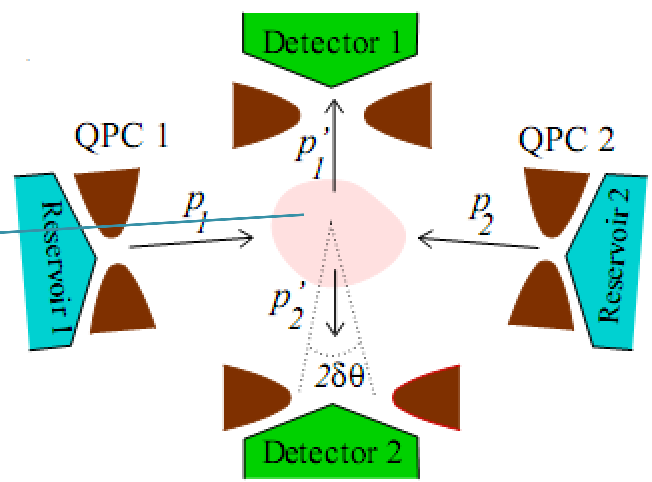
Electron spin entangled pair production:

•Allowing only those electrons to pass the quantum point contact (QPC) to QD (quantum dot) which scatter at π/2.

•At π/2 scattering angle-triplet state vanishes leaving singlet state.

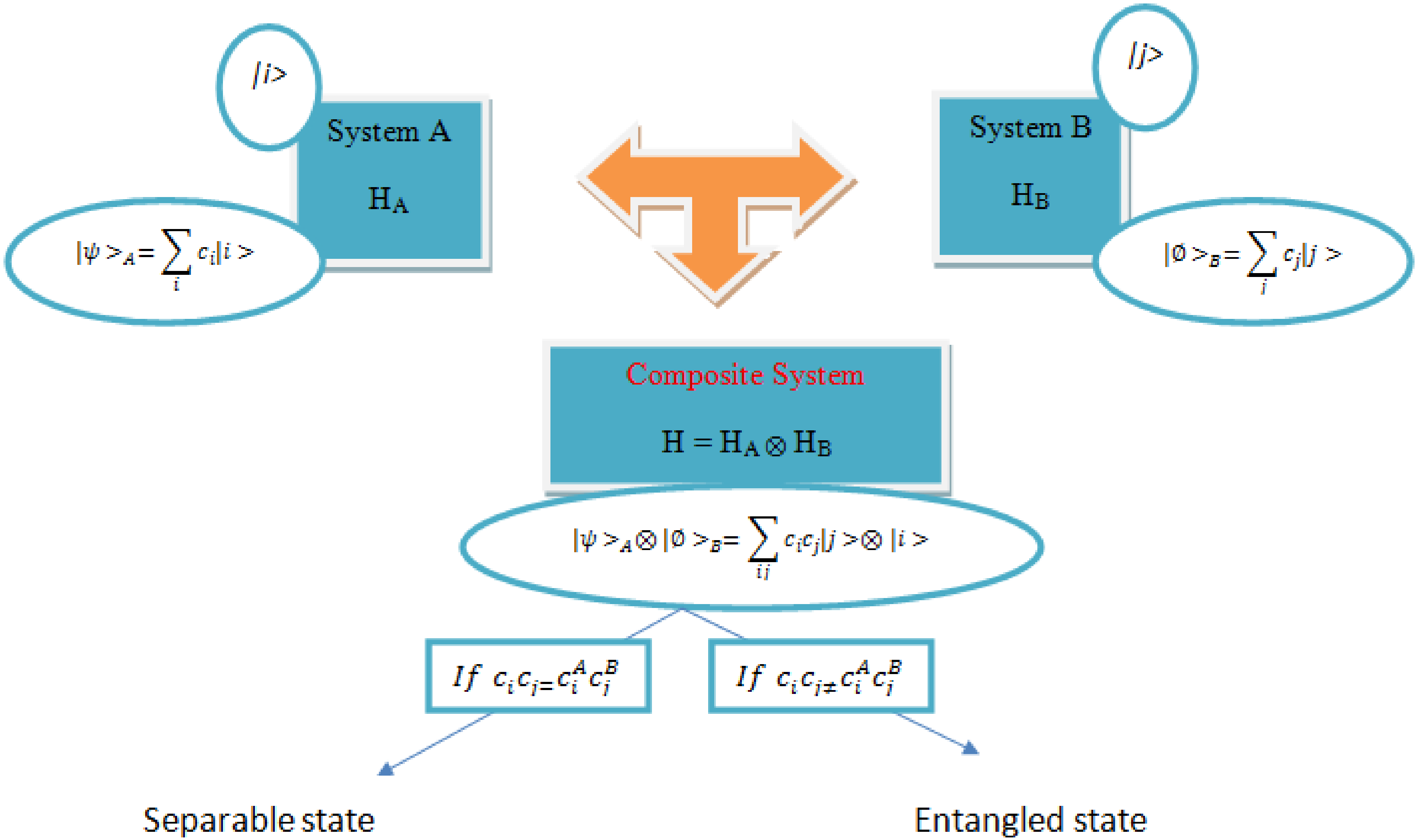
•Thus, each entangled single electron are detected at detectors (1, 2).

•Scattering amplitude always favors singlet state around π/2 scattering angle.



[Phys. Rev. Lett 92, 246803 (2004)]

Separable and mixed state

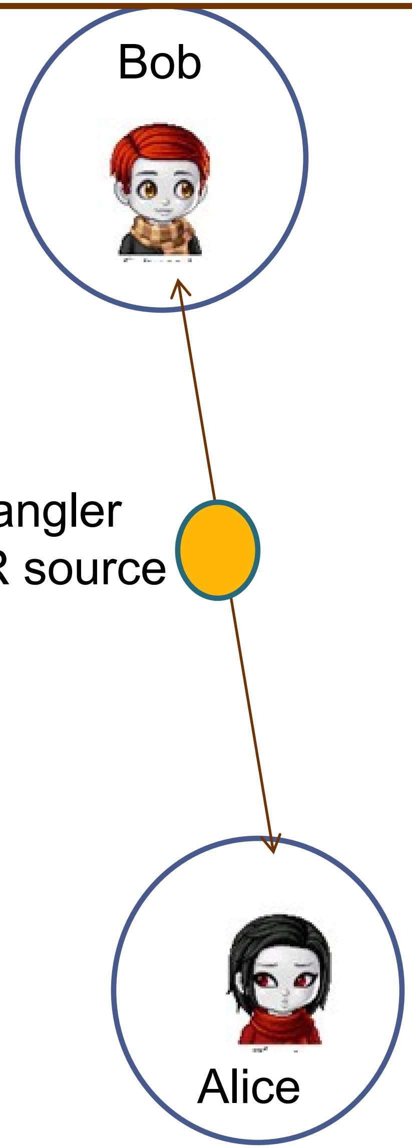


CAN WE TRANSPORT ENTANGLED INFORMATION? YES

Einstein, Podolsky and Rosen (EPR) - A paradox

Step 1: An entangler source, supplies Bob and Alice (separated by long distance) each an entangled info.
Step 2: Bob measures it (along certain direction): $|\uparrow>$.
Step 3: Alice also decides to measure along Same direciton: result is: $|\downarrow>$

$$|\psi> = \frac{1}{\sqrt{2}}(a|\uparrow>_A \otimes |\uparrow>_B - b|\downarrow>_B \otimes |\downarrow>_A)$$



Outcome: Quantum mechanical state collpses to $|\uparrow>_A$ $|\downarrow>_B$, after Bob has measured, so Bob knows that Alice has $|\downarrow>$.

Einstein thought that some local hidden variable is influencing the instantaneous change of information between two locations – spooky action at the distance.

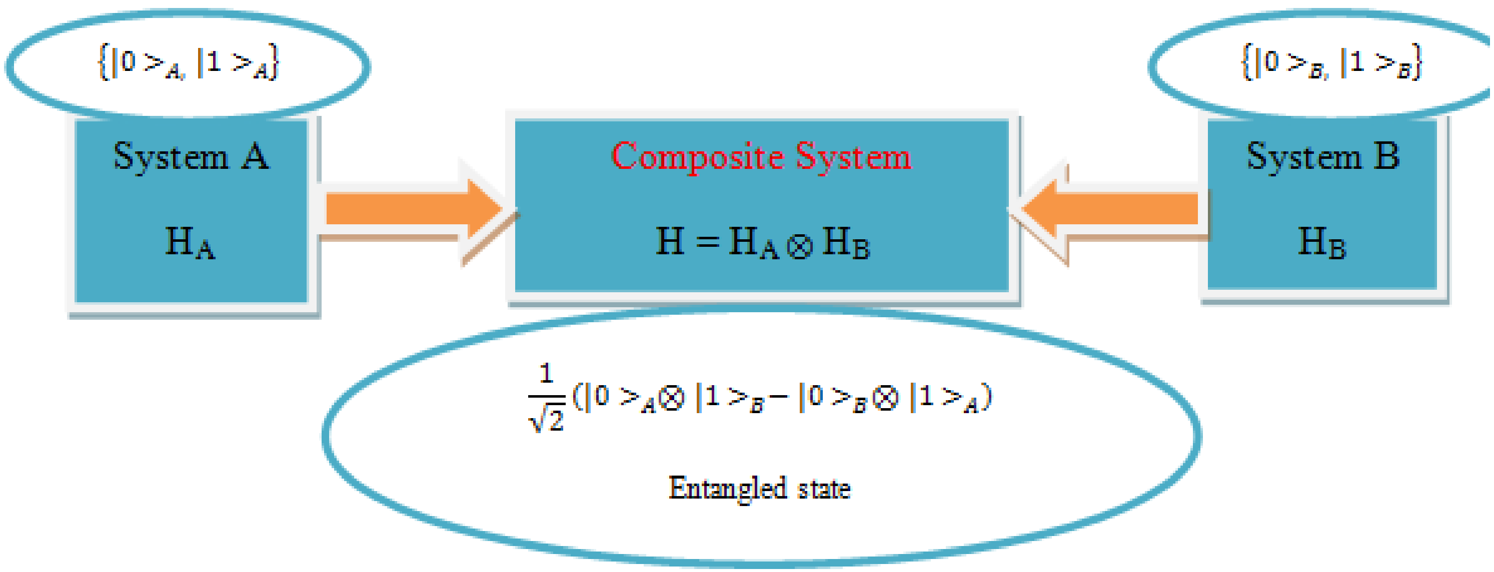
Quantum mechanical approach- Not the local hidden variable rather the measurement process itself influences the result.

[Quantum Optics, Oxford University Press]

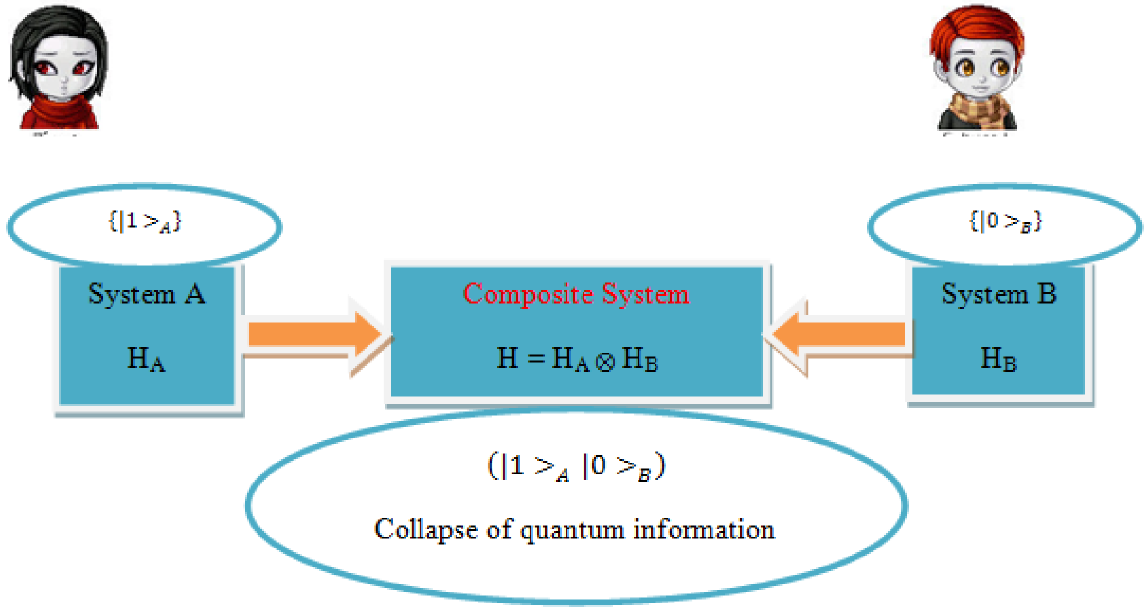
Before measurement composite system is in entangled state $|\psi>_A \otimes |\emptyset>_B$

Alice

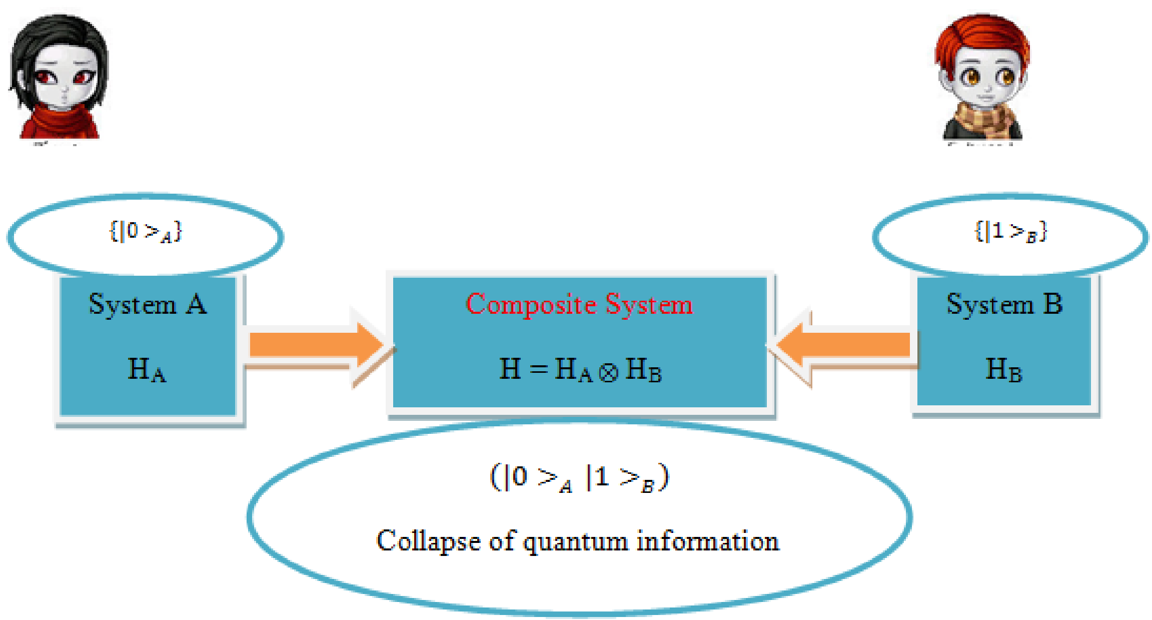
Bob



Case 1: Alice measures |1>



Case 2: Alice measures |0> and Bob automatically has |1>

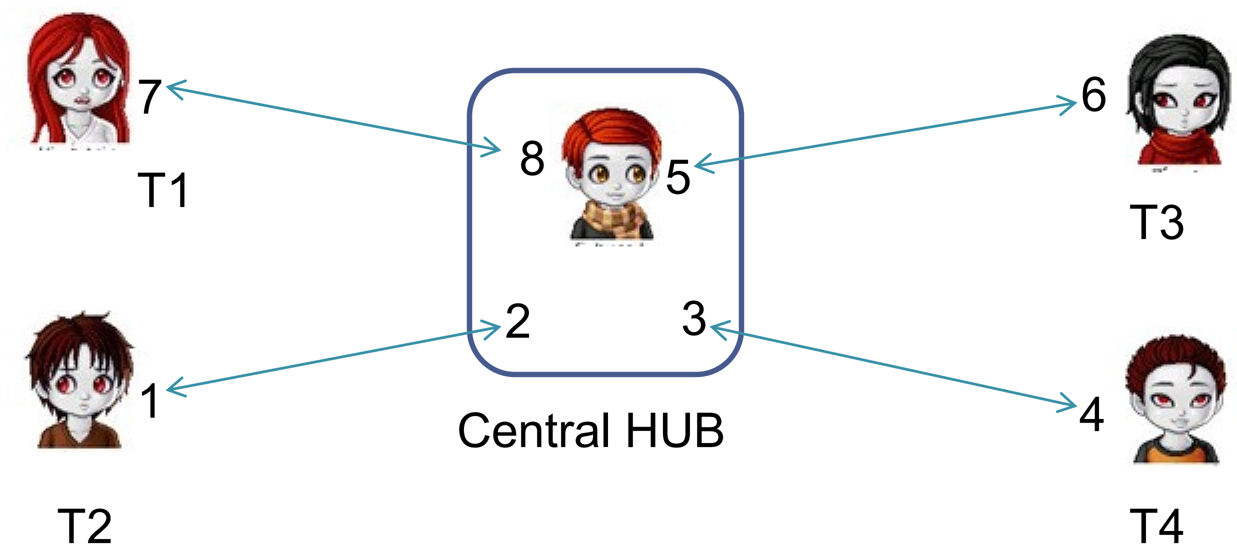


Quantum teleportation-Entanglement swapping

- Information are used to transmit in conjunction with a classical information channel, where transmitted information cannot travel faster than light. This process is known as quantum teleportation.

•If, (1,2), (3,4), (5,6) and (8,7) share the entangled information between terminal station (T) with central hub.

•Individual remote locations T1 to T4 will immediately exchange information with the central HUB, by simply controlling four points of central HUB.



[The physics of quantum information, Springer 2001]

Applications of entangled states

- Quantum informations contains more information than classical
- Entangled states can be teleported to any location., towards high speed communication systems.
- Forms the basic system of communication in nano-level devices.
- Is the basis of quantum computer, quantum cryptography and quantum communication.

DIFFICULTIES!!!!

Quantum Decoherence or Dephasing

- Decoherence is the irreversible correlation between entangled state and the environment.
- Results in wave function collapse, disappearance of phase relation between systems, entanglement with the environment.

THANK YOU!