Title: An Introduction to Quantum Information

Date: Aug 17, 2009 01:00 PM

URL: http://pirsa.org/09080062

Abstract: A game that illustrates that quantum theory requires non-locality; an overview of the concept and basic mathematics of entanglement; and the concept of spin introduced via a Stern Gerlach set-up.

An Introduction to Quantum Information

ISSYP 2009

A Game of Probabilities: Set-up

- Two people, called observers
- Two priors, duck or goose
- Two outcome choices, it or not it

A Game of Probabilities: Part 1

How to win:

1. If both observers have the same prior information, they both choose the same outcome.
2. If the observers have different prior information, they choose the opposite outcomes.

A Game of Probabilities: Part 3

How to win:

1. If both observers have the prior, Goose, they both choose the opposite outcomes.
2. If both observers have the prior, Duck, they choose the same outcome.
3. If the observers have different priors, they choose the same outcome.

A Game of Probabilities: Part 3

How to win:

1. If both observers have the prior, Goose, they both choose the opposite outcomes.
2. If both observers have the prior, Duck, they choose the same outcome.
3. If the observers have different priors, they choose the same outcome.

A Game of Probabilities

A Game of Probabilities

- What is the best probability of winning?

A Game of Probabilities

- What is the best probability of winning?
- Classically, 75%

A Game of Probabilities

- What is the best probability of winning?
- Classically, 75%
- With quantum systems, we can do better!

Entanglement

"Spooky action-at-a-distance"

But first … some notation

But first ... some notation

$$ket \rightarrow |\psi\rangle$$

But first … some notation

$$ket \rightarrow |\psi\rangle$$

But first … some notation

$$ket \rightarrow |\psi\rangle$$

$$tensor \rightarrow |\psi\rangle_A \otimes |\varphi\rangle_B$$

Composite system

- Every composite system can be represented as

$$|\psi\rangle_{AB} = \sum_{i,j} c_{ij} |i\rangle_A \otimes |j\rangle_B$$

Separable states

- If $|\psi\rangle_{AB} = |\psi\rangle_A \otimes |\varphi\rangle_B$

where $c_{ij} = c_i^A c_j^B$

$$|\psi\rangle_A = \sum_i c_i^A |i\rangle_A \qquad |\varphi\rangle_B = \sum_j c_j^B |j\rangle_B$$

Composite system

- Every composite system can be represented as

$$\left|\psi\right\rangle_{AB} = \sum_{i,j} c_{ij} \left|i\right\rangle_A \otimes \left|j\right\rangle_B$$

Separable states

- If $|\psi\rangle_{AB} = |\psi\rangle_A \otimes |\varphi\rangle_B$

where $c_{ij} = c_i^A c_j^B$

$$|\psi\rangle_A = \sum_i c_i^A |i\rangle_A \qquad |\varphi\rangle_B = \sum_j c_j^B |j\rangle_B$$

If a state is not separable, it is entangled!

Separable states

- If $|\psi\rangle_{AB} = |\psi\rangle_A \otimes |\varphi\rangle_B$

where $c_{ij} = c_i^A c_j^B$

$$|\psi\rangle_A = \sum_i c_i^A |i\rangle_A \qquad |\varphi\rangle_B = \sum_j c_j^B |j\rangle_B$$

If a state is not separable, it is entangled!

Example

- Separable or entangled?

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B\right)$$

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

Example

- Separable or entangled?

Separable states

- If $|\psi\rangle_{AB} = |\psi\rangle_A \otimes |\varphi\rangle_B$

where $c_{ij} = c_i^A c_j^B$

$$|\psi\rangle_A = \sum_i c_i^A |i\rangle_A \qquad |\varphi\rangle_B = \sum_j c_j^B |j\rangle_B$$

Composite system

- Every composite system can be represented as

$$\left|\psi\right\rangle_{AB} = \sum_{i,j} c_{ij} \left|i\right\rangle_{A} \otimes \left|j\right\rangle_{B}$$

Separable states

- If $|\psi\rangle_{AB} = |\psi\rangle_A \otimes |\varphi\rangle_B$

where $c_{ij} = c_i^A c_j^B$

$$|\psi\rangle_A = \sum_i c_i^A |i\rangle_A \qquad |\varphi\rangle_B = \sum_j c_j^B |j\rangle_B$$

Composite system

- Every composite system can be represented as

$$|\psi\rangle_{AB} = \sum_{i,j} c_{ij} |i\rangle_A \otimes |j\rangle_B$$

Example

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

- Separable!

$$|\psi\rangle_A = |0\rangle_A \qquad |\varphi\rangle_B = \frac{1}{\sqrt{2}}\left(|0\rangle_B + |1\rangle_B\right)$$

Example

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|1\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

- Separable!

$$|\psi\rangle_A = |0\rangle_A \qquad |\varphi\rangle_B = \frac{1}{\sqrt{2}}\left(|0\rangle_B + |1\rangle_B\right)$$

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|1\rangle_A|0\rangle_B + |0\rangle_A|1\rangle_B\right)$$

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B\right)$$

- Entangled!

So what does this math tell you?

Example

- Separable or entangled?

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B\right)$$

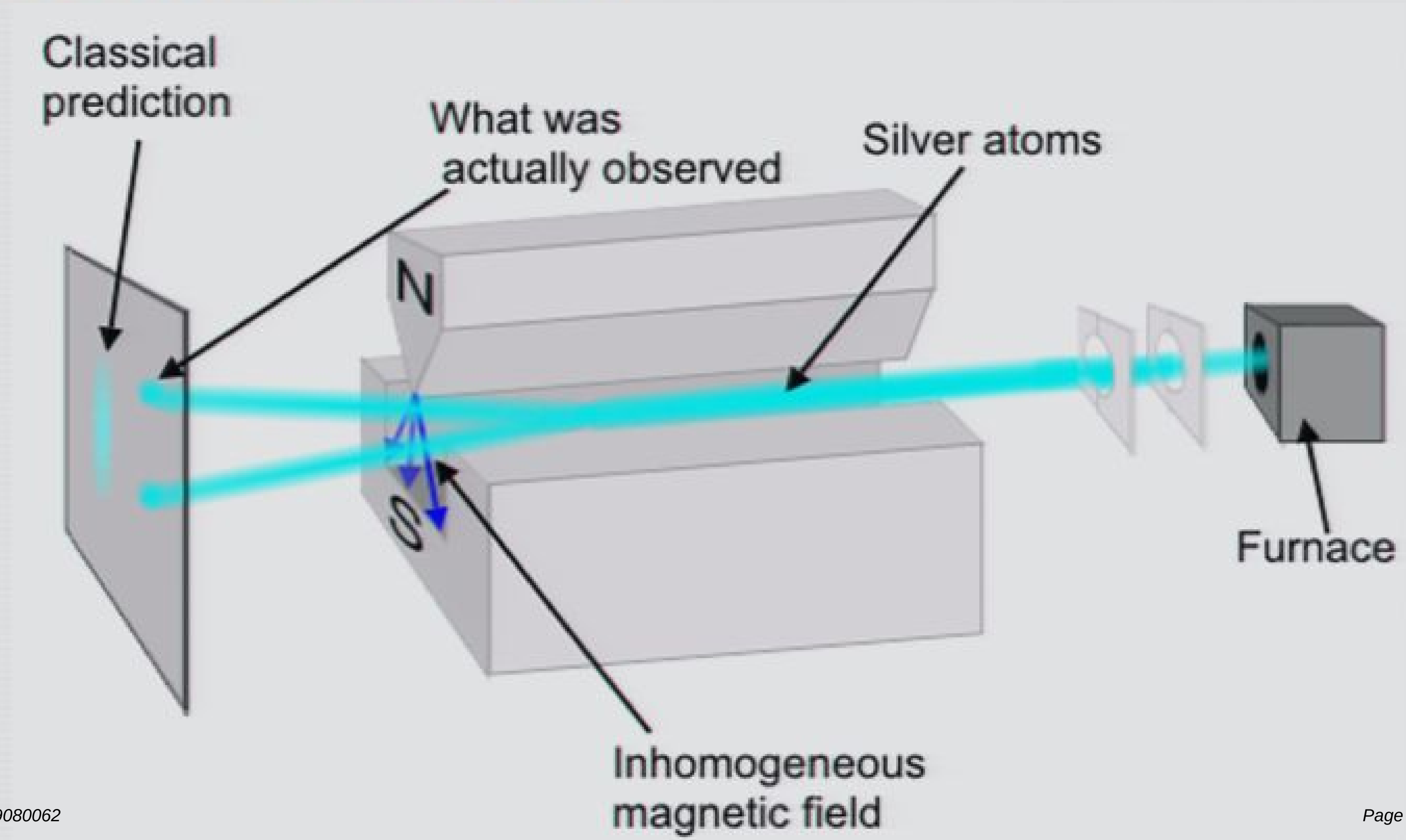
- Entangled!

So what does this math tell you?

Spin

My favourite quantum feature

Stern-Gerlach



Spin is…

- an intrinsic property
- equivalent to polarization for light (photons)
- the basis for the qubit
- weird

Using spin: NMR

- Rough procedure: count number of protons, number of neutrons, and probe with EM radiation
- The spin of a molecule is dependent on the parity of the number of protons and the number of neutrons.
- Spin gives rise to a magnetic moment with a proportionality constant called the gyromagnetic ratio.
- NMR works on the principle that an object with a non-zero spin will absorb (and then emit) radiation at characteristic frequencies.

End of slide show, click to exit.

Using spin: NMR

- Rough procedure: count number of protons, number of neutrons, and probe with EM radiation
- The spin of a molecule is dependent on the parity of the number of protons and the number of neutrons.
- Spin gives rise to a magnetic moment with a proportionality constant called the gyromagnetic ratio.
- NMR works on the principle that an object with a non-zero spin will absorb (and then emit) radiation at characteristic frequencies.