50 ideas to change science forever: Nanotechnology

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Quantum mechanics will go mechanical and your computer will run on ghostly knots, or spintronics, or maybe even slowed-down light

No small matter (Image: Eyes of Science/SPL)

Quantum optomechanics

Exploring the quantum-classical boundary

At the heart of modern physics lies a circle to be squared. Experiment tells us time and time again that the world at its most fundamental works according to the counter-intuitive laws of quantum mechanics. And yet the macroscopic world we live in seems solidly classical.

Quantum optomechanics could help us resolve this paradox. It uses the pressure of confined photons, the quantum-mechanical particles of light, to manipulate the properties of mechanical objects ranging from the nanoscale to the macroscale.

Recent experiments have, for example, demonstrated how laser cooling - a technique initially invented to cool clouds of atoms - can be used to curb the vibrations of small mechanical devices. This opens up the fascinating prospect of mechanical resonators operating at the frigid temperatures where quantum effects come into play.

Such quantum resonators would have applications in sensing, metrology and quantum information processing, but what I find most intriguing is the possibility that an object visible to the naked eye can be put into a quantum superposition between two separated locations - so it is both here *and* there. Testing the predictions of quantum theory in a completely new regime of size and mass will bring fresh insights into where the boundary between the classical and the quantum worlds lies - and perhaps even to the great unfinished business of unifying quantum physics and gravity. **Markus Aspelmeyer**

Markus Aspelmeyer researches the foundations of quantum physics at the University of Vienna, Austria

Slow light

Lowering the speed limit

Light, the fastest thing in the cosmos, can be slowed to walking pace or even stopped in its tracks. Who would have thought it?

Actually, it is a sleight of hand: it is not the light that is slowed or stopped, but the information that it carries. Send an energy-tuned pulse of light into a cloud of supercooled atoms known as a Bose-Einstein condensate, and it resonates with the atoms of the condensate, allowing information to be transferred from the light to the atoms. A second laser pulse can then pull the information out of the atoms and carry it away.

This is good news. If we can master the fiddly details of the technique, the ability to store light-borne data indefinitely could usher in the age of super-fast optical computers that do away with cumbersome silicon components.

Topological insulators

A new spin on electronics

For the time after electronics there is spintronics, in which information is transported and devices controlled not by currents of many electrons, but by the quantum-mechanical spins of individual electrons.

There are still a few obstacles on the way. One is that spin is a magnetic effect, but on the small scale of, say, a computer chip, we only really know how to manipulate electric fields.

That is where topological insulators come in, a new class of material only postulated in 2005. Quantum-mechanical effects within them allow the spins of electrons on their surfaces to be controlled directly by electric fields.

The result is an "electron superhighway" along which electrons flow in one-way "lanes" according to their spin. Collisions are suppressed and business is conducted altogether more smartly than on a conventional silicon chip, so they don't heat up as much as today's power-hungry chips. If the technique can be scaled up, the result could be cooler, faster spintronic devices for all.

Anyons

The fillip that quantum computing needs?

Some human tribes have been encoding numbers in knots for millennia. The tribe known as physicists has recently discovered that quantum particles can encode numbers too. Now they are tying the two ideas together, using particles' convoluted trajectories to represent bits of information.

The study of knots is known as topology, and topological quantum computing could create a revolution in number-crunching. The particles involved are not your average electrons or atoms, but non-Abelian anyons, ghostly entities that exist only as the product of the motion of other things. If you want the eye of a storm, you first need a storm; if you want non-Abelian anyons, you first need to create and control particular electron movements in disappearingly thin two-dimensional crystals.

That is still presenting a knotty problem, but success could see us finally harnessing supercharged quantum computing power.

Magnetic monopoles

Electromagnetism's missing link

Break a bar magnet in half and, like the broom in Disney's *The Sorceror's Apprentice*, you get two new magnets, each with two poles. Can you ever have just one pole - a monopole?

Yes, say physicists. Magnets are described by the theory of electromagnetism. The "electro" side involves attractive and repulsive forces and isolated positive and negative charges, so symmetry demands that the attractive and repulsive forces of magnetism should also be accompanied by isolated poles. What's more, our best theory describing the earliest moments of the universe requires monopoles to exist.

So for the past 80 years we have been combing through environments as diverse as moon dust, cosmic rays and the debris of collisions in particle accelerators to find them. We've just started seeing things that fit the description in highly specialised crystals known as spin ices. But the question is still whether we will ever spot one in the wild.

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