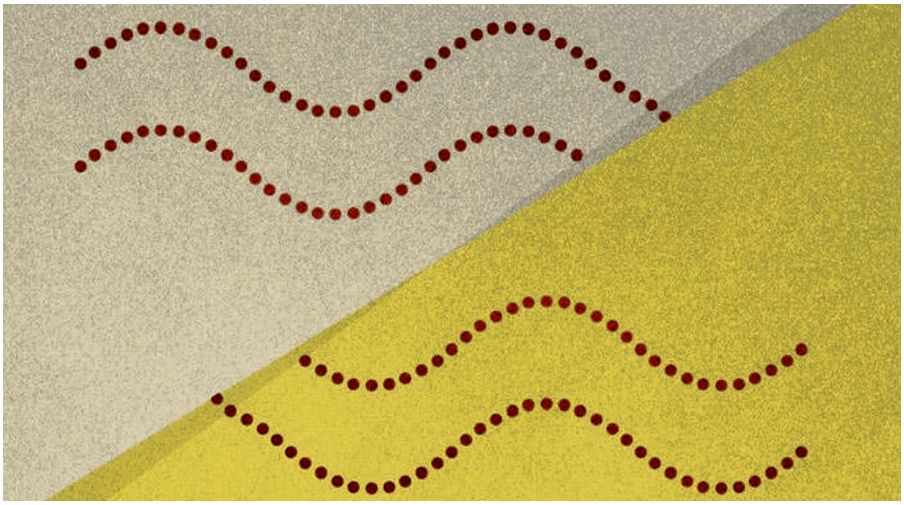


QUANTUM PHYSICS

Tripping the light fantastic

Geoff Pryde on the weird world of quantum entanglement.

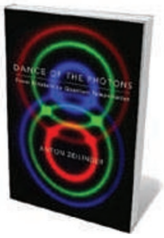
The only way to understand the quantum world is to measure it. This empirical view is dear to the heart of Anton Zeilinger, now at the University of Vienna, a leading figure in quantum physics through his work on correlated photons. In *Dance of the Photons,* he explores the phenomenon of quantum entanglement, the quantum correlations in the properties of particles.

When two photons are made to interact, they share their quantum information and become 'entangled'. If one travels off, it retains knowledge about its counterpart. So measuring one can determine the state of the other, even if they are far apart. Albert Einstein was worried by such reasoning: instant messaging between entangled particles contradicted his theory of relativity, which stated that signals cannot travel faster than the speed of light, unless you allow the crazy idea that particles do not have real properties independent of measurement. Quantum mechanics, he decided, was not up to explaining the world.

Zeilinger explains that Einstein was wrong. Experiments in the 1980s and 1990s proved the weird predictions of quantum entanglement to be true. Putting the reader in the role of discoverer, he describes these tests through the eyes of fictional students Alice and Bob, namesakes of the characters regularly put to work in explaining quantum physics. Examining the philosophical and technological implications of spooky quantum phenomena, he points to big issues that demand further thought — the inherent randomness of quantum physics and the role of the observer in determining a quantum particle's reality.

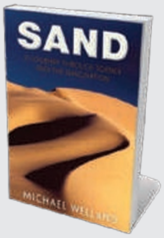
As well as giving an overview of other work, Zeilinger relates in detail his own group's research. For instance, he describes a 'delayed choice entanglement swapping' experiment he has carried out using four photons (1, 2, 3, 4). Two pairs share prior information: photons 1 and 2 are entangled, photons 3 and 4 are also entangled, but there is no correlation between those pairs. Making a particular type of quantum measurement — known as a Bell measurement — jointly on photons 2 and 3 entangles them and then destroys them. Through their prior links, this connection then entangles the states of photons 1 and 4, even though they have never interacted and may be very distant from one another. This remarkable property also has practical significance — the ability for two parties to share entanglement over long distances could have applications in secure communications and powerful distributed processing.

Even stranger things can happen. It is possible to delay the measurement on photons 2 and 3 until after photons 1 and 4 have been detected. One need not even decide whether to make that measurement until after 1 and 4 are detected. Yet the experiment seems to 'know' what you will do in advance: 1 and 4 appear entangled if a later measurement of 2 and 3 is made; they are not entangled if not. It is as if photons 1 and 4 knew the future — whether or not the measurement would be made at a later time. The state of the photon not only seems to depend on the choice of measurement, but also on measurements that are yet to be made. This has implications for our ideas about reality and time, but Zeilinger reminds us that we must always make a careful accounting of the data. The reward for following Alice and Bob's reasoning as they teach us how to puzzle out these types of result is a rich understanding of entanglement beyond the simplified picture.

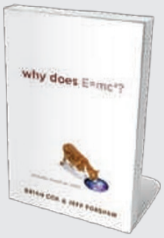


Dance of the Photons: From Einstein to Quantum Teleportation
ANTON ZEILINGER
FSG: 2010. 320 pp. $26

Zeilinger adds local colour throughout the book. In his tale, however, the real treasure of Vienna is not its opera, nor Ludwig Boltzmann's blackboard (which was used for the book's sketches), but a set of dark tunnels under the River Danube. These are home to a photon teleportation experiment, in which the quantum polarization state (which shows the orientation of the plane in which the light wave oscillates) of a photon on one side of



Sand: A Journey through Science and the Imagination
Michael Welland (Oxford Univ. Press, 2010; £9.99)
The world is visible in a grain of sand in geologist Michael Welland's acclaimed book. From dunes to ancient glass to electronics, he opens doors to its mysteries. "Nothing like it has been published before," wrote Andrew Robinson in his review of the hardback edition (*Nature* **460,** 798–799; 2009).



Why Does $E=mc^2$? (And Why Should We Care?)
Brian Cox and Jeff Forshaw (Da Capo, 2010; £8.99)
Physicists Brian Cox and Jeff Forshaw provide an accessible explanation of Einstein's iconic equation. They explain the equivalence of mass and energy and look ahead to investigations of the nature of mass at the Large Hadron Collider at CERN, the particle-physics lab in Switzerland.

the Danube is instantaneously transferred to a photon on the other side. Again, the author gives the science a human face: we meet Rupert, possibly a caricature of Zeilinger's postdoc, who is condemned to the tunnels to keep the equipment running. Fortunately, Zeilinger instils him with a sense of humour.

The Vienna group's latest entanglement experiments are performed on a far larger scale — between two of the Canary Islands. A telescope with a one-metre-diameter mirror is used to catch an entangled photon that has travelled 144 kilometres through the turbulent atmosphere. Optimizing the optics, stabilizing the pointing systems and synchronizing the electronics over picoseconds make these experiments challenging, but they have enabled even more careful tests of the counter-intuitive features of quantum entanglement. By using satellites to send the quantum signals, such techniques will one day allow us to distribute entangled information between far-distant locations on Earth.

The book concludes with an outlook of where entanglement will and won't take us. Teleporting humans may be out, as we can't entangle two atom-for-atom clones of a person. But the powerful way in which quantum states carry information opens the path to quantum computing and quantum cryptography. By sharing entanglement over optical fibres (as in the Danube experiment), secret keys can be distributed over short distances. Using entanglement swapping (as in the delayed choice experiment), we might build a quantum repeater — a device for extending key distribution over much longer ranges. Using satellites, secure worldwide communication networks between classical and quantum computers will become possible.

Dance of the Photons is an enjoyable introduction to the strange world of quantum phenomena and the technologies they empower. It gives a foundation from which to ponder the nature of randomness and reality — and whether, in Vienna, the photon dance is performed to a Strauss waltz. Maybe Rupert can tell us over a lager, if he's ever allowed out of the tunnels. ■

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MATHEMATICS

Deception by numbers

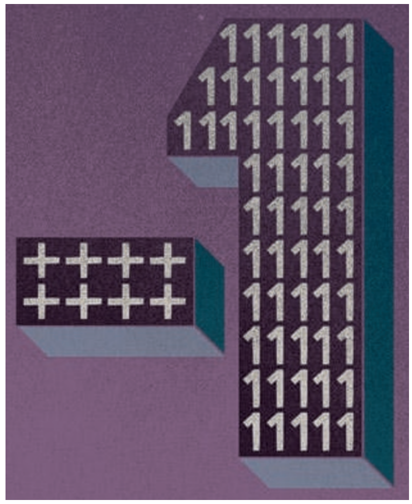
Jascha Hoffman reads about the rise of nonsense statistics in everything from adverts to voting.

The statement, published in a newspaper, that only 0.027% of US felony convictions are wrongful is false. Based on a back-of-the-envelope calculation, it was nevertheless quoted in a court case that ended with a prisoner being sent to his death. Such bad figures are "toxic to democracy", argues science journalist and former mathematics student Charles Seife in his latest book *Proofiness*, a field guide for spotting the numeric impostors. Seife's polemic against the reporters, politicians, scientists, lawyers and bankers who spread tenacious and specious statistical claims is strident but sobering.

Seife coins the term "proofiness" to refer to the misuse of numbers, deliberate or otherwise. He dubs the simplest quantitative sins "fruit-packing". These include: "cherry-picking" the data, as he says Al Gore did when describing climate change in *An Inconvenient Truth*; "comparing apples to oranges", as economics pundits do when they neglect to adjust for price inflation; and "apple-polishing", as when advertisers use graphics to mislead.

Proofiness: The Dark Arts of Mathematical Deception
CHARLES SEIFE
Viking: 2010. 295 pp. $25.95

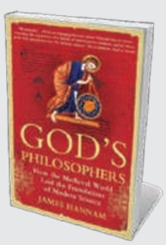
Seife finds bogus figures in every corner of public life — where there are numbers, they will be fudged. He does not spare his fellow hacks, citing the opinion poll as a method for journalists to manufacture their own stories. Surveys, no matter how large their



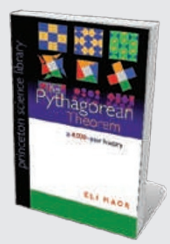
sample sizes and small their margins of random error, may be skewed by slanted questions, biased samples and lying respondents, he explains.

Even the simple act of counting ballots can be fraught with controversy, as in the contested Florida presidential recount in 2000. Claiming the margin of error to have been larger than the 537-vote difference between George W. Bush and Gore in that state, Seife suggests that the race should have been declared too close to call — and therefore, by Florida law, settled by the drawing of lots. He also describes economist Kenneth Arrow's impossibility theorem, which expresses how no voting system can fully capture the preferences of a group.

Seife faults some scientists, too, for over-interpreting their data and making extravagant causal inferences when the evidence is slim. This is particularly problematic in health and nutrition research, he argues,



God's Philosophers: How the Medieval World Laid the Foundations of Modern Science
James Hannam (Icon Books, 2010; £9.99)
Historian James Hannam debunks myths about the European 'dark ages', explaining that medieval people didn't think the world was flat. Rather, the many achievements during the period fed into the later works of Galileo and Newton.



The Pythagorean Theorem: A 4,000-Year History
Eli Maor (Princeton Univ. Press, 2010; $17.95)
Pythagoras's famous geometric theorem is central to science. Mathematics historian Eli Maor describes its origins and explains how it features in every scientific field today, pointing out that the formula was known by the Babylonians 1,000 years before Pythagoras.