QUANTUM PHYSICS

Death by experiment for 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. SEE LETTER P.682

HOWARD WISEMAN

The world is made up of real stuff, existing in space and changing only through local interactions — this local-realism hypothesis is about the most intuitive scientific postulate imaginable. But quantum mechanics implies that it is false, as has been known for more than 50 years[1]. However, brilliantly successful though quantum mechanics has been, it is still only a theory, and no definitive experiment has disproved the local-realism hypothesis — until now. On page 682 of this issue, Hensen *et al.*[2] report the first violation of a constraint called a Bell inequality, under conditions that prevent alternative explanations of the experimental data. Their findings therefore rigorously reject local realism, for the first time.

Bell inequalities are named after John Bell, the physicist who discovered in 1964 that the predictions of quantum mechanics are incompatible with the local-realism hypothesis[1]. There are many different ways to make this hypothesis precise[3], but Hensen and colleagues' exposition basically follows Bell's original formulation, which states it as the conjunction of two other hypotheses: realism (which Bell called predetermination), essentially meaning that measurements reveal pre-existing physical properties of the world; and locality, roughly meaning that any change

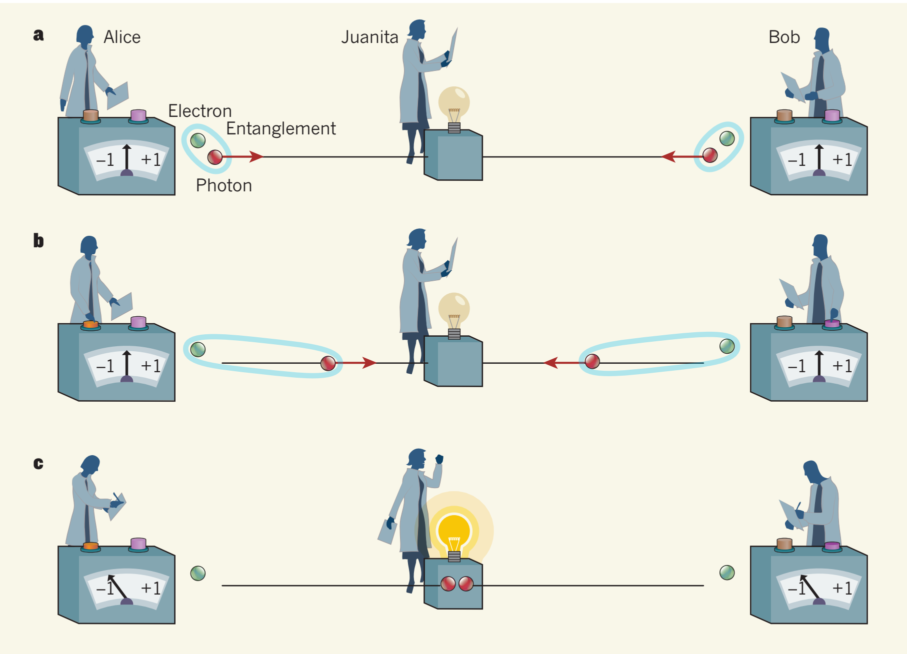

Figure 1 | Violation of a three-party Bell inequality. A Bell inequality is a mathematical relationship regarding the statistics of measurement outcomes obtained by two or more parties. Under certain physical conditions relating to the timing of events, a violation of a Bell inequality proves that local realism — a hypothesis satisfied in all of science except quantum mechanics — is false. Hensen *et al.*[2] have violated a Bell inequality in such a way that the requisite physical conditions were satisfied for the first time, using the scheme shown in this cartoon. **a**, At separate locations, Alice and Bob create entangled states of an electron and a photon, then send the photons to Juanita's laboratory. **b**, Alice and Bob randomly choose a setting for measurements of their respective electrons. **c**, 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 (as shown here) that indicates entanglement between Alice's and Bob's electrons. By collating the results over many runs, Hensen *et al.* showed that a Bell inequality had been violated by a statistically significant amount.

NATURE

50 Years Ago

It may not be generally realized that work is in progress on the colossal project of constructing a 40-in. diameter, 300 miles long, Trans-Alpine oil pipeline to convey oil from the Adriatic to the heart of Germany … Among the many practical problems concerned with such a project, apart from tunnelling and mechanical excavation in the high Alps, are the necessity to dredge the harbour at Trieste so that it can eventually accommodate oil tankers of 160,000 dead weight tons; setting storage tanks there on piles because available land is a rocky hill site; construction of several thousand feet of piers in the Adriatic … Involved also in the scheme is the building of five separate pumping stations, each equipped with two 4,000-horse-power electric centrifugal pumps required to lift hundreds of thousands of tons of oil from sea-level to one of the highest points of Felber Tauern.
From *Nature* 30 October 1965

100 Years Ago

'Distances at which sounds of heavy gun-firing are heard' — Referring to the correspondence on this subject, I have been collecting information as to places at which the sound of the firing in Belgium has been heard in this country … Here, at a distance of about 125 miles from Ypres (taking that town for convenience, as a known centre) I have heard firing quite unmistakably since the beginning of the war — often all day, and for many days in succession, and frequently at night too. So far as I have been able to ascertain, the greatest distance from Ypres at which the firing has been heard unmistakably is about 140 miles … Observations seem to show that the direction of the wind has less to do with the transmission of the sound than certain atmospheric conditions.
From *Nature* 28 October 1915

enacted at one place cannot have an effect at another place unless there would have been time for a light signal to get from the first place to the second place. The speed of light is relevant because, according to Einstein's theory of relativity, no causal influence can travel faster than light.

A Bell inequality is a mathematical relationship regarding the statistics of measurement outcomes obtained by two or more parties, and also involving the measurement settings chosen by those parties. Suppose that the parties are in well-separated laboratories, and that the measurement settings are chosen and implemented, and 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. Then, by definition, all Bell inequalities will be satisfied by all local-realistic theories. An experiment violating a Bell inequality therefore implies that either locality or realism is false. Bell's theorem is that, according to quantum mechanics, such an experiment is possible if the parties share particles prepared in a suitable entangled state. Entanglement is a holistic property of a system of quantum particles that can persist even when the particles are far apart.

Bell inequalities have been violated experimentally many times before[4–9]. However, all of these experiments had loopholes. Either the parties were not far enough apart, given how long it took for the processes involved (randomly choosing a setting, adjusting the apparatus appropriately and obtaining an outcome), or the measurements were inefficient, so that quite often no outcome at all was registered. The inefficiency is relevant because it can allow the existence of local realistic theories — albeit highly contrived ones — that exploit the existence of null outcomes to simulate the correlations of quantum mechanics.

Several groups worldwide have been racing to perform the first Bell experiment that combines large separation, efficient detection and fast operation of the apparatus. Hensen *et al.* have won the race by using a new scheme. Previously, the leading approach was to prepare an entangled state of two photons, send one to one laboratory — conventionally called Alice's — and the other to a second laboratory, Bob's. By contrast, Hensen and colleagues' experiment should be regarded as using a three-party Bell inequality.

In this three-party approach (Fig. 1), Alice and Bob each prepare an entangled state of a photon and an electron, keep their electrons in a diamond lattice and send their photons to Juanita, as I'll call her. Alice and Bob then each choose a setting and measure their electrons, which can be done efficiently, while Juanita performs a joint measurement on the two photons. Alice's and Bob's outcomes will be purely random unless Juanita gets a rare 'successful' result, in which case the outcomes indicate entanglement between Alice's and Bob's electrons. Unlike Alice and Bob, Juanita always makes the same measurement, and so its inefficiency does not open a loophole.

Hensen and co-workers' experiment was made possible only by combining state-of-the art quantum technologies — it was performed in the Netherlands, but used diamond substrates prepared in the United Kingdom and fast random-number generators developed in Spain. Maintaining optimal operation of all the devices during the experiments was extremely challenging, and the rate of events (defined as Juanita getting a successful outcome) was only about one per hour. As a consequence, only 245 such events were recorded, and the statistical uncertainty in the reported Bell-inequality violation is comparatively large. Nevertheless, from a careful analysis of the entire data set, including runs in which Juanita did not get the desired outcome, Hensen *et al.* reject the local-realism null hypothesis at a confidence level conventionally considered to be statistically significant. It is to be hoped that more data will be generated soon.

The authors' approach might allow them to implement quantum-information protocols enabling secure communication, even when the devices used are not trusted by the users. For this to be practical, the event rate would have to be massively increased above its current level. However, the basic technology and the scheme (involving joint measurements by the intermediary Juanita) are promising.

The immediate significance of the reported experiment, however, is in hammering the final nail in the coffin of local realism. Some almost metaphysical loopholes remain open — if the results can be replicated with humans, rather than machines, freely choosing the measurement settings and consciously registering the outcomes, then the coffin will have been interred and buried. That experiment, however, is for many years hence. For the moment, we should celebrate Hensen and colleagues' landmark achievement in physics. ■

Howard Wiseman *is at the Centre for Quantum Computation and Communication Technology, Centre for Quantum Dynamics, Griffith University, Brisbane QLD 4111, Australia.*
e-mail: h.wiseman@griffith.edu.au

1. Bell, J. S. *Physics* **1,** 195–200 (1964).
2. Hensen, B. *et al. Nature* **526,** 682–686 (2015).
3. Wiseman, H. M. *J. Phys. A* **47,** 424001 (2014).
4. Freedman, S. J. & Clauser, J. F. *Phys. Rev. Lett.* **28,** 938–941 (1972).
5. Aspect, A., Dalibard, J. & Roger, G. *Phys. Rev. Lett.* **49,** 1804–1807 (1982).
6. Weihs, G., Jennewein, T., Simon, C., Weinfurter, H. & Zeilinger, A. *Phys. Rev. Lett.* **81,** 5039–5043 (1998).
7. Rowe, M. A. *et al. Nature* **409,** 791–794 (2001).
8. Giustina, M. *et al. Nature* **497,** 227–230 (2013).
9. Christensen, B. G. *et al. Phys. Rev. Lett.* **111,** 130406 (2013).

This article was published online on 21 October 2015.

NON-CODING RNA

Antibiotic tricks a switch

A screen for compounds that block a bacterial biosynthetic pathway has uncovered an antibiotic lead that shuts off pathogen growth by targeting a molecular switch in a regulatory RNA structure. **SEE ARTICLE P.672**

THOMAS HERMANN

The golden age of antibiotic discovery, between 1940 and 1960, was heralded by the work of Selman Waksman. A biochemist and microbiologist, Waksman coined the term 'antibiotic' and was the first to use systematic screening to discover antibacterial leads[1]. Efforts in his laboratory yielded more than 20 natural antibiotics — most notably streptomycin in 1943, the first effective treatment for tuberculosis[2]. The discovery won Waksman the 1952 Nobel Prize in Physiology or Medicine. Waksman's research caught the attention of scientists at the US pharmaceutical company Merck, and the ensuing collaboration was instrumental in developing streptomycin for clinical use. On page 672 of this issue, Howe *et al.*[3] from the research laboratories of the present Merck describe a new antibiotic lead, identified using a sophisticated refinement of the phenotypic-screening approach introduced by Waksman.

Seven decades after Waksman's research, the flood of antibiotics emerging from natural sources has dwindled to a trickle, and, for various reasons[4], few companies remain active in antibiotic drug discovery. This is despite an urgent clinical need for new agents in the face of rising resistance to existing antibiotics[5]. On this background, Howe and colleagues' surprising discovery of a drug target in a bacterial non-coding RNA (ncRNA) provides a welcome bright spot.