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Bell's theorem

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In theoretical physics , the **Bell Theorem** (Bell's theorem) show

> Any physics theory about localized hidden variables cannot replicate every prediction of quantum mechanics.

Bell's theorem is an infeasible theorem , also known as **Bell's inequality** . This theorem is extremely important in physics and philosophy of science , because this theorem means that quantum physics must violate the principle of locality or counterfactual certainty [1] [2] . Published in 1964, Bell's theorem was named after the Irish physicist John Bell .

The experimental results of the Bell's theorem are consistent with the predictions of quantum mechanics theory and show that some quantum effects seem totravelatsuperluminal speed. As the result of this verification, all classified as hidden variable theory, stand the test of quantum theory can only be limited to non-local species. In 2015,Ronald Hansen and others atDelft University of Technologysaid in the cover article ofNaturethat all loopholes were successfully closed. At present, quantum theory describes quantum entanglement more accurately than the theory of localized hidden variables. [3]

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Overview

Bell's inequality is: **|Pxz-Pzy|≤1+Pxy** .

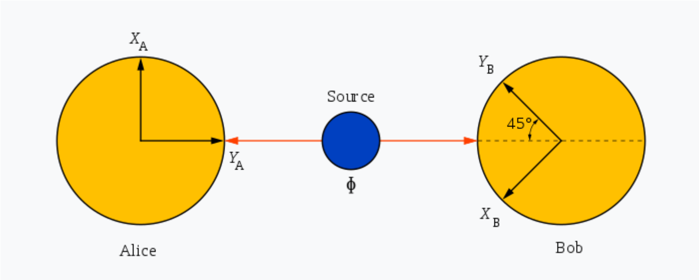
Where Ax is positive means that the spin state of the A quantum is positive on the x-axis, and Pxz represents the positive correlation between Ax and positive and Bz .

In classical mechanics , this inequality holds. In the quantum world, this inequality does not hold.

Bell's theorem means that the prediction of the locality principle advocated by Albert Einstein does not conform to the theory of quantum mechanics. Since the results of many experiments are consistent with the predictions of quantum mechanics theory, the quantum correlations shown are far more powerful than the theory of localized implicit variables. Therefore, physicists refuse to accept the interpretation of these experimental results by local realism. In the dilemma of not finding a satisfactory answer, physicists can only reluctantly admit that this is a non-causal superluminal effect .

Bell theorem can be applied to any two intertwined qubit quantum system thereof. The most common example is a particle system entangled in spin or polarization .

Continue to develop the Einstein-Podolski-Rosenberg (referred to as EPR佯谬) discussion [4] (but choose the example of spin , as the David Bohm version of the EPR condolences [5] Bell has carefully designed a thought experiment : two single-state spin 1/2 particles generated from decay will move in opposite directions, respectively, along separate locations at two distant locations from the decay site. The direct axis measures the spin of two particles. The result of each measurement is "upward spin" (marked as "+") or "down spin" (marked as "−").



For particles like photons, the experimental proof of Bell's theorem. The decay of unstable particles produces a pair of single−state particles whose two particles move in opposite directions, respectively. Assume that at two locations separated from the decay site by a variety of angles θArbitrarily set to the experimental parameters, and then measure the spin of the two particles, the obtained data can calculate the entanglement properties of the system .

The probability of measuring consistent results at two locations will be due to two straight axes**a** versus **b** Angle between angles θ And change, except for parallel or anti-parallel settings (θIt is 0° or 180°) and will suffer uncertainty. Therefore, Bell's theorem can only be applied to statistical results obtained from multiple measurements. Now set the experimental rules, assuming that Alice and Bob are measured separately at these two locations. If at a certain measurement, Alice measures the result as an upward spin, and Bob measures the result as a downward spin, then The two results are consistent, the correlation coefficient is "+1", and vice versa; otherwise, as follows, if both Alice and Bob measure the result of either an upward spin or a downward spin, then the two results Inconsistent, the correlation coefficient is "-1". Then, hypothesis**a** versus **b**Parallel to each other, the measurement of these quantum entangled particles will always yield consistent results (completely correlated); assuming that the two straight axes are perpendicular to each other, only a 50% probability will result in a consistent result, and the probability of obtaining an inconsistent result is also 50%. These basic cases are listed below:

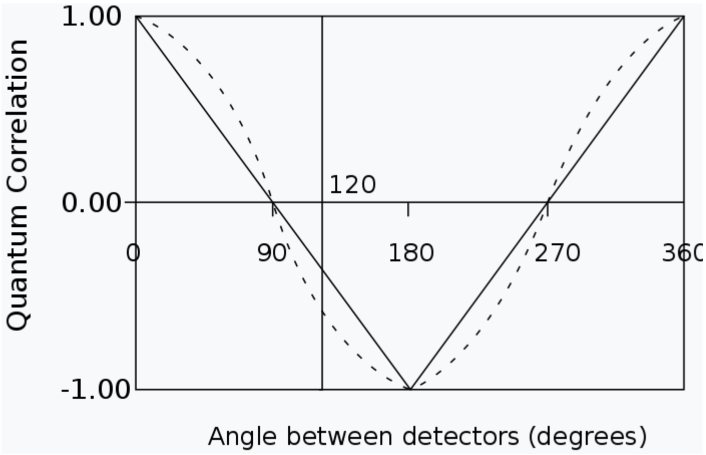
Co−axial axis $\theta = 0°$ **:**	**First pair**	**2nd pair**	**Third pair**	**4th pair**	**...**	**a total of n pairs**
Alice:	+	−	−	+	...	
Bob:	−	+	+	−	...	
Correlation coefficient: (	**+1**	**+1**	**+1**	**+1**	**...**	**) /** n **= +1**
					(100% consistent)	

Orthogonal axis $\theta = 90°$ **:**	**First pair**	**2nd pair**	**Third pair**	**4th pair**	**... a total of n pairs**	
Alice:	+	−	+	−	...	
Bob:	−	−	+	+	...	
Correlation coefficient: (	**+1**	**−1**	**−1**	**+1**	**...**	**) /** n **= 0**
					(50% consistent)	

As shown on the right, assume the angle between the two straight axes. θBetween the above basic case angles, the establishment of the local implicit variable theory means that the quantum correlation changes linearly. But according to quantum mechanics theory, quantum correlation should be an angle cosine $\cos\theta$Variety. The key point is that the actual entanglement experiment results support the prediction of quantum mechanics theory.

Bell derives the results of local realism. In this guide, in addition to requiring basic unification, without making any other special assumptions, the mathematical problems discovered by Bell are obviously different from the predictions of quantum mechanics, and more different from the experimental observations obtained later. In this way, Bell's theorem excludes the localized implicit variable as a credible interpretation of quantum mechanics, although the door to the theory of non-localized implicit variable is still open. Bell's conclusion [4] :

> In order to determine the results of individual measurements, some theories strictly require the addition of additional parameters to quantum mechanics and require that this action does not change statistical predictions. For these theories, there must be a mechanism in which the change in the operating setpoint of one measuring instrument affects the reading of another measuring instrument, no matter how far the distance between the two instruments is. In addition, signals involving this mechanism must arrive instantaneously, so these theories do not have Lorentz invariance .



For the quantum correlation of spins (assuming 100% detection efficiency), the prediction of the local implicit variable theory is shown by the solid line, and the quantum mechanical prediction is shown by the dotted line.

Over the years, many experiments have attempted to validate Bell's theorem and to derive experimental data that Bell's inequality has been violated. But many of the shortcomings of these experiments have been found, including "detection loopholes", "communication loopholes", etc. [6] . Due to advances in technology, experiments have gradually improved, and they are able to supplement these vulnerabilities, but so far (2014) no experiment can fully complement these vulnerabilities [6] . But physicists believe that the perfect Bell theorem experiment can occur within five years. Although perfect experiments have not yet appeared, the mainstream quantum mechanics textbook has regarded Bell's theorem as the fundamental physics theorem [2] [7] . However, no physical theorem can be accepted without question; still some physicists refute that the hidden assumptions or experimental loopholes of Bell's theorem negate the correctness of the theory [8] [9] .

See

- Bell predicted the experiment (Quantum Mechanical Bell the Test Prediction)
- CHSH inequality (CHSH inequality)
- GHZ experiment (GHZ Experiment)
- Leggett inequality (Leggett inequality)
- Leggett – Gao grid inequality (Leggett-Garg inequality)
- Mott problem (Mott problem)
- Ren Ninge negative result experiment
- Quantum uncertainty
- Quantum mechanics
- Quantum topography
- Quantum mysticism (Quantum mysticism)
- Relational quantum mechanics (Relational Quantum Mechanics) (Renninger-negative Experiment Result)

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Advanced reading

Here are some of the books written specifically for the general reader that relate to Bell's theorem:

- Amir D. Aczel, *Entanglement: The greatest mystery in physics* (Four Walls Eight Windows, New York, 2001).
- A. Afriat and F. Selleri, *The Einstein, Podolsky and Rosen Paradox* (Plenum Press, New York and London, 1999)
- J. Baggott, *The Meaning of Quantum Theory* (Oxford University Press, 1992)
- N. David Mermin, "Is the moon there when nobody looks? Reality and the quantum theory", in *Physics Today* , April 1985, pp. 38—47.
- Louisa Gilder, *The Age of Entanglement: When Quantum Physics Was Reborn* (New York: Alfred A. Knopf, 2008)
- Nick Herbert, *Quantum Reality: Beyond the New Physics* (Anchor, 1987, ISBN 0-385-23569-0)
- D. Wick, *The infamous boundary: seven decades of controversy in quantum physics* (Birkhauser, Boston 1995)

External link

- Edited by Gary Felder, a professor at Smith College in the United States, ghostly super-distance: an explanation of Bell's theorem (http://www.felderbooks.com/papers/bell.html)
- Quantum Lab , Department of Physics, University of Erlangen-Nuremberg, Germany : Interactive experiment of photons (http://www.didaktik.physik.uni-erlangen.de/quantumlab/english/index.html) .
