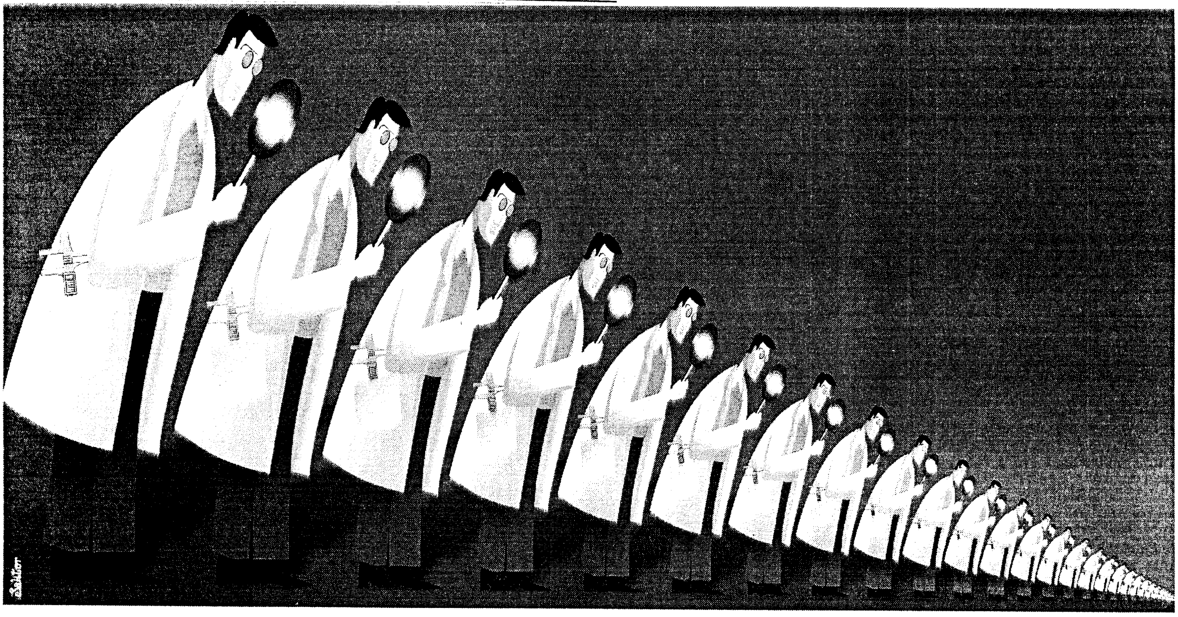


Hot world of cold atoms

An ultra-cool wave is sweeping across quantum physics, reports **Leigh Dayton**

WILLIAM Phillips works in what's definitely a three-dimensional physics laboratory in Gaithersburg, Maryland. But he has spent the past few months stuffing three-dimensional atoms into a one-dimensional world — just to see what happens.

"Weird things happen when you change the dimensions of the world you live in," says the multi-dimensional Phillips, a Nobel laureate, physicist and head of the laser cooling and trapping group of the US National Institute of Standards and Technology.

Cooling, trapping, atoms, weirdness and shifting dimensions — if this all seems baffling, just wait. Things are about to get stranger still. That's because Phillips and his misbehaving atoms are part of the hottest new field of quantum physics, cold atoms, also called atom optics. And cold is definitely the operative word, as University of Queensland physicist Peter Drummond explains.

"In the 20th century, the biggest thing in ultra-cold physics was liquid helium, which is four degrees above absolute zero," he explains, adding that absolute zero is so cold that even atoms and molecules barely budge. "In the last decade we've gone so far beyond that it's unbelievable. We're now a billion times colder than that."

In other words, scientists have whipped up in their laboratories the coldest material that has existed anywhere in the universe.

As Phillips and Drummond note, at such incredibly cold temperatures the unexpected is expected. That's why physicists worldwide are jumping on the cold-atom bandwagon.

"It's like opening up a whole new universe," says Hans Bachor, a physicist with the Australian National University and the driving force behind the new Australian Research Council Centre of Excellence for Quantum-Atom Optics, a consortium of scientists with the ANU, UQ, and Melbourne's Swinburne University of Technology.

Phillips, Drummond and Bachor all wax lyrical at the promise of cold atoms, from fundamental research to faster, smaller and more powerful nano-machines and devices. They're not alone. "The possibilities for new science and technologies are mind-boggling at the moment," says Keith Burnett, head of atomic and laser physics at Britain's Oxford University.

The pace of discovery is certainly as breathtaking as the concept of cold atoms. Last year, for instance, the centre became one of just five groups in the world to build an atom laser, a device that fires a stream of all-in-step frozen atoms — in this case rubidium atoms — so fine that it's invisible to the naked eye.

International teams have also begun to experiment with something called the Bose-Einstein condensate, a strange state of matter that was predicted more than 70 years ago, yet only created experimentally in 1995 when researchers showed that intensely cold atoms behave like waves and form a gigantic matter-wave. The condensates are being used as the source of atoms for the newfangled atom lasers.

Just this year, teams of physicists, including Burnett's, have created super molecules, the largest particles known to follow the mysterious rules of quantum physics. Until now the workhorse of quantum physics was the photon of light.

"It has no mass and the wave-like properties of the photon are particularly easy to see," Drummond says, hinting that another Nobel prize for work on all things cold is tipped for the super-molecule people. Phillips earned his gong for developing methods to cool and trap individual atoms.

With so much intellectual energy flowing, the ARC centre — funded from 2003 to 2007 — is next week sponsoring an international workshop to tap into the hottest developments in this coldest of realms. Phillips and Burnett are on the guest list, along with leaders from France, Canada, Israel and New Zealand.

Bachor is keen to ensure that Australia is not progressively left out when the next generation of scientists bring the theoretical promise of the frontier field in from the, well, cold. That's why the overseas hot shots have agreed to participate in a summer school, sponsored by the centre, for 62 budding physics students from Australian, NZ and Singaporean universities.

"If we want to take on the US and Europe we have to be competitive and we have to co-operate within Australia and New Zealand," says Bachor, who thinks big as well as small. "We need to be a regional powerhouse."

To get a real-world feel of the power of cold atoms, Bachor suggests an intellectual tour of the atom laser. It is, he says, a "scientific toolbox" that will allow scientists to build things such as exquisitely sensitive sensors for nano-machines or futuristic communication systems filled with enormously powerful and vanishingly small quantum chips.

The atom laser could also give existing optical lasers the boot in many everyday applications such as CD and DVD players. That's so, Bachor says, because the beam of matter produced by the laser is potentially far more precise than the beam of light kicked out by optical lasers.

Phillips adds that the kind of precision offered by atom lasers and super-cold atoms would push the bounds of accuracy in applications as diverse as scientific instruments such as interferometers, gyroscopes and even global positing systems and clocks.

"Atomic clocks are the most accurate clocks we've ever had. But the atoms are moving so fast that the time to make the necessary measurements is limited. But by getting the atoms cold they move very, very slowly so we can make the clock even better," Phillips says.

Proving the point, Phillips is deeply involved in an atomic clock space mission scheduled to fly to the International Space Station in 2008. The idea is to study laser-cooled atoms in microgravity. "We're also thinking of using cooled atomic clocks on interplanetary missions or to explore Mars, places where you need more accuracy but you can't update [precision settings] as easily as on Earth."

While such projects are exciting and potentially useful, the real enthusiasm for the cool crowd is the prospect of testing the theories of quantum physics, or mechanics, the system of laws that govern the behaviour of matter and energy at the atomic level. "At the moment, we all believe quantum mechanics is correct. It seems to describe nature with remarkable accuracy," Phillips says. "But we have to test it to see if it's true."

He says Bachor's scientific toolkit can also be applied to solutions to the "thought problems" of great thinkers who didn't have the technology to put their ideas to the test, referring particularly to Albert Einstein.

"The year 2005 is the 100th anniversary of Einstein's annus mirabillus," Phillips observes. "In 1905, he published three papers that revolutionised everything: the photoelectric effect, the Brownian effect and special relativity. We'd like to make accurate tests of his theory, especially gravity," he says.

Here Phillips echoes the sentiments of his colleagues. It's easy to imagine them reciting a scientific version of the well-loved nursery rhyme *The House that Jack Built*. Cold atoms will be the tools that build the devices to test the theories that Einstein built. If so, they're giving an ironic spin to the quantum world, a universe where things are precisely imprecise. It all makes Phillips's one-dimensional atoms look like intellectual child's play.

Quantum's ripple effect

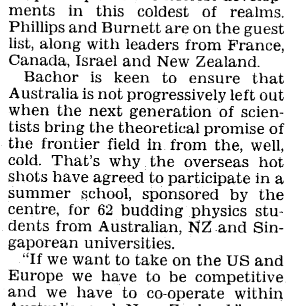
WE live in a quantum universe. According to leading cosmologist and physicist Paul Davies, it's a misconception that the complex field of quantum physics, or quantum mechanics, applies just to the tiny world of molecules, atoms, subatomic particles and the strange things they get up to.

"Increasingly, scientists believe quantum physics is the correct theory of the whole world," Davies says from Macquarie University's Australian Centre for Astrobiology. That is, the whole of reality, the entire universe, behaves according to the weird rules that dictate the maybe this, maybe that quantum behaviour of elementary particles of energy and matter.

"Today the universe is very big, but once it was very small – small enough for quantum effects to be very important," Davies explains. "Most cosmologists believe that the birth of the universe was a quantum event. We can't understand how the universe came to exist except as a quantum mechanical process."

Moreover, after that "originating event" roughly 13 billion years ago, quantum mechanics continued to drive cosmic history. For instance, in the first trillion trillion trillionth of a second, the universe enormously inflated in size to become very smooth, and so-called "quantum fluctuations" imprinted tiny but conspicuous rumples on the smooth background. "These quantum ripples can be seen today, writ large in the sky, as hot and cold splodges in the heat radiation left over from the big bang," Davies says.

Those ripples were the seeds of the galaxies. And because everything from plants to people is made of material created in the explosions of stars, Davies says we owe our existence to those "ripples at the edge of time" and to the quantum mechanics that built them.



Creative forces: The Whirlpool Galaxy