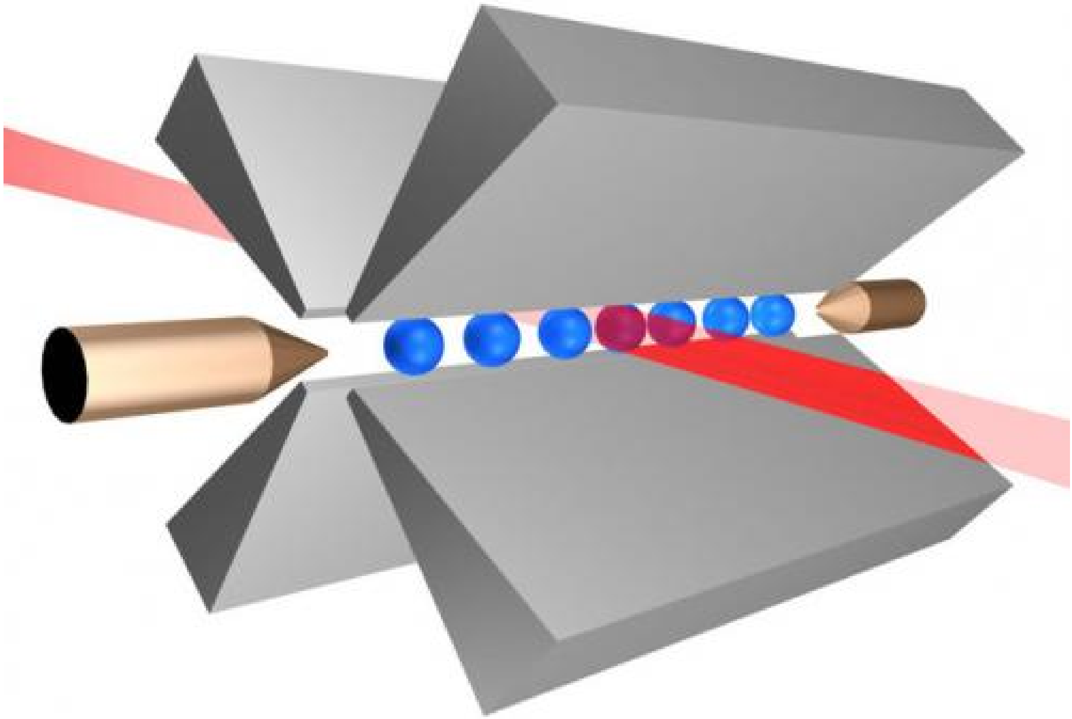
Quantum computer makes finding new physics more difficult

January 29 2015, by Pete Shadbolt



An ion trap of the type used in the experiment. Credit: Institute of Theoretical Physics, Innsbruck

Physicists often work unusual hours. You will find them running experiments at 4am and 10pm. This is because, so long as the pertinent conditions inside a lab – such as temperature or light level – are fixed, the outcome of an experiment should not depend on location of the lab in space or time.

This property of the world to behave according to the same laws of physics everywhere is called Lorentz covariance, after the Dutch Nobel-Prize winner Hendrik Lorentz. All existing evidence suggests that the world is naturally Lorentz covariant.

Even a small violation of this property would be shocking. In particular, it would imply the existence of a "preferred frame": by travelling at an appropriate velocity, in just the right part of the universe, an observer would perceive physics to be significantly simpler than it is from all other points of view. Such a violation would break the standard model, our best description of the behaviour of light and matter.

Disappearing aether

Historically Lorentz covariance has not always been accepted. In the late 19th century, many scientists supported the idea of an aether, a homogeneous material permeating the universe, relative to which all light moves. As the Earth travels through the aether, light travelling in the same direction as the Earth should appear to move slowly, while light travelling in the opposite direction should appear to zoom past – like an express train on the other side of the tracks. In 1887, this idea was soundly rebuffed by an experiment by Michelson and Morley, who showed that the speed of light is constant, regardless of the orientation or motion of the lab.

Since the Michelson-Morley experiment, Lorentz covariance has been tested in a wide variety of experiments, to increasingly high precision. Even a very tiny asymmetry would break our models and so these new experiments can only ever increase our confidence in a Lorentz-covariant world: it remains conceivable that a violation will one day be detected. Some modern quantum field theories flaunt the rules. Searching for experimental violations has the appeal of a lottery – with very small probability, you could discover fundamentally new physics.

If new physics is waiting to be found, it just lost a big hiding place. New results, published today in *Nature*, dramatically improve the precision with which Lorentz covariance can be tested. The research was performed by the research group of Hartmut Häffner at the University of California at Berkeley.

Quantum computers to the rescue

Häffner's day job is quantum computing. Using electrons associated with single atoms (ions) of calcium, suspended in an electric trap at extremely low temperatures, Häffner and his team can create qubits.

Qubits are the quantum-mechanical analogue of classical bits – the 0s and 1s that run our classical computers. But they are unlike classical bits and more like Schrodinger's cat, because they can be "dead" and "alive" at the same time, which is to say they can be in two different states at once.

The world at the scale of an electron works very differently than the one we live in. But suspending our beliefs of the world of big things has plenty of benefits. Quantum computing has the promise of very powerful applications, including efficient code-breaking and fast simulation of chemical reactions. It has driven massive development of quantum computing hardware, drawing interest from Google, Microsoft and the UK government.

Häffner realised that this new fancy hardware could be used for experiments unrelated to quantum computing. It occurred to him that two entangled qubits could serve as sensitive detectors of slight disturbances in space.

"I wanted to do the experiment because I thought it was elegant and that it would be a cool thing to apply our quantum computers to a completely different field of physics," he said. "But I didn't think we would be competitive with experiments being performed by people working in this field. That was completely out of the blue."

Häffner and his team conducted an experiment analogous to the Michelson-Morley experiment, but with electrons instead of photons of light. In a vacuum chamber, he and his colleagues isolated two calcium ions, partially entangled them as in a quantum computer, and then monitored the electron energies in the ions over a period of 24 hours.

If space were squeezed in one or more directions – if the world is not Lorentz-covariant – then the orientation of the lab would make a difference to the energy of the electrons. This would give rise to a noticeable oscillating signal over a 12-hour period, as the earth rotates. It didn't, showing that space is uniform in all directions, and doesn't change shape for any reason. Häffner's experiment achieved a precision of one part in a billion-billion, 100 times better than previous experiments involving electrons, and five times better than optical tests such as the Michelson-Morley experiment.

Häffner now hopes to make more sensitive quantum computer detectors using other ions, such as ytterbium, to gain another 10,000-fold increase in the precision measurement of Lorentz symmetry. He is also exploring with colleagues future experiments to detect the spatial distortions caused by the effects of dark matter particles, which are a complete mystery despite comprising 27% of the mass of the universe.

"For the first time we have used tools from quantum information to perform a test of fundamental symmetries, that is, we engineered a quantum state which is immune to the prevalent noise but sensitive to the Lorentz-violating effects," Häffner said. "We were surprised the experiment just worked and now we have a fantastic new method at hand which can be used to make very precise measurements of perturbations of space."

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Citation: Quantum computer makes finding new physics more difficult (2015, January 29) retrieved 13 September 2024 from https://phys.org/news/2015-01-quantum-physics-difficult.html