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THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2022 "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science" to **Alain Aspect**, **John F. Clauser** and **Anton Zeilinger**.

The Nobel Prize 2022 **in Physics**

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Entangled quantum states from theory to technology

Alain Aspect, John Clauser and Anton Zeilinger have each conducted groundbreaking experiments using entangled quantum states, in which two particles behave like a single unit even when they are separated. Their results have cleared the way for new technology based upon quantum information.

There is now a large field of research that includes quantum computers, quantum networks and secure quantum encrypted communication. Some of the important breakthroughs behind these developments were made by this year's Nobel laureates in Physics. All three have used an important phenomenon in quantum mechanics called entanglement. Entangled particles have shared quantum properties.

Quantum mechanics says that particles can have undefined properties before they are measured. Instead of a fixed state they have a combination of all possibilities, each with a certain probability of being measured. After they are measured, only one possibility remains.

For example, entangled photons (light particles) may be polarised parallel to each other, even if the direction of that polarisation is unclear until a measurement is made. Measuring one photon in such an entangled pair determines the plane in which it is polarised. At the same time, this determines the result of the measurement of the other particle, even if it is hundreds of kilometres away.

It appears that each particle can detect what happens to the other, despite them being unable to signal each other.

For a long time, one question was whether the particles in an entangled pair contained local hidden variables, like a set of instructions describing what they will show as the results of an experiment. In the 1960s, John Stewart Bell discovered that there are cases in which quantum mechanics predicts a result that cannot be understood using local hidden variables. This made it possible to test which description is correct.

John Clauser and some of his colleagues developed Bell's idea into a form suitable for an experiment using photons. The trick was to measure the polarisation of two entangled photons in different planes.

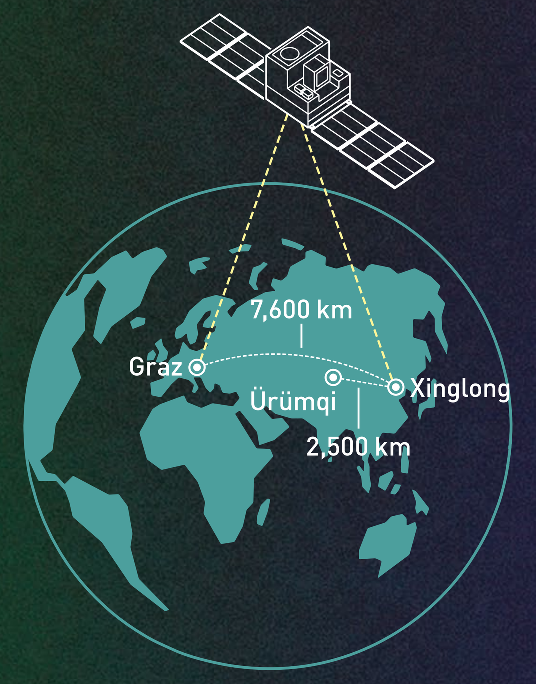
Alain Aspect further developed this experiment. Later, Anton Zeilinger conducted various experiments using entangled states for quantum communication. He utilised how shining a laser on a special type of crystal will create many entangled pairs of photons.

A long-distance relationship

Two particles can be entangled through being created together, in a reaction that gave them a shared quantum property. They share this property between them, making them a single unit even when they are sent in different directions.

Communication and encryption

Anton Zeilinger has conducted many experiments that have sent entangled quantum states over great distances, which can be used for secure, quantum-encrypted communication. In 2017, Zeilinger's research group held a quantum encrypted videocall with a Chinese research group, where the encryption key had been created via the Chinese Micius satellite.

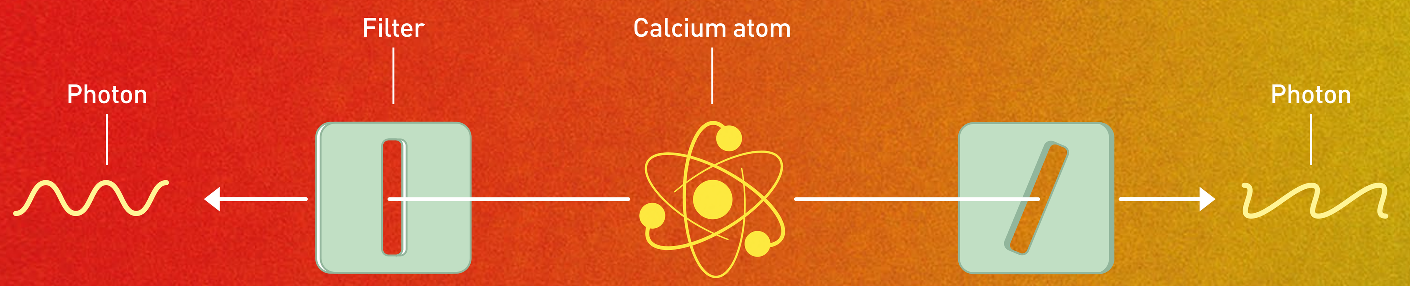


Bell's inequality

John Bell formulated a mathematical inequality that applies to the correlation between results from a series of repeated experiments if there are hidden variables. However, quantum mechanics allows results that violate this inequality.

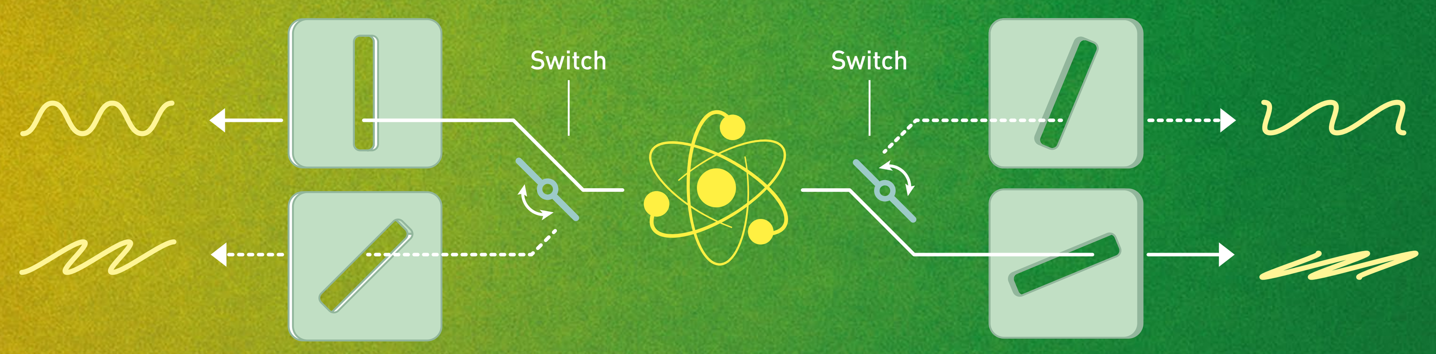
Quantum mechanics is correct

John Clauser used calcium atoms that could emit entangled photons after he had illuminated them with a special light. He set up a filter on either side to measure the photons' polarisation, with each filter set at a different angle. After a series of measurements, he was able to show that the results violated Bell's inequality but agreed with quantum mechanics.



Closing a loophole

Alain Aspect developed this experiment, using a new way of exciting the atoms so they emitted entangled photons at a higher rate. He was also able to switch between different settings, so the system would not contain any advance information that could affect the results and imitate what was predicted by quantum mechanics.



Alain Aspect

Born 1947 in Agen, France. Professor at Institut d'Optique Graduate School – Université Paris-Saclay and École Polytechnique, Palaiseau, France.

John F. Clauser

Born 1942 in Pasadena, CA, USA. Research Physicist, J.F. Clauser & Assoc., Walnut Creek, CA, USA.

Anton Zeilinger

Born 1945 in Ried im Innkreis, Austria. Professor Emeritus at the University of Vienna, Austria and Senior Scientist at the Austrian Academy of Sciences.

Photo: Portrait of Alain Aspect: Peter Badge; Portrait of John F. Clauser: JC Penny Portraits; Portrait of Anton Zeilinger: Daniel Hinterramskogler/Austrian Academy of Sciences

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More information about the Nobel Prize in Physics 2022 is available at *www.kva.se/nobelphysics2022* and *www.nobelprize.org*, with video and detailed information about the prize and the laureates.

Editors: Ulf Danielsson, Thors Hans Hansson, Anders Irbäck and Mats Larsson, Nobel Committee for Physics, Royal Swedish Academy of Sciences; Anna Davour, science writer; Clare Barnes, translator and Marianne Nordenlöw, editor, Royal Swedish Academy of Sciences. **Graphic design:** IVY Agency **Illustrations:** Johan Jarnestad/Infographics.se **Print:** Åtta45

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