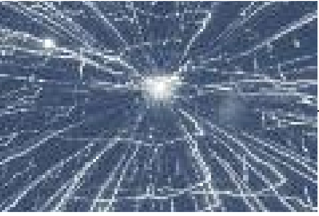


QUANTUM STEPS

THE NEXT BIG STEP IN QUANTUM PHYSICS COULD WELL COME FROM A DEVELOPING COUNTRY, SAYS LUIZ DAVIDOVICH (TWAS FELLOW 2002), PROFESSOR OF PHYSICS, AT THE FEDERAL UNIVERSITY OF RIO DI JANEIRO IN BRAZIL.

In the conventional (and, for physicists, classical) world we live in, people and things can be in only one place at one time. Those who think or say otherwise are, to say the least, thought to be a bit out of touch with reality.

But in the world of quantum physics, subatomic particles such as electrons theoretically exist in different places at the same time.

This aspect of quantum physics is called superposition.

Indeed superposition and other counterintuitive elements of quantum theory have been found to conform closely to both mathematical calculations and experimental evidence. This has made quantum physics both elegant and potentially applicable.

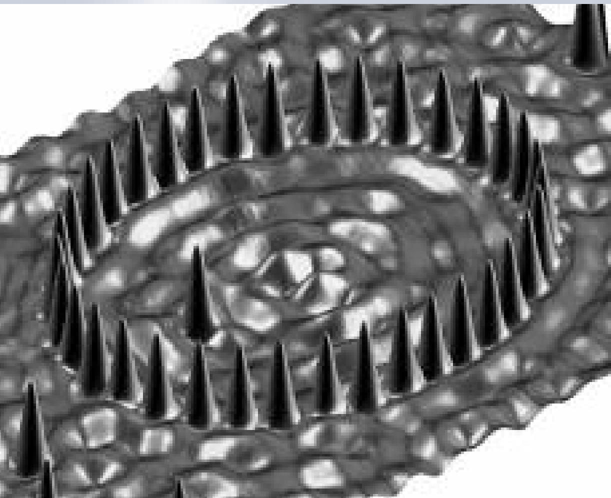
But such insights have posed gnarly questions for physicists, not the least of which is: How does this mysterious subatomic world translate into the world of macroscopic objects that we can see and touch?

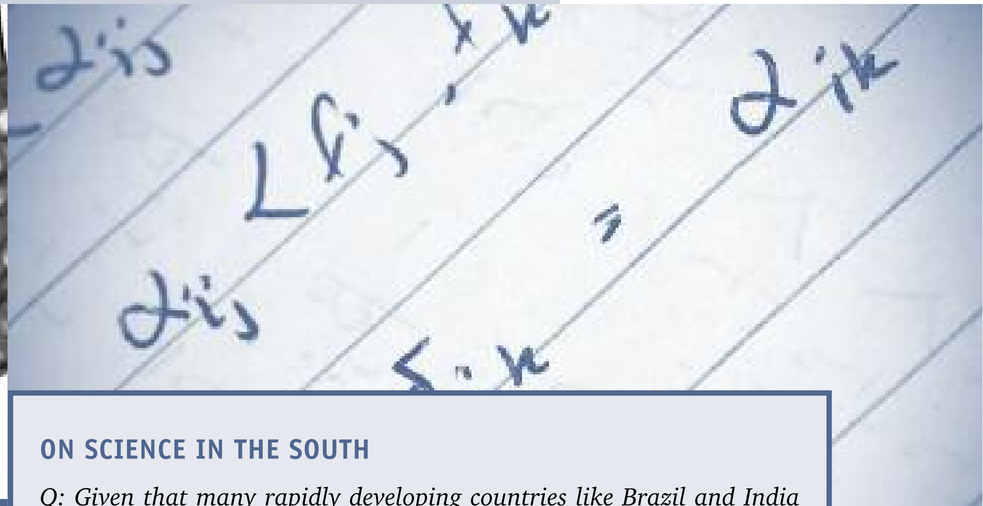
If all of this sounds mind-bendingly complex and confusing, don't fret. Quantum theory is notoriously difficult to grasp, let alone comprehend, even for physicists and mathematicians. As Richard Feynman, one of the field's superstars, is reported to have said in 'The Character of Physical Law', a series of lectures published in print by the BBC in 1965, "I think I can safely say that nobody understands it."

Luiz Davidovich, one of Brazil's most prominent quantum physicists and a TWAS member since 2002, has dedicated his professional life to investigating the weird (at least weird for non-physicists) world of quantum physics. One of the things he has been interested in is how the environment – that is, everything surrounding the particle – influences quantum phenomena. "It is the largely invisible neighbourhoods in which subatomic particles reside that likely hold the key to understanding the subtle transitions between the classical and the quantum world," he explains.

Davidovich's personal background is typical of the patchwork of nationalities and cultures that characterize the Americas' multi-ethnic and multi-cultural societies.

His grandparents came from Russia to Brazil in the beginning of the 20th century, escaping the turmoil of





ON SCIENCE IN THE SOUTH

Q: Given that many rapidly developing countries like Brazil and India are making such rapid advances in science and technology, how can TWAS continue to stay relevant to them?

Davidovich: "I believe the continued relevance of TWAS depends on two things. First, that it promotes the exchange of students and scientists, thus helping to foster understanding between different cultures and reducing the scientific gap between countries. Second, that it promotes the exchange of successful experiences in developing countries. This would include, for instance, strategic technologies, models for the development of science, technology and innovation, approaches to science education, and the structure of higher education. All of this is important for all developing countries, including Brazil, which, despite its growth in science capacity and excellence, still faces big challenges regarding capacity building and the promotion of innovation.

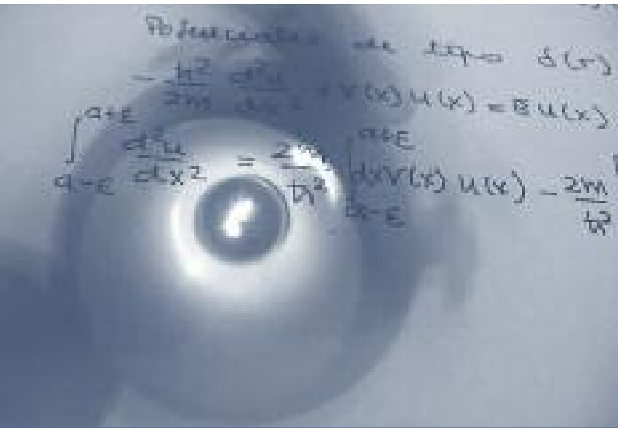
"All developing countries also confront challenges stemming from their late start. For this reason, they could all learn a great deal from the successes and failures of more scientifically advanced countries as well as from the experiences of countries that are in comparable stages of scientific capacity building and economic development. TWAS can help in this pursuit by fostering dialogue and collaboration."

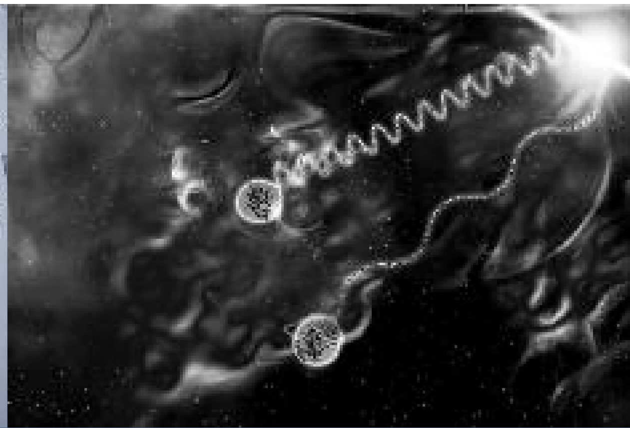
the Russian revolution, as did many of their fellow citizens. He says that at the time, people from the Old World didn't really know the difference between North and South America. For many, the New World was as mysterious as the quantum world is for many of us today. In fact, it was simply chance that landed his family far south of the Rio Grande. They could have just as easily wound up on the east side of Manhattan or the north side of Chicago.

Not that Davidovich ever saw working in a developing country as a drawback – especially now in such a rapidly developing country as Brazil.

In recent years, Brazil's science and technology budget has risen sharply. When former president Luiz Inácio Lula da Silva took office in 2003, total funding for science and technology stood at 21.4 billion reals (USD11.4 billion). By the time he stepped down last year after serving two terms, it had soared to 43.1 billion Brazilian reals (USD22.9 billion). Publications by Brazilian scientists in international peer-reviewed science journals leapt from 14,237 to 30,415 in the same period, according to data from Thomson Reuters.

"Physics in Brazil has certainly benefited from the strong push for science in general," he explains. Among other things, President Lula made sure that a portion of the taxes levied on Brazilian industries, such as the country's oil company Petrobras, were channeled back into the research community to stimulate additional growth. There was also more money for "blue-skies" research, including public funds for a National Institute of Science and Technology for Quantum Information that engages about 70 researchers in more than 10 institutions.





A great deal has been said about Brazil's rapid rise in international science and technology. But Davidovich reckons the best is yet to come.

"There are many projects that have not yet produced findings. For instance, Brazilian universities and research centres across the country have recently received money to launch laboratories in a broad range of fields. I think that we will see these laboratories generating significant results over the next few years," he says.

SYSTEMS QUANTUM

Davidovich's network spans the globe. He received his PhD in 1975 from Rochester University in New York, USA. He has worked at the *Seminar für Theoretische Physik* in Zürich, Switzerland, and visited universities and research centres in France, Germany, the USA, and the UK, to name just a few places, to pursue a broad range of collaborative research projects.

> ***Physics in Brazil has benefited from the strong push for science in general.***

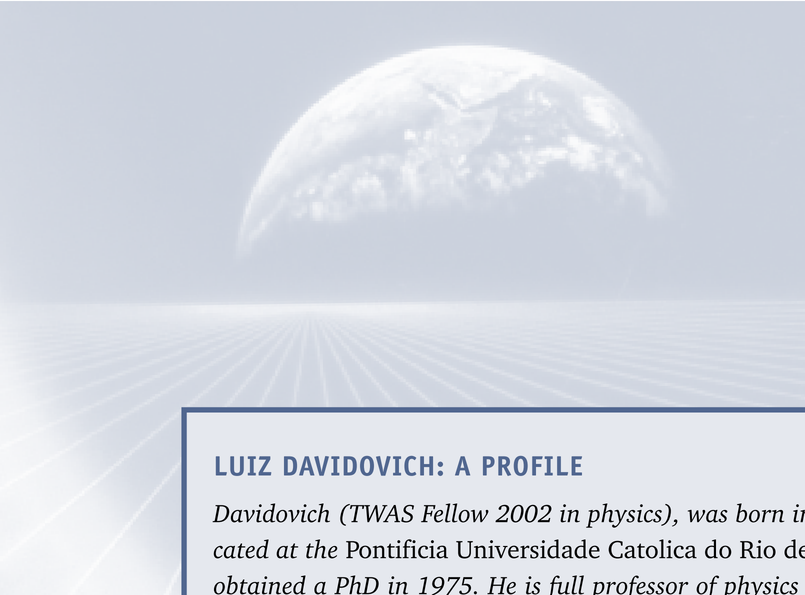
One of the seminal experiments he was involved in was with colleagues at *Ecole Normale Supérieure* in France. The initiative had to do with understanding how quantum systems turn into classical ones – that is, how systems that behave in strange counterintuitive ways begin to behave in ways that we are familiar with and that conform to our perceived notions of space and time.

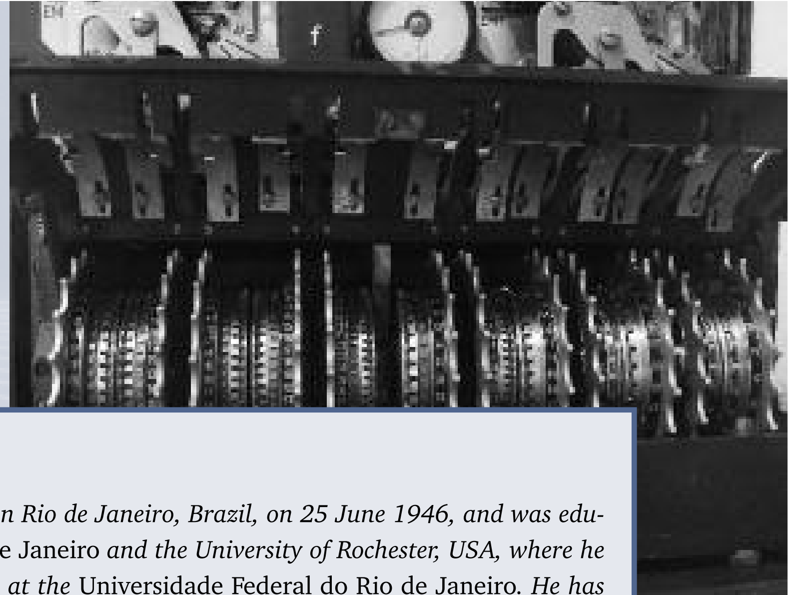
It turns out that the environment around the system plays a crucial role. The larger the system, the faster it loses its quantum characteristics. This explains why an electron can be observed in a superposed state, while a human cell cannot.

From there, it was not a big step for Davidovich to work on understanding what might arguably be called the holy grail of quantum theory applications – the quantum computer.

A quantum computer uses the quantum superposition of particles to carry out calculations much faster than classical computers. Such a computer would not only gain its creator fame but could also earn him or her a great deal of money by enhancing the accuracy and efficiency of a wide range of pursuits – some which would be legal and productive, but some others that could prove to be illegal and risky. For example, a quantum computer could be used to create more precise behavioural models of global climate. But it could also be used to crack high security encryption schemes that banks and the military rely on to keep information safe.

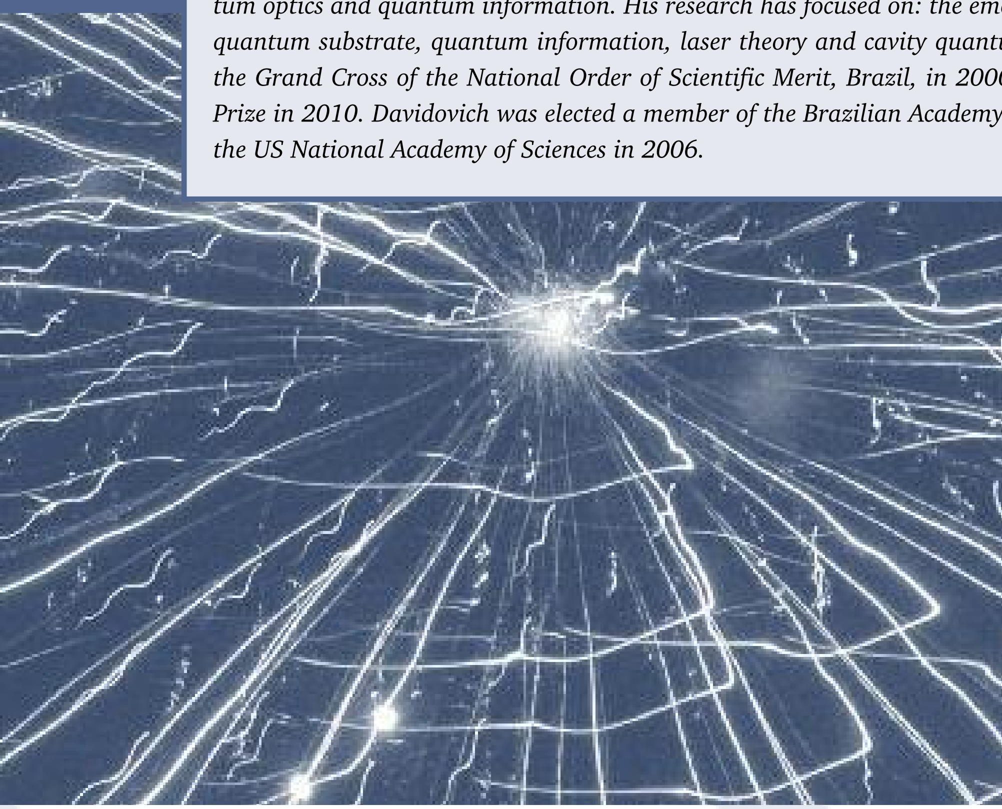
A popular way of encrypting secret data makes use of the fact that it is much easier to multiply large prime numbers with each other to calculate their product than it is to divide a given large number into its prime factors. Multiply large enough numbers together and you soon run out of time in the universe to factor it into primes. Banks and governments rely on this to protect sensitive information. It is part of the mathe-





LUIZ DAVIDOVICH: A PROFILE

Davidovich (TWAS Fellow 2002 in physics), was born in Rio de Janeiro, Brazil, on 25 June 1946, and was educated at the Pontificia Universidade Catolica do Rio de Janeiro *and the University of Rochester, USA, where he obtained a PhD in 1975. He is full professor of physics at the* Universidade Federal do Rio de Janeiro. *He has held a number of visiting scientist positions in France, Germany, the USA and the UK. His interests cover quantum optics and quantum information. His research has focused on: the emergence of the classical world from the quantum substrate, quantum information, laser theory and cavity quantum electrodynamics. He was awarded the Grand Cross of the National Order of Scientific Merit, Brazil, in 2000, and the Brazilian National Science Prize in 2010. Davidovich was elected a member of the Brazilian Academy of Sciences in 1996 and a member of the US National Academy of Sciences in 2006.*



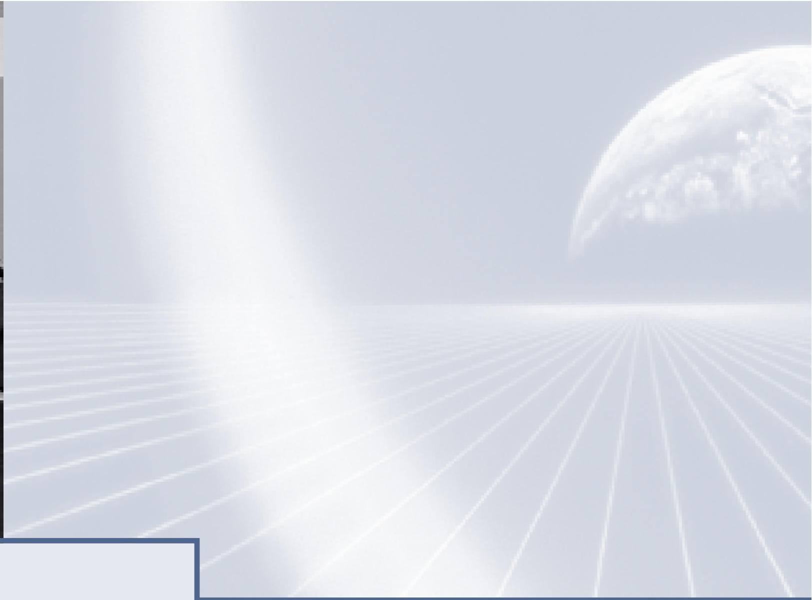
matical puzzle pieced together to protect the sensitive credit card information that customers give out when buying goods from reputable sites on the internet. However, a quantum computer would drastically reduce the time it would take to factor primes, allowing its owners to break the code and turn the world – not to mention your wallet – upside down overnight.

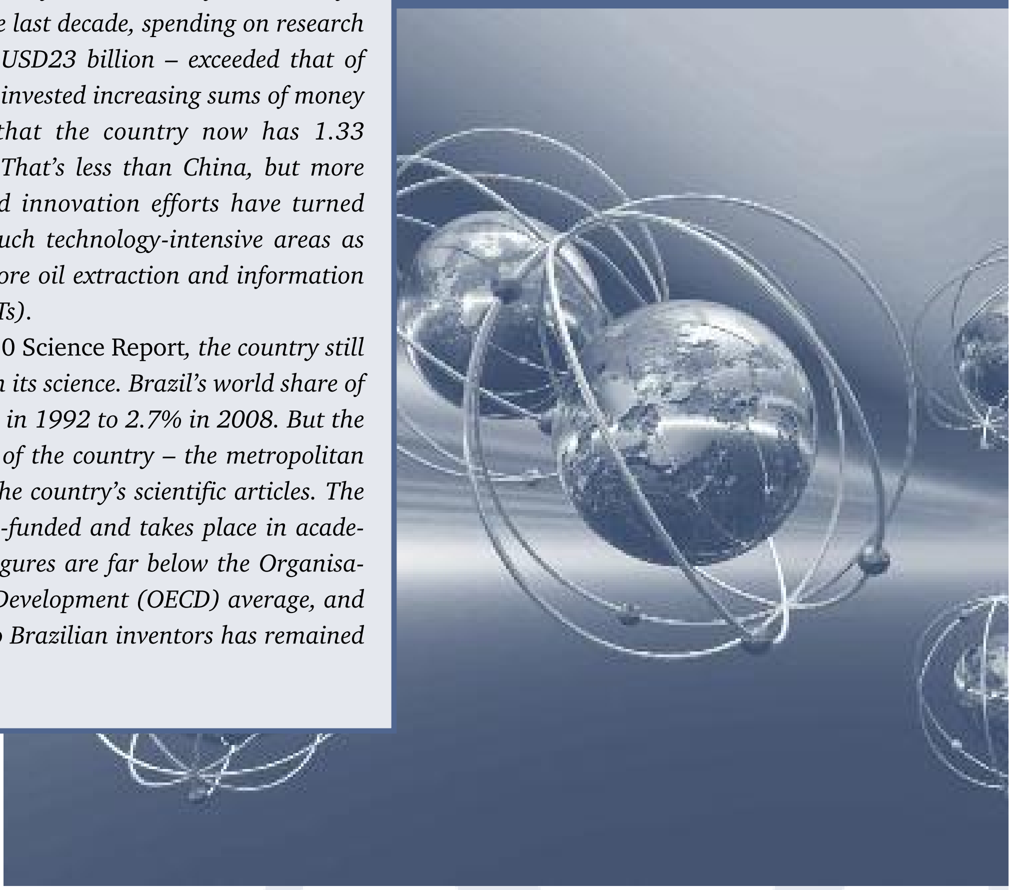
The issue caused such a worry after it was discovered in the 1990s, says Davidovich, that the US military would issue calls for research proposals on the topic from anywhere in the world, on the condition that the results from the research were published at workshops held in the US. "In other words, if somebody came up with a way of building a quantum computer, the US military wanted to know about it," says Davidovich.

However, a quantum computer is easier to envision in theory than it is to build in practice. And, when all is said and done, a chalkboard computer is no computer at all.

To break modern cryptography, you would need a computer made up of a system of 1,000 particles, says Davidovich. But such large collections of particles easily deteriorate into classical states. In an article published in 2007 in the journal *Science*, Davidovich and his colleagues in Brazil showed how something called 'entanglement' between particles – crucial to the concept of quantum computing – was frightfully easy to destroy.

"Physicists call that the sudden death of entanglement," he says. Entangled particles are special. That's





SCIENCE IN BRAZIL

Brazilian science has exploded in recent years. Driven by the country's extraordinary economic growth in the last decade, spending on research and development (R&D) in 2008 – USD23 billion – exceeded that of Spain and Italy. The government has invested increasing sums of money into PhD training. The result is that the country now has 1.33 researchers per 1,000 labour force. That's less than China, but more than Mexico. National research and innovation efforts have turned Brazil into a prominent player in such technology-intensive areas as biofuels, agricultural research, off-shore oil extraction and information and communication technologies (ICTs).

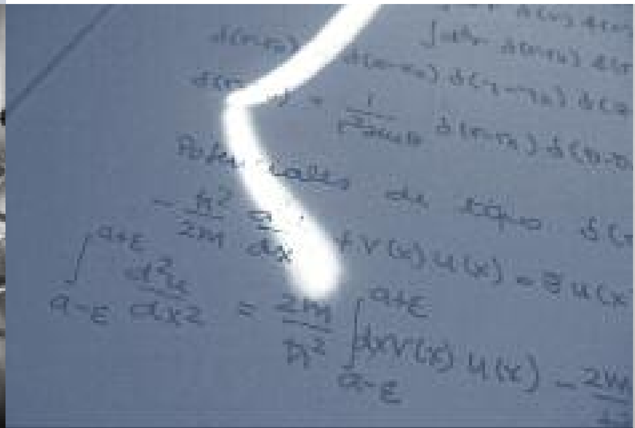
However, according to UNESCO's 2010 Science Report*, the country still lags behind in terms of capitalising on its science. Brazil's world share of articles may have climbed from 0.8% in 1992 to 2.7% in 2008. But the growth comes mainly from one part of the country – the metropolitan area of São Paolo produces 60% of the country's scientific articles. The lion's share of R&D in Brazil is state-funded and takes place in academia. The country's industrial R&D figures are far below the Organisation for Economic Co-operation and Development (OECD) average, and the number of US patents awarded to Brazilian inventors has remained stagnant.*

because, while an observer can measure the global state of an entangled pair of particles – their relative position to one another – you cannot know the individual positions of the two particles.

"You don't know, not because you haven't looked, but because the positions are in an "entangled state."

Stated another way, once you measure the position of one of the particles, you can infer the corresponding property of the other, since you know its relative position with respect to the measured particle. But this measurement leads to a change of the state of the two particles, so it is still impossible to assign a specific property to each particle before the measurement was made."

In this sense, quantum physics is a lot like real estate. The key to the value of both lies in location,


location, location. But since you are never certain of the location of quantum particle, you can never know its value.

QUANTUM DIFFICULTIES

The experiment outlined in *Science* found that quantum entanglement was less resistant to the environment than other properties of the particles, such as their energies.

The findings were bad news for quantum computing, but good news for banks and defence ministries. "This implies that there are many deeply embedded difficulties to building quantum computers," says Davidovich.

In fact, Davidovich is sceptical that anyone will gain the knowledge and insights they need to build a quantum computer of the kind that can crack security encryptions with the technologies that are currently available.

"Many people have tried to build systems of many entangled atoms. The latest system, constructed in Innsbruck, Austria, in 2010, entangled 14 atoms. But the "entangled" state that was produced was far from the ideal state that scientists would need to construct an encryption-breaking quantum computer. Moreover, as the system grows in complexity, so do the imperfections. "If you want to have 1,000 entangled atoms as part of the system to ensure its effectiveness, the current intellectual building blocks that can be used to construct the system are not likely to allow you to do this," Davidovich says.

However, he is more upbeat about the possibilities of building quantum computers for the purpose of simulating quantum systems. This would enable researchers to do the kind of modelling that is currently impossible with classical computing speeds. "I think here we have good prospects for success," he says.

So, the current state of research should build public confidence that, in fact, this research can have a positive impact on society. For example, quantum computers that can aid in understanding complex processes in nature could well be on their way, according to Davidovich. However, quantum computers that could prove effective in breaking computer codes and, in the wrong hands, that could be used to access sensitive personal information and critical military data won't be available any time soon and may never become a reality.

You can't buy technology from abroad at the cutting edge of knowledge.

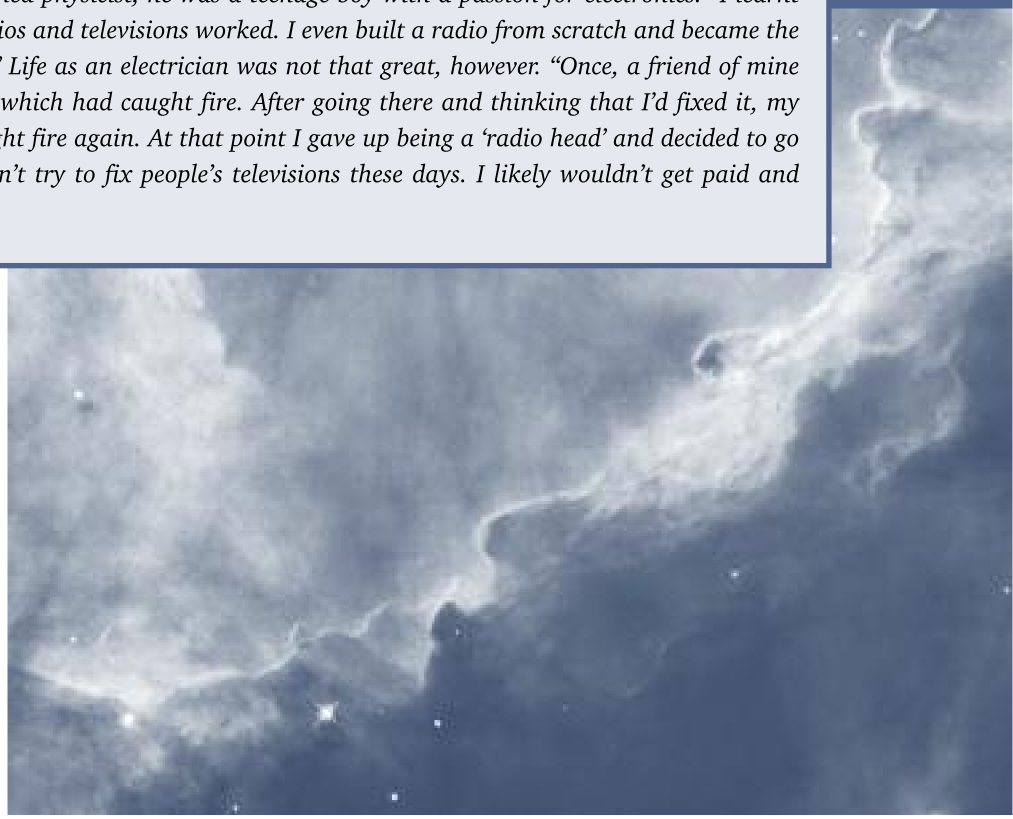
LEVELLING THE FIELD

What is more, Davidovich believes developing country scientists will play a leading role in the next steps in quantum theory.

"To build a quantum computer that could do something like find the prime factors of a large number, you need new ideas," he says, "and new ideas can come from anywhere. What is required is an inviting ambience that encourages creativity and bright young peo-

THE RELUCTANT ELECTRICIAN

Before Luiz Davidovich was a renowned physicist, he was a teenage boy with a passion for electronics. "I learnt via a correspondence course how radios and televisions worked. I even built a radio from scratch and became the go-to person for when radios broke." Life as an electrician was not that great, however. "Once, a friend of mine wanted me to fix his family's radio, which had caught fire. After going there and thinking that I'd fixed it, my friend called me and said it had caught fire again. At that point I gave up being a 'radio head' and decided to go into more theoretical work. I wouldn't try to fix people's televisions these days. I likely wouldn't get paid and might get sued."



ple to turn their minds to these problems. Obviously, you don't need to be in the United States or Europe for this to happen."

He hopes that other developed countries will follow Brazil's lead and think seriously about building their capacity for conducting research and encouraging innovation within their borders.

"The idea that research and innovation can be bought is flawed," he says. "Some years ago influential people in Brazil said that we didn't need to develop high technology because we could buy it from other countries. But you can't buy technology from abroad at the cutting edge of knowledge. It's not for sale. And technology changes so fast that by the time you get to use it, it's no longer new. That means you are always behind the curve. When the Brazilian government started to put money into research, it was based, in part, on the notion that it's always better for a country to be ahead of the curve than behind it."

That, Davidovich might have added, is not just true for countries but also true for both the classical and quantum worlds. Then again, as research conducted by Davidovich and other physicists has shown, when it comes to the world of quantum physics, it's theoretically possible to be both ahead of and behind the curve at the same time. ■