"These results paint a shocking portrait of the research environment – and one we must all help change," says Jeremy Farrar, director of Wellcome, a major research funder in London that conducted the study with market-research agency Shift Learning. "A poor research culture ultimately leads to poor research."

Farrar says that Wellcome – which supports some 15,000 people working in science worldwide – is committed to addressing the issues highlighted by the survey, and he calls on the entire research system to get on board. "The pressures of working in research must be recognized and acted upon by all, from funders to leaders of research and to heads of universities and institutions," he says.

Unsustainable environment

Wellcome conducted the survey, published on 15 January, as part of a broader drive to improve working environments in science. It says the push for excellence has created a troubling culture. "It's more than clear that our current research practice is not sustainable," says Beth Thompson, who leads Wellcome's research-culture initiatives. "We knew things were not right, from our own discussions with scientists, from high-profile bullying cases, reports of misconduct and irreproducibility."

The results come from an online survey open to all researchers, which was answered by around 4,300 people across career stages and disciplines. Respondents hailed from 87 countries; three-quarters were in the United Kingdom. Workshops with 36 UK-based researchers and in-depth interviews with 94 also informed the findings.

Most researchers reported having pride in their institutions and passion for their work, but spoke of the high personal toll of their environment (see 'Cost of the culture'). Many accepted that pressure and long hours came with the territory – two-thirds of respondents said they worked for more than 40 hours a week. But researchers said that the situation was worsening and that the negative aspects were no longer offset by job security and the ability to work autonomously, flexibly and creatively. Barely 30% of respondents felt that there was job security in research careers.

Many blamed funders and institutes that emphasize performance indicators and metrics such as number of publications and the impact factors of journals in which researchers publish. They said that the importance of these metrics is often stressed in ways that reduce morale and encourage researchers to game the system. Some said that good management could shelter scientists from such distorting pressures, but that it was too seldom applied.

One-quarter of respondents thought that the quality of research suffered in the unsupportive environments. The same proportion had felt pressured by their supervisors to produce a particular result.

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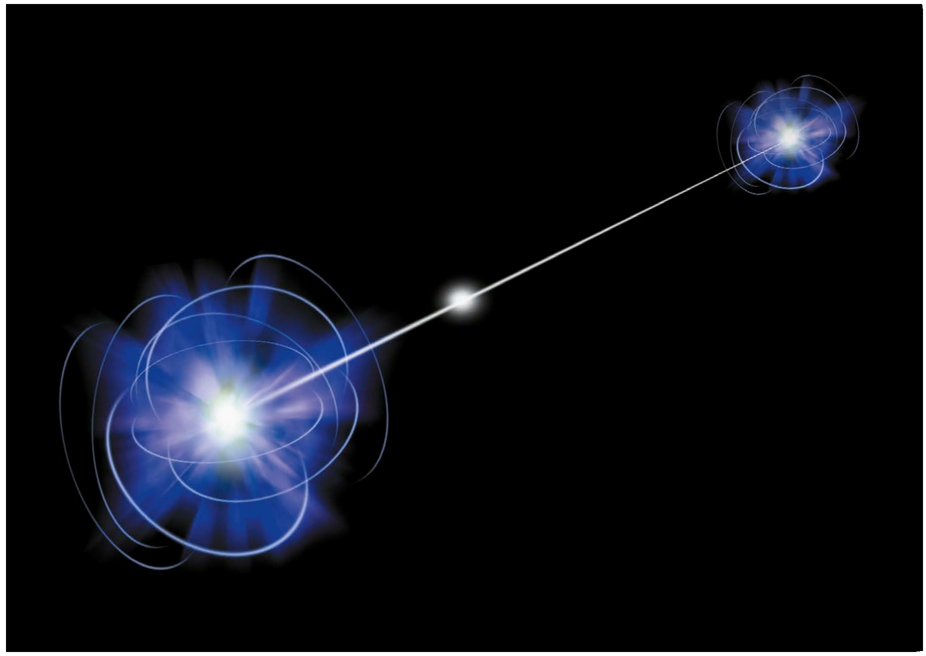

Quantum entanglement is at the centre of a new mathematical proof.

THE 'SPOOKINESS' OF QUANTUM PHYSICS COULD BE INCALCULABLE

Proof at the nexus of pure mathematics and algorithms puts 'quantum weirdness' on a new level.

By Davide Castelvecchi

Albert Einstein famously said that quantum mechanics should allow two objects to affect each other's behaviour instantly across vast distances, something he dubbed "spooky action at a distance"[1]. Decades after his death, experiments confirmed this. But, to this day, it remains unclear exactly how much coordination nature allows between distant objects. Now, five researchers say that they have solved a theoretical problem that shows that the answer is, in principle, unknowable.

The team's proof[2], presented in a 165-page paper, was posted on the arXiv preprint repository on 14 January, and has yet to be peer reviewed. If it holds up, it will solve in one fell swoop a number of related problems in pure mathematics, quantum mechanics and a branch of computer science known as complexity theory. In particular, it will answer a mathematical question that has gone unsolved for more than 40 years.

If their proof checks out, "it's a super-beautiful result" says Stephanie Wehner, a theoretical quantum physicist at Delft University of Technology in the Netherlands.

At the heart of the paper is proof of a theorem in complexity theory, which is concerned with efficiency of algorithms. Earlier studies had shown this problem to be mathematically equivalent to the question of spooky action at a distance – also known as quantum entanglement[3].

Quantum game theory

The theorem concerns a game-theory problem, with a team of two players who are able to coordinate their actions through quantum entanglement, even though they are not allowed to talk to each other. This allows both players to 'win' much more often than they would without quantum entanglement. But it is intrinsically impossible for the two players to calculate an optimal strategy, the authors show. This implies that it is impossible to calculate how much coordination they could theoretically achieve. "There is no algorithm that is going to tell you what is the maximal violation you can get in quantum mechanics," says co-author Thomas Vidick at the California Institute of Technology in Pasadena.

"What's amazing is that quantum

complexity theory has been the key to the proof," says Toby Cubitt, a quantum-information theorist at University College London.

News of the paper spread quickly through social media after the work was posted, sparking excitement. "I thought it would turn out to be one of those complexity-theory questions that might take 100 years to answer," tweeted Joseph Fitzsimons, chief executive of Horizon Quantum Computing, a start-up company in Singapore.

"I'm shitting bricks here," commented another physicist, Mateus Araújo at the Austrian Academy of Sciences in Vienna. "I never thought I'd see this problem being solved in my lifetime."

Observable properties

On the pure-maths side, the problem was known as the Connes' embedding problem, after the French mathematician and Fields medalist Alain Connes. It is a question in the theory of operators, a branch of maths that itself arose from efforts to provide the foundations of quantum mechanics in the 1930s. Operators are matrices of numbers that can have either a finite or an infinite number of rows and columns. They have a crucial role in quantum theory, whereby each operator encodes an observable property of a physical object.

In a 1976 paper[4], using the language of operators, Connes asked whether quantum systems with infinitely many measurable variables could be approximated by simpler systems that have a finite number.

But the paper by Vidick and his collaborators shows that the answer is no — there are, in principle, quantum systems that cannot be approximated by 'finite' ones. According to work by physicist Boris Tsirelson[5], who reformulated the problem, this also means that it is impossible to calculate the amount of correlation that two such systems can display across space when entangled.

"I thought it would turn out to be one of those questions that might take 100 years to answer."

Disparate fields

The proof has come as a surprise to much of the community. "I was sure that Tsirelson's problem had a positive answer," commented Araújo on one blog, adding that the result shook his basic conviction that "nature is in some vague sense fundamentally finite".

But researchers have barely begun to grasp the implications of the results. Quantum entanglement is at the heart of the nascent fields of quantum computing and quantum communications, and could be used as the basis of super-secure networks. In particular, measuring the amount of correlation between entangled objects in a communication system can provide proof that it is safe from eavesdropping. But the results probably do not have technological implications, Wehner says, because all applications use quantum systems that are finite. In fact, it could be difficult to even conceive an experiment that could test quantum weirdness on an intrinsically infinite system, she says.

The confluence of complexity theory, quantum information and mathematics means that there are very few researchers who say that they are able to grasp all the facets of this paper. Connes himself told *Nature* that he was not qualified to comment. But he added that he was surprised by how many ramifications it has turned out to have. "It is amazing that the problem went so deep and I never foresaw that!"

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