Death by experiment for local realism

tea talk

12-11-15

Quantum physics and local-realism

- A fundamental scientific assumption called **local-realism** conflicts with certain predictions of **quantum mechanics**.
- Those predictions have now been verified, with none of the **loopholes** that have compromised earlier tests.

Local-realism hypothesis

Conjunction of two other hypotheses:

- Realism: Measurements reveal pre-existing physical properties of the world.
- Locality: an object is only directly influenced by its immediate surroundings. No causal influence can travel faster than light.

Bell's theorem

It is named after John Bell, the physicist who discovered in 1964 that the predictions of quantum mechanics are incompatible with the local-realism hypothesis.

- Implication of local-realism: separated measurement processes are independent.

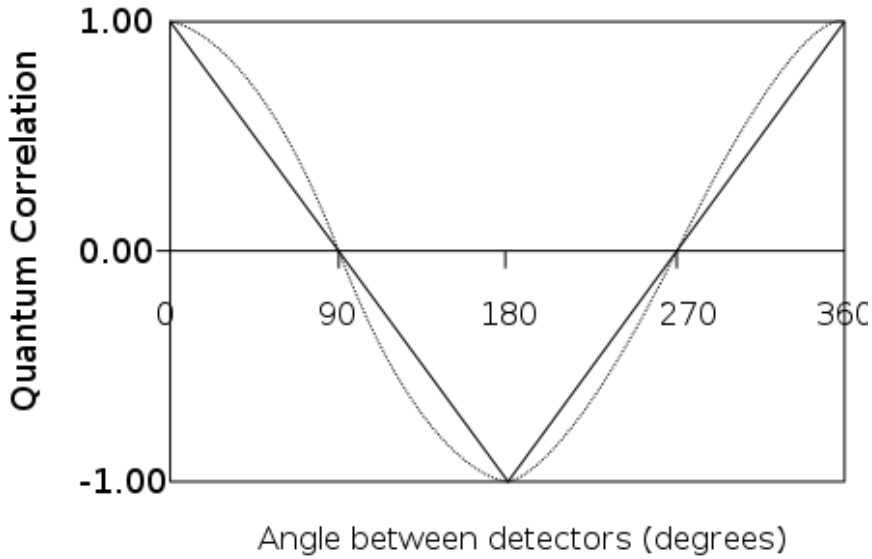
Based on this premise:
Probability of a coincidence between separated measurements of particles with correlated orientation:

$$P(a,b) = \int d\lambda\, \rho(\lambda)\, p_A(a,\lambda)\, p_B(b,\lambda)$$

A source is assumed to produce particles in the state λ with probability $\rho(\lambda)$.
$p_A(a,\lambda)$=probability of detection of particle A, with hidden state λ, set in direction a.

Bell's theorem

- The local hidden variable prediction for the probability of coincidence is proportional to the angle (b − a).
- The quantum correlation curve is a cosine relationship



Theorem

No physical theory of local hidden variables can ever reproduce all of the predictions of quantum mechanics.

Bell inequalities

A Bell inequality It is a mathematical relationship regarding the statistics of measurements outcomes obtained by two or more parties.

1. The parties are in well-separated laboratories.
2. The measurement settings are chosen and implemented,
3. Finally, the outcomes obtained, in a sufficiently short time that the only way the choice of setting by any party could affect the outcome of any other party would be through a faster-than-light influence.
4. Then, by definition, all Bell inequalities will be satisfied by all local-realistic theories.

Bell inequalities

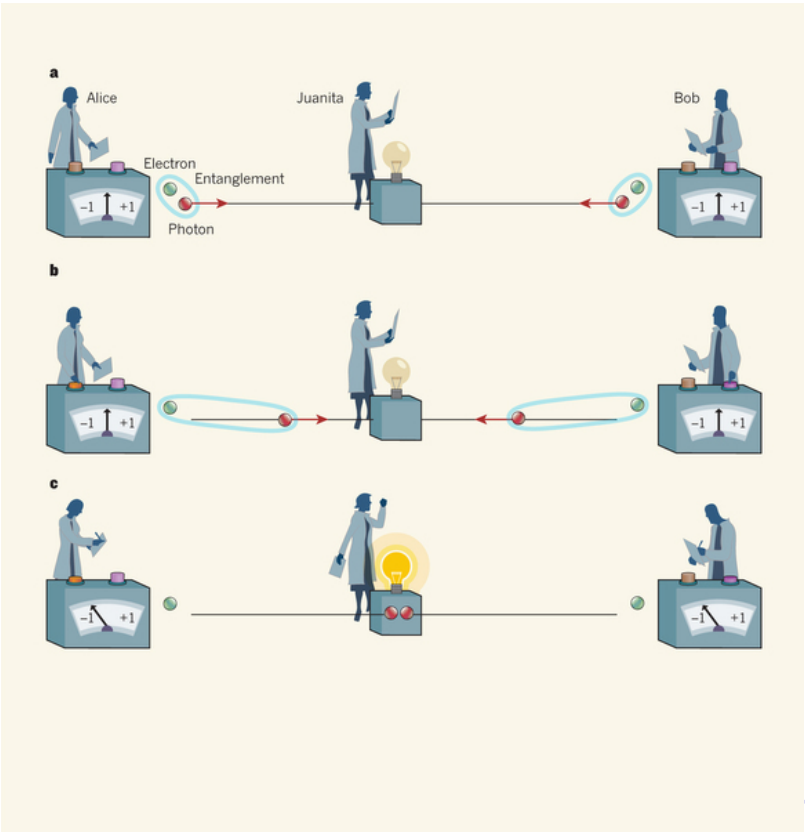
An experiment violating a Bell inequality therefore implies that either locality or realism is false.

- Bell inequalities have been violated experimentally many times before
- However, all of these experiments had loopholes.

1. Either the parties were not far enough apart.
2. or the measurements were inefficient, so that quite often no outcome at all was registered (local realistic theories can exploit the existence of null outcomes to simulate the correlations of QM)

Violation of a three-party Bell inequality

1. At separate locations, Alice and Bob create entangled states of an electron and a photon, then send the photons to Juanita's laboratory.
2. Alice and Bob randomly choose a setting for (efficient) measurements of their respective electrons
3. They obtain their measurement outcomes, and Juanita performs a joint measurement of the photons. Alice's and Bob's outcomes are purely random unless Juanita gets a rare successful outcome (can be inefficient) that indicates entanglement between Alice's and Bob's electrons.



Violation of a three-party Bell inequality

- Hensen et al. reject the local-realism null hypothesis at a confidence level conventionally considered to be statistically significant.
- A probability of at most P=0.039 that a local-realist model could produce data with a violation as large as they observe.
- The immediate significance of the reported experiment is in hammering the final nail in the coffin of local realism.