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It is a quantum fractal algorithmic universe

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Open Technology Grant For 2D Single Photon Emitters

Information technologies are at the heart of modern society. The future of this sector lies in quantum information technologies, which promise a big leap forward in computation and communication. The Dutch Research Council (NWO) has awarded a consortium with an €850,000 Open Technology Grant to develop central building blocks for future quantum computers.

The consortium, led by UvA-physicist Peter Schall, will consist of the University of Amsterdam, TU Delft and industry partners Toyota and Quix.

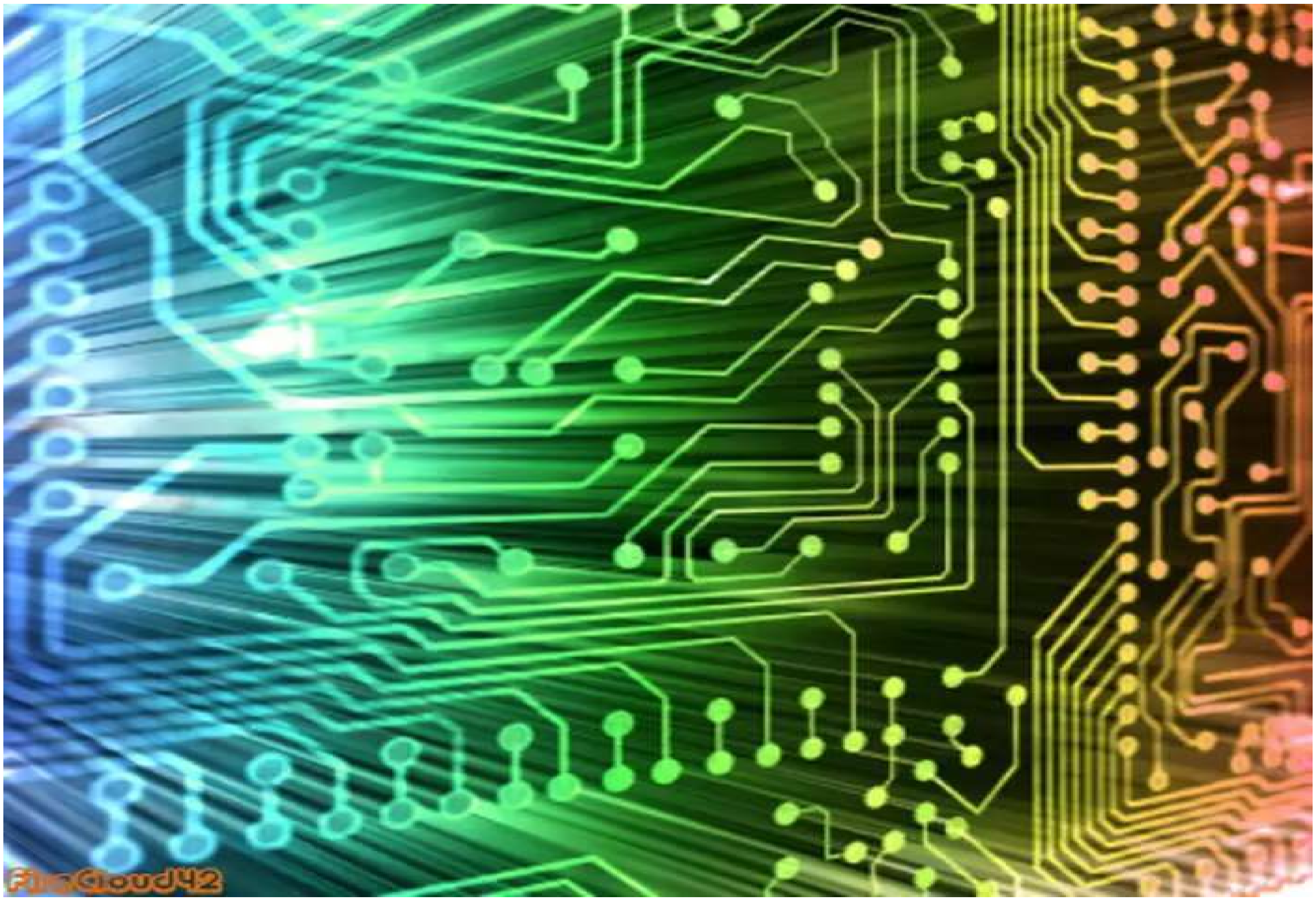


Image credit: Deviant Art, user firecloud42, CC BY-NC 3.0 Deed.

In future quantum computers, the electronics of present computer chips may be partially replaced by technology based on light. Quantum computing based on light offers an alternative, potentially very powerful technology that can be used at room temperature rather than at the very low temperatures at which many quantum computers work.

A single-photon emitter is the key building block of a light-based quantum computing chip. Such a device provides single quanta of light – photons – one by one. Single photon emitters are still challenging to make and integrate into optical quantum chips, but recently developed materials that are only a few layers of atoms thick – making them effectively two-dimensional – do offer prospects for bright single-photon sources, which makes them promising for use in optical quantum computer chips.

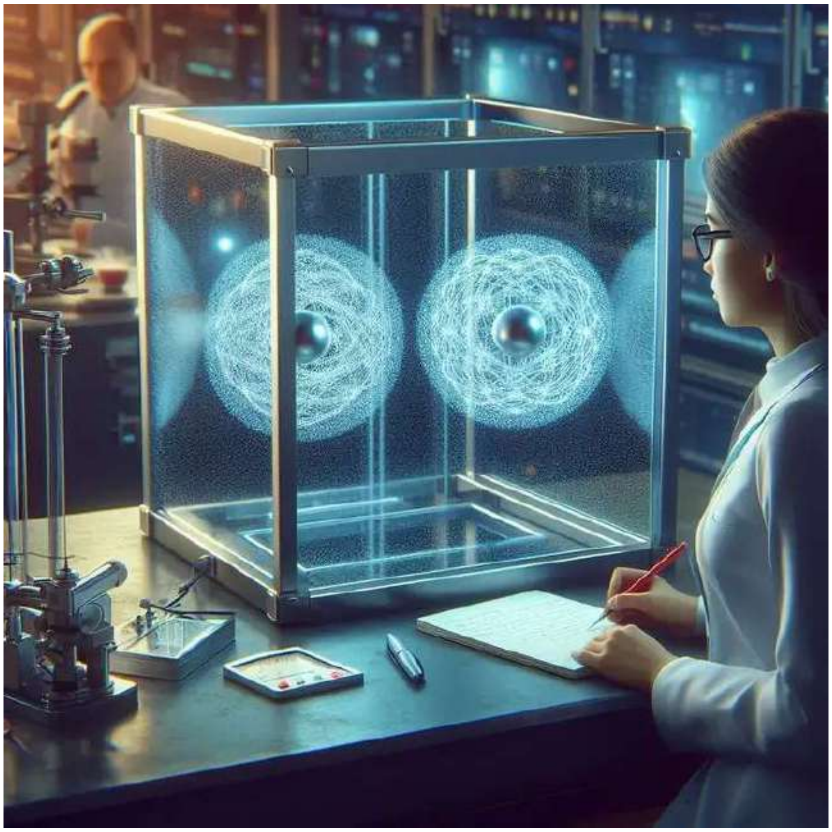
With a cross-disciplinary consortium of experts in 2D materials, spectroscopy and nanophotonics, as well as users in optical quantum computing and automobile industry, UvA, TU Delft, Toyota and Quix now aim to develop efficient 2D single photon emitters for integration into photonic chips for quantum as well as classical information applications. This week, the NWO domain Applied and Engineering Sciences awarded the consortium an €850,000 Open Technology Grant, which will fund the research for the next four years.

Revealing The Quantumness Of Gravity

Gravity is part of our everyday life. Still, the gravitational force remains mysterious: to this day we do not understand whether its ultimate nature is geometrical, as Einstein envisaged, or governed by the laws of quantum mechanics.

Until now, all experimental proposals to answer this question have relied on creating the quantum phenomenon of entanglement between heavy, macroscopic masses. But the heavier an object is, the more it sheds its quantum features and becomes ‘classical’, making it incredibly challenging to make a heavy mass behave as a quantum particle.

In a study published in Physical Review X this week, researchers from Amsterdam and Ulm propose an experiment that circumvents these issues.



Quantum gravity in the lab. AI-generated image.

Classical or quantum?

Successfully combining quantum mechanics and gravitational physics is one of the main challenges of modern science. Generally speaking, progress in this area is hindered because we cannot yet perform experiments in regimes where both quantum and gravitational effects are relevant. At a more fundamental level, as Nobel Prize laureate Roger Penrose once put it, we do not even know whether a combined theory of gravity and quantum mechanics will require a 'quantisation of gravity' or a 'gravitisation of quantum mechanics'. In other words: is gravity fundamentally a quantum force, its properties being determined at the smallest possible scales, or is it a 'classical' force for which a large-scale geometrical description suffices? Or is it something different yet?

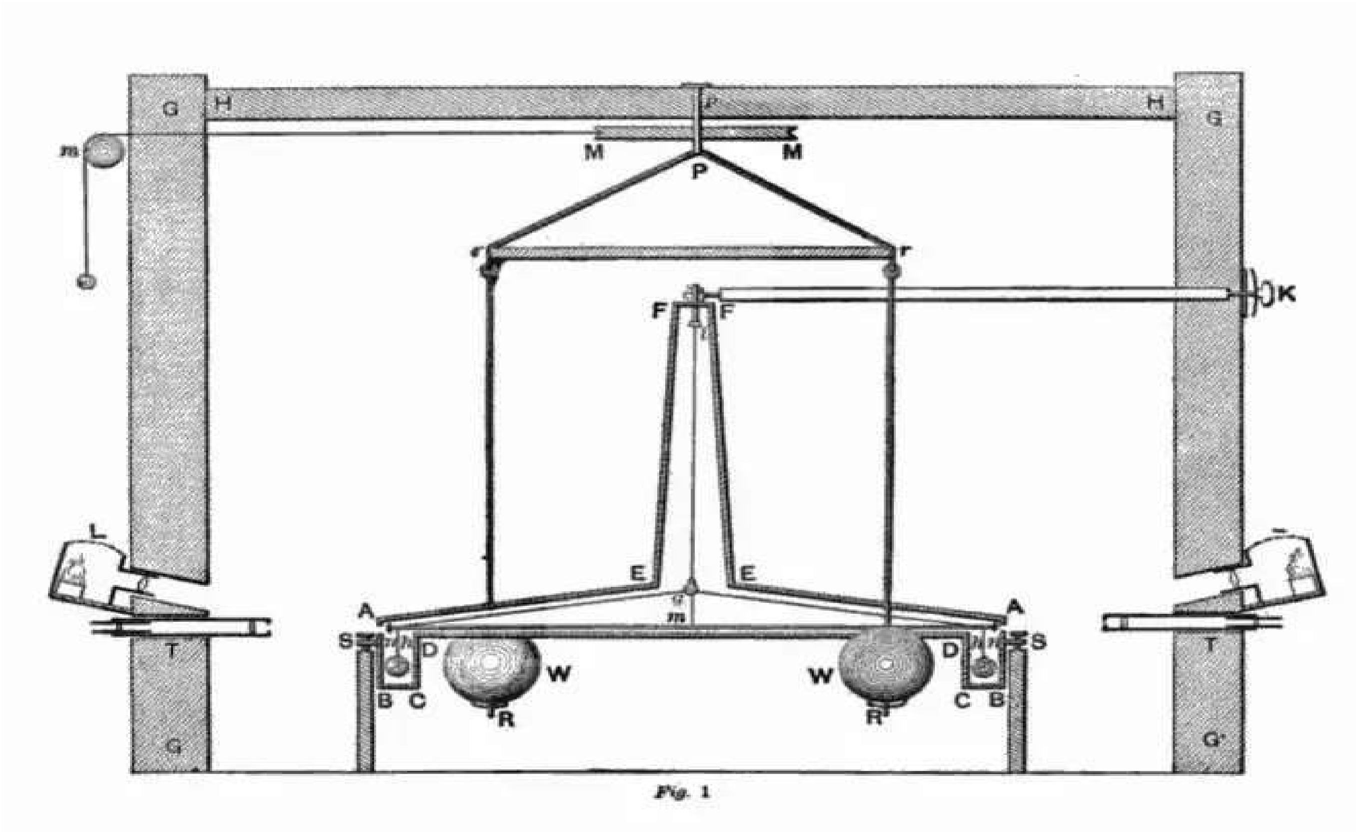
It has always seemed that to answer these questions, a central role would be played by the typically quantum phenomenon of *entanglement*. As Ludovico Lami, mathematical physicist at the University of Amsterdam and QuSoft, puts it: "The central question, initially posed by Richard Feynman in 1957, is to understand whether the gravitational field of a massive object can enter a so-called *quantum superposition*, where it would be in several states at the same time. Prior to our work, the main idea to decide this question experimentally was to look for gravitationally induced entanglement – a way in which distant but related masses could share quantum information. The existence of such entanglement would falsify the hypothesis that the gravitational field is purely local and classical."

A different angle

The main problem with the previous proposals is that distant but related massive objects – known as delocalised states – are very challenging to create. The heaviest object for which quantum delocalisation has been observed to date is a large molecule, much lighter than the smallest source mass whose gravitational field has been detected, which is just below 100 mg – more than a billion billion times heavier. This pushed any hope of an experimental realisation decades away.

In the new work, Lami and his colleagues from Amsterdam and Ulm – interestingly, the place where Einstein was born – present a possible way out of this deadlock. They propose an experiment that would reveal the quantumness of gravity without generating any entanglement.

Lami: "We design and investigate a class of experiments involving a system of massive 'harmonic oscillators' – for example, torsion pendula, essentially like the one that Cavendish used in his famous 1797 experiment to measure the strength of the gravitational force. We establish mathematically rigorous bounds on certain experimental signals for quantumness that a local classical gravity should not be able to overcome. We have carefully analysed the experimental requirements needed to implement our proposal in an actual experiments, and find that even though some degree of technological progress is still needed, such experiments could really be within reach soon."



A drawing of the torsion balance used by Henry Cavendish in 1797 to measure the strength of gravity. Similar 'harmonic oscillators' can now be used to reveal the quantumness of gravity.

A shadow of entanglement

Surprisingly, to analyse the experiment, the researchers still need the mathematical machinery of entanglement theory in quantum information science. How is that possible? Lami: "The reason is that, although entanglement is not physically there, it is still there in spirit — in a precise mathematical sense. It is enough that entanglement *could have been* generated."

The paper in which Lami and colleagues explain their findings was published in Physical Review X this week. The researchers hope that their paper is only the beginning, and that their proposal will help design experiments that may answer the fundamental question about the quantumness of gravity much earlier than expected.

Scientists Twist For Quantum Nature Of Gravity

Einstein's theory of general relativity explains that a curvature of the directions of space and time causes gravity. The most familiar manifestation of this is the Earth's gravity, which keeps us on the ground and explains why balls fall to the floor and individuals have weight when stepping on a scale.

IceCube lab under the stars in Antarctica. Image Credit: Martin Wolf, IceCube/NSF

In the field of high-energy physics, on the other hand, scientists study tiny invisible objects that obey the laws of quantum mechanics—characterized by random fluctuations that create uncertainty in the positions and energies of particles like electrons, protons and neutrons. Understanding the randomness of quantum mechanics is required to explain the behavior of matter and light on a subatomic scale.

For decades, scientists have been trying to unite those two fields of study to achieve a quantum description of gravity. This would combine the physics of curvature associated with general relativity with the mysterious random fluctuations associated with quantum mechanics.

A new study in Nature Physics from physicists at The University of Texas at Arlington reports on a deep new probe into the interface between these two theories, using ultra-

high energy neutrino particles detected by a particle detector set deep into the Antarctic glacier at the south pole.
“The challenge of unifying quantum mechanics with the theory of gravitation remains one of the most pressing unsolved problems in physics,” said co-author Benjamin Jones, associate professor of physics. “If the gravitational field behaves in a similar way to the other fields in nature, its curvature should exhibit random quantum fluctuations.”

Jones and UTA graduate students Akshima Negi and Grant Parker were part of an international IceCube Collaboration team that included more than 300 scientists from around the U.S., as well as Australia, Belgium, Canada, Denmark, Germany, Italy, Japan, New Zealand, Korea, Sweden, Switzerland, Taiwan and the United Kingdom.
To search for signatures of quantum gravity, the team placed thousands of sensors throughout one square kilometer near the south pole in Antarctica that monitored neutrinos, unusual but abundant subatomic particles that are neutral in charge and have no mass. The team was able to study more than 300,000 neutrinos. They were looking to see whether these ultra-high-energy particles were bothered by random quantum fluctuations in spacetime that would be expected if gravity were quantum mechanical, as they travel long distances across the Earth.

“We searched for those fluctuations by studying the flavors of neutrinos detected by the IceCube Observatory,” Negi said. “Our work resulted in a measurement that was far more sensitive than previous ones (over a million times more, for some of the models), but it did not find evidence of the expected quantum gravitational effects.”

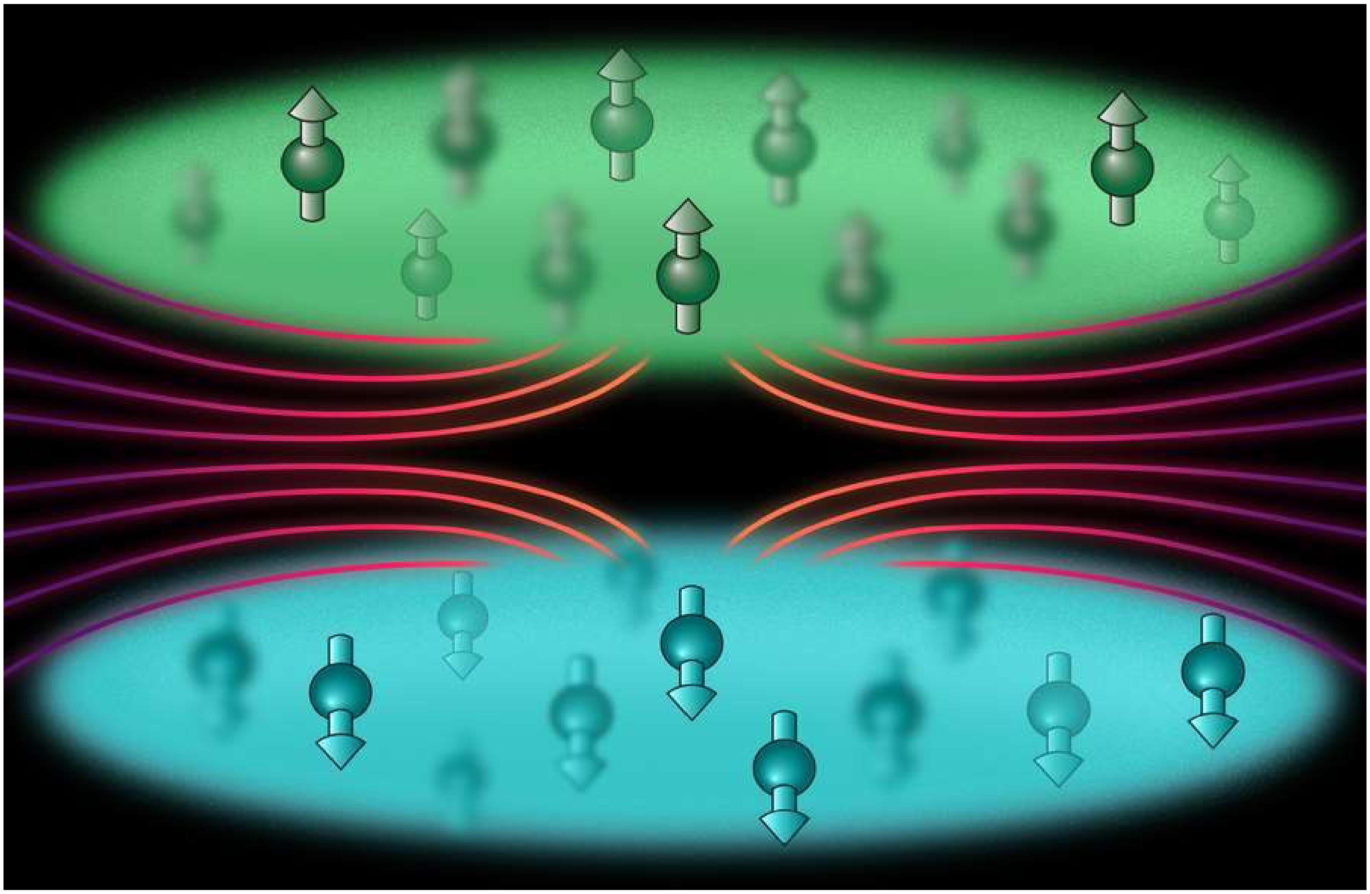
This non-observation of a quantum geometry of spacetime is a powerful statement about the still-unknown physics that operate at the interface of quantum physics and general relativity.

“This analysis represents the final chapter in UTA’s nearly decade-long contribution to the IceCube Observatory,” said Jones. “My group is now pursuing new experiments that aim to understand the origin and value of the neutrinos mass using atomic, molecular and optical physics techniques.”

Physicists Arrange Atoms In Extremely Close Proximity

The technique opens possibilities for exploring exotic states of matter and building new quantum materials.

Proximity is key for many quantum phenomena, as interactions between atoms are stronger when the particles are close. In many quantum simulators, scientists arrange atoms as close together as possible to explore exotic states of matter and build new quantum materials.

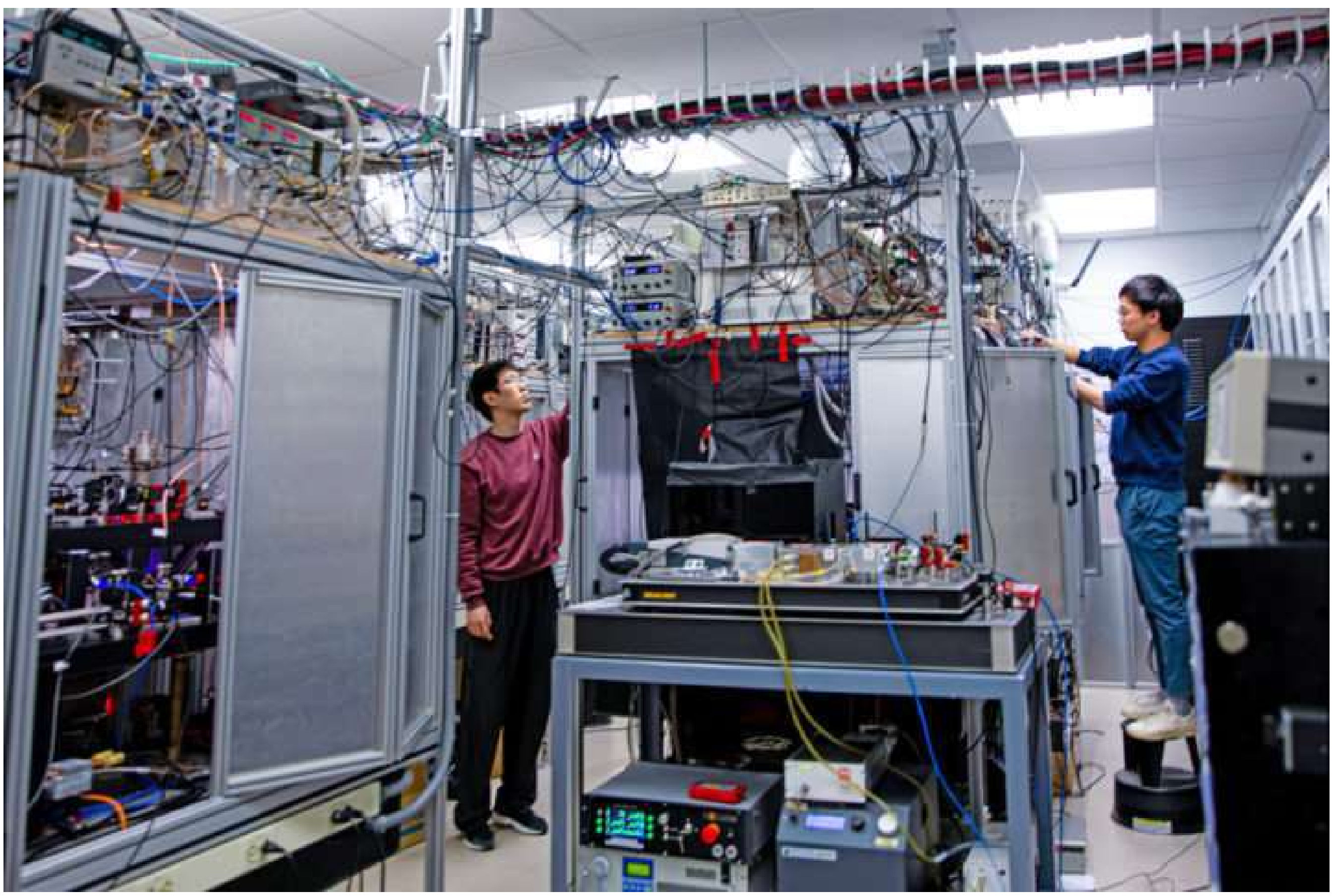


The technique opens possibilities for exploring exotic states of matter and building new quantum materials. MIT physicists developed a technique to arrange atoms (represented as spheres with arrows) in much closer proximity than previously possible, down to 50 nanometers. The group plans to use the method to manipulate atoms into configurations that could generate the first purely magnetic quantum gate — a key building block for a new type of quantum computer. In this image, the magnetic interaction is represented by the colorful lines. Image credit: Courtesy of the researchers; MIT News

They typically do this by cooling the atoms to a stand-still, then using laser light to position the particles as close as 500 nanometers apart — a limit that is set by the wavelength of light. Now, MIT physicists have developed a technique that allows them to arrange atoms in much closer proximity, down to a mere 50 nanometers. For context, a red blood cell is about 1,000 nanometers wide.

The physicists demonstrated the new approach in experiments with dysprosium, which is the most magnetic atom in nature. They used the new approach to manipulate two layers of dysprosium atoms, and positioned the layers precisely 50 nanometers apart. At this extreme proximity, the magnetic interactions were 1,000 times stronger than if the layers were separated by 500 nanometers.

What's more, the scientists were able to measure two new effects caused by the atoms' proximity. Their enhanced magnetic forces caused "thermalization," or the transfer of heat from one layer to another, as well as synchronized oscillations between layers. These effects petered out as the layers were spaced farther apart.



Graduate students Li Du, left, and Yu-Kun Lu adjust the control electronics of the laser systems. Image: Courtesy of the researchers / MIT

“We have gone from positioning atoms from 500 nanometers to 50 nanometers apart, and there is a lot you can do with this,” says Wolfgang Ketterle, the John D. MacArthur Professor of Physics at MIT. “At 50 nanometers, the behavior of atoms is so much different that we’re really entering a new regime here.”

Ketterle and his colleagues say the new approach can be applied to many other atoms to study quantum phenomena. For their part, the group plans to use the technique to manipulate atoms into configurations that could generate the first purely magnetic quantum gate — a key building block for a new type of quantum computer.

The team has published their results today in the journal *Science*. The study’s co-authors include lead author and physics graduate student Li Du, along with Pierre Barral, Michael Cantara, Julius de Hond, and Yu-Kun Lu — all members of the MIT-Harvard Center for Ultracold Atoms, the Department of Physics, and the Research Laboratory of Electronics at MIT.

Peaks and valleys

To manipulate and arrange atoms, physicists typically first cool a cloud of atoms to temperatures approaching absolute zero, then use a system of laser beams to corral the atoms into an optical trap.

Laser light is an electromagnetic wave with a specific wavelength (the distance between maxima of the electric field) and frequency. The wavelength limits the smallest pattern into which light can be shaped to typically 500 nanometers, the so-called optical resolution limit. Since atoms are attracted by laser light of certain frequencies, atoms will be positioned at the points of peak laser intensity. For this reason, existing techniques have been limited in how close they can position atomic particles, and could not be used to explore phenomena that happen at much shorter distances.

“Conventional techniques stop at 500 nanometers, limited not by the atoms but by the wavelength of light,” Ketterle explains. “We have found now a new trick with light where we can break through that limit.”

The team’s new approach, like current techniques, starts by cooling a cloud of atoms — in this case, to about 1 microkelvin, just a hair above absolute zero — at which point, the atoms come to a near-standstill. Physicists can then use lasers to move the frozen particles into desired configurations.

Then, Du and his collaborators worked with two laser beams, each with a different frequency, or color, and circular polarization, or direction of the laser’s electric field. When the two beams travel through a super-cooled cloud of atoms, the atoms can orient their spin in opposite directions, following either of the two lasers' polarization. The result is that the beams produce two groups of the same atoms, only with opposite spins.

Each laser beam formed a standing wave, a periodic pattern of electric field intensity with a spatial period of 500 nanometers. Due to their different polarizations, each standing wave attracted and corralled one of two groups of atoms, depending on their spin. The lasers could be overlaid and tuned such that the distance between their respective peaks is as small as 50 nanometers, meaning that the atoms gravitating to each respective laser's peaks would be separated by the same 50 nanometers.

But in order for this to happen, the lasers would have to be extremely stable and immune to all external noise, such as from shaking or even breathing on the experiment. The team realized they could stabilize both lasers by directing them through an optical fiber, which served to lock the light beams in place in relation to each other.

"The idea of sending both beams through the optical fiber meant the whole machine could shake violently, but the two laser beams stayed absolutely stable with respect to each others," Du says.

Magnetic forces at close range

As a first test of their new technique, the team used atoms of dysprosium — a rare-earth metal that is one of the strongest magnetic elements in the periodic table, particularly at ultracold temperatures. However, at the scale of atoms, the element's magnetic interactions are relatively weak at distances of even 500 nanometers. As with common refrigerator magnets, the magnetic attraction between atoms increases with proximity, and the scientists suspected that if their new technique could space dysprosium atoms as close as 50 nanometers apart, they might observe the emergence of otherwise weak interactions between the magnetic atoms.

"We could suddenly have magnetic interactions, which used to be almost neglible but now are really strong," Ketterle says.

The team applied their technique to dysprosium, first super-cooling the atoms, then passing two lasers through to split the atoms into two spin groups, or layers. They then directed the lasers through an optical fiber to stabilize them, and found that indeed, the two layers of dysprosium atoms gravitated to their respective laser peaks, which in effect separated the layers of atoms by 50 nanometers — the closest distance that any ultracold atom experiment has been able to achieve.

At this extremely close proximity, the atoms' natural magnetic interactions were significantly enhanced, and were 1,000 times stronger than if they were positioned 500 nanometers apart. The team observed that these interactions resulted in two novel quantum phenomena: collective oscillation, in which one layer's vibrations caused the other layer to vibrate in sync; and thermalization, in which one layer transferred heat to the other, purely through magnetic fluctuations in the atoms.

"Until now, heat between atoms could only by exchanged when they were in the same physical space and could collide," Du notes. "Now we have seen atomic layers, separated by vacuum, and they exchange heat via fluctuating magnetic fields."

The team's results introduce a new technique that can be used to position many types of atom in close proximity. They also show that atoms, placed close enough together, can exhibit interesting quantum phenomena, that could be harnessed to build new quantum materials, and potentially, magnetically-driven atomic systems for quantum computers.

"We are really bringing super-resolution methods to the field, and it will become a general tool for doing quantum simulations," Ketterle says. "There are many variants possible, which we are working on."

This research was funded, in part, by the National Science Foundation and the Department of Defence.

Unlocking The Mysteries Of Quantum Computers

In the realm of computing, a new frontier has emerged, shrouded in mystery and fascination: quantum computing. For many, the mere mention of quantum computers conjures images of futuristic technology and unparalleled computational power. However, understanding the true essence of quantum computing requires delving beyond the surface and embarking on a journey of exploration.

Amidst the myriad of misconceptions surrounding quantum computers, one truth becomes abundantly clear: they are not mere iterations of classical supercomputers. Quantum computers defy conventional paradigms, offering a tantalizing glimpse into a realm of unparalleled computational prowess. As we delve deeper into the intricacies of quantum mechanics, the enigmatic nature of these revolutionary machines gradually begins to unravel.

Quantum systems. Illustrative photo. Image credit: quantumai.google

The Quantum Revolution

At the heart of quantum computing lies the intricate dance of qubits, quantum counterparts to classical bits. Unlike their binary predecessors, qubits exist in a state of superposition, embodying a spectrum of possibilities. Harnessing the power of quantum probability, these enigmatic entities pave the way for a paradigm shift in computing, promising unprecedented capabilities and insights.

Our quest for understanding takes us to the forefront of quantum research, where we are granted exclusive access to IBM's groundbreaking quantum computer. Encased within a frigid cocoon of subzero temperatures, the quantum computer beckons, offering a tantalizing glimpse into the future of computing technology.

Simulating Nature

Beyond the realm of computation lies a world of boundless possibilities: the simulation of nature itself. Armed with the computational prowess of quantum computers, scientists are poised to unlock the secrets of the universe, from the intricacies of molecular interactions to the development of groundbreaking materials and medicines. The promise of quantum simulation heralds a new era of scientific discovery and innovation.

Yet, amidst the boundless potential of quantum computing lies a looming dilemma: the threat to digital security posed by quantum supremacy. With the advent of Shor's algorithm, quantum computers have the potential to unravel the very fabric of encryption, rendering conventional cryptographic schemes obsolete. As we navigate the path to quantum-safe encryption, the race to safeguard digital infrastructure intensifies.

Final word

As we chart the course ahead, the horizon of quantum computing stretches infinitely before us, beckoning with untold possibilities. Quantum computing holds the key to unlocking new realms of knowledge and understanding. With each technological leap, we inch closer to unraveling the mysteries of the quantum mechanical world, reshaping the very fabric of our reality.

As our journey draws to a close, we reflect upon the profound impact of our exploration into the realm of quantum computing. With gratitude and optimism, we embrace the boundless potential of this revolutionary technology, recognizing its capacity to reshape our world for the better. As we bid farewell to one adventure, we eagerly anticipate the myriad of possibilities that lie ahead in the ever-evolving landscape of quantum exploration.

END OF NEWS LETTER

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