Quantum Light on Cave Art

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Researchers at the University of York have shown that a new quantum-based procedure for distributing secure information along communication lines could be successful in preventing serious security breaches. [27]

In the new study, Bomantara and Gong have developed a method for harnessing the unique properties of time crystals for quantum computing that is based on braiding. [26]

An Aalto University study has provided new evidence that time crystals can physically exist – a claim currently under hot debate. [25]

Yale physicists have uncovered hints of a time crystal—a form of matter that "ticks" when exposed to an electromagnetic pulse—in the last place they expected: a crystal you might find in a child's toy. [24]

The research shows that concentrated electrolytes in solution affect hydrogen bonding, ion interactions, and coordination geometries in currently unpredictable ways. [23]

*An exotic state of matter that is dazzling scientists with its electrical properties, can also exhibit unusual optical properties, as shown in a theoretical study by researchers at A*STAR. [22]*

The breakthrough was made in the lab of Andrea Alù, director of the ASRC's Photonics Initiative. Alù and his colleagues from The City College of New York, University of Texas at Austin and Tel Aviv University were inspired by the seminal work of three British researchers who won the 2016 Noble Prize in Physics for their work, which teased out that particular properties of matter (such as electrical conductivity) can be preserved in certain materials despite continuous changes in the matter's form or shape. [21]
Researchers at the University of Illinois at Urbana-Champaign have developed a new technology for switching heat flows 'on' or 'off'. [20]
Thermoelectric materials can use thermal differences to generate electricity. Now there is an inexpensive and environmentally friendly way of producing them with the simplest tools: a pencil, photocopy paper, and conductive paint. [19]
A team of researchers with the University of California and SRI International has developed a new type of cooling device that is both portable and efficient.
[18]

Thermal conductivity is one of the most crucial physical properties of matter when it comes to understanding heat transport, hydrodynamic evolution and energy balance in systems ranging from astrophysical objects to fusion plasmas. [17]

Researchers from the Theory Department of the MPSD have realized the control of thermal and electrical currents in nanoscale devices by means of quantum local observations. [16]

Physicists have proposed a new type of Maxwell's demon—the hypothetical agent that extracts work from a system by decreasing the system's entropy—in which the demon can extract work just by making a measurement, by taking advantage of quantum fluctuations and quantum superposition. [15]

Pioneering research offers a fascinating view into the inner workings of the mind of 'Maxwell's Demon', a famous thought experiment in physics. [14]

For more than a century and a half of physics, the Second Law of Thermodynamics, which states that entropy always increases, has been as close to inviolable as any law we know. In this universe, chaos reigns supreme.
[13]

Physicists have shown that the three main types of engines (four-stroke, twostroke, and continuous) are thermodynamically equivalent in a certain quantum regime, but not at the classical level. [12]

For the first time, physicists have performed an experiment confirming that thermodynamic processes are irreversible in a quantum system—meaning that, even on the quantum level, you can't put a broken egg back into its shell. The results have implications for understanding thermodynamics in quantum systems and, in turn, designing quantum computers and other quantum information technologies. [11]

Disorder, or entropy, in a microscopic quantum system has been measured by an international group of physicists. The team hopes that the feat will shed light on the "arrow of time": the observation that time always marches towards the future. The experiment involved continually flipping the spin of carbon atoms with an oscillating magnetic field and links the emergence of the arrow of time to quantum fluctuations between one atomic spin state and another. [10]

Mark M. Wilde, Assistant Professor at Louisiana State University, has improved this theorem in a way that allows for understanding how quantum measurements can be approximately reversed under certain circumstances. The new results allow for understanding how quantum information that has been lost during a measurement can be nearly recovered, which has potential implications for a variety of quantum technologies. [9]

Today, we are capable of measuring the position of an object with unprecedented accuracy, but quantum physics and the Heisenberg uncertainty principle place fundamental limits on our ability to measure. Noise that arises as a result of the quantum nature of the fields used to make those measurements imposes what is called the "standard quantum limit." This same limit influences both the ultrasensitive measurements in nanoscale devices and the kilometer-scale gravitational wave detector at LIGO. Because of this troublesome background noise, we can never know an object's exact location, but a recent study provides a solution for rerouting some of that noise away from the measurement. [8]

The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the Wave-Particle Duality and the electron's spin also, building the Bridge between the Classical and Quantum Theories.

The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate and the Weak and Strong Interactions by the diffraction patterns. The Weak Interaction changes the diffraction patterns by moving the electric charge from one side to the other side of the diffraction pattern, which violates the CP and Time reversal symmetry.

The diffraction patterns and the locality of the self-maintaining electromagnetic potential explains also the Quantum Entanglement, giving it as a natural part of the relativistic quantum theory.

Contents

Author: George Rajna

Preface

Physicists are continually looking for ways to unify the theory of relativity, which describes largescale phenomena, with quantum theory, which describes small-scale phenomena. In a new proposed experiment in this area, two toaster-sized "nanosatellites" carrying entangled condensates orbit around the Earth, until one of them moves to a different orbit with different gravitational field strength. As a result of the change in gravity, the entanglement between the condensates is predicted to degrade by up to 20%. Experimentally testing the proposal may be possible in the near future. [5]

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently – instead, a quantum state may be given for the system as a whole. [4]

I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

Quantum physicists shining new light on cave art

Leslie Van Gelder, a well-known American-born archeologist has been working with Dr. Harald Schwefel, and other physicists at Otago University to develop a lamp that mimics the flickering torch light that paleolithic cave artists worked by many thousands of years ago. The lamps will help Leslie and other archeologists reveal intimate details of these ancient people.

The collaboration brings together quantum physicists and archeologists with indigenous Australian land-owners, deer stalkers, artists, ancient DNA specialists, university students and a product designer. The story shows the unexpected ways cutting edge science research can enrich cultural understanding and heritage. It speaks to a willingness and generosity in the New Zealand science community to try something different and help each other out.

Tens of thousands of years ago ancient people of Europe and Australia trekked deep into caves by torchlight creating images on the walls of horses, bison, reindeer and stencil outlines of their own hands. In the flickering firelight of their ancient lamps, the figures would appear to move. The shadows on the curved cave walls gave them an illusion of volume and life and the colours appeared inky-rich and deep. This was how the ancient artists would have seen their work. But in the past few decades open flames have been banned in heritage cave sights and the LED lights that replaced them have taken away much of the mystery.

"The flat grey and white light of the torches made with LED's produce an almost clinical light and rob the animals of their warm colors and their shadows," Leslie says.

It was a conversation with a cave guide in Europe in 2016 that gave Leslie the idea for creating the new lamps. Not only could this give a more authentic experience of the caves. It would also help to answer important research questions.

As a researcher I have been drawn to questions of light for the last decade," Leslie says. "These new lamps will help us to explore questions of how people moved through the caves and drew the on the walls... Some of the images are found high up in hard to reach places. The artists would have had to climb five metres up a wall or stalactite to reach them, which would require both hands. So someone else must have held the light. I have a soft spot for the people in the shadows who might not have made the drawings themselves but allowed someone else to by holding their light."

Leslie returned to Glenorchy in New Zealand where she lives, with a mission to find a more authentic lighting solution. The first step was to try to create an authentic copy of the ancient lamps to work out what qualities of the light the lamps needed to mimic. She sourced animal fat from local deerstalkers and a butcher to mimic the reindeer and auroch tallow used in ancient lamps. She worked with a local sculptor to fashion a stone base using primitive tools.

To create a modern equivalent she needed some physicists. This is where the Dodd-Walls Centre comes in. This national centre of collaborative research brings together scientists across the country doing world-leading research in light and quantum science. Leslie discovered the Director of the Dodd-Walls Centre, Professor David Hutchinson while searching the University of Otago website.

"He looked approachable and was leading an interdisciplinary centre that focuses on light," says Leslie. "So I wrote to him. He replied straight away and said he could help. I wasn't expecting it to be that easy!"

Professor Hutchinson put Leslie in touch with Dr. Schwefel, a Principal Investigator with the Dodd-Walls Centre, also based at the University of Otago. In his core research Dr. Schwefel develops world-leading components for incredibly powerful quantum computers. He recently published a paper in the prestigious scientific journal Nature announcing his invention of a device that could revolutionise internet efficiency and speed. So this project came out of left field.

"It was really great to see how we could use our knowledge of light and its spectral properties to provide help for the archeology community" says Dr. Schwefel. "Once we identified what we wanted to achieve in terms of the flickering pattern and spectrum, then it was pretty straight-forward to devise a candle-like structure that had the correct flickering pattern."

 Tallow candle burning in stone lamp. Credit: Leslie Van Gelder

Dr. Schwefel brought in two Ph.D. students as consultants and a summer student Timothy Marshall, who worked with the Dodd-Walls Centre Industry manager, Luke Taylor to create the product. The Dodd-Walls Centre funded the whole project.

"They asked me for a Christmas wish list of all the things I wanted the lamp to do," Leslie explains. "It's incredibly hard to find funding in the archaeology community," Leslie says. "This was an amazing gift to have their support."

In the summer of 2018-19, Timothy worked with Dr. Schwefel and Luke Taylor to produce six hand held lamps that Leslie could take as prototypes to a cave in Australia where she was working in March.

"Working to my 'wish list' for color, intensity, and flicker, their team did an amazing job and a week before I left, a suitcase arrived for me in Glenorchy that had 6 beautiful lamps. The glass for them had been hand blown by the chemistry department's glassblower, the bodies of each lamp mimicked stone from different parts of the world and the mechanism were three LED lights colored to the sodium line they had discovered in their light spectrum analysis. Luke and Timothy had done a series of experiments with wind and wick length to produce a series of potential flicker patterns so the lamps in the end had 13 different intensity and flicker pattern that I could change with just the flick of a button. Magic!"

There was an almost audible silence when the team of scientists, archeologists and traditional indigenous land owners entered the cave in Australia that Leslie had lit using the new lamps.

"It was a very moving experience to see the cave in the flickering warm light of the 'paleo-lamps," Leslie says.

This is just the beginning of the collaboration. Having discovered ancient fire-sticks in the Australian cave, Leslie will work with Harald and the team alongside the local Aboriginal community to develop a new lamp to mimic its light.

Even though the project was tangent to Harald's core focus on quantum computing and photonics, it provided an excellent opportunity to contribute to a new field. It also gave the students valuable experience of developing a product and getting it to market with a deadline.

According to Leslie the archeology community have been impressed and inspired by the project. presented the story at a specialist conference on rock art.

"I presented the story at a rock art conference recently," She says. "Some archeologists told me it restored their faith in archeology. There is a real respect and interest in the perspective from another field like physics."

Next spring Leslie will be returning to Europe to continue her cave research there. She will be taking with her a box of the new lamps as a gift from the Dodd-Walls Centre.

"I look forward to seeing what we might be able to see for the first time in the shadows and flickering lights of our lamps," Leslie says. [33]

Digital quantum simulators can be astonishingly robust

In solving quantum-physical problems in many-body systems, such as predicting material properties, conventional computers rapidly reach the limits of their capacity. Digital quantum simulators might help, but until now they are drastically limited to small systems with few particles and only short simulation times. Now, Heidelberg University physicist Dr. Philipp Hauke and colleagues from Dresden and Innsbruck (Austria) have demonstrated that such simulations can be more robust and hence much more stable than previously assumed. The results of their research were published in *Science Advances*.

In quantum physics, many-body theory describes a large number of interacting particles. In the state of thermodynamic equilibrium, the many-body system can be described by only a handful of values such as temperature or pressure, which are largely homogeneous for the entire system. But what happens over time after a major perturbation, such as when energy is abruptly deposited in a material sample by short laser pulses? Precisely calculating the so-called nonequilibrium dynamics of interacting many-body systems is a high-profile problem in quantum physics.

Calculations using conventional computers require resources that increase exponentially with the number of constituent quantum particles. "So computationally exact methods fail with just a few dozen particles. That is far less than the number needed to predict material properties, for example. In such cases, scientists rely on approximation methods that are often uncontrolled, particularly when it comes to dynamic properties," explains Dr. Hauke, a researcher at the Kirchhoff Institute for Physics and the Institute for Theoretical Physics of Heidelberg University. Digital quantum simulation provides one possible workaround. The nonequilibrium dynamics are studied with simulators that themselves are governed by quantum-mechanical laws.

Depicting the time evolution in a quantum computer requires discretising it into individual operations. But this approach—also known as Trotterization—unavoidably generates an error inherent in the simulation itself. This Trotter error can be mitigated by sufficiently fine discretisations. Extremely small discretisation steps must be chosen, however, to depict reliably a longer time evolution. Until now, research has maintained that the error quickly grows over long time periods and with a larger number of particles—which for all practical purposes drastically limits digital quantum simulation to small systems and short times.

Using numerical demonstrations and analytical arguments, the researchers have now shown that quantum simulation is much more "robust" and hence more stable than previously assumed, as long as only values that are relevant in practice—such as averages across the entire system—are considered and not the full state of each individual particle. For such values, there is a sharp threshold between a region with controllable errors and a simulation that can no longer deliver a usable result. Below this threshold, the Trotter error has only limited impact—in fact for all time periods that could be practically simulated and largely independent of the number of constituent particles.

At the same time, the research showed that digital quantum simulation can deliver astonishingly precise results using unexpectedly large Trotter steps. "A simulation that can predict the behaviour of many quantum particles over a longer time therefore becomes more and more likely. This further opens the door for practical applications, ranging from materials science and quantum chemistry to issues in fundamental physics," states Dr. Hauke, who heads the "Quantum optics and quantum many-body theory" research group. [32]

Accelerating quantum technologies with materials processing at the atomic scale

'Quantum technologies' utilise the unique phenomena of quantum superposition and entanglement to encode and process information, with potentially profound benefits to a wide range of information technologies from communications to sensing and computing.

However a major challenge in developing these technologies is that the quantum phenomena are very fragile, and only a handful of physical systems have been identified in which they survive long enough and are sufficiently controllable to be useful. Atomic defects in materials such as diamond are one such system, but a lack of techniques for fabricating and engineering crystal defects at the atomic scale has limited progress to date.

A team of scientists demonstrate, in a paper published in *Optica*, the success of the new method to create particular defects in diamondsknown as nitrogen-vacancy (NV) colour centres. These comprise a nitrogen impurity in the diamond (carbon) lattice located adjacent to an empty lattice site or vacancy. The NV centres are created by focusing a sequence of ultrafast laser pulses into the diamond, the first of which has an energy high enough to generate vacancies at the centre of the laser focus, with subsequent pulses at a lower energy to mobilise the vacancies until one of them binds to a nitrogen impurity and forms the required complex.

The new research was carried out by a team led by Prof Jason Smith in the Department of Materials, University of Oxford, and Dr. Patrick Salter and Prof Martin Booth in the Dept of Engineering Science, University of Oxford, in collaboration with colleagues at the University of Warwick. It took place within the research programme of NQIT, the Quantum Computing Technology Hub of the UK Quantum Technologies Programme, with support from DeBeers UK who supplied the diamond sample.

The scientists' new method involves a sensitive fluorescence monitor being employed to detect light emitted from the focal region, so that the process can be actively controlled in response to the observed signal. By combining local control and feedback, the new method facilitates the production of arrays of single NV centres with exactly one colour centre at each site—a key capability in building scalable technologies. It also allows precise positioning of the defects, important for the engineering of integrated devices. The rapid single-step process is easily automated with each NV centre taking only seconds to create.

Prof Martin Booth says: 'Colour centres in diamond offer a very exciting platform for developing compact and robust quantum technologies, and this new process is a potential game-changer in the engineering of the required materials. There is still more work to do in optimising the process, but hopefully this step will help to accelerate delivery of these technologies.'

The scientists believe that this method might ultimately be used to fabricate centimetre-sized diamond chips containing 100,000 or more NV centres as a route towards the 'holy grail' of quantum technologies, a universal fault-tolerant quantum computer.

Prof Jason Smith says: 'The first quantum computers are now starting to emerge but these machines, impressive as they are, only scratch the surface of what might be achieved and the platforms being used may not be sufficiently scalable to realise the full power that quantum computing has to offer. Diamond colour centres may provide a solution to this problem by packing high densities of qubits onto a solid state chip, which could be entangled with each other using optical methods to form the heart of a quantum computer. The ability to write NV centres into diamond with a high degree of control is an essential first step towards these and other devices.' [31]

Unprecedented insight into two-dimensional magnets using diamond quantum sensors

For the first time, physicists at the University of Basel have succeeded in measuring the magnetic properties of atomically thin van der Waals materials on the nanoscale. They used diamond quantum sensors to determine the strength of the magnetization of individual atomic layers of the material chromium triiodide. In addition, they found a long-sought explanation for the unusual magnetic properties of the material. The journal *Science* has published the findings.

The use of atomically thin, two-dimensional van der Waals materials promises innovations in numerous fields in science and technology. Scientists around the world are constantly exploring new ways to stack different single atomic layers and thus engineer new materials with unique, emerging properties.

These super-thin composite materials are held together by van der Waals forces and often behave differently to bulk crystals of the same material. Atomically thin van der Waals materials include insulators, semiconductors, superconductors and a few materials with magnetic properties. Their use in spintronics or ultra-compact magnetic memory media is highly promising.

The first quantitative measurement of magnetization

Until now, it has not been possible to determine the strength, alignment and structure of these magnets quantitatively nor on the nanoscale. The team headed by Georg-H.-Endress Professor Patrick Maletinsky from the Department of Physics and the Swiss Nanoscience Institute at the University of Basel have demonstrated that the use of diamond tips decorated with single electron spins in an atomic force microscope is ideally suited to these types of studies.

"Our method, which uses the individual spins in diamond color centers as sensors, opens up a whole new field. The magnetic properties of two-dimensional materials can now be studied on the nanoscale and even in a quantitative manner. Our innovative quantum sensors are perfectly suited to this complex task," says Maletinsky.

The number of layers is critical

Using this technology which was originally developed in Basel and which is based on a single electron spin, the scientists collaborated with researchers from the University of Geneva to determine the magnetic properties of single atomic layers of chromium triiodide (CrI_3). The researchers were thus able to find the answer to a key scientific question about the magnetism of this material.

As a three-dimensional, bulk crystal, chromium triiodide is fully magnetically ordered. In the case of few atomic layers, however, only stacks with an odd number of atomic layers show a non-zero magnetization. Stacks with an even number of layers exhibit an antiferromagneticbehavior; i.e. they are not magnetized. The cause of this "even/odd-effect" and the discrepancy to bulk material was previously unknown.

Strain as the cause

Maletinsky's team was able to demonstrate that this phenomenon is due to the specific atomic arrangement of the layers. During sample preparation, the individual chromium triiodide layers slightly move against one another. The resulting strain in the lattice means the spins of successive layers are unable to align in the same direction; instead, the spin direction alternates in the layers. With an even number of layers, the magnetization of the layers cancel out; with an odd number, the strength of the measured magnetization corresponds to that of a single layer.

However, when the strain in the stack is released—for example, by puncturing the sample—the spins of all layers can align in the same direction, as is also observed in bulk crystals. The magnetic strength of the entire stack is then consistent with the sum of the individual layers.

The work conducted by the Basel scientists thereby not only answers a key question about two-dimensional van der Waals magnets, it also opens interesting perspectives on how their innovative quantum sensors can be used in the future to study two-dimensional magnets in order to contribute to the development of novel electronic components. [30]

Implanting diamonds with flaws offers key technology for quantum communications

Diamonds are prized for their purity, but their flaws might hold the key to a new type of highly secure communications.

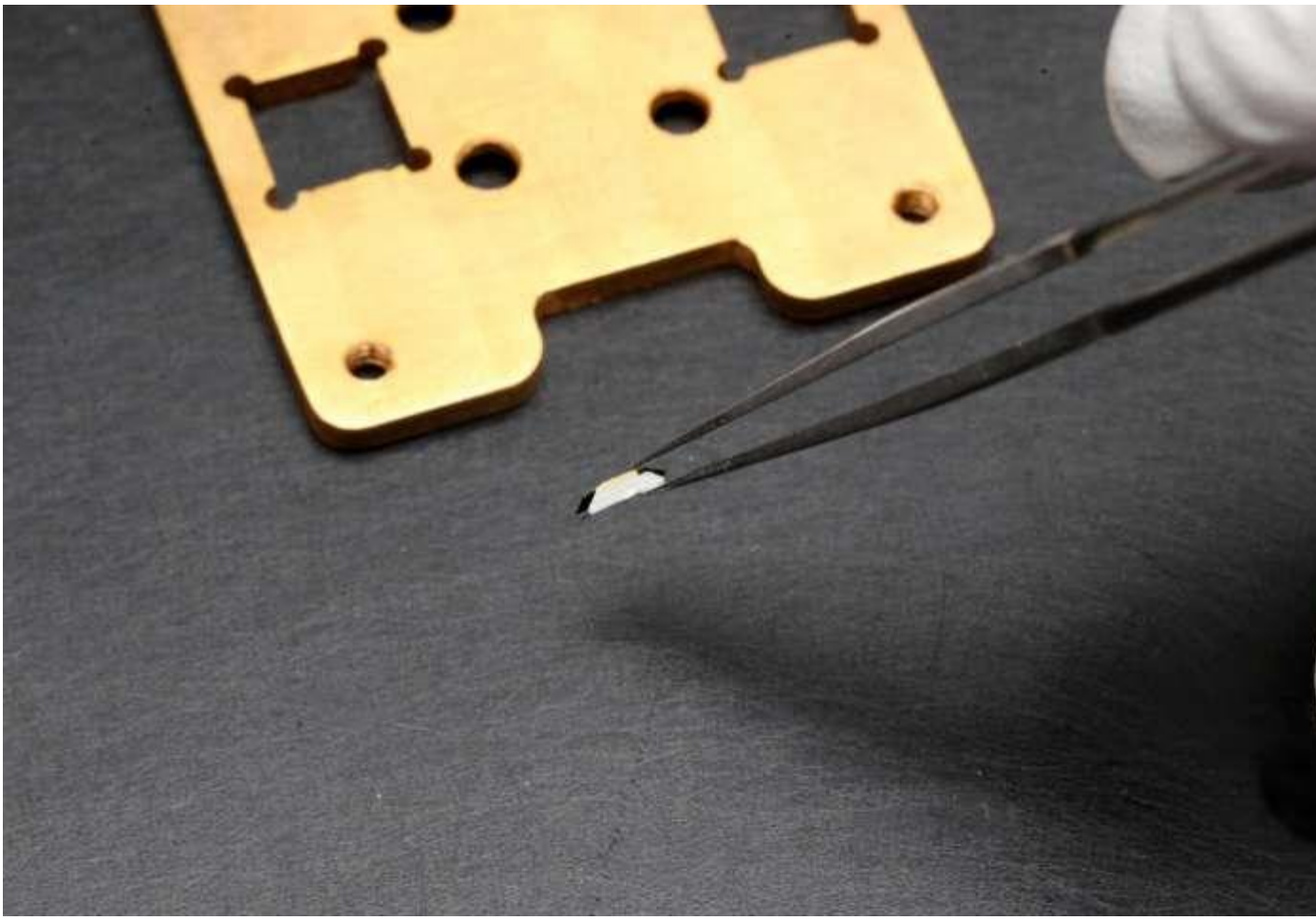
Princeton University researchers are using diamonds to help create a communication network that relies on a property of subatomic particles known as their quantum state. Researchers believe such quantum information networks would be extremely secure and could also allow new quantum computers to work together to complete problems that are currently unsolvable. But scientists currently designing these networks face several challenges, including how to preserve fragile quantum information over long distances.

Now, researchers have arrived at a possible solution using synthetic diamonds.

In an article published this week in the journal *Science*, the researchers describe how they were able to store and transmit bits of quantum information, known as qubits, using a diamond in which they had replaced two carbon atoms with one silicon atom.

In standard communications networks, devices called repeaters briefly store and re-transmit signals to allow them to travel greater distances. Nathalie de Leon, an assistant professor of electrical engineering at Princeton University and the lead researcher, said the diamonds could serve as quantum repeaters for networks based on qubits.

The idea of a quantum repeater has been around for a long time, "but nobody knew how to build them," de Leon said. "We were trying to find something that would act as the main component of a quantum repeater."



Princeton University researchers are using diamonds to preserve fragile quantum information over long distances. Credit: Frank Wojciechowski for Princeton University

The key challenge in creating quantum repeaters has been finding a material that could both store and transmit qubits. So far, the best way to transmit qubits is to encode them in particles of light, called photons. Optical fibers currently used across much of the network already transmit information via photons. However, qubits in an optical fiber can travel only short distances before their special quantum properties are lost and the information is scrambled. It is difficult to trap and store a photon, which by definition moves at the speed of light.

Instead, researchers have looked to solids such as crystals to provide the storage. In a crystal, such as a diamond, qubits could theoretically be transferred from photons to electrons, which are easier to store. The key place to carry out such a transfer would be flaws within the diamond, locations where elements other than carbon are trapped in the diamond's carbon lattice. Jewelers have known for centuries that impurities in diamonds produce different colors. To de Leon's team, these color centers, as the impurities are called, represent an opportunity to manipulate light and create a quantum repeater.

Previous researchers first tried using defects called nitrogen vacancies—where a nitrogen atom takes the place of one of the carbon atoms—but found that although these defects store

information, they don't have the correct optical properties. Others then decided to look at silicon vacancies—the substitution of a carbon atom with a silicon atom. But silicon vacancies, while they could transfer the information to photons, lacked long coherence times.

"We asked, 'What do we know about what causes the limitations of these two color centers?'," de Leon said. "Can we just design something else from scratch, something that addresses all these problems?"

The Princeton-led team and their collaborators decided to experiment with the electrical charge of the defect. Silicon vacancies in theory should be electrically neutral, but it turns out other nearby impurities can contribute electrical charges to the defect. The team thought there might be a connection between the charge state and the ability to keep electron spins in the proper orientation to store qubits.

The researchers partnered with Element Six, an industrial diamond manufacturing company, to construct electrically neutral silicon vacancies. Element Six started by laying down layers of carbon atoms to form the crystal. During the process, they added boron atoms, which have the effect of crowding out other impurities that could spoil the neutral charge.

"We have to do this delicate dance of charge compensation between things that can add charges or take away charges," de Leon said. "We control the distribution of charge from the background defects in the diamonds, and that allows us to control the charge state of the defects that we care about."

Next, the researchers implanted silicon ions into the diamond, and then heated the diamonds to high temperatures to remove other impurities that could also donate charges. Through several iterations of materials engineering, plus analyses performed in collaboration with scientists at the Gemological Institute of America, the team produced neutral silicon vacancies in diamonds.

The neutral silicon vacancy is good at both transmitting quantum information using photons and storing quantum information using electrons, which are key ingredients in creating the essential quantum property known as entanglement, which describes how pairs of particles stay correlated even if they become separated. Entanglement is the key to quantum information's security: recipients can compare measurements of their entangled pair to see if an eavesdropper has corrupted one of the messages.

The next step in the research is to build an interface between the neutral silicon vacancy and the photonic circuits to bring the photons from the network into and out of the color center.

Ania Bleszynski Jayich, a physics professor at the University of California, Santa Barbara, said the researchers had successfully met a longstanding challenge of finding a diamond flaw with characteristics favorable to working with quantum properties of both photons and electrons.

"The success of the authors' materials-engineering approach to identifying promising solid-state defect-based quantum platforms highlights the versatility of solid-state defects and is likely to inspire a more comprehensive and extensive search across a larger cross-section of material and defect candidates," said Jayich, who was not involved in the research.

The Princeton team included Brendon Rose, a postdoctoral research associate, and graduate students Ding Huang and Zi-Huai Zhang, who are members of de Leon's laboratory. The de Leon team also included postdoctoral research associates Paul Stevenson, Sorawis Sangtawesin, and Srikanth Srinivasan, a former postdoctoral researcher now at IBM. Additional contributions came from staff researcher Alexei Tyryshkin and Professor of Electrical Engineering Stephen Lyon. The team collaborated with Lorne Loudin at the Gemological Institute of America and Matthew Markham, Andrew Edmonds and Daniel Twitchen at Element Six. [29]

Fibre-optic transmission of 4000 km made possible by ultra-low-noise optical amplifiers

Researchers from Chalmers University of Technology, Sweden, and Tallinn University of Technology, Estonia, have demonstrated a 4000 kilometre fibre-optical transmission link using ultra low-noise, phase-sensitive optical amplifiers. This is a reach improvement of almost six times what is possible when using conventional optical amplifiers. The results are published in *Nature Communications*.

Video streaming, cloud storage and other online services have created an insatiable demand for higher transmission capacity. To meet this demand, new technologies capable of significant improvements over existing solutions are being explored worldwide.

The reach and capacity in today's fibre optical transmission links are both limited by the accumulation of noise, originating from optical amplifiers in the link, and by the signal distortion from nonlinear effects in the transmission fibre. In this ground-breaking demonstration, the researchers showed that the use of phase-sensitive amplifiers can significantly, and simultaneously, reduce the impact of both of these effects.

"While there remain several engineering challenges before these results can be implemented commercially, the results show, for the first time, in a very clear way, the great benefits of using these amplifiers in optical communication," says Professor Peter Andrekson, who leads the research on optical communication at Chalmers University of Technology.

The amplifiers can provide a very significant reach improvement over conventional approaches, and could potentially improve the performance of future fibre-optical communication systems.

"Such amplifiers may also find applications in quantum informatics and related fields, where generation and processing of quantum states are of interest, as well as in spectroscopy or any other application which could benefit from ultra-low-noise amplification," says Professor Peter Andrekson. [28]

Quantum step forward in protecting communications from hackers

Researchers at the University of York have shown that a new quantum-based procedure for distributing secure information along communication lines could be successful in preventing serious security breaches.

Securing highly sensitive information, such as hospital records and bank details, is a major challenge faced by companies and organisation throughout the world.

Standard communication systems are vulnerable to hacks, where encrypted information can be intercepted and copied. It is currently possible for hackers to make a copy of transmitted information, but it would not be possible to read it without a method of breaking the encryption that protects it.

This means that information might be secure for a period of time, but there is no guarantee that it would be secure forever, as supercomputers in development could potentially decipher particular encryptions in the future.

Researchers at York investigated a prototype, based on the principles of quantum mechanics, that has the potential to side-step the vulnerabilities of current communications, but also allow information to be secure in the future.

Powerful attack

Dr. Cosmo Lupo, from the University of York's Department of Computer Science, said: "Quantum mechanics has come a long way, but we are still faced with significant problems that have to be overcome with further experimentation.

"One such problem is that a hacker can attack the electronic devices used for information transmission by jamming the detectors that are used to collect and measure the photons that carries information.

"Such an attack is powerful because we assume that a given device works according to its technical specifications and will therefore perform its job. If a hacker is able to attack a detector and change the way it works, then the security is unavoidably compromised."

"The principles of quantum mechanics, however, allows for communication security even without making assumptions on how the electronic devices will work. By removing these assumptions we pay the price of lowering the communication rate, but gain in improving the security standard."

Two signals

Instead of relying on possibly compromised electronic components at the point at which information needs to be detected and read, the researchers found that if the untrusted detectors existed at a separate point in the communications – somewhere between the sender and receiver—the communication was far more secure.

The detector would receive a combination of two signals, one from the sender and one from the receiver. The detector would only be able to read the result of this combined signal, but not its component parts.

Dr. Lupo said: "In our work, not only have we provided a first rigorous mathematical proof that this 'detector- independent' design works, but we have also considered a scheme that is compatible with existing optical fibre communication networks.

"In principle our proposal can allow for the exchange of unbreakable codes across the internet without major changes in the actual infrastructure.

"We are still at prototype stage, but by finding ways to reduce the cost of these systems, we are that much closer to making quantum communications a reality."

The research is published in the journal *Physical Review Letters*. [27]

Braiding may be key to using time crystals in quantum computing

Over the past few years, physicists have predicted that a new form of matter called time crystals may have potential applications in quantum computing. Now in a new study, physicists Raditya Weda Bomantara and Jiangbin Gong at the National University of Singapore have taken some of the first steps toward showing exactly how that might be done. They theoretically demonstrate that, by braiding two different modes of time crystals, it's possible to generate the states that are necessary to perform universal quantum computation.

Time crystals have attracted the attention of physicists since the concept was first proposed by Frank Wilczek in 2012. Five years later, in 2017, time crystals were experimentally realized for the first time. Just as ordinary crystals are characterized by their repeating patterns in space, time crystals—which are always moving—have the unique feature that their motion exhibits repeating patterns in time. To realize a time crystal, a periodically driven laser sets the particles in a superconducting loop in motion. When the system is manipulated in a precise way, the particles' motion collectively synchronizes in a periodic manner, resulting in a time crystal.

In the new study, Bomantara and Gong have developed a method for harnessing the unique properties of time crystals for quantum computing that is based on braiding. To do this, they turned to a particular type of time crystal called a Majorana time crystal, whose name comes from the way it's created, which is from the quantum coherence between two types of Majorana edge modes (0 and π) in a superconducting chain.

The reason for choosing Majorana time crystals is that they share similarities with a type of quasiparticle called non-Abelian anyons, which can be braided and have recently been considered as a potential component of a topological quantum computer. By making use of this connection to non-Abelian anyons, the physicists showed that it's possible to mimic non-Abelian braiding in Majorana time crystals.

"Loosely speaking, braiding refers to exchanging the location of two particles," Gong told *Phys.org*. "In order to carry out this exchange, the particles are to be systematically moved around each other in such a way that if we draw the paths traversed by the two particles in spacetime, they form a braid. We know in real life that there are different types of braids, and that converting one braid to another requires certain operations that nature cannot do by itself. As a result, by storing information in these different types of braids, we can manipulate this information (hence performing quantum computation) by changing one type of braid to another (hence called braiding) without worrying that some external disturbance may destroy them."

The braiding method in the new study consists of a four-step process that involves slowly tuning the parameters of the system that generates the Majorana time crystals. In each step, the 0 and π modes are shifted, so that at the end of the entire process, the sequence of transformations results in one complete braiding operation that resets the system to its initial configuration.

In the future, time crystals may lead to new ways to perform certain quantum computational tasks. With this goal in mind, the physicists also showed that their quantum control protocol can be applied to time crystals to generate "magic states," which are a basic requirement for quantum computing.

"Braiding time crystals is potentially useful for quantum computation because we exploit their time-domain features and thus obtain more qubits for encoding information, and hence achieve savings in hardware," Gong said.

In the future, the physicists plan to further explore the possibilities of braiding time crystals. For one thing, they expect that extending braiding from one superconducting wire to an array of wires may allow them to simulate more intricate braiding processes.

"Given that we have now shown how the time dimension can be used as a resource for performing quantum computation, one future direction we have in mind will be to explore the possibility of storing and manipulating information with even fewer physical resources by enlarging the system in the time direction and by making use of more Majorana modes in periodically driven quantum wires," Gong said. "As a long-term goal, we plan to use this idea to design a robust quantum computer architecture with an optimal amount of resources—that is, one that is relatively small in physical size, but does not take a very long time to operate." [26]

Time crystals may hold secret to coherence in quantum computing

An Aalto University study has provided new evidence that time crystals can physically exist – a claim currently under hot debate.

A time crystal is a structure that does not repeat in space, like normal three-dimensional crystals such as snowflakes or diamonds, but in time. In practice this means that crystals constantly undergo spontaneous change, breaking the symmetry of time by achieving a self-sustaining oscillation.

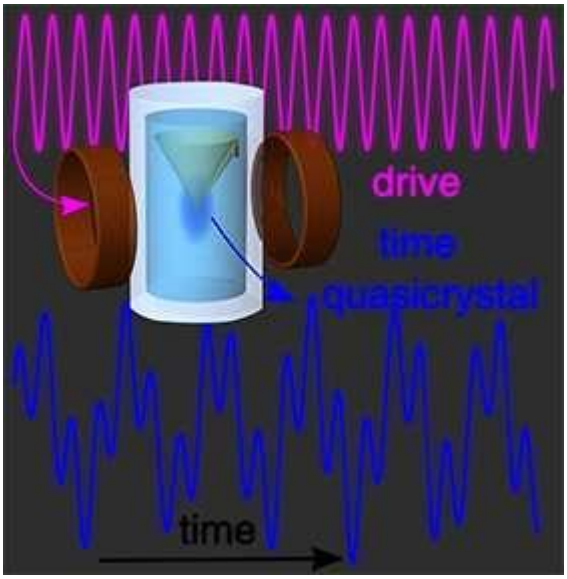
The value is in the time crystal's coherency, a property that allows temporal and spatial consistency, amounting to longevity otherwise not possible.

"Nature has given us a system that wants to be coherent over time," says Senior Scientist Vladimir Eltsov, leader of the ROTA research group at Aalto University.

"The system spontaneously begins to evolve in time coherently, over long periods of time, even infinitely long," he says.

With more understanding, the coherent nature of a time crystal may pave the way for eventual real-world applications. Researchers are hunting for systems that preserve coherence over the long term to make, for example, quantum information processing devices, but they struggle with sources resistant to decay.

Until recently, there has been little experimental evidence of the phenomenon. Physicists around the world have been racing to determine if – and how – these unique structures can be observed.



Credit: Aalto University

"There has been a lot of theoretical papers, but very few practical realizations. So ours is one of the few, and the first to demonstrate quasi-crystals," says Eltsov explains.

By understanding the fundamentals of time crystals – as in, when and how they materialize – researchers may be one day able to harness these principles to develop coherency in other devices, regardless of environmental factors.

The finding, achieved by studying the Bose–Einstein condensation of magnons in superfluid Helium-3, also has implications for other branches of physics.

"Helium-3 is related to practically all branches of physics: gravity, topology, particle physics, cosmology," says Professor Emeritus Grigori Volovik at Aalto University, a global pioneer in the study of connections between cosmology, high-energy physics and condensed matter.

In the future it may even be possible to look at time itself, including the possibility of constructing the boundary between time going forward and back, as theory suggests.

"It is an entire universe of study," Volovik says.

The scientists observed the time quasicrystal and its transition to a superfluid time crystal at the Low Temperature Laboratory at Aalto University in Finland, which has a long-standing history of research on superfluidity.

The results of the study, funded by the European Research Council, were published in *Physical Review Letters* on May 25, 2018. [25]

Physicists find signs of a time crystal

Yale physicists have uncovered hints of a time crystal—a form of matter that "ticks" when exposed to an electromagnetic pulse—in the last place they expected: a crystal you might find in a child's toy.

The discovery means there are now new puzzles to solve, in terms of how time crystals form in the first place.

Ordinary crystals such as salt or quartz are examples of three-dimensional, ordered spatial crystals. Their atoms are arranged in a repeating system, something scientists have known for a century.

Time crystals, first identified in 2016, are different. Their atoms spin periodically, first in one direction and then in another, as a pulsating force is used to flip them. That's the "ticking." In addition, the ticking in a time crystal is locked at a particular frequency, even when the pulse flips are imperfect.

Scientists say that understanding time crystals may lead to improvements in atomic clocks, gyroscopes, and magnetometers, as well as aid in building potential quantum technologies. The U.S. Department of Defense recently announced a program to fund more research into time crystal systems.

Yale's new findings are described in a pair of studies, one in *Physical Review Letters* and the other in *Physical Review B*. The studies represent the second known experiment observing a telltale signature for a discrete time crystal (DTC) in a solid. Previous experiments led to a flurry of media attention in the past year.

Yale researchers Jared Rovny, left, Robert Blum, center, and Sean Barrett, right, made the discovery. Credit: Yale University

"We decided to try searching for the DTC signature ourselves," said Yale physics professor Sean Barrett, principal investigator for the two new studies. "My student Jared Rovny had grown monoammonium phosphate (MAP) crystals for a completely different experiment, so we happened to have one in our lab."

MAP crystals are considered so easy to grow that they are sometimes included in crystal growing kits aimed at youngsters. It would be unusual to find a time crystal signature inside a MAP crystal, Barrett explained, because time crystals were thought to form in crystals with more internal "disorder."

The researchers used nuclear magnetic resonance (NMR) to look for a DTC signature—and quickly found it. "Our crystal measurements looked quite striking right off the bat," Barrett said. "Our work suggests that the signature of a DTC could be found, in principle, by looking in a children's crystal growing kit."

Another unexpected thing happened, as well. "We realized that just finding the DTC signature didn't necessarily prove that the system had a quantum memory of how it came to be," said Yale graduate student Robert Blum, a co-author on the studies. "This spurred us to try a time crystal 'echo,' which revealed the hidden coherence, or quantum order, within the system," added Rovny, also a Yale graduate student and lead author of the studies.

Barrett noted that his team's results, combined with previous experiments, "present a puzzle" for theorists trying to understand how time crystals form.

"It's too early to tell what the resolution will be for the current theory of discrete time crystals, but people will be working on this question for at least the next few years," Barrett said. [24]

Tracking mechanisms of crystallization in real time

Researchers at the Interfacial Dynamics in Radioactive Environments and Materials (IDREAM) Energy Frontier Research Center quantified transient penta-coordinated Al3+ species during the crystallization of gibbsite from hydrous aluminum gels in solutions of concentrated sodium hydroxide. The research shows that concentrated electrolytes in solution affect hydrogen bonding, ion interactions, and coordination geometries in currently unpredictable ways.

These mechanistic studies support the development of new process flow sheets to accelerate the processing of radioactive wastes at two Department of Energy sites. Further, the studies may provide less energy-intensive routes for industrial aluminum production.

Gibbsite (α-Al(OH)3) is an important mineral resource for industrial aluminum production. It is also present in large quantities in the high-level radioactive waste tanks at U.S. Department of Energy sites in Washington state and South Carolina. Traditional processing for either aluminum production or radioactive waste treatment is an energy-intensive activity. Processing involves heating to facilitate dissolution of gibbsite in highly alkaline solutions of concentrated electrolytes. Heating is followed by cooling to encourage precipitation from these chemically extreme systems.

For radioactive waste treatment, the dissolution and precipitation steps are often quite slow. Why? In part, both processes involve changes in the coordination geometry of the trivalent aluminum. In the solid phase, it is six coordinate to give an octahedral geometry. To move into the solution phase, the aluminum ion must change its geometry to a four-coordinate tetrahedral form.

Led by Jian Zhi Hu and Kevin Rosso, the team conducted high-field magic angle spinning nuclear magnetic resonance spectroscopy studies that probed ion interactions, solute organization, and solvent properties during gibbsite precipitation. The team captured real-time system dynamics as a function of experimental conditions, revealing previously unknown mechanistic details.

The team's work shows that the change in coordination is not a simple transition between the tetrahedral to octahedral species. The change involves an intermediate penta-coordinated aluminum metal center. Further, these species are influenced by subtle changes in solute and solvent organization. These changes lead to gel networks that can sometimes facilitate formation or dissolution of the solid phase. Understanding how aluminum coordination changes in extreme environments may lead to efficiencies in aluminum production and accelerate radioactive waste processing. [23]

The quantum states on the surface of conducting materials can strongly interact with light

An exotic state of matter that is dazzling scientists with its electrical properties, can also exhibit unusual optical properties, as shown in a theoretical study by researchers at A*STAR.

Atomically thin materials, such as graphene, derive some of their properties from the fact that electrons are confined to traveling in just two-dimensions. Similar phenomena are also seen in some three-dimensional materials, in which electrons confined to the surface behave very differently from those within the bulk—for example, topological insulators, whose surface electrons conduct electricity even though their bulk electrons do not. Recently, another exciting class of materials has been identified: the topological semimetal.

The difference in insulator and conductor electrical properties is down to the bandgap: a gap between the ranges, or bands, of energy that an electron traveling through the material can assume. In an insulator, the lower band is full of electrons and the bandgap is too large to enable a current to flow. In a semimetal, the lower band is also full but the lower and upper bands touch at some points, enabling the flow of a small current.

This lack of a full bandgap means that topological semimetals should theoretically exhibit very different properties from those of the more conventional topological insulators.

To prove this, Li-kun Shi and Justin Song from the A*STAR Institute of High Performance Computing used an 'effective Hamiltonian' approximation to show that the two-dimensional surface states in semimetals, known as Fermi arcs, possess a light–matter interaction much stronger than that found in other gapless two-dimensional systems, such as graphene.

"Typically, the bulk dominates material absorption," explains Song. "But we show that Dirac semimetals are unusual in that they possess a very optically active surface due to these peculiar Fermi arc states."

Shi and Song analyzed a proto-typical semimetal with a symmetric band structure where the electronic bands touch at two places, known as Dirac points, and predicted the strength with which incident radiation induces electron transitions from the lower band to the upper one. They found that surface absorption depends heavily on the polarization of light, being 100 to 1,000 times stronger when light is polarized perpendicular—rather than parallel—to the crystal's rotational axis. This strong anisotropy offers a way of optically investigating and probing the topological surfaces states of Dirac semimetals.

"Our goal is to identify more unconventional optics that arise due to Fermi arcs," says Song. "Topological semimetals could host unusual opto-electronic behavior that goes beyond conventional materials." [22]

Breakthrough in circuit design makes electronics more resistant to damage and defects

People are growing increasingly dependent on their mobile phones, tablets and other portable devices that help them navigate daily life. But these gadgets are prone to failure, often caused by small defects in their complex electronics, which can result from regular use. Now, a paper in today's *Nature Electronics* details an innovation from researchers at the Advanced Science Research Center (ASRC) at The Graduate Center of The City University of New York that provides robust protection against circuitry damage that affects signal transmission.

The breakthrough was made in the lab of Andrea Alù, director of the ASRC's Photonics Initiative. Alù and his colleagues from The City College of New York, University of Texas at Austin and Tel Aviv University were inspired by the seminal work of three British researchers who won the 2016 Noble Prize in Physics for their work, which teased out that particular properties of matter (such as electrical conductivity) can be preserved in certain materials despite continuous changes in the matter's form or shape. This concept is associated with topology—a branch of mathematics that studies the properties of space that are preserved under continuous deformations.

"In the past few years there has been a strong interest in translating this concept of matter topology from material science to light propagation," said Alù. "We achieved two goals with this project: First, we showed that we can use the science of topology to facilitate robust electromagnetic-wave propagation in electronics and circuit components. Second, we showed that the inherent robustness associated with these topological phenomena can be self-induced by the signal traveling in the circuit, and that we can achieve this robustness using suitably tailored nonlinearities in circuit arrays."

To achieve their goals, the team used nonlinear resonators to mold a band-diagram of the circuit array. The array was designed so that a change in signal intensity could induce a change in the band diagram's topology. For low signal intensities, the electronic circuit was designed to support a trivial topology, and therefore provide no protection from defects. In this case, as defects were introduced into the array, the signal transmission and the functionality of the circuit were negatively affected.

As the voltage was increased beyond a specific threshold, however, the band-diagram's topology was automatically modified, and the signal transmission was not impeded by arbitrary defects introduced across the circuit array. This provided direct evidence of a topological transition in the circuitry that translated into a self-induced robustness against defects and disorder.

"As soon as we applied the higher-voltage signal, the system reconfigured itself, inducing a topology that propagated across the entire chain of resonators allowing the signal to transmit without any problem," said A. Khanikaev, professor at The City College of New York and co-author in the study. "Because the system is nonlinear, it's able to undergo an unusual transition that makes signal transmission robust even when there are defects or damage to the circuitry."

"These ideas open up exciting opportunities for inherently robust electronics and show how complex concepts in mathematics, like the one of topology, can have real-life impact on common electronic devices," said Yakir Hadad, lead author and former postdoc in Alù's group, currently a professor at Tel-Aviv University, Israel. "Similar ideas can be applied to nonlinear optical circuits and extended to two and three-dimensional nonlinear metamaterials." [21]

Researchers develop heat switch for electronics

Researchers at the University of Illinois at Urbana-Champaign have developed a new technology for switching heat flows 'on' or 'off'. The findings were published in the article "Millimeter-scale liquid metal droplet thermal switch," which appeared in *Applied Physics Letters*.

Switches are used to control many technical products and engineered systems. Mechanical switches are used to lock or unlock doors, or to select gears in a car's transmission system. Electrical switches are used to turn on and off the lights in a room. At a smaller scale, electrical switches in the form of transistors are used to turn electronic devices on and off, or to route logic signals within a circuit.

Engineers have long desired a switch for heat flows, especially in electronics systems where controlling heat flows can significantly improve system performance and reliability. There are however significant challenges in creating such a heat switch.

"Heat flow occurs whenever you have a region of higher temperature near a region of lower temperature," said William King, the Andersen Chair Professor in the Department of Mechanical Science and Engineering and the project co-leader. "In order to control the heat flow, we engineered a specific heat flow path between the hot region and cold region, and then created a way to break the heat flow path when desired."

"The technology is based on the motion of a liquid metal droplet," said Nenad Miljkovic, Assistant Professor in the Department of Mechanical Science and Engineering and the project co-leader. "The metal droplet can be positioned to connect a heat flow path, or moved away from the heat flow path in order to limit the heat flow."

The researchers demonstrated the technology in a system modeled after modern electronics systems. On one side of the switch there was a heat source representing the power electronics component, and on the other side of the switch, there was liquid cooling for heat removal. When the switch was on, they were able to extract heat at more than 10 W/cm2. When the switch was off, the heatflow dropped by nearly 100X.

Besides King and Miljkovic, other authors of the paper include Paul Braun, Racheff Professor of Materials Science and Engineering and the Director of Materials Research Laboratory; and graduate students Tianyu Yang, Beomjin Kwon and Patricia B. Weisensee (now an assistant professor at Washington University in St. Louis) from mechanical science and engineering and Jin Gu Kang and Xuejiao Li from materials science and engineering.

King says that the next step for the research is to integrate the switch with power electronics on a circuit board. The researchers will have a working prototype later this year. [20]

Converting heat into electricity with pencil and paper

Thermoelectric materials can use thermal differences to generate electricity. Now there is an inexpensive and environmentally friendly way of producing them with the simplest tools: a pencil, photocopy paper, and conductive paint. These are sufficient to convert a temperature difference into electricity via the thermoelectric effect, which has now been demonstrated by a team at the Helmholtz-Zentrum Berlin.

The thermoelectric effect was discovered almost 200 years ago by Thomas J. Seebeck. If two metals of different temperatures are brought together, they can develop an electrical voltage. This effect allows residual heat to be converted partially into electrical energy. Residual heat is a by-product of almost all technological and natural processes, such as in power plants and household appliances, not to mention the human body. It is also one of the most under-utilised energy sources in the world.

Tiny effect

However, as useful an effect as it is, it is extremely small in ordinary metals. This is because metals not only have high electrical conductivity, but high thermal conductivity as well, so that differences in temperature disappear immediately. Thermoelectric materials need to have low thermal conductivity despite their high electrical conductivity. Thermoelectric devices made of inorganic semiconductor materials such as bismuth telluride are already being used today in certain technological applications. However, such material systems are expensive and their use only pays off in certain situations. Researchers are exploring whether flexible, nontoxic organic materials based on carbon nanostructures, for example, might also be used in the human body.

The team led by Prof. Norbert Nickel at the HZB has now shown that the effect can be obtained much more simply—using a normal HB-grade pencil, they covered a small area with pencil on ordinary photocopy paper. As a second material, they applied a transparent, conductive co-polymer paint (PEDOT: PSS) to the surface.

The pencil traces on the paper delivered a voltage comparable to other far more expensive nanocomposites that are currently used for flexible thermoelectric elements. And this voltage could be increased tenfold by adding indium selenide to the graphite from the pencil.

The researchers investigated graphite and co-polymer coating films using a scanning electron microscope and Raman scattering at HZB. "The results were very surprising for us as well," says Nickel. "But we have now found an explanation of why this works so well—the pencil deposit left on the paper forms a surface characterised by unordered graphite flakes, some graphene, and clay. While this only slightly reduces the electrical conductivity, heat is transported much less effectively."

These simple constituents might be usable in the future to print extremely inexpensive, environmentally friendly, and non-toxic thermoelectric components onto paper. Such tiny and flexible components could also be used directly on the body and could use body heat to operate small devices or sensors. [19]

A new efficient and portable electrocaloric cooling device

A team of researchers with the University of California and SRI International has developed a new type of cooling device that is both portable and efficient. In their paper published in the journal Science, the team describes their new device and possible applications for its use. Q.M. Zhang and Tian Zhang with the Pennsylvania State University offer some background on electrocaloric theory and outline the work done by the team in California in a Perspectives piece in the same journal issue.

As most everyone knows, conventional air conditioners are bulky, heavy, use a lot of electricity and often leak greenhouse gases into the atmosphere. Thus, conditions are ripe for something new. Some new devices have been developed such as thermoelectric coolers, which make use of ceramics, but they are not efficient enough to play a major role in cooling. A more recent development is the use of devices exploiting the electrocaloric effect, which is where heat moves through certain materials when an electric current is applied. In this new effort, the researchers used a polymer as the material.

The new cooling device was made by layering a polymer between a heat sink and a heat source. Applying electric current to the polymer when it was touching the heat sink caused its molecules to line up, which reduced entropy, forcing heat into the sink. The polymer was then moved into contact with the heat source while the current was turned off. The molecules relaxed, which caused the temperature to drop. Repeating this process resulted in cooling.

The researchers report that the device is extremely efficient, portable and configurable. They suggest the same technology could be used to create coolers for a chair or hat, for example, or perhaps to chill smartphone batteries. They proved this last claim by actually building such a device and using it to cool down a battery heated by ordinary use—after only five seconds, the temperature of the battery had lessened by 8° C. Comparatively, air cooling the battery reduced its temperature just 3° C in 50 seconds. [18]

Fast heat flows in warm, dense aluminum

Thermal conductivity is one of the most crucial physical properties of matter when it comes to understanding heat transport, hydrodynamic evolution and energy balance in systems ranging from astrophysical objects to fusion plasmas.

In the warm dense matter (WDM) regime, experimental data are very rare, so many theoretical models remain untested.

But LLNL researchers have tested theory by developing a platform called "differential heating" to conduct thermal conductivity measurements. Just as land and water on Earth heat up differently in sunlight, a temperature gradient can be induced between two different materials. The subsequent heat flow from the hotter material to the cooler material is detected by time-resolved diagnostics to determine thermal conductivity.

In an experiment using the Titan laser at the Lab's Jupiter Laser Facility, LLNL researchers and collaborators achieved the first measurements of thermal conductivity of warm dense aluminum—a prototype material commonly used in model development—by heating a dual-layer target of gold and aluminum with laser-generated protons.

"Two simultaneous time-resolved diagnostics provided excellent data for gold, the hotter material, and aluminum, the colder material," said Andrew Mckelvey, a graduate student from the University of Michigan and the first author of a paper appearing in Scientific Reports . "The systematic data sets can constrain both the release equation of state (EOS) and thermal conductivity."

By comparing the data with simulations using five existing thermal conductivity models, the team found that only two agree with the data. The most commonly used model in WDM, called the LeeMore model, did not agree with data. "I am glad to see that Purgatorio, an LLNL-based model, agrees with the data," said Phil Sterne, LLNL co-author and the group leader of EOS development and application group in the Physics Division. "This is the first time these thermal conductivity models of aluminum have been tested in the WDM regime."

"Discrepancy still exists at early time up to 15 picoseconds," said Elijah Kemp, who is responsible for the simulation efforts. "This is likely due to non-equilibrium conditions, another active research area in WDM."

The team is led by Yuan Ping through her early career project funded by the Department of Energy Office of Fusion Energy Science Early Career Program. "This platform can be applied to many pairs of materials and by various heating methods including particle and X-ray heating," Ping said. [17]

Controlling heat and particle currents in nanodevices by quantum observation

Researchers from the Theory Department of the MPSD have realized the control of thermal and electrical currents in nanoscale devices by means of quantum local observations.

Measurement plays a fundamental role in quantum mechanics. The best-known illustration of the principles of superposition and entanglement is Schrödinger's cat. Invisible from the outside, the cat resides in a coherent superposition of two states, alive and dead at the same time.

By means of a measurement, this superposition collapses to a concrete state. The cat is now either dead or alive. In this famous thought experiment, a measurement of the "quantum cat" can be seen as an interaction with a macroscopic object collapsing the superposition onto a concrete state by destroying its coherence.

In their new article published in npj Quantum Materials, researchers from the Max Planck Institute for the Structure and Dynamics of Matter and collaborators from the University of the Basque Country (UPV/EHU) and the Bremen Center for Computational Materials Science discovered how a microscopic quantum observer is able to control thermal and electrical currents in nanoscale devices. Local quantum observation of a system can induce continuous and dynamic changes in its

quantum coherence, which allows better control of particle and energy currents in nanoscale systems.

Classical non-equilibrium thermodynamics was developed to understand the flow of particles and energy between multiple heat and particle reservoirs. The best-known example is Clausius' formulation of the second law of thermodynamics, stating that when two objects with different temperatures are brought in contact, heat will exclusively flow from the hotter to the colder one.

In macroscopic objects, the observation of this process does not influence the flow of energy and particles between them. However, in quantum devices, thermodynamical concepts need to be revisited. When a classical observer measures a quantum system, this interaction destroys most of the coherence inside the system and alters its dynamical response.

Instead, if a quantum observer acts only locally, the system quantum coherence changes continuously and dynamically, thus providing another level of control of its properties. Depending on how strong and where these local quantum observations are performed, novel and surprising quantum transport phenomena arise.

The group of Prof.Dr. Angel Rubio at the Theory Department of the MPSD, along with their colleagues, have demonstrated how the concept of quantum measurements can offer novel possibilities for a thermodynamical control of quantum transport (heat and particle). This concept offers possibilities far beyond those obtained using standard classical thermal reservoirs.

The scientists studied this idea in a theoretical quantum ratchet. Within this system, the left and right side are connected to hot and cold thermal baths, respectively. This configuration forces the energy to flow from hot to cold and the particles to flow clockwise inside the ratchet. The introduction of a quantum observer, however, inverts the particle ring-current against the natural direction of the ratchet—a phenomenon caused by the localized electronic state and the disruption of the system's symmetry.

Furthermore, the quantum observation is also able to invert the direction of the heat flow, contradicting the second law of thermodynamics. "Such heat and particle current control might open the door for different strategies to design quantum transport devices with directionality control of the injection of currents. There could be applications in thermoelectricity, spintronics, photonics, and sensing, among others. These results have been an important contribution to my PhD thesis," says Robert Biele, first author of the paper.

From a more fundamental point of view, this work highlights the role of a quantum observer. In contrast to Schrödinger's cat, where the coherent state is destroyed via the interaction with a macroscopic "observer," here, by introducing a local quantum observer, the coherence is changed locally and dynamically, allowing researchers to tune between the coherent states of the system. "This shows how thermodynamics is very different in the quantum regime. Schrödinger's cat paradox leads to new thermodynamic forces never seen before," says César A. Rodríguez Rosario.

In the near future, the researchers will apply this concept to control spins for applications in spin injection and novel magnetic memories. Angel Rubio suggests that "The quantum observer—besides controlling the particle and energy transfer at the nanoscale—could also observe spins,

select individual components, and give rise to spin-polarized currents without spin-orbit coupling. Observation could be used to write a magnetic memory." [16]

Maxwell's demon extracts work from quantum measurement

Physicists have proposed a new type of Maxwell's demon—the hypothetical agent that extracts work from a system by decreasing the system's entropy—in which the demon can extract work just by making a measurement, by taking advantage of quantum fluctuations and quantum superposition.

The team of Alexia Auffèves at CNRS and Université Grenoble Alpes have published a paper on the new Maxwell's demon in a recent issue of Physical Review Letters.

"In the classical world, thermodynamics teaches us how to extract energy from thermal fluctuations induced on a large system (such as a gas or water) by coupling it to a hot source," Auffèves told Phys.org. "In the quantum world, the systems are small, and they can fluctuate—even if they are not hot, but simply because they are measured. In our paper, we show that it is possible to extract energy from these genuinely quantum fluctuations, induced by quantum measurement."

In the years since James Clerk Maxwell proposed the first demon around 1870, many other versions have been theoretically and experimentally investigated. Most recently, physicists have begun investigating Maxwell's demons that operate in the quantum regime, which could one day have implications for quantum information technologies.

Most quantum versions of the demon have a couple things in common: They are thermally driven by a heat bath, and the demon makes measurements to extract information only. The measurements do not actually extract any work, but rather the information gained by the measurements allows the demon to act on the system so that energy is always extracted from the cycle.

The new Maxwell's demon differs from previous versions in that there is no heat bath—the demon is not thermally driven, but measurement-driven. Also, the measurements have multiple purposes: They not only extract information about the state of the system, but they are also the "fuel" for extracting work from the system. This is because, when the demon performs a measurement on a qubit in the proposed system, the measurement projects the qubit from one state into a superposition of states, which provides energy to the qubit simply due to the measurement process. In their paper, the physicists proposed an experiment in which projective quantum non-demolition measurements can be performed with light pulses repeated every 70 nanoseconds or so.

Since recent experiments have already demonstrated the possibility of performing measurements at such high frequencies, the physicists expect that the new Maxwell's demon could be readily implemented using existing technology. In the future, they also plan to investigate potential applications for quantum computing.

"This engine is a perfect proof of concept evidencing that quantum measurement has some energetic footprint," Auffèves said. "Now I would like to reverse the game and use this effect to

estimate the energetic cost of quantum tasks, if they are performed in the presence of some measuring entity. This is the case in a quantum computer, which is continuously 'measured' by its surroundings. This effect is called decoherence and is the biggest enemy of quantum computation. Our work provides tools to estimate the energy needed to counteract it." [15]

Physicists read Maxwell's Demon's mind

Pioneering research offers a fascinating view into the inner workings of the mind of 'Maxwell's Demon', a famous thought experiment in physics.

An international research team, including Dr Janet Anders from the University of Exeter, have used superconducting circuits to bring the 'demon' to life.

The demon, first proposed by James Clerk Maxwell in 1867, is a hypothetical being that can gain more useful energy from a thermodynamic system than one of the most fundamental laws of physics—the second law of thermodynamics—should allow.

Crucially, the team not only directly observed the gained energy for the first time, they also tracked how information gets stored in the demon's memory.

The research is published in the leading scientific journal Proceedings of the National Academy of Sciences (PNAS).

The original thought experiment was first proposed by mathematical physicist James Clerk Maxwell—one of the most influential scientists in history—150 years ago.

He hypothesised that gas particles in two adjacent boxes could be filtered by a 'demon' operating a tiny door, that allowed only fast energy particles to pass in one direction and low energy particles the opposite way.

As a result, one box gains a higher average energy than the other, which creates a pressure difference. This non-equilibrium situation can be used to gain energy, not unlike the energy obtained when water stored behind a dam is released.

So although the gas was initially in equilibrium, the demon can create a non-equilibrium situation and extract energy, bypassing the second law of thermodynamics.

Dr Anders, a leading theoretical physicist from the University of Exeter's physics department adds: "In the 1980s it was discovered that this is not the full story. The information about the particles' properties remains stored in the memory of the demon. This information leads to an energetic cost which then reduces the demon's energy gain to null, resolving the paradox."

In this research, the team created a quantum Maxwell demon, manifested as a microwave cavity, that draws energy from a superconducting qubit. The team was able to fully map out the memory of the demon after its intervention, unveiling the stored information about the qubit state.

Dr Anders adds: "The fact that the system behaves quantum mechanically means that the particle can have a high and low energy at the same time, not only either of these choices as considered by Maxwell."

This ground-breaking experiment gives a fascinating peek into the interplay between quantum information and thermodynamics, and is an important step in the current development of a theory for nanoscale thermodynamic processes.

'Observing a Quantum Maxwell demon at Work' is published in PNAS. [14]

Researchers posit way to locally circumvent Second Law of Thermodynamics

For more than a century and a half of physics, the Second Law of Thermodynamics, which states that entropy always increases, has been as close to inviolable as any law we know. In this universe, chaos reigns supreme.

But researchers with the U.S. Department of Energy's (DOE's) Argonne National Laboratory announced recently that they may have discovered a little loophole in this famous maxim.

Their research, published in Scientific Reports, lays out a possible avenue to a situation where the Second Law is violated on the microscopic level.

The Second Law is underpinned by what is called the H-theorem, which says that if you open a door between two rooms, one hot and one cold, they will eventually settle into lukewarm equilibrium; the hot room will never end up hotter.

But even in the twentieth century, as our knowledge of quantum mechanics advanced, we didn't fully understand the fundamental physical origins of the H-theorem.

Recent advancements in a field called quantum information theory offered a mathematical construction in which entropy increases.

"What we did was formulate how these beautiful abstract mathematical theories could be connected to our crude reality," said Valerii Vinokur, an Argonne Distinguished Fellow and corresponding author on the study.

The scientists took quantum information theory, which is based on abstract mathematical systems, and applied it to condensed matter physics, a well-explored field with many known laws and experiments.

"This allowed us to formulate the quantum H-theorem as it related to things that could be physically observed," said Ivan Sadovskyy, a joint appointee with Argonne's Materials Science Division and the Computation Institute and another author on the paper. "It establishes a connection between welldocumented quantum physics processes and the theoretical quantum channels that make up quantum information theory."

The work predicts certain conditions under which the H-theorem might be violated and entropy—in the short term—might actually decrease.

As far back as 1867, physicist James Clerk Maxwell described a hypothetical way to violate the Second Law: if a small theoretical being sat at the door between the hot and cold rooms and only let through particles traveling at a certain speed. This theoretical imp is called "Maxwell's demon."

"Although the violation is only on the local scale, the implications are far-reaching," Vinokur said. "This provides us a platform for the practical realization of a quantum Maxwell's demon, which could make possible a local quantum perpetual motion machine."

For example, he said, the principle could be designed into a "refrigerator" which could be cooled remotely—that is, the energy expended to cool it could take place anywhere.

The authors are planning to work closely with a team of experimentalists to design a proof-ofconcept system, they said.

The study, "H-theorem in quantum physics," was published September 12 in Nature Scientific Reports. [13]

What is quantum in quantum thermodynamics?

A lot of attention has been given to the differences between the quantum and classical worlds. For example, quantum entanglement, superposition, and teleportation are purely quantum phenomena with no classical counterparts. However, when it comes to certain areas of thermodynamics— specifically, thermal engines and refrigerators—quantum and classical systems so far appear to be nearly identical. It seems that the same thermodynamic laws that govern the engines in our vehicles may also accurately describe the tiniest quantum engines consisting of just a single particle.

In a new study, physicists Raam Uzdin, Amikam Levy, and Ronnie Kosloff at the Hebrew University of Jerusalem have investigated whether there is anything distinctly quantum about thermodynamics at the quantum level, or if "quantum" thermodynamics is really the same as classical thermodynamics.

For the first time, they have shown a difference in the thermodynamics of heat machines on the quantum scale: in part of the quantum regime, the three main engine types (two-stroke, four-stroke, and continuous) are thermodynamically equivalent. This means that, despite operating in different ways, all three types of engines exhibit all of the same thermodynamic properties, including generating the same amounts of power and heat, and doing so at the same efficiency. This new "thermodynamical equivalence principle" is purely quantum, as it depends on quantum effects, and does not occur at the classical level.

The scientists also showed that, in this quantum regime where all engines are thermodynamically equivalent, it's possible to extract a quantum-thermodynamic signature that further confirms the presence of quantum effects. They did this by calculating an upper limit on the work output of a classical engine, so that any engine that surpasses this bound must be using a quantum effect—namely, quantum coherence—to generate the additional work. In this study, quantum coherence, which accounts for the wave-like properties of quantum particles, is shown to be critical for power generation at very fast engine cycles.

"To the best of my knowledge, this is the first time [that a difference between quantum and classical thermodynamics has been shown] in heat machines," Uzdin told Phys.org. "What has been surprising [in the past] is that the classical description has still held at the quantum level, as many authors have shown. The reasons are now understood, and in the face of this classicality, people

have started to stray to other types of research, as it was believed that nothing quantum can pop up.

Thus, it was very difficult to isolate a generic effect, not just a numerical simulation of a specific case, with a complementing theory that manages to avoid the classicality and demonstrate quantum effects in thermodynamic quantities, such as work and heat."

One important implication of the new results is that quantum effects may significantly increase the performance of engines at the quantum level. While the current work deals with single-particle engines, the researchers expect that quantum effects may also emerge in multi-particle engines, where quantum entanglement between particles may play a role similar to that of coherence. [12]

Physicists confirm thermodynamic irreversibility in a quantum system

The physicists, Tiago Batalhão at the Federal University of ABC, Brazil, and coauthors, have published their paper on the experimental demonstration of quantum thermodynamic irreversibility in a recent issue of Physical Review Letters.

Irreversibility at the quantum level may seem obvious to most people because it matches our observations of the everyday, macroscopic world. However, it is not as straightforward to physicists because the microscopic laws of physics, such as the Schrödinger equation, are "time-symmetric," or reversible. In theory, forward and backward microscopic processes are indistinguishable.

In reality, however, we only observe forward processes, not reversible ones like broken egg shells being put back together. It's clear that, at the macroscopic level, the laws run counter to what we observe. Now the new study shows that the laws don't match what happens at the quantum level, either.

Observing thermodynamic processes in a quantum system is very difficult and has not been done until now. In their experiment, the scientists measured the entropy change that occurs when applying an oscillating magnetic field to carbon-13 atoms in liquid chloroform. They first applied a magnetic field pulse that causes the atoms' nuclear spins to flip, and then applied the pulse in reverse to make the spins undergo the reversed dynamics.

If the procedure were reversible, the spins would have returned to their starting points—but they didn't. Basically, the forward and reverse magnetic pulses were applied so rapidly that the spins' flipping couldn't always keep up, so the spins were driven out of equilibrium. The measurements of the spins indicated that entropy was increasing in the isolated system, showing that the quantum thermodynamic process was irreversible.

By demonstrating that thermodynamic irreversibility occurs even at the quantum level, the results reveal that thermodynamic irreversibility emerges at a genuine microscopic scale. This finding makes the question of why the microscopic laws of physics don't match our observations even more pressing. If the laws really are reversible, then what are the physical origins of the time-asymmetric entropy production that we observe?

The physicists explain that the answer to this question lies in the choice of the initial conditions. The microscopic laws allow reversible processes only because they begin with "a genuine equilibrium process for which the entropy production vanishes at all times," the scientists write in their paper. Preparing such an ideal initial state in a physical system is extremely complex, and the initial states of all observed processes aren't at "genuine equilibrium," which is why they lead to irreversible processes.

"Our experiment shows the irreversible nature of quantum dynamics, but does not pinpoint, experimentally, what causes it at the microscopic level, what determines the onset of the arrow of time," coauthor Mauro Paternostro at Queen's University in Belfast, UK, told Phys.org. "Addressing it would clarify the ultimate reason for its emergence."

The researchers hope to apply the new understanding of thermodynamics at the quantum level to high-performance quantum technologies in the future.

"Any progress towards the management of finite-time thermodynamic processes at the quantum level is a step forward towards the realization of a fully fledged thermo-machine that can exploit the laws of quantum mechanics to overcome the performance limitations of classical devices," Paternostro said. "This work shows the implications for reversibility (or lack thereof) of nonequilibrium quantum dynamics. Once we characterize it, we can harness it at the technological level." [11]

Physicists put the arrow of time under a quantum microscope

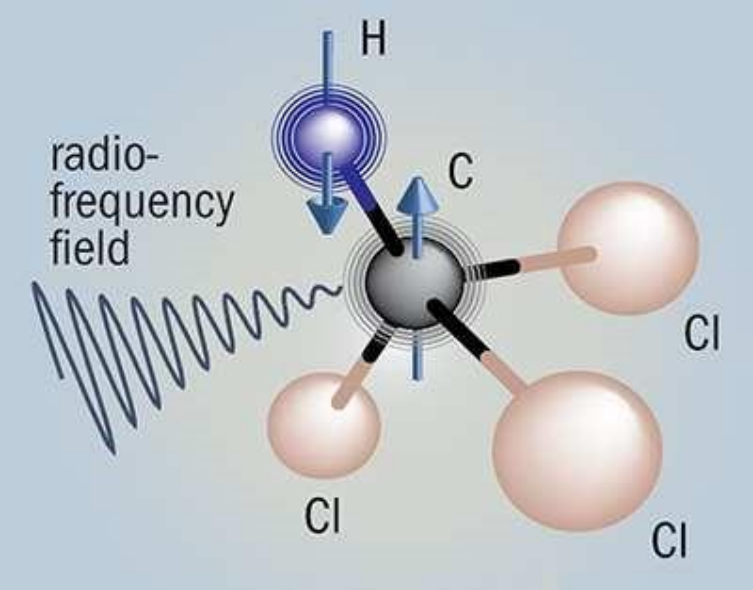


Diagram showing the spin of a carbon atom in a chloroform molecule

Disorder, or entropy, in a microscopic quantum system has been measured by an international group of physicists. The team hopes that the feat will shed light on the "arrow of time": the observation that time always marches towards the future. The experiment involved continually flipping the spin of carbon atoms with an oscillating magnetic field and links the emergence of the arrow of time to quantum fluctuations between one atomic spin state and another.

"That is why we remember yesterday and not tomorrow," explains group member Roberto Serra, a physicist specializing in quantum information at the Federal University of ABC in Santo André, Brazil. At the fundamental level, he says, quantum fluctuations are involved in the asymmetry of time.

Egging on

The arrow of time is often taken for granted in the everyday world. We see an egg breaking, for example, yet we never see the yolk, white and shell fragments come back together again to recreate the egg. It seems obvious that the laws of nature should not be reversible, yet there is nothing in the underlying physics to say so.

The dynamical equations of an egg breaking run just as well forwards as they do backwards.

Entropy, however, provides a window onto the arrow of time. Most eggs look alike, but a broken egg can take on any number of forms: it could be neatly cracked open, scrambled, splattered all over a pavement, and so on. A broken egg is a disordered state – that is, a state of greater entropy – and because there are many more disordered than ordered states, it is more likely for a system to progress towards disorder than order.

This probabilistic reasoning is encapsulated in the second law of thermodynamics, which states that the entropy of a closed system always increases over time.

According to the second law, time cannot suddenly go backwards because this would require entropy to decrease. It is a convincing argument for a complex system made up of a great many interacting particles, like an egg, but what about a system composed of just one particle?

Murky territory

Serra and colleagues have delved into this murky territory with measurements of entropy in an ensemble of carbon-13 atoms contained in a sample of liquid chloroform. Although the sample contained roughly a trillion chloroform molecules, the non-interacting quantum nature of the molecules meant that the experiment was equivalent to performing the same measurement on a single carbon atom, one trillion times.

Serra and colleagues applied an oscillating external magnetic field to the sample, which continually flipped the spin state of a carbon atom between up and down.

They ramped up the intensity of the field oscillations to increase the frequency of the spin-flipping, and then brought the intensity back down again.

Had the system been reversible, the overall distribution of carbon spin states would have been the same at the end as at the start of the process. Using nuclear magnetic resonance and quantum-state tomography, however, Serra and colleagues measured an increase in disorder among the final spins. Because of the quantum nature of the system, this was equivalent to an increase in entropy in a single carbon atom.

According to the researchers, entropy rises for a single atom because of the speed with which it is forced to flip its spin. Unable to keep up with the field-oscillation intensity, the atom begins to

fluctuate randomly, like an inexperienced dancer failing to keep pace with up-tempo music. "It's easier to dance to a slow rhythm than a fast one," says Serra.

Many questions remain

The group has managed to observe the existence of the arrow of time in a quantum system, says experimentalist Mark Raizen of the University of Texas at Austin in the US, who has also studied irreversibility in quantum systems. But Raizen stresses that the group has not observed the "onset" of the arrow of time. "This [study] does not close the book on our understanding of the arrow of time, and many questions remain," he adds.

One of those questions is whether the arrow of time is linked to quantum entanglement – the phenomenon whereby two particles exhibit instantaneous correlations with each other, even when separated by vast distances. This idea is nearly 30 years old and has enjoyed a recent resurgence in popularity. However, this link is less to do with growing entropy and more to do with an unstoppable dispersion of quantum information.

Indeed, Serra believes that by harnessing quantum entanglement, it may even be possible to reverse the arrow of time in a microscopic system. "We're working on it," he says. "In the next generation of
our experiments on quantum thermodynamics we will explore such aspects." [10]

Small entropy changes allow quantum measurements to be nearly reversed

In 1975, Swedish physicist Göran Lindblad developed a theorem that describes the change in entropy that occurs during a quantum measurement. Today, this theorem is a foundational component of quantum information theory, underlying such important concepts as the uncertainty principle, the second law of thermodynamics, and data transmission in quantum communication systems.

Now, 40 years later, physicist Mark M. Wilde, Assistant Professor at Louisiana State University, has improved this theorem in a way that allows for understanding how quantum measurements can be approximately reversed under certain circumstances. The new results allow for understanding how quantum information that has been lost during a measurement can be nearly recovered, which has potential implications for a variety of quantum technologies.

Quantum relative entropy never increases

Most people are familiar with entropy as a measure of disorder and the law that "entropy never decreases"—it either increases or stays the same during a thermodynamic process, according to the second law of thermodynamics. However, here the focus is on "quantum relative entropy," which in some sense is the negative of entropy, so the reverse is true: quantum relative entropy never increases, but instead only decreases or stays the same.

In fact, this was the entropy inequality theorem that Lindblad proved in 1975: that the quantum relative entropy cannot increase after a measurement. In this context, quantum relative entropy is interpreted as a measure of how well one can distinguish between two quantum states, so it's this distinguishability that can never increase. (Wilde describes a proof of Lindblad's result in greater detail in his textbook Quantum Information Theory, published by Cambridge University Press.)

One thing that Lindblad's proof doesn't address, however, is whether it makes any difference if the quantum relative entropy decreases by a little or by a lot after a measurement.

In the new paper, Wilde has shown that, if the quantum relative entropy decreases by only a little, then the quantum measurement (or any other type of so-called "quantum physical evolution") can be approximately reversed.

"When looking at Lindblad's entropy inequality, a natural question is to wonder what we could say if the quantum relative entropy goes down only by a little when the quantum physical evolution is applied," Wilde told Phys.org. "It is quite reasonable to suspect that we might be able to approximately reverse the evolution. This was arguably open since the work of Lindblad in 1975, addressed in an important way by Denes Petz in the late 1980s (for the case in which the quantum relative entropy stays the same under the action of the evolution), and finally formulated as a conjecture around 2008 by Andreas Winter. What my work did was to prove this result as a theorem: if the quantum relative entropy goes down only by a little under a quantum physical evolution, then we can approximately reverse its action."

Wide implications

Wilde's improvements to Lindblad's theorem have a variety of implications, but the main one that Wilde discusses in his paper is how the new results allow for recovering quantum information.

"If the decrease in quantum relative entropy between two quantum states after a quantum physical evolution is relatively small," he said, "then it is possible to perform a recovery operation, such that one can perfectly recover one state while approximately recovering the other. This can be interpreted as quantifying how well one can reverse a quantum physical evolution." So the smaller the relative entropy decrease, the better the reversal process.

The ability to recover quantum information could prove useful for quantum error correction, which aims to protect quantum information from damaging external effects. Wilde plans to address this application more in the future with his colleagues.

As Wilde explained, Lindblad's original theorem can also be used to prove the uncertainty principle of quantum mechanics in terms of entropies, as well as the second law of thermodynamics for quantum systems, so the new results have implications in these areas, as well.

"Lindblad's entropy inequality underlies many limiting statements, in some cases said to be physical laws or principles," Wilde said. "Examples are the uncertainty principle and the second law of thermodynamics. Another example is that this entropy inequality is the core step in determining

limitations on how much data we can communicate over quantum communication channels. We could go as far as to say that the above entropy inequality constitutes a fundamental law of quantum information theory, which is a direct mathematical consequence of the postulates of quantum mechanics."

Regarding the uncertainty principle, Wilde and two coauthors, Mario Berta and Stephanie Wehner, discuss this angle in a forthcoming paper. They explain that the uncertainty principle involves quantum measurements, which are a type of quantum physical evolution and therefore subject to Lindblad's theorem. In one formulation of the uncertainty principle, two experiments are performed on different copies of the same quantum state, with both experimental outcomes having some uncertainty.

"The uncertainty principle is the statement that you cannot generally make the uncertainties of both experiments arbitrarily small, i.e., there is generally a limitation," Wilde said. "It is now known that a statement of the uncertainty principle in terms of entropies can be proved by using the 'decrease of quantum relative entropy inequality.' So what the new theorem allows for doing is relating the uncertainties of the measurement outcomes to how well we could try to reverse the action of one of the measurements. That is, there is now a single mathematical inequality which captures all of these notions."

In terms of the second law of thermodynamics, Wilde explains how the new results have implications for reversing thermodynamic processes in both classical and quantum systems.

"The new theorem allows for quantifying how well we can approximately reverse a thermodynamic transition from one state to another without using any energy at all," he said.

He explained that this is possible due to the connection between entropy, energy, and work. According to the second law of thermodynamics, a thermodynamic transition from one quantum state to another is allowed only if the free energy decreases from the original state to the final state. During this process, one can gain work and store energy. This law can be rewritten as a statement involving relative entropies and can be proved as a consequence of the decrease of quantum relative entropy.

"What my new work with Stephanie Wehner and Mischa Woods allows for is a refinement of this statement," Wilde said. "We can say that if the free energy does not go down by very much under a thermodynamic transition (i.e., if there is not too much work gained in the process), then it is possible to go back approximately to the original state from the final state, without investing any work at all. The key word here is that you can go back only approximately, so we are not in violation of the second law, only providing a refinement of it."

In addition to these implications, the new theorem can also be applied to other research topics in quantum information theory, including the Holevo bound, quantum discord, and multipartite information measures.

Wilde's work was funded in part by The DARPA Quiness program (ending now), which focused on quantum key distribution, or using quantum mechanics to ensure secret communication between two parties. He describes more about this application, in particular how Alice and Bob might use a

quantum state to share secrets that can be kept private from an eavesdropper Eve (and help them survive being attacked by a bear), in a recent blog post. [9]

Tricking the uncertainty principle

"If you want to know where something is, you have to scatter something off of it," explains Professor of Applied Physics Keith Schwab, who led the study. "For example, if you shine light at an object, the photons that scatter off provide information about the object. But the photons don't all hit and scatter at the same time, and the random pattern of scattering creates quantum fluctuations"—that is, noise. "If you shine more light, you have increased sensitivity, but you also have more noise. Here we were looking for a way to beat the uncertainty principle—to increase sensitivity but not noise."

Schwab and his colleagues began by developing a way to actually detect the noise produced during the scattering of microwaves—electromagnetic radiation that has a wavelength longer than that of visible light. To do this, they delivered microwaves of a specific frequency to a superconducting electronic circuit, or resonator, that vibrates at 5 gigahertz—or 5 billion times per second. The electronic circuit was then coupled to a mechanical device formed of two metal plates that vibrate at around 4 megahertz—or 4 million times per second. The researchers observed that the quantum noise of the microwave field, due to the impact of individual photons, made the mechanical device shake randomly with an amplitude of 10-15 meters, about the diameter of a proton.

"Our mechanical device is a tiny square of aluminum—only 40 microns long, or about the diameter of a hair. We think of quantum mechanics as a good description for the behaviors of atoms and electrons and protons and all of that, but normally you don't think of these sorts of quantum effects manifesting themselves on somewhat macroscopic objects," Schwab says. "This is a physical manifestation of the uncertainty principle, seen in single photons impacting a somewhat macroscopic thing."

Once the researchers had a reliable mechanism for detecting the forces generated by the quantum fluctuations of microwaves on a macroscopic object, they could modify their electronic resonator, mechanical device, and mathematical approach to exclude the noise of the position and motion of the vibrating metal plates from their measurement.

The experiment shows that a) the noise is present and can be picked up by a detector, and b) it can be pushed to someplace that won't affect the measurement. "It's a way of tricking the uncertainty principle so that you can dial up the sensitivity of a detector without increasing the noise," Schwab says.

Although this experiment is mostly a fundamental exploration of the quantum nature of microwaves in mechanical devices, Schwab says that this line of research could one day lead to the observation of quantum mechanical effects in much larger mechanical structures. And that, he notes, could allow the demonstration of strange quantum mechanical properties like superposition and entanglement in large objects—for example, allowing a macroscopic object to exist in two places at once.

"Subatomic particles act in quantum ways—they have a wave-like nature—and so can atoms, and so can whole molecules since they're collections of atoms,"

Schwab says. "So the question then is: Can you make bigger and bigger objects behave in these weird wave-like ways? Why not? Right now we're just trying to figure out where the boundary of quantum physics is, but you never know." [8]

Particle Measurement Sidesteps the Uncertainty Principle

Quantum mechanics imposes a limit on what we can know about subatomic particles. If physicists measure a particle's position, they cannot also measure its momentum, so the theory goes. But a new experiment has managed to circumvent this rule—the so-called uncertainty principle—by ascertaining just a little bit about a particle's position, thus retaining the ability to measure its momentum, too.

The uncertainty principle, formulated by Werner Heisenberg in 1927, is a consequence of the fuzziness of the universe at microscopic scales. Quantum mechanics revealed that particles are not just tiny marbles that act like ordinary objects we can see and touch. Instead of being in a particular place at a particular time, particles actually exist in a haze of probability. Their chances of being in any given state are described by an equation called the quantum wavefunction. Any measurement of a particle "collapses" its wavefunction, in effect forcing it to choose a value for the measured characteristic and eliminating the possibility of knowing anything about its related properties.

Recently, physicists decided to see if they could overcome this limitation by using a new engineering technique called compressive sensing. This tool for making efficient measurements has already been applied successfully in digital photographs, MRI scans and many other technologies. Normally, measuring devices would take a detailed reading and afterward compress it for ease of use. For example, cameras take large raw files and then convert them to compressed jpegs. In compressive sensing, however, engineers aim to compress a signal while measuring it, allowing them to take many fewer measurements—the equivalent of capturing images as jpegs rather than raw files.

This same technique of acquiring the minimum amount of information needed for a measurement seemed to offer a way around the uncertainty principle. To test compressive sensing in the quantum world, physicist John C. Howell and his team at the University of Rochester set out to measure the position and momentum of a photon—a particle of light. They shone a laser through a box equipped with an array of mirrors that could either point toward or away from a detector at its end. These mirrors formed a filter, allowing photons through in some places and blocking them in others. If a photon made it to the detector, the physicists knew it had been in one of the locations where the mirrors offered a throughway. The filter provided a way of measuring a particle's position without knowing exactly where it was—without collapsing its wavefunction. "All we know is either the photon can get through that pattern, or it can't," says Gregory A. Howland, first author of a paper reporting the research published June 26 in Physical Review Letters. "It turns out that because of that we're still able to figure out the momentum—where it's going. The penalty

that we pay is that our measurement of where it's going gets a little bit of noise on it." A less precise momentum measurement, however, is better than no momentum measurement at all.

The physicists stress that they have not broken any laws of physics. "We do not violate the uncertainty principle," Howland says. "We just use it in a clever way." The technique could prove powerful for developing technologies such as quantum cryptography and quantum computers, which aim to harness the fuzzy quantum properties of particles for technological applications. The more information quantum measurements can acquire, the better such technologies could work. Howland's experiment offers a more efficient quantum measurement than has traditionally been possible, says Aephraim M. Steinberg, a physicist at the University of Toronto who was not involved in the research. "This is one of a number of novel techniques which seem poised to prove indispensible for economically characterizing large systems." In other words, the physicists seem to have found a way to get more data with less measurement—or more bangs for their buck. [7]

A new experiment shows that measuring a quantum system does not necessarily introduce uncertainty

Contrary to what many students are taught, quantum uncertainty may not always be in the eye of the beholder. A new experiment shows that measuring a quantum system does not necessarily introduce uncertainty. The study overthrows a common classroom explanation of why the quantum world appears so fuzzy, but the fundamental limit to what is knowable at the smallest scales remains unchanged.

At the foundation of quantum mechanics is the Heisenberg uncertainty principle. Simply put, the principle states that there is a fundamental limit to what one can know about a quantum system. For example, the more precisely one knows a particle's position, the less one can know about its momentum, and vice versa. The limit is expressed as a simple equation that is straightforward to prove mathematically.

Heisenberg sometimes explained the uncertainty principle as a problem of making measurements. His most well-known thought experiment involved photographing an electron. To take the picture, a scientist might bounce a light particle off the electron's surface. That would reveal its position, but it would also impart energy to the electron, causing it to move. Learning about the electron's position would create uncertainty in its velocity; and the act of measurement would produce the uncertainty needed to satisfy the principle.

Physics students are still taught this measurement-disturbance version of the uncertainty principle in introductory classes, but it turns out that it's not always true. Aephraim Steinberg of the University of Toronto in Canada and his team have performed measurements on photons (particles of light) and showed that the act of measuring can introduce less uncertainty than is required by Heisenberg's principle. The total uncertainty of what can be known about the photon's properties, however, remains above Heisenberg's limit.

Delicate measurement

Steinberg's group does not measure position and momentum, but rather two different inter-related properties of a photon: its polarization states. In this case, the polarization along one plane is intrinsically tied to the polarization along the other, and by Heisenberg's principle, there is a limit to the certainty with which both states can be known.

The researchers made a 'weak' measurement of the photon's polarization in one plane — not enough to disturb it, but enough to produce a rough sense of its orientation. Next, they measured the polarization in the second plane. Then they made an exact, or 'strong', measurement of the first polarization to see whether it had been disturbed by the second measurement.

When the researchers did the experiment multiple times, they found that measurement of one polarization did not always disturb the other state as much as the uncertainty principle predicted. In the strongest case, the induced fuzziness was as little as half of what would be predicted by the uncertainty principle.

Don't get too excited: the uncertainty principle still stands, says Steinberg: "In the end, there's no way you can know [both quantum states] accurately at the same time." But the experiment shows that the act of measurement isn't always what causes the uncertainty. "If there's already a lot of uncertainty in the system, then there doesn't need to be any noise from the measurement at all," he says.

The latest experiment is the second to make a measurement below the uncertainty noise limit. Earlier this year, Yuji Hasegawa, a physicist at the Vienna University of Technology in Austria, measured groups of neutron spins and derived results well below what would be predicted if measurements were inserting all the uncertainty into the system.

But the latest results are the clearest example yet of why Heisenberg's explanation was incorrect. "This is the most direct experimental test of the Heisenberg measurement-disturbance uncertainty principle," says Howard Wiseman, a theoretical physicist at Griffith University in Brisbane, Australia "Hopefully it will be useful for educating textbook writers so they know that the naive measurement-disturbance relation is wrong."

Shaking the old measurement-uncertainty explanation may be difficult, however. Even after doing the experiment, Steinberg still included a question about how measurements create uncertainty on a recent homework assignment for his students. "Only as I was grading it did I realize that my homework assignment was wrong," he says. "Now I have to be more careful." [6]

Quantum entanglement

Measurements of physical properties such as position, momentum, spin, polarization, etc. performed on entangled particles are found to be appropriately correlated. For example, if a pair of particles is generated in such a way that their total spin is known to be zero, and one particle is found to have clockwise spin on a certain axis, then the spin of the other particle, measured on the same axis, will be found to be counterclockwise. Because of the nature of quantum measurement, however, this behavior gives rise to effects that can appear paradoxical: any measurement of a property of a particle can be seen as acting on that particle (e.g. by collapsing a number of

superimposed states); and in the case of entangled particles, such action must be on the entangled system as a whole. It thus appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances. [4]

The Bridge

The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories. [1]

Accelerating charges

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field. In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion. The same thing happens on the atomic scale giving a dp impulse difference and a dx way difference between the different part of the not point like particles.

Relativistic effect

Another bridge between the classical and quantum mechanics in the realm of relativity is that the charge distribution is lowering in the reference frame of the accelerating charges linearly: $ds/dt = at$ (time coordinate), but in the reference frame of the current it is parabolic: $s = a/2\ t^2$ (geometric coordinate).

Heisenberg Uncertainty Relation

In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass.

This means that the electron and proton are not point like particles, but has a real charge distribution.

Wave – Particle Duality

The accelerating electrons explains the wave – particle duality of the electrons and photons, since the elementary charges are distributed on delta x position with delta p impulse and creating a

wave packet of the electron. The photon gives the electromagnetic particle of the mediating force of the electrons electromagnetic field with the same distribution of wavelengths.

Atomic model

The constantly accelerating electron in the Hydrogen atom is moving on the equipotential line of the proton and it's kinetic and potential energy will be constant. Its energy will change only when it is changing its way to another equipotential line with another value of potential energy or getting free with enough kinetic energy. This means that the Rutherford-Bohr atomic model is right and only that changing acceleration of the electric charge causes radiation, not the steady acceleration. The steady acceleration of the charges only creates a centric parabolic steady electric field around the charge, the magnetic field. This gives the magnetic moment of the atoms, summing up the proton and electron magnetic moments caused by their circular motions and spins.

The Relativistic Bridge

Commonly accepted idea that the relativistic effect on the particle physics it is the fermions' spin - another unresolved problem in the classical concepts. If the electric charges can move only with accelerated motions in the self maintaining electromagnetic field, once upon a time they would reach the velocity of the electromagnetic field. The resolution of this problem is the spinning particle, constantly accelerating and not reaching the velocity of light because the acceleration is radial. One origin of the Quantum Physics is the Planck Distribution Law of the electromagnetic oscillators, giving equal intensity for 2 different wavelengths on any temperature. Any of these two wavelengths will give equal intensity diffraction patterns, building different asymmetric constructions, for example proton - electron structures (atoms), molecules, etc. Since the particles are centers of diffraction patterns they also have particle – wave duality as the electromagnetic waves have. [2]

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry. The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions,

the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and
makes possible a different time dilation as of the special relativity.

The limit of the velocity of particles as the speed of light appropriate only for electrical charged particles, since the accelerated charges are self maintaining locally the accelerating electric force. The neutrinos are CP symmetry breaking particles compensated by time in the CPT symmetry, that is the time coordinate not works as in the electromagnetic interactions, consequently the speed of neutrinos is not limited by the speed of light.

The weak interaction T-asymmetry is in conjunction with the T-asymmetry of the second law of thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes the
weak interaction, for example the Hydrogen fusion.

Probably because it is a spin creating movement changing linear oscillation to 2 dimensional oscillation by changing d to u quark and creating anti neutrino going back in time relative to the proton and electron created from the neutron, it seems that the anti neutrino fastest then the velocity of the photons created also in this weak interaction?

A quark flavor changing shows that it is a reflection changes movement and the CP- and T-symmetry breaking!!! This flavor changing oscillation could prove that it could be also on higher level such as atoms, molecules, probably big biological significant molecules and responsible on the aging of the life.

Important to mention that the weak interaction is always contains particles and antiparticles, where the neutrinos (antineutrinos) present the opposite side. It means by Feynman's interpretation that these particles present the backward time and probably because this they seem to move faster than the speed of light in the reference frame of the other side.

Finally since the weak interaction is an electric dipole change with ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows

the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.
The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.
We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change.
There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.
The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing.

Van Der Waals force

Named after the Dutch scientist Johannes Diderik van der Waals – who first proposed it in 1873 to explain the behaviour of gases – it is a very weak force that only becomes relevant when atoms and molecules are very close together. Fluctuations in the electronic cloud of an atom mean that it will have an instantaneous dipole moment. This can induce a dipole moment in a nearby atom, the result being an attractive dipole–dipole interaction.

Electromagnetic inertia and mass

Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

Relativistic change of mass

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

The frequency dependence of mass

Since $E = hv$ and $E = mc^2$, $m = hv/c^2$ that is the m depends only on the v frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_o inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron – Proton mass rate

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force. [2]

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

Gravity from the point of view of quantum physics

The Gravitational force

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

Since graviton is a tensor field, it has spin = 2, could be 2 photons with spin = 1 together.

You can think about photons as virtual electron – positron pairs, obtaining the necessary virtual mass for gravity.

The mass as seen before a result of the diffraction, for example the proton – electron mass rate Mp=1840 Me. In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass.

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force

experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.
There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

The Higgs boson

By March 2013, the particle had been proven to behave, interact and decay in many of the expected ways predicted by the Standard Model, and was also tentatively confirmed to have + parity and zero spin, two fundamental criteria of a Higgs boson, making it also the first known scalar particle to be discovered in nature, although a number of other properties were not fully proven and some partial results do not yet precisely match those expected; in some cases data is also still awaited or being analyzed.

Since the Higgs boson is necessary to the W and Z bosons, the dipole change of the Weak interaction and the change in the magnetic effect caused gravitation must be conducted. The Wien law is also important to explain the Weak interaction, since it describes the T_{max} change and the diffraction patterns change. [2]

Higgs mechanism and Quantum Gravity

The magnetic induction creates a negative electric field, causing an electromagnetic inertia. Probably it is the mysterious Higgs field giving mass to the charged particles? We can think about the photon as an electron-positron pair, they have mass. The neutral particles are built from negative and positive charges, for example the neutron, decaying to proton and electron. The wave – particle duality makes sure that the particles are oscillating and creating magnetic induction as an inertial mass, explaining also the relativistic mass change. Higher frequency creates stronger magnetic induction, smaller frequency results lesser magnetic induction. It seems to me that the magnetic induction is the secret of the Higgs field.

In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge

bosons in a gauge theory with mass through absorption of Nambu–Goldstone bosons arising in spontaneous symmetry breaking.

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the $W^{\pm}$, and Z weak gauge bosons through electroweak symmetry breaking. The Large Hadron Collider at CERN announced results consistent with the Higgs particle on July 4, 2012 but stressed that further testing is needed to confirm the Standard Model.

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [3]

Conclusions

The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]

The Secret of Quantum Entanglement that the particles are diffraction patterns of the electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]

One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .
The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions.

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