# Quantum Walks Topological Order

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*Now, a team of physicists from The University of Queensland and the NÉEL Institute has shown that, as far as quantum physics is concerned, the chicken and the egg can both come first. [17]*

*In 1993, physicist Lucien Hardy proposed an experiment showing that there is a small probability (around 6-9%) of observing a particle and its antiparticle interacting with each other without annihilating—something that is impossible in classical physics. [16]*

*Scientists at the University of Geneva (UNIGE), Switzerland, recently reengineered their data processing, demonstrating that 16 million atoms were entangled in a one-centimetre crystal. [15]*

*The fact that it is possible to retrieve this lost information reveals new insight into the fundamental nature of quantum measurements, mainly by supporting the idea that quantum measurements contain both quantum and classical components. [14]*

*Researchers blur the line between classical and quantum physics by connecting chaos and entanglement. [13]*

*Yale University scientists have reached a milestone in their efforts to extend the durability and dependability of quantum information. [12]*

*Using lasers to make data storage faster than ever. [11]*

*Some three-dimensional materials can exhibit exotic properties that only exist in "lower" dimensions. For example, in one-dimensional chains of atoms that emerge within a bulk sample, electrons can separate into three distinct entities, each carrying information about just one aspect of the electron's identity—spin, charge, or orbit. The spinon, the entity that carries information about electron spin, has been known to control magnetism in certain insulating materials whose electron spins can point in any direction and easily flip direction. Now, a new study just published in Science reveals that spinons are also present in a metallic material in which the orbital movement of electrons around the atomic nucleus is the driving force behind the material's strong magnetism. [10]*

*Currently studying entanglement in condensed matter systems is of great interest. This interest stems from the fact that some behaviors of such systems can only be explained with the aid of entanglement. [9]*

*Researchers from the Norwegian University of Science and Technology (NTNU) and the University of Cambridge in the UK have demonstrated that it is possible to directly generate an electric current in a magnetic material by rotating its magnetization. [8]*

*This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. 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 changing acceleration of the electrons explains the created negative electric field of the magnetic induction, the changing relativistic mass and the Gravitational Force, giving a Unified Theory of the physical forces. Taking into account the Planck Distribution Law of the electromagnetic oscillators also, we can explain the electron/proton mass rate and the Weak and Strong Interactions.*

# Contents

Author: George Rajna

# Preface

Surprisingly nobody found strange that by theory the electrons are moving with a constant velocity in the stationary electric current, although there is an accelerating force **F = q E**, imposed by the **E** electric field along the wire as a result of the **U** potential difference. The accelerated electrons are creating a charge density distribution and maintaining the potential change along the wire. This charge distribution also creates a radial electrostatic field around the wire decreasing along the wire. The moving external electrons in this electrostatic field are experiencing a changing electrostatic field causing exactly the magnetic effect, repelling when moving against the direction of the current and attracting when moving in the direction of the current. This way the **A** magnetic potential is based on the real charge distribution of the electrons caused by their acceleration, maintaining the **E** electric field and the **A** magnetic potential at the same time.

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the electromagnetic matter. If the charge could move faster than the electromagnetic field, this self maintaining electromagnetic property of the electric current would be failed.

More importantly the accelerating electrons can explain the magnetic induction also. The changing acceleration of the electrons will create a –**E** electric field by changing the charge distribution, increasing acceleration lowering the charge density and decreasing acceleration causing an increasing charge density.

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as a relativistic changing electromagnetic mass. If the mass is electromagnetic, then the gravitation is also electromagnetic effect. The same charges would attract each other if they are moving parallel by the magnetic effect.

## Measuring a dynamical topological order parameter in quantum walks

Nonequilibrium dynamical processes are central in many quantum technological contexts. However, it has remained a key challenge to identify concepts for their characterization and classification, as the resulting quantum states purposely defy a description in terms of equilibrium statistical physics in order to realize states not accessible by conventional means. Scientists have now achieved a characterization in terms of a dynamical topological order parameter for quantum walks, which represent a paradigmatic class of nonequilibrium processes.

Coherence in quantum dynamics is at the heart of fascinating phenomena beyond the realm of classical physics, such as quantum interference effects, entanglement production and geometric phases.

Quantum processes of inherent dynamical nature defy a description in terms of an equilibrium statistical physics ensemble. Up to now, to identify general principles behind the underlying unitary quantum dynamics which preserve quantum coherence remains a key challenge.

Quantum walks provide a powerful and flexible platform to experimentally realize and probe coherent quantum time evolution far from thermal equilibrium. As opposed to classical random walks, quantum walks are characterized by quantum superpositions of amplitudes rather than classical probability distributions. This genuine quantum character has already been harnessed in various fields of physics, ranging from the design of efficient algorithms in quantum information processing, observation of correlated dynamics and Anderson localization, to the realization of exotic physical phenomena in the context topological phases.

While the topological order can be retrieved in the real space, accessing the full complex amplitude information characterizing the coherent superposition remains as one of the key challenges in quantum walk experiments.

In a new paper published in *Light Science & Application*, scientists from the CAS Key Laboratory of Quantum Information and international collaborators reported on the direct observation of a dynamical topological order parameter (DTOP) that provides a dynamical characterization of quantum walks.

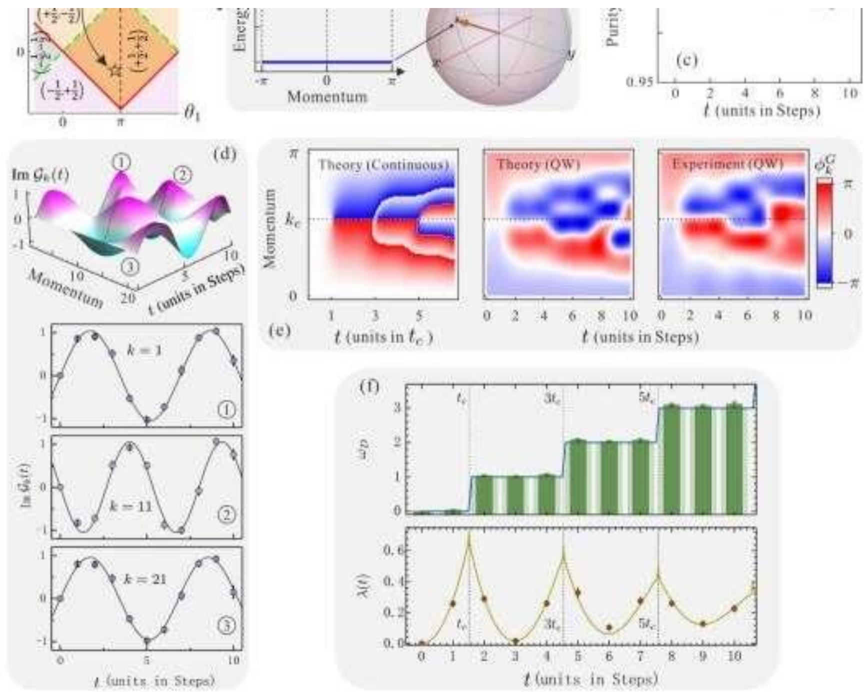



**Figure 2 | Experimental measurement of DTOP for observing DQPT.** (a) shows the quenching strategy in phase diagram: starting from a ground state of Hamiltonian

Experimental measurement of DTOP for observing DQPT Credit: by Xiao-Ye Xu, Qin-Qin Wang, Markus Heyl, Jan Carl Budich, Wei-Wei Pan, Zhe Chen, Munsif Jan, Kai Sun, Jin-Shi Xu, Yong-Jian Han, Chuan-Feng Li, Guang-Can Guo

To this end, they realized a split-step quantum walk in a photonic system using the framework of time multiplexing. Using a previously developed technique, they achieved full state tomography of the time-evolved quantum state for up to 10 complete time steps. Importantly, this provided the full complex amplitude information of the quantum walk state.

"This is essential for our central goal of a dynamical classification of the quantum walk using the DTOP, since the DTOP measures the phase winding number ω_D (t) in momentum-space, namely of the so called Pancharatnam geometric phase (PGP)".

From the experimental results, they found that dynamical transitions between topologically distinct classes of quantum walks can be uniquely distinguished by the observed time-dependent behavior of ω_D (t).

"For a quench between two systems with the same topological character, we find ω_D (t)=0 for all time steps; instead, for a quench between two topologically different systems, ω_D (t) also starts at ω_D (t=0)=0, but monotonously changes its value at certain critical times," they added.

Generalizing these observations, they further established a unique relation between the behavior of ω_D (t) and the change over a parameter quench in the topological properties of an effective Floquet Hamiltonian that stroboscopically describes the quantum walk.

The scientists conclude: "In this way, we provide a nonequilibrium perspective onto quantum walks, which can be understood as a starting point towards approaching time-dependent processes from an inherently dynamical angle that goes beyond the notion of equilibrium statistical physics. With this and the mapping onto quenches in an equivalent quantum many-body system, our experiment offers a versatile platform to study coherent nonequilibrium dynamics of many paradigmatic models such as the Su-Schrieffer-Heeger model, the p-wave Kitaev chain, or the transverse field Ising model in the future." [23]

## A bridge to the quantum world

Monika Aidelsburger uses a special type of optical lattice to simulate quantum many-body phenomena that are otherwise inaccessible to experimental exploration. She has now been awarded an ERC Starting Grant to pursue this work.

Over the past decade, researchers led by Professor Immanuel Bloch, who holds a Chair in Experimental Physics at LMU, have developed several techniques and strategies to probe the secrets of the quantum world. Much progress has been made, but many phenomena of interest remain unexplored, and theoretical schemes are often difficult to test. Bloch's team is primarily interested in quantum interactions that can be modelled using ultracold gases trapped in optical lattices formed by laser beams. Dr. Monika Aidelsburger, leader of a research group in Bloch's department, has now been awarded a highly endowed Starting Grant by the European Research Council (ERC) to extend this line of work. Her aim is to use ultracold ytterbium atoms trapped in optical lattices to simulate models of quantum behavior in condensed matter on a scale that is three orders of magnitude larger than in real solids.

Indeed, Aidelsburger, who is also part of the Max Planck Institute for Quantum Optics, hopes to take this strategy further, and use it to simulate 'lattice gauge theories', which describe fundamental interactions between particles in terms of 'gauge fields'. In these models, matter fields (substance particles) are depicted as points on a fictitious lattice, and the force fields that act on them are represented by the links between these nodes. Lattice gauge theories are of fundamental significance in many branches of quantum physics. Not only do they form the basis for the Standard Model of particle physics, they can also be applied to the physics that underlies the behavior of strongly interacting electrons in solids, and can account for important phenomena in quantum electrodynamics. Therefore, Aidelsburger's experimental approach to simulating lattice gauge theories in optical lattices would provide a link between classical and quantum physics, and allow analogous simulations of phenomena observed in settings other than solid-state physics. Aidelsburger's research has so far focused on simulating the effects of magnetic fields. "This is because magnetic fields too can be described in terms of gauge fields," she explains. Physicists hope to extend these ideas and apply them to other quantum many-body phenomena that have remained largely inaccessible.

## Two long-lived states

The experimental platform is currently being designed and soon the optical tables in Aidelsburger's laboratory will be arrayed with carefully positioned lenses and mirrors, lasers and optical fibers. Controlled manipulations of ultracold atoms in optical lattices have already been successfully used to probe and simulate quantum phenomena that have been observed in condensed-matter systems. These experiments were carried out under conditions in which the atoms can 'tunnel' between lattice sites, although their collective motions are influenced by the global parameters of the lattices. Extension of the strategy to lattice gauge theories will require site-specific control over the motions of the atoms in the lattice.

Setting up such an experiment is extremely demanding, because the symmetries inherent to gauge theories must be precisely reproduced. "A successful implementation necessitates the use of completely new approaches," says Aidelsburger. "This carries a high risk, but having a working quantum simulator of such a model would constitute a tremendous advance." Bloch's team has learned a lot about how to keep quantum gases at temperatures only a smidgen above absolute zero, generate and manipulate optical lattices and control the motions of atoms of various elements such as rubidium, sodium and lithium, to name only a few. Aidelsburger's experiments will use yterrbium (Yb) atoms, because they exhibit two long-lived quantum states, which make them particularly useful for the planned simulations. Strongly focused laser beams will be employed to site- specifically control the motions of the atoms within the lattice. In the simulation, the two atomic states will play both the roles of the matter particles and the particles that mediate the forces that act upon them.

It is technically feasible to couple the motion of the two long-lived states of Yb atoms in the lattice. "This local coupling allows us for the first time to experimentally represent the fundamental building blocks of simple lattice gauge theories in an experimental setting," says Aidelsburger. Moreover, the technique can be straightforwardly extended to larger lattice structures and higher dimensions. This would allow researchers to simulate lattice gauge theories that play an important role in both condensed-matter physics and quantum electrodynamics using tractable experimental procedures. That would be a truly ground-breaking achievement. "Our strategy opens up entirely new experimental opportunities to explore certain phenomena and develop ideas for new theories," says Aidelsburger.

## The fine adjustments

The prospect of being able to work for the next few years in Immanuel Bloch's department as a tenure-track professor was one reason why she decided to return to Munich after her spell as a postdoc at the Collège de France in Paris. "Young researchers need such longer-term perspectives," she says, "especially if they wish to carry out such a complex and demanding experimental task." The design and construction of a new system can take up to three years. One begins with simple models, and asks whether their simulation produces results that agree with those obtained with theory, or are compatible with predictions derived using well established numerical methods, such as Monte Carlo simulations. These tests serve as a calibration scale for experiments – and allow researchers to adjust conditions appropriately and gradually increase the level of complexity of the experiments. In addition, the experimental systems must be constantly checked to ensure that they provide a correct description of the phenomena they set out to describe. "This is where close collaboration with theorists in other fields is especially important," says Aidelsburger. "The risks involved are considerable, as this is largely unknown territory for us all. We have to bring very different areas of physics together. It is my fervent hope that the initial experiments with simple models will yield results that find an echo in diverse disciplines."

In the simplest models, the Yb atoms can adopt either of two defined states, the ground state and a single metastable excited state. The aim is to progressively add further states to the system, allowing more complex interactions to be implemented. This would be an important step toward the ultimate goal of using ultracold atoms to simulate the strong nuclear force – the interaction between quarks (the fundamental constituents of atomic nuclei) and gluons (the force particles that hold atomic nuclei together). The latter task will require the implementation of far more complex lattice gauge theories.

Individual cells in two-dimensional optical lattices consisting of 100 × 100 atoms can now be addressed and their occupancies controlled, allowing dynamical effects to be observed in detail. Thus, it is possible to determine whether or not a particular lattice cell is occupied under specific conditions, and the state of every atom in the lattice can be probed practically in real time. With these achievements under their belts, physicists are well on the way to realizing the idea of a quantum simulator that the famous American physicist Richard Feynman formulated in the 1980s. "We hope that our set-up will pave the way to experimentally investigate fundamental issues in quantum chromodynamics," says Aidelsburger – before adding an emphatic qualifier: "But we are still at the very beginning." [22]

# Merging mathematical and physical models toward building a more perfect flying vehicle

When designing flying vehicles, there are many aspects of which we can be certain but there are also many uncertainties. Most are random, and others are just not well understood. University of Illinois Professor Harry Hilton brought together several mathematical and physical theories to help look at problems in more unified ways and solve physical engineering problems.

"There are many equations because there are many phenomena. They are an attempt to describe mathematically the physical phenomena so that you can solve these problems. Words alone won't solve the problem. In this case, the problem is how do to build the perfect flying vehicle for specific missions and purposes," said Harry Hilton, a professor emeritus in the Department of Aerospace Engineering in the College of Engineering at the University of Illinois at Urbana-Champaign. Hilton looked at models independently of each other, then put them together.

"If you don't use the right model, the rest becomes an exercise in futility. It may be a model that's self-consistent but has no reality," he said. "Of course, the only way you can validate a model is to run experiments and even then, you're introducing another reality into the picture which is the experiment and not the real airplane. So each one of these is an idealization."

Hilton began by analyzing the da Vinci-Euler-Bernoulli theory of elastic bending. "It's deterministic, that is, determined that it is true with a probability of 1, based on a set of equations that give a set of answers," Hilton said. Added to that is the Timoshenko theory that takes load and other realistic properties such as wind shear into consideration. Hilton merges those theories with properties of viscoelastic materials—which includes time dependent material behavior and is of particular importance in modern composite materials and metals at elevated temperatures.

On top of it all, there are probabilities that certain things will happen.

"We may assume that the loads and material properties are certain, but they're not. Think about wind gusts. They can be sudden and unpredictable in strength and direction," he said. "It's the difference between deterministic—which means the probability is one and events are going to happen as opposed to a probability between zero and 1 where zero is never and 1 is always. "Probability happens in the real world. What's the probability of you getting hit by a car when you cross Green Street? Pretty high. When you cross Wright Street, maybe not as likely," he said.

Hilton's analysis provides a new model that takes into consideration as many, but still not all, known phenomena. These analyses, while more inclusive, form a linear beginning as a stepping stone to the real nonlinear random world.

"We use both math and physics in engineering, but within limitations. In physics, we don't always understand what's going on," he said. "That's the case here as well. There are pieces of principles that haven't been resolved. The mathematics are very exact but we tend to shade the equations in terms of what we can solve, rather than what it should be.

"The probabilistic analyses really pay off when designing a missile because you have just one flight to get it right. Either it hits the target or it doesn't. But it never comes back and is reused."

About his merging of models and its potential impact, Hilton quoted Winston Churchill from a speech he gave in 1942 concerning the Second Battle of El Alamein."Churchill said, 'It's not the beginning of the end but the end of the beginning.' You could look at it that way. We're so far from the total knowledge that any one of these types of fundamental analytical papers is an end of the beginning."

The paper, "A Unified Linear Bending/Shear Beam (Spar) Theory: From Deterministic da Vinci-Euler-Bernoulli Elastic Beams to Nonhomogeneous Generalized Linear Viscoelastic Timoshenko ones with Random Properties, Loads and Realistic Physical Starting Transients, and Including Moving Shear Centers and Neutral Axes, Part I:Theoretical Modeling and Analyses," was written by Harry H. Hilton. It appears in MESA, the international journal of Mathematics in Engineering, Science and Aerospace. [21]

## Russian and German physicists developed a mathematical model of trapped atoms and ions

A team of physicists from RUDN, JINR (Dubna), and the University of Hamburg (Germany) developed a mathematical model for describing physical processes in hybrid systems that consists of atoms and ions cooled down to temperatures close to absolute zero. Such atom-ionic systems might serve as a basis for the elements of the quantum computer—a device operating on quantum phenomena and exceeding regular computers by calculation speed. Right now, this is just a hypothetical concept, but the new development could make it reality sooner. The results of the study were presented at the 22nd International Conference on Few-Body Systems in Physics that took place in Caen (France) in July 9-13.

It is difficult to study processes at the level of individual atoms and ions at room temperature due to their thermal motion, which causes disturbances that lead to considerable inaccuracy of measurements. The main cause of observation errors is the Doppler effect. However, if the atoms are cooled down, reducing the speed of their thermal motion, this effect can be suppressed.

Atoms can be cooled using a laser, but it's important to select the proper frequency and direction. The same laser can create a so-called trap for cooled atoms—a standing light wave (i.e. a wave that does not move but fluctuates in one place) keeps the atoms fixed in a confined region of space. This trap can be compared to an egg case that prevents the eggs from moving around. Such a trap can be used as a model system for studying quantum processes including solid state physics and high energy physics. However, it is quite difficult to give a detailed mathematical description of systems of trapped quantum particles.

"The two-body problem (e.g. a hydrogen atom or two colliding atoms) is the basis of quantum mechanics. Each body has three coordinates (X, Y, and Z). In free space, this problem may be reduced to relative motion of two particles by separation of their center-of-mass. The number of variables left in the problem is now three instead of six. The absence of a preferred direction helps reduce this problem to an even simpler one-dimensional radial equation (i.e. an equation with one variable) by separation of angular variables. But when two quantum particles are trapped, an additional condition appears, which is preferential direction. In this case, the problem cannot be reduced to a one-dimensional equation. It becomes two-dimensional if the atoms are identical and six-dimensional if they are distinguishable or if an atom-ionic system is considered. Many scientists are able to solve two-dimensional equations, but three-dimensional ones are already quite a complicated problem for modern numerical mathematics. This is the area where new methods have to be developed," said Vladimir Melezhik, the author of the study.

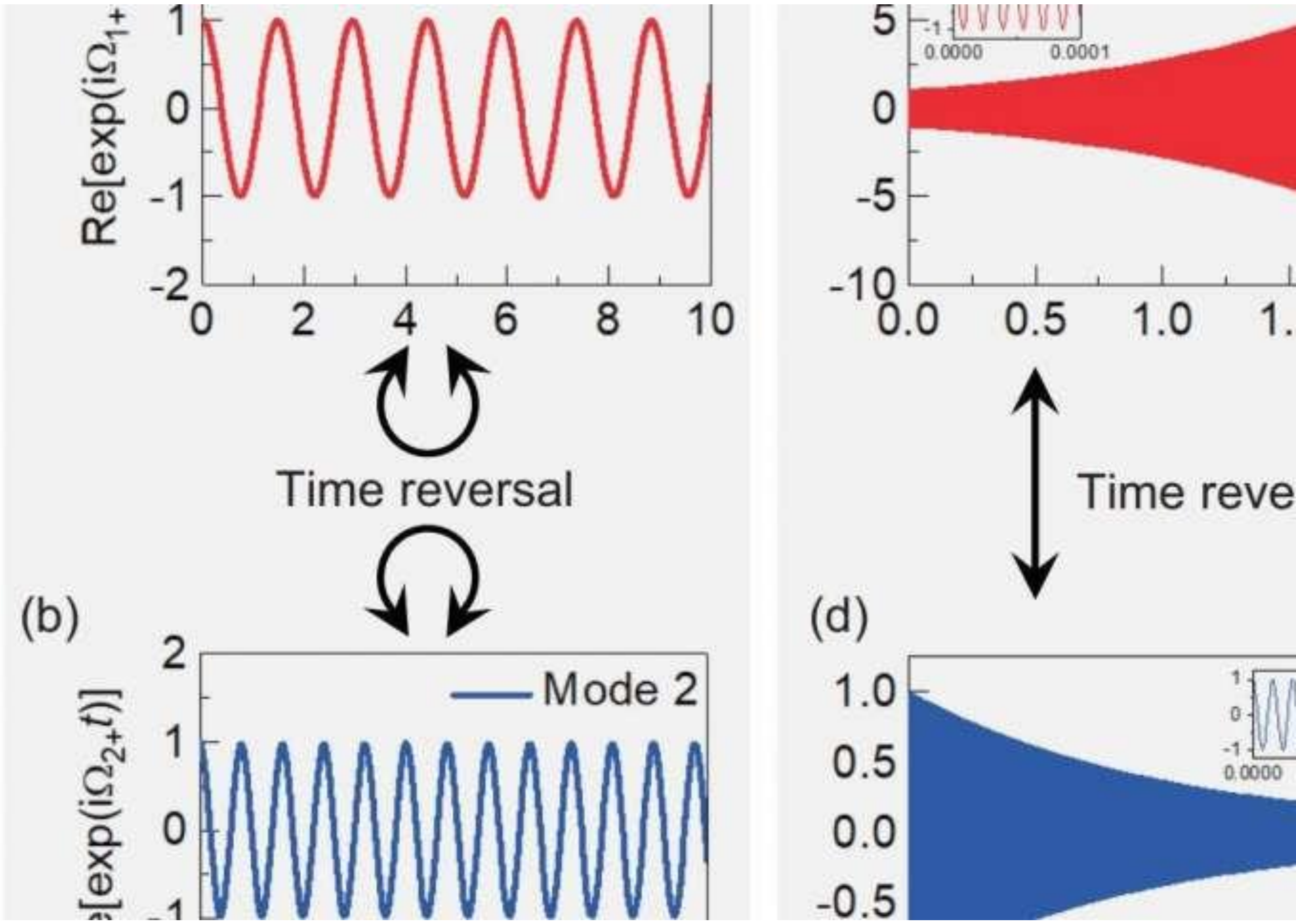
Together with physicists from the University of Hamburg, Melezhik developed a mathematical method reducing multi-dimensional calculations to a system of one-dimensional equations to simplify and speed up the calculations. The authors used it to describe atomic systems with different parameters (intensity of effective interparticle interaction, initial state population, and particle energy). The method also proved applicable to hybrid atom-ionic systems. If ions are trapped, new complex quantum effects can be studied. The developed algorithm provides for the calculation of collisions of atoms and ions to each other and the laser trap. In the future, such hybrid structures can potentially help to model the elements of quantum computers. [20]

## Physicists revealed spontaneous T-symmetry breaking and exceptional points in cavity QED

Spontaneous symmetry breaking (SSB) is a physics phenomenon in which a symmetric system produces symmetry-violating states. Recently, extensive study shows that the parity-time symmetry breaking in open systems leads to exceptional points, promising for novel applications leasers and sensing.

In this work, the researchers theoretically demonstrated spontaneous time-reversal symmetry (T-symmetry) breaking in a cavity quantum electrodynamics system. The system is composed of an ensemble of 2-level atoms inside a cavity. The atoms are kept near their highest excited states and act like an oscillator with a negative mass. The researchers utilize the dipole interaction between the atoms and the cavity mode to induce the T-symmetry breaking and to obtain exceptional points (EPs).

"The dipole interaction provides a linear coupling between the collective motion of the atoms and the cavity mode," said Yu-Kun Lu, who is an undergraduate at Peking University. "For small coupling strength, the system undergoes harmonic oscillation, which is invariant under time-reversal operation. When the coupling strength reaches a threshold, the system becomes unstable against the pair-production (annihilation) process, and the excitation number of the cavity mode and the atoms will increase (decrease) with time, thus leading to the spontaneous T-symmetry breaking." The critical point between the T-symmetric and T-symmetry broken phase is proved to be an EP.




Demonstration of T-symmetry breaking in the eigenmode dynamics. Credit: ©Science China Press

"To demonstrate the existence of EP, we showed the dependence of the eigenfrequencies as well as the eigenmode on the cavity-atom detuning, and we found they coalesce at the critical point, and thus proved it to be an EP," said Pai Peng, a former undergraduate in Prof. Xiao's group and now a Ph.D. at Massachusetts Institute of Technology. Moreover, due to the singular topology of the EP, the dynamics in the vicinity of the EP is robust.

"After encircling a whole loop around EP, the final state only depends on the direction of the loop but not its shape, and thus the result is topological protected," said Qi-Tao Cao, a Ph.D. at Peking University.

"EPs used to be studied exclusively in open systems. The demonstration of EP in the present system broadens the understanding of SSB and singularities in physics," said Prof. Xiao. "Apart from its fundamental interest, spontaneous T-symmetry breaking without gain or loss also provides a new platform for various applications, such as sensing and quantum information processing." [19]

## Testing whether Planck's radiation law applies at a very small scale

A recent discovery by William & Mary and University of Michigan researchers transforms our understanding of one of the most important laws of modern physics. The discovery, published in the journal *Nature*, has broad implications for science, impacting everything from nanotechnology to our understanding of the solar system.

"This changes everything, even our ideas about planetary formation," said Mumtaz Qazilbash, associate professor of physics at William & Mary and co-author on the paper. "The full extent of what this means is an important question and, frankly, one I will be continuing to think about."

Qazilbash and two W&M graduate students, Zhen Xing and Patrick McArdle, partnered with a team of engineers from the University of Michigan to test whether Planck's radiation law, a foundational scientific principle grounded in quantum mechanics, applies at the smallest length scales.

The other co-authors on the Nature paper include Dakotah Thompson, Linxiao Zhu, Rohith Mittapally, Seid Sadat, Pramod Reddy and Edgar Meyhofer. Qazilbash's research was funded by the National Science Foundation.

Through a series of experiments, the team was able to show Planck's law does not apply for objects smaller than a certain length scale—and the result is 100 times higher than what the law would predict. Qazilbash said the real challenge was not only proving the discrepancy, but also explaining it.

"That's the thing with physics," Qazilbash said. "It's important to experimentally measure something, but also important to actually understand what is going on."

Planck's radiation law is a pillar of modern physics and one of the most important results in quantum mechanics. Formulated in 1900 by German physicist Max Planck, the law is a mathematical equation that explains the relationship between the temperature of an object and the energy emitted from that object in the form of electromagnetic radiation.

At the turn of the 20th century, physicists began to understand that, at the atomic level, everything in the universe behaves as both a particle and a wave. They came to this conclusion by studying light and sub-atomic particles. Light is simultaneously a stream of particles called photons and a wave of fluctuating electric and magnetic fields. The waves of light (of which visible light is only a small part of the spectrum) were called electromagnetic radiation, a largely invisible interaction between all objects in the universe.

"The full spectra of these wavelengths from hot objects were measured well before Max Planck came along, but nobody understood what was going on," Qazilbash said. "The theories at that time could not explain it."

Planck theorized an answer that would become the bedrock of quantum physics.

"Planck came up with quantization," Qazilbash said. "His theory was that light is not just simply an electromagnetic wave, but that it is a quantized electromagnetic wave. It's emitted and absorbed in discrete quanta called photons. That's how he was able to explain this phenomena."

Moreover, Planck based his theory on the hypothesis that a photon's energy depends on its frequency, meaning the energy of electromagnetic waves is also quantized. He articulated the relationship between energy and frequency in his radiation law. Until recently, the law was assumed to apply to all objects in the universe.

Then in 2009, physicists attempted to apply the law to two objects that were so close there was less than a wavelength of radiation between them. The scientists found that the law did not hold up when the objects were in what is termed the "near field." Qazilbash and his research team decided to test the law in the far field—farther apart than a wavelength of radiation—with objects that were smaller than a wavelength in thickness.

"What our work shows is that if the objects are very small, there is a violation of the law," Qazilbash said. "This has never been experimentally shown before."

Such an experiment required collaboration between disciplines, Qazilbash explained. The William & Mary physics team partnered with the engineering department at University of Michigan for this project. The wavelengths of infrared light that are relevant for testing the law were only about 10 microns (about a fifth of the average cross-section of a human hair), so the engineers had to create an object even smaller. They eventually developed a membrane of silicon nitride only a few hundred nanometers (or less than half a micron) thick.

To see if the law applied, the researchers placed two identical membranes at a relatively large distance apart. Next, they heated one of the membranes and measured the heat increase in the second. If Planck's law holds true, then the heat increase in the second membrane should have been in accord with Planck's prediction. What the researchers found instead was a 100-fold difference in radiative heat transfer than what Planck's law would have predicted.

"Planck's radiation law says if you apply the ideas that he formulated to two objects, then you should get a defined rate of energy transfer between the two," Qazilbash said. "Well, what we have observed experimentally is that rate is actually 100 times higher than Planck's law predicts if the objects are very, very small."

The reason for such a huge disparity has to do with the nature of waves, Qazilbash explained.

"Think of a guitar string," he said. "It has some fundamental resonances. The frets are at a particular length to align with the best harmonics. If you pluck it in those places, it's going to resonate at certain wavelengths more efficiently. It's the same thing here with light. If the material and geometry of an object are such that electromagnetic waves can couple more effectively to it, then it will emit and absorb radiation more effectively."

The implications for discovering a 100-fold discrepancy in Planck's radiation law are broad and touch nearly all aspects of modern physics, Qazilbash said. In the digital age, hardware developers are looking for ways to design smaller and faster technology. This discovery has the potential to change the future of nanotechnology.

"Now we know that nanoscale objects can emit and absorb radiation much more effectively than we ever thought was possible," Qazilbash said.

Qazilbash added that it's not only a revelation for small-scale objects and nanotechnology. The discovery also relates to climate science, planetary atmospheres, astrophysics and the makeup of solar systems.

"This discovery touches so many fields," Qazilbash said. "Wherever you have radiation playing an important role in physics and science, that's where this discovery is important." [18]

## Quantum weirdness in 'chicken or egg' paradox

The "chicken or egg" paradox was first proposed by philosophers in Ancient Greece to describe the problem of determining cause-and-effect.

Now, a team of physicists from The University of Queensland and the NÉEL Institute has shown that, as far as quantum physics is concerned, the chicken and the egg can both come first.

Dr Jacqui Romero from the ARC Centre of Excellence for Engineered Quantum Systems said that in quantum physics, cause-and-effect is not always as straightforward as one event causing another.

"The weirdness of quantum mechanics means that events can happen without a set order," she said.

"Take the example of your daily trip to work, where you travel partly by bus and partly by train.

"Normally, you would take the bus then the train, or the other way round.

"In our experiment, both of these events can happen first," Dr Romero said.

"This is called `indefinite causal order' and it isn't something that we can observe in our everyday life."

To observe this effect in the lab, the researchers used a setup called a photonic quantum switch.

UQ's Dr Fabio Costa said that with this device the order of events—transformations on the shape of light—depends on polarisation.

"By measuring the polarisation of the photons at the output of the quantum switch, we were able to show the order of transformations on the shape of light was not set."

"This is just a first proof of principle, but on a larger scale indefinite causal order can have real practical applications, like making computers more efficient or improving communication."

The research was published in *Physical Reviews Letters* by the American Physical Society. [17]

## Generalized Hardy's paradox shows an even stronger conflict between quantum and classical physics

In 1993, physicist Lucien Hardy proposed an experiment showing that there is a small probability (around 6-9%) of observing a particle and its antiparticle interacting with each other without annihilating—something that is impossible in classical physics. The way to explain this result is to require quantum theory to be nonlocal: that is, to allow for the existence of long-range quantum correlations, such as entanglement, so that particles can influence each other across long distances.

So far, Hardy's paradox has been experimentally demonstrated with two particles, and a few special cases with more than two particles have been proposed but not experimentally demonstrated. Now in a new paper published in *Physical Review Letters*, physicists have presented a generalized Hardy's paradox that extends to any number of particles. Further, they show that any version of Hardy's paradox that involves three or more particles conflicts with local (classical) theory even more strongly than any of the previous versions of the paradox do. To illustrate, the physicists proposed an experiment with three particles in which the probability of observing the paradoxical event reaches an estimated 25%.

"In this paper, we show a family of generalized Hardy's paradox to the most degree, in that by adjusting certain parameters they not only include previously known extensions as special cases, but also give sharper conflicts between quantum and classical theories in general," coauthor Jing-Ling Chen at Nankai University and the National University of Singapore told *Phys.org*. "What's more, based on the paradoxes, we are able to write down novel Bell's inequalities, which enable us to detect more quantum entangled states." [16]

## A single photon reveals quantum entanglement of 16 million atoms

Quantum theory predicts that a vast number of atoms can be entangled and intertwined by a very strong quantum relationship, even in a macroscopic structure. Until now, however, experimental evidence has been mostly lacking, although recent advances have shown the entanglement of 2,900 atoms. Scientists at the University of Geneva (UNIGE), Switzerland, recently reengineered their data processing, demonstrating that 16 million atoms were entangled in a one-centimetre crystal. They have published their results in Nature Communications.

The laws of quantum physics allow immediately detecting when emitted signals are intercepted by a third party. This property is crucial for data protection, especially in the encryption industry, which can now guarantee that customers will be aware of any interception of their messages. These signals also need to be able to travel long distances using special relay devices known as quantum repeaters—crystals enriched with rare earth atoms and cooled to 270 degrees below zero (barely three degrees above absolute zero), whose atoms are entangled and unified by a very strong quantum relationship. When a photon penetrates this small crystal block, entanglement is created between the billions of atoms it traverses. This is explicitly predicted by the theory, and it is exactly what happens as the crystal re-emits a single photon without reading the information it has received.

It is relatively easy to entangle two particles: Splitting a photon, for example, generates two entangled photons that have identical properties and behaviours. Florian Fröwis, a researcher in the applied physics group in UNIGE's science faculty, says, "But it's impossible to directly observe the process of entanglement between several million atoms since the mass of data you need to collect and analyse is so huge."

As a result, Fröwis and his colleagues chose a more indirect route, pondering what measurements could be undertaken and which would be the most suitable ones. They examined the characteristics of light re-emitted by the crystal, as well as analysing its statistical properties and the probabilities following two major avenues—that the light is re-emitted in a single direction rather than radiating uniformly from the crystal, and that it is made up of a single photon. In this way, the researchers succeeded in showing the entanglement of 16 million atoms when previous observations had a ceiling of a few thousand. In a parallel work, scientists at University of Calgary, Canada, demonstrated entanglement between many large groups of atoms. "We haven't altered the laws of physics," says Mikael Afzelius, a member of Professor Nicolas Gisin's applied physics group. "What has changed is how we handle the flow of data."

Particle entanglement is a prerequisite for the quantum revolution that is on the horizon, which will also affect the volumes of data circulating on future networks, together with the power and operating mode of quantum computers. Everything, in fact, depends on the relationship between two particles at the quantum level—a relationship that is much stronger than the simple correlations proposed by the laws of traditional physics.

Although the concept of entanglement can be hard to grasp, it can be illustrated using a pair of socks. Imagine a physicist who always wears two socks of different colours. When you spot a red sock on his right ankle, you also immediately learn that the left sock is not red. There is a correlation, in other words, between the two socks. In quantum physics, an infinitely stronger and more mysterious correlation emerges—entanglement.

Now, imagine there are two physicists in their own laboratories, with a great distance separating the two. Each scientist has a a photon. If these two photons are in an entangled state, the physicists will see non-local quantum correlations, which conventional physics is unable to explain. They will find that the polarisation of the photons is always opposite (as with the socks in the above example), and that the photon has no intrinsic polarisation. The polarisation measured for each photon is, therefore, entirely random and fundamentally indeterminate before being measured. This is an unsystematic phenomenon that occurs simultaneously in two locations that are far apart—and this is exactly the mystery of quantum correlations. [15]

## Physicists retrieve 'lost' information from quantum measurements

Typically when scientists make a measurement, they know exactly what kind of measurement they're making, and their purpose is to obtain a measurement outcome. But in an "unrecorded measurement," both the type of measurement and the measurement outcome are unknown.

Despite the fact that scientists do not know this information, experiments clearly show that unrecorded measurements unavoidably disturb the state of the system being measured for quantum (but not classical) systems. In classical systems, unrecorded measurements have no effect.

Although the information in unrecorded measurements appears to be completely lost, in a paper published recently in EPL, Michael Revzen and Ady Mann, both Professors Emeriti at the Technion-Israel Institute of Technology, have described a protocol that can retrieve some of the lost information.

The fact that it is possible to retrieve this lost information reveals new insight into the fundamental nature of quantum measurements, mainly by supporting the idea that quantum measurements contain both quantum and classical components.

Previously, analysis of quantum measurement theory has suggested that, while a quantum measurement starts out purely quantum, it becomes somewhat classical when the quantum state of the system being measured is reduced to a "classical-like" probability distribution. At this point, it is possible to predict the probability of the result of a quantum measurement.

As the physicists explain in the new paper, this step when a quantum state is reduced to a classical-like distribution is the traceable part of an unrecorded measurement—or in other words, it is the "lost" information that the new protocol retrieves. So the retrieval of the lost information provides evidence of the quantum-to-classical transition in a quantum measurement.

"We have demonstrated that analysis of quantum measurement is facilitated by viewing it as being made of two parts," Revzen told Phys.org. "The first, a pure quantum one, pertains to the non-commutativity of measurements' bases. The second relates to classical-like probabilities.

"This partitioning circumvents the ever-present polemic surrounding the whole issue of measurements and allowed us, on the basis of the accepted wisdom pertaining to classical measurements, to suggest and demonstrate that the non-commutative measurement basis may be retrieved by measuring an unrecorded measurement."

As the physicists explain, the key to retrieving the lost information is to use quantum entanglement to entangle the system being measured by an unrecorded measurement with a second system. Since the two systems are entangled, the unrecorded measurement affects both systems. Then a control measurement made on the entangled system can extract some of the lost information. The scientists explain that the essential role of entanglement in retrieving the lost information affirms the intimate connection between entanglement and measurements, as well as the uncertainty principle, which limits the precision with which certain measurements can be made. The scientists also note that the entire concept of retrieval has connections to quantum cryptography.

"Posing the problem of retrieval of unrecorded measurement is, we believe, new," Mann said. "The whole issue, however, is closely related to the problem of the combatting eavesdropper in quantum cryptography which aims, in effect, at detection of the existence of 'unrecorded measurement' (our aim is their identification).

The issue of eavesdropper detection has been under active study for some time."

The scientists are continuing to build on the new results by showing that some of the lost information can never be retrieved, and that in other cases, it's impossible to determine whether certain information can be retrieved.

"At present, we are trying to find a comprehensive proof that the retrieval of the measurement basis is indeed the maximal possible retrieval, as well as to pin down the precise meaning of the ubiquitous 'undetermined' case," Revzen said. "This is, within our general study of quantum measurement, arguably the most obscure subject of the foundation of quantum mechanics." [14]

## Researchers blur the line between classical and quantum physics by connecting chaos and entanglement

Using a small quantum system consisting of three superconducting qubits, researchers at UC Santa Barbara and Google have uncovered a link between aspects of classical and quantum physics thought to be unrelated: classical chaos and quantum entanglement. Their findings suggest that it would be possible to use controllable quantum systems to investigate certain fundamental aspects of nature.

"It's kind of surprising because chaos is this totally classical concept—there's no idea of chaos in a quantum system," Charles Neill, a researcher in the UCSB Department of Physics and lead author of a paper that appears in Nature Physics. "Similarly, there's no concept of entanglement within classical systems. And yet it turns out that chaos and entanglement are really very strongly and clearly related."

Initiated in the 15th century, classical physics generally examines and describes systems larger than atoms and molecules. It consists of hundreds of years' worth of study including Newton's laws of motion, electrodynamics, relativity, thermodynamics as well as chaos theory—the field that studies the behavior of highly sensitive and unpredictable systems. One classic example of chaos theory is the weather, in which a relatively small change in one part of the system is enough to foil predictions—and vacation plans—anywhere on the globe.

At smaller size and length scales in nature, however, such as those involving atoms and photons and their behaviors, classical physics falls short. In the early 20th century quantum physics emerged, with its seemingly counterintuitive and sometimes controversial science, including the notions of superposition (the theory that a particle can be located in several places at once) and entanglement (particles that are deeply linked behave as such despite physical distance from one another).

And so began the continuing search for connections between the two fields.

All systems are fundamentally quantum systems, according Neill, but the means of describing in a quantum sense the chaotic behavior of, say, air molecules in an evacuated room, remains limited.

Imagine taking a balloon full of air molecules, somehow tagging them so you could see them and then releasing them into a room with no air molecules, noted co-author and UCSB/Google researcher Pedram Roushan. One possible outcome is that the air molecules remain clumped together in a little cloud following the same trajectory around the room. And yet, he continued, as we can probably intuit, the molecules will more likely take off in a variety of velocities and directions, bouncing off walls and interacting with each other, resting after the room is sufficiently saturated with them.

"The underlying physics is chaos, essentially," he said. The molecules coming to rest—at least on the macroscopic level—is the result of thermalization, or of reaching equilibrium after they have achieved uniform saturation within the system. But in the infinitesimal world of quantum physics, there is still little to describe that behavior. The mathematics of quantum mechanics, Roushan said, do not allow for the chaos described by Newtonian laws of motion.

To investigate, the researchers devised an experiment using three quantum bits, the basic computational units of the quantum computer. Unlike classical computer bits, which utilize a binary system of two possible states (e.g., zero/one), a qubit can also use a superposition of both states (zero and one) as a single state.

Additionally, multiple qubits can entangle, or link so closely that their measurements will automatically correlate. By manipulating these qubits with electronic pulses, Neill caused them to interact, rotate and evolve in the quantum analog of a highly sensitive classical system.

The result is a map of entanglement entropy of a qubit that, over time, comes to strongly resemble that of classical dynamics—the regions of entanglement in the quantum map resemble the regions of chaos on the classical map. The islands of low entanglement in the quantum map are located in the places of low chaos on the classical map.

"There's a very clear connection between entanglement and chaos in these two pictures," said Neill. "And, it turns out that thermalization is the thing that connects chaos and entanglement. It turns out that they are actually the driving forces behind thermalization.

"What we realize is that in almost any quantum system, including on quantum computers, if you just let it evolve and you start to study what happens as a function of time, it's going to thermalize," added Neill, referring to the quantum-level equilibration. "And this really ties together the intuition between classical thermalization and chaos and how it occurs in quantum systems that entangle."

The study's findings have fundamental implications for quantum computing. At the level of three qubits, the computation is relatively simple, said Roushan, but as researchers push to build increasingly sophisticated and powerful quantum computers that incorporate more qubits to study highly complex problems that are beyond the ability of classical computing—such as those in the realms of machine learning, artificial intelligence, fluid dynamics or chemistry—a quantum processor optimized for such calculations will be a very powerful tool.

"It means we can study things that are completely impossible to study right now, once we get to bigger systems," said Neill. [13]

## New device lengthens the life of quantum information

Yale University scientists have reached a milestone in their efforts to extend the durability and dependability of quantum information.

For the first time, researchers at Yale have crossed the "break even" point in preserving a bit of quantum information for longer than the lifetime of its constituent parts. They have created a novel system to encode, spot errors, decode, and correct errors in a quantum bit, also known as a "qubit." The development of such a robust method of Quantum Error Correction (QEC) has been one of the biggest remaining hurdles in quantum computation.

The findings were published online July 20 in the journal Nature.

"This is the first error correction to actually detect and correct naturally occurring errors," said Robert Schoelkopf, Sterling Professor of Applied Physics and Physics at Yale, director of the Yale Quantum Institute, and principal investigator of the study. "It is just the beginning of using QEC for real computing. Now we need to combine QEC with actual computations."

Error correction for quantum data bits is exceptionally difficult because of the nature of the quantum state. Unlike the "classical" state of either zero or one, the quantum state can be a zero, a one, or a superposition of both zero and one. Furthermore, the quantum state is so fragile that the act of observing it will cause a qubit to revert back to a classical state.

Co-lead author Andrei Petrenko, who is a Yale graduate student, added: "In our experiment we show that we can protect an actual superposition and the QEC doesn't learn whether the qubit is a zero or a one, but can still compensate for the errors."

The team accomplished it, in part, by finding a less complicated way to encode and correct the information. The Yale researchers devised a microwave cavity in which they created an even number of photons in a quantum state that stores the qubit. Rather than disturbing the photons by measuring them—or even counting them—the researchers simply determined whether there were an odd or even number of photons. The process relied on a kind of symmetry, via a technique the team developed previously.

"If a photon is lost, there will now be an odd number," said co-lead author Nissim Ofek, a Yale postdoctoral associate. "We can measure the parity, and thus detect error events without perturbing or learning what the encoded quantum bit's value actually is."

The cavity developed by Yale is able to prolong the life of a quantum bit more than three times longer than typical superconducting qubits today. It builds upon more than a decade of development in circuit QED architecture.

Schoelkopf and his frequent Yale collaborators, Michel Devoret and Steve Girvin, have made a series of quantum superconducting breakthroughs in recent years, directed at creating electronic devices that are the quantum version of the integrated circuit. Devoret, Yale's F.W.

Beinecke Professor of Physics, and Girvin, Yale's Eugene Higgins Professor of Physics and Applied Physics, are co-authors of the Nature paper. [12]

## Using lasers to make data storage faster than ever

As we use more and more data every year, where will we have room to store it all? Our rapidly increasing demand for web apps, file sharing and social networking, among other services, relies on information storage in the "cloud" – always-on Internet-connected remote servers that store, manage and process data. This in turn has led to a pressing need for faster, smaller and more energy-efficient devices to perform those cloud tasks.

Two of the three key elements of cloud computing, microchips and communications connections, are getting ever faster, smaller and more efficient. My research activity has implications for the third: data storage on hard drives.

Computers process data, at its most fundamental level, in ones and zeroes. Hard disks store information by changing the local magnetization in a small region of the disk: its direction up or down corresponds to a "1" or "0" value in binary machine language.

The smaller the area of a disk needed to store a piece of information, the more information can be stored in a given space. A way to store information in a particularly tiny area is by taking advantage of the fact that individual electrons possess magnetization, which is called their spin. The research field of spin electronics, or "spintronics," works on developing the ability to control the direction of electrons' spins in a faster and more energy efficient way.

## Shining light on magnets

I work to control electrons' spins using extremely short laser pulses – one quadrillionth of a second in duration, or one "femtosecond." Beyond just enabling smaller storage, lasers allow dramatically faster storage and retrieval of data. The speed comparison between today's technology and femtosecond spintronics is like comparing the fastest bullet train on Earth to the speed of light.

In addition, if the all-optical method is used to store information in materials that are transparent to light, little or no heating occurs – a huge benefit given the economic and environmental costs presented by the need for massive data-center cooling systems.

## Ultrafast laser-control of magnetism

A decade ago, studies first demonstrated that laser pulses could control electron spins to write data and could monitor the spins to read stored data. Doing this involved measuring tiny oscillations in the electrons' magnetization. After those early investigations, researchers believed – wrongly, as it turned out – that lasers could not affect or detect fluctuations smaller than the wavelength of the lasers' own light. If this were true, it would not be possible to control magnets on a scale as short as one nanometer (one millionth of a millimeter) in as little time as a femtosecond.

Very recently an international team of researchers of which I am a member has provided an experimental demonstration that such a limitation does not actually exist. We were able to affect magnets on as small as one nanometer in length, as quickly as every 45 femtoseconds. That's one ten-millionth the size, and more than 20,000 times as fast as today's hard drives operate.

This suggests that future devices may be able to work with processing speeds as fast as 22 THz – 1,000 times faster than today's GHz clock speeds in commercial computers. And devices could be far smaller, too.

## Novel scientific frontiers

In addition to the practical effects on modern computing, the scientific importance of this research is significant. Conventional theories and experiments about magnetism assume that materials are in what is called "equilibrium," a condition in which the quantities defining a system (temperature, pressure, magnetization) are either constant or changing only very slowly.

However, sending in a femtosecond laser pulse disrupts a magnet's equilibrium. This lets us study magnetic materials in real time when they are not at rest, opening new frontiers for fundamental research. Already, we have seen exotic phenomena such as loss or even reversal of magnetization. These defy our current understanding of magnetism because they are impossible in equilibrium states. Other phenomena are likely to be discovered with further research.

Innovative science begins with a vision: a scientist is a dreamer who is able to imagine phenomena not observed yet. The scientific community involved in the research area of ultrafast magnetism is working on a big leap forward. It would be a development that doesn't mean just faster laptops but always-on, connected computing that is significantly faster, smaller and cheaper than today's systems. In addition, the storage mechanisms won't generate as much heat, requiring far less cooling of data centers – which is a significant cost both financially and environmentally. Achieving those new capabilities requires us to push the frontier of fundamental knowledge even farther, and paves the way to technologies we cannot yet imagine. [11]

## Scientists find surprising magnetic excitations in a metallic compound

Some three-dimensional materials can exhibit exotic properties that only exist in "lower" dimensions. For example, in one-dimensional chains of atoms that emerge within a bulk sample, electrons can separate into three distinct entities, each carrying information about just one aspect of the electron's identity—spin, charge, or orbit. The spinon, the entity that carries information about electron spin, has been known to control magnetism in certain insulating materials whose electron spins can point in any direction and easily flip direction. Now, a new study just published in Science reveals that spinons are also present in a metallic material in which the orbital movement of electrons around the atomic nucleus is the driving force behind the material's strong magnetism.

"In this bulk metallic compound, we unexpectedly found one-dimensional magnetic excitations that are typical of insulating materials whose main source of magnetism is the spin of its electrons," said physicist Igor Zaliznyak, who led the research at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory. "Our new understanding of how spinons contribute to the magnetism of an orbital-dominated system could potentially lead to the development of technologies that make use of orbital magnetism—for example, quantum computing components such as magnetic data processing and storage devices."

The experimental team included Brookhaven Lab and Stony Brook University physicists Meigan Aronson and William Gannon (both now at Texas A&M University) and Liusuo Wu (now at DOE's Oak Ridge National Laboratory), all of whom pioneered the study of the metallic compound made of ytterbium, platinum, and lead (Yb2Pt2Pb) nearly 10 years ago. The team used magnetic neutron scattering, a technique in which a beam of neutrons is directed at a magnetic material to probe its microscopic magnetism on an atomic scale. In this technique, the magnetic moments of the neutrons interact with the magnetic moments of the material, causing the neutrons to scatter. Measuring the intensity of these scattered neutrons as a function of the momentum and energy transferred to the material produces a spectrum that reveals the dispersion and magnitude of magnetic excitations in the material.

At low energies (up to 2 milli electron volts) and low temperatures (below 100 Kelvin, or minus 279 degrees Fahrenheit), the experiments revealed a broad continuum of magnetic excitations moving in one direction. The experimental team compared these measurements with theoretical predictions of what should be observed for spinons, as calculated by theoretical physicists Alexei Tsvelik of Brookhaven Lab and Jean-Sebastian Caux and Michael Brockmann of the University of Amsterdam. The dispersion of magnetic excitations obtained experimentally and theoretically was in close agreement, despite the magnetic moments of the Yb atoms being four times larger than what would be expected from a spin-dominated system.

"Our measurements provide direct evidence that this compound contains isolated chains where spinons are at work. But the large size of the magnetic moments makes it clear that orbital motion, not spin, is the dominant mechanism for magnetism," said Zaliznyak.

The paper in Science contains details of how the scientists characterized the direction of the magnetic fluctuations and developed a model to describe the compound's behavior. They used their model to compute an approximate magnetic excitation spectrum that was compared with their experimental observations, confirming that spinons are involved in the magnetic dynamics in Yb2Pt2Pb.

The scientists also came up with an explanation for how the magnetic excitations occur in Yb atoms: Instead of the electronic magnetic moments flipping directions as they would in a spinbased system, electrons hop between overlapping orbitals on adjacent Yb atoms. Both mechanisms—flipping and hopping—change the total energy of the system and lead to similar magnetic fluctuations along the chains of atoms.

"There is strong coupling between spin and orbital motion. The orbital alignment is rigidly determined by electric fields generated by nearby Pb and Pt atoms. Although the Yb atoms cannot flip their magnetic moments, they can exchange their electrons via orbital overlap," Zaliznyak said.

During these orbital exchanges, the electrons are stripped of their orbital "identity," allowing electron charges to move independently of the electron orbital motion around the Yb atom's nucleus—a phenomenon that Zaliznyak and his team call charge-orbital separation.

Scientists have already demonstrated the other two mechanisms of the three-part electron identity "splitting"—namely, spin-charge separation and spin-orbital separation. "This research completes the triad of electron fractionalization phenomena," Zaliznyak said. [10]

## Entanglement of Spin-12 Heisenberg Antiferromagnetic Quantum Spin Chains

Currently studying entanglement in condensed matter systems is of great interest. This interest stems from the fact that some behaviors of such systems can only be explained with the aid of entanglement. The magnetic susceptibility at low temperatures, quantum phase transitions, chemical reactions are examples where the entanglement is key ingredient for a complete understanding of the system. Furthermore, in order to produce a quantum processor, the entanglement of study condensed matter systems becomes essential. In condensed matter, said magnetic materials are of particular interest. Among these we will study the ferromagnetism which are described by Heisenberg model. We use the Hilbert-Schmidt norm for measuring the distance between quantum states. The choice of this norm was due mainly to its application simplicity and strong geometric appeal. The question of whether this norm satisfies the conditions desirable for a good measure of entanglement was discussed in 1999 by C. Witte and M. Trucks. They showed that the norm of Hilbert-Schmidt is not increasing under completely positive trace-preserving maps making use of the Lindblad theorem. M. Ozawa argued that this norm does not satisfy this condition by using an example of a completely positive map which can enlarge the Hilbert Schmidt norm between two states. However this does not prove the fact that the entanglement measure based on the Hilbert-Schmidt norm is not entangled monotone. This problem has come up in several contexts in recent years. Superselection structure of dynamical semigroups, entropy production of a quantum chanel, condensed matter theory and quantum information are some examples. Several authors have been devoted to this issue in recent years and other work on this matter is in progress by the author and collaborators. The study of entanglement in Heisenberg chains is of great interest in physics and has been done for several years. [9]

## New electron spin secrets revealed: Discovery of a novel link between magnetism and electricity

The findings reveal a novel link between magnetism and electricity, and may have applications in electronics.

The electric current generation demonstrated by the researchers is called charge pumping. Charge pumping provides a source of very high frequency alternating electric currents, and its magnitude and external magnetic field dependency can be used to detect magnetic information.

The findings may, therefore, offer new and exciting ways of transferring and manipulating data in electronic devices based on spintronics, a technology that uses electron spin as the foundation for information storage and manipulation.

The research findings are published as an Advance Online Publication (AOP) on Nature Nanotechnology's website on 10 November 2014.

Spintronics has already been exploited in magnetic mass data storage since the discovery of the giant magnetoresistance (GMR) effect in 1988. For their contribution to physics, the discoverers of GMR were awarded the Nobel Prize in 2007.

The basis of spintronics is the storage of information in the magnetic configuration of ferromagnets and the read-out via spin-dependent transport mechanisms.

"Much of the progress in spintronics has resulted from exploiting the coupling between the electron spin and its orbital motion, but our understanding of these interactions is still immature. We need to know more so that we can fully explore and exploit these forces," says Arne Brataas, professor at NTNU and the corresponding author for the paper.

An electron has a spin, a seemingly internal rotation, in addition to an electric charge. The spin can be up or down, representing clockwise and counterclockwise rotations.

Pure spin currents are charge currents in opposite directions for the two spin components in the material.

It has been known for some time that rotating the magnetization in a magnetic material can generate pure spin currents in adjacent conductors.

However, pure spin currents cannot be conventionally detected by a voltmeter because of the cancellation of the associated charge flow in the same direction.

A secondary spin-charge conversion element is then necessary, such as another ferromagnet or a strong spin-orbit interaction, which causes a spin Hall effect.

Brataas and his collaborators have demonstrated that in a small class of ferromagnetic materials, the spin-charge conversion occurs in the materials themselves.

The spin currents created in the materials are thus directly converted to charge currents via the spin-orbit interaction.

In other words, the ferromagnets function intrinsically as generators of alternating currents driven by the rotating magnetization.

"The phenomenon is a result of a direct link between electricity and magnetism. It allows for the possibility of new nano-scale detection techniques of magnetic information and for the generation of very high-frequency alternating currents," Brataas says. [8]

## Simple Experiment

Everybody can repeat my physics teacher's - Nándor Toth - middle school experiment, placing aluminum folios in form V upside down on the electric wire with static electric current, and seeing them open up measuring the electric potential created by the charge distribution, caused by the acceleration of the electrons.

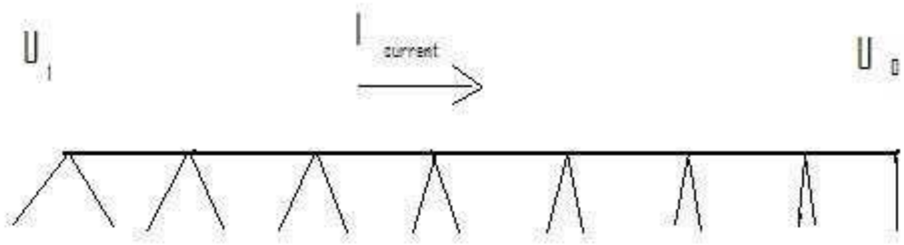



Figure 1.) Aluminium folios shows the charge distribution on the electric wire

He wanted to show us that the potential decreasing linearly along the wire and told us that in the beginning of the wire it is lowering harder, but after that the change is quite linear.

You will see that the folios will draw a parabolic curve showing the charge distribution along the wire, since the way of the accelerated electrons in the wire is proportional with the square of time. The free external charges are moving along the wire, will experience this charge distribution caused electrostatic force and repelled if moving against the direction of the electric current and attracted in the same direction – the magnetic effect of the electric current.

## Uniformly accelerated electrons of the steady current

In the steady current **I= dq/dt**, the **q** electric charge crossing the electric wire at any place in the same time is constant. This does not require that the electrons should move with a constant v velocity and does not exclude the possibility that under the constant electric force created by the **E = - dU/dx** potential changes the electrons could accelerating.

If the electrons accelerating under the influence of the electric force, then they would arrive to the $\mathbf{x = 1/2\ at^2}$ in the wire. The **dx/dt = at**, means that every second the accelerating q charge will take a linearly growing length of the wire. For simplicity if a=2 then the electrons would found in the wire at x = 1, 4, 9, 16, 25 …, which means that the dx between them should be 3, 5, 7, 9 …, linearly increasing the volume containing the same q electric charge. It means that the density of the electric charge decreasing linearly and as the consequence of this the U field is decreasing linearly as expected: **-dU/dx = E = const**.

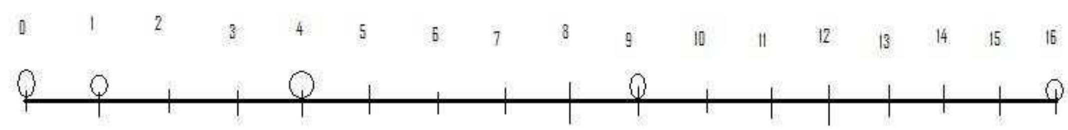



Figure 2.) The accelerating electrons created charge distribution on the electric wire

This picture remembers the Galileo's Slope of the accelerating ball, showed us by the same teacher in the middle school, some lectures before. I want to thank him for his enthusiastic and impressive lectures, giving me the associating idea between the Galileo's Slope and the accelerating charges of the electric current.

We can conclude that the electrons are accelerated by the electric **U** potential, and with this accelerated motion they are maintaining the linear potential decreasing of the **U** potential along they movement. Important to mention, that the linearly decreasing charge density measured in the referential frame of the moving electrons. Along the wire in its referential frame the charge density lowering parabolic, since the charges takes way proportional with the square of time.

The decreasing **U** potential is measurable, simply by measuring it at any place along the wire. One of the simple visualizations is the aluminum foils placed on the wire opening differently depending on the local charge density. The static electricity is changing by parabolic potential giving the equipotential lines for the external moving electrons in the surrounding of the wire.

## Magnetic effect of the decreasing U electric potential

One **q** electric charge moving parallel along the wire outside of it with velocity v would experience a changing **U** electric potential along the wire. If it experiencing an emerging potential, it will repel the charge, in case of decreasing **U** potential it will move closer to the wire. This radial electric field will move the external electric charge on the parabolic curve, on the equipotential line of the accelerated charges of the electric current. This is exactly the magnetic effect of the electric current. A constant force, perpendicular to the direction of the movement of the matter will change its direction to a parabolic curve.

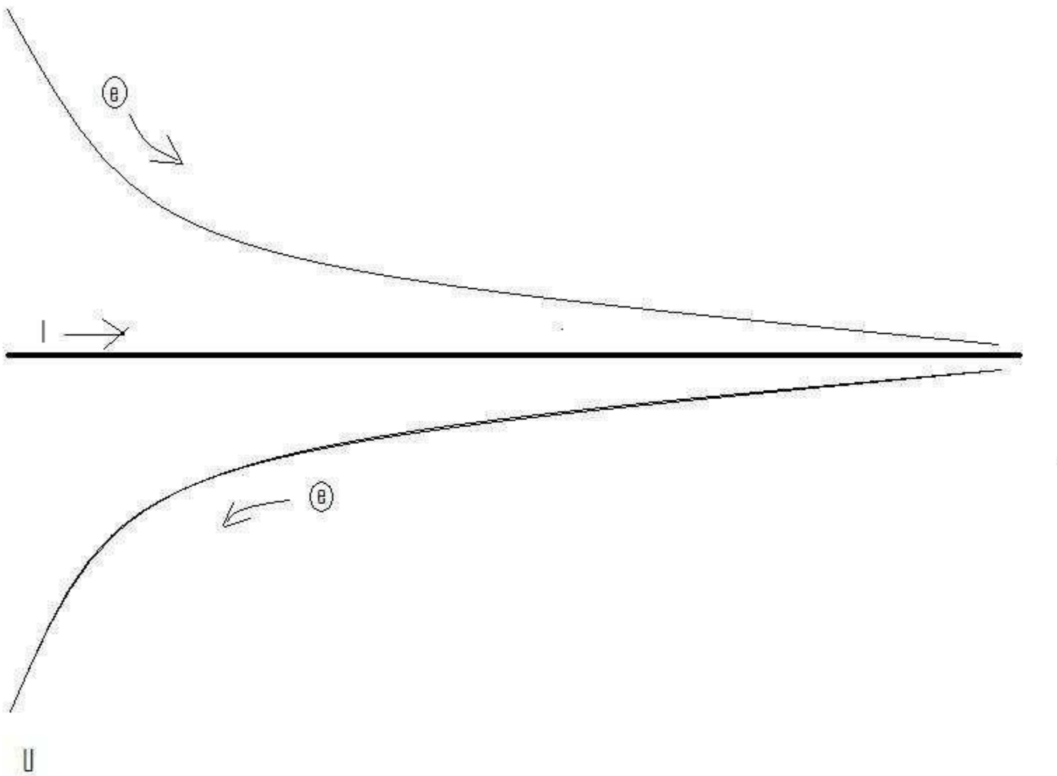



Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

Considering that the magnetic effect is **F=q v x B**, where the **B** is concentric circle around the electric wire, it is an equipotential circle of the accelerating electrons caused charge distribution. Moving on this circle there is no electric and magnetic effect for the external charges, since **vxB=0**. Moving in the direction of the current the electric charges crosses the biggest potential change, while in any other direction – depending on the angle between the current and velocity of the external charge there is a modest electric potential difference, giving exactly the same force as the **v x B** magnetic force.

Getting the magnetic force from the **F = dp/dt** equation we will understand the magnetic field velocity dependency. Finding the appropriate trajectory of the moving charges we need simply get it from the equipotential lines on the equipotential surfaces, caused by the accelerating charges of the electric current. We can prove that the velocity dependent force causes to move the charges on the equipotential surfaces, since the force due to the potential difference according to the velocity angle – changing only the direction, but not the value of the charge's velocity.

## The work done on the charge and the Hamilton Principle

One basic feature of magnetism is that, in the vicinity of a magnetic field, a moving charge will experience a force. Interestingly, the force on the charged particle is always perpendicular to the direction it is moving. Thus magnetic forces cause charged particles to change their direction of motion, but they do not change the speed of the particle. This property is used in high-energy particle accelerators to focus beams of particles which eventually collide with targets to produce new particles. Another way to understand this is to realize that if the force is perpendicular to the motion, then no work is done. Hence magnetic forces do no work on charged particles and cannot increase their kinetic energy. If a charged particle moves through a constant magnetic field, its speed stays the same, but its direction is constantly changing. [2]

In electrostatics, the work done to move a charge from any point on the equipotential surface to any other point on the equipotential surface is zero since they are at the same potential. Furthermore, equipotential surfaces are always perpendicular to the net electric field lines passing through it. [3]

Consequently the work done on the moving charges is zero in both cases, proving that they are equal forces, that is they are the same force.

The accelerating charges self-maintaining potential equivalent with the Hamilton Principle and the Euler-Lagrange equation. [4]

## The Magnetic Vector Potential

Also the **A** magnetic vector potential gives the radial parabolic electric potential change of the charge distribution due to the acceleration of electric charges in the electric current.

Necessary to mention that the **A** magnetic vector potential is proportional with a, the acceleration of the charges in the electric current although this is not the only parameter.

The **A** magnetic vector potential is proportional with **I=dQ/dt** electric current, which is proportional with the strength of the charge distribution along the wire. Although it is proportional also with the U potential difference I=U/R, but the R resistivity depends also on the cross-sectional area, that is bigger area gives stronger I and **A**. [7] This means that the bigger potential differences with smaller cross-section can give the same **I** current and **A** vector potential, explaining the gauge transformation.

Since the magnetic field B is defined as the curl of **A**, and the curl of a gradient is identically zero, then any arbitrary function which can be expressed as the gradient of a scalar function may be added to A without changing the value of B obtained from it. That is, A' can be freely substituted for A where

$$\vec{A'} = \vec{A} + \vec{\nabla}\phi$$

Such transformations are called gauge transformations, and there have been a number of "gauges" that have been used to advantage is specific types of calculations in electromagnetic theory. [5]

Since the potential difference and the vector potential both are in the direction of the electric current, this gauge transformation could explain the self maintaining electric potential of the accelerating electrons in the electric current. Also this is the source of the special and general relativity.

## The Constant Force of the Magnetic Vector Potential

Moving on the parabolic equipotential line gives the same result as the constant force of gravitation moves on a parabolic line with a constant velocity moving body.

## Electromagnetic four-potential

The electromagnetic four-potential defined as:

| **SI units** | **cgs units** |
|---|---|
| $A^\alpha = (\phi/c, \mathbf{A})$ | $A^\alpha = (\phi, \mathbf{A})$ |

in which $\phi$ is the electric potential, and **A** is the magnetic vector potential. [6] This is appropriate with the four-dimensional space-time vector (T, **R**) and in stationary current gives that the potential difference is constant in the time dimension and vector potential (and its curl, the magnetic field) is constant in the space dimensions.

# Magnetic induction

Increasing the electric current **I** causes increasing magnetic field **B** by increasing the acceleration of the electrons in the wire. Since l=at, if the acceleration of electrons is growing, than the charge density **dQ/dl** will decrease in time, creating a **–E** electric field. Since the resistance of the wire is constant, only increasing U electric potential could cause an increasing electric current **I=U/R=dQ/dt**. The charge density in the static current changes linear in the time coordinates. Changing its value in time will causing a static electric force, negative to the accelerating force change. This explains the relativistic changing mass of the charge in time also.

Necessary to mention that decreasing electric current will decrease the acceleration of the electrons, causing increased charge density and **E** positive field.

The electric field is a result of the geometric change of the **U** potential and the timely change of the **A** magnetic potential:

**E = - dA/dt - dU/dr**

$$\mathbf{B} = \nabla \times \mathbf{A}\,, \quad \mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t}\,,$$

The acceleration of the electric charges proportional with the A magnetic vector potential in the electric current and also their time dependence are proportional as well. Since the A vector potential is appears in the equation, the proportional **a** acceleration will satisfy the same equation.

Since increasing acceleration of charges in the increasing electric current the result of increasing potential difference, creating a decreasing potential difference, the electric and magnetic vector potential are changes by the next wave - function equations:

$$\frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} - \nabla^2\varphi = \frac{\rho}{\varepsilon_0}$$

$$\nabla^2\mathbf{A} - \frac{1}{c^2}\frac{\partial^2\mathbf{A}}{\partial t^2} = -\mu_0\mathbf{J}$$

The simple experiment with periodical changing **U** potential and **I** electric current will move the aluminium folios with a moving wave along the wire.

The Lorentz gauge says exactly that the accelerating charges are self maintain their accelerator fields and the divergence (source) of the A vector potential is the timely change of the electric potential.

$$\nabla \cdot \vec{A} + \frac{1}{c^2}\frac{\partial\varphi}{\partial t} = 0.$$

Or

$$\vec{E} = -\nabla\,\varphi - \frac{\partial\vec{A}}{\partial t}.$$

The timely change of the A vector potential, which is the proportionally changing acceleration of the charges will produce the negative electric field.

## Lorentz transformation of the Special Relativity

In the referential frame of the accelerating electrons the charge density lowering linearly because of the linearly growing way they takes every next time period. From the referential frame of the wire there is a parabolic charge density lowering.

The difference between these two referential frames, namely the referential frame of the wire and the referential frame of the moving electrons gives the relativistic effect. Important to say that the moving electrons presenting the time coordinate, since the electrons are taking linearly increasing way every next time period, and the wire presenting the geometric coordinate.

The Lorentz transformations are based on moving light sources of the Michelson - Morley experiment giving a practical method to transform time and geometric coordinates without explaining the source of this mystery.

The real mystery is that the accelerating charges are maintaining the accelerating force with their charge distribution locally. The resolution of this mystery that the charges are simply the results of the diffraction patterns, that is the charges and the electric field are two sides of the same thing. Otherwise the charges could exceed the velocity of the electromagnetic field.

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.

## 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 the 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.

## Fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: **1/2 h = dx dp** or **1/2 h = dt dE**, that is the value of the basic energy status, consequently related to the $m_o$ inertial mass of the fermions.

The photon's 1 spin value and the electric charges 1/2 spin gives us the idea, that the electric charge and the electromagnetic wave two sides of the same thing, 1/2 – (-1/2) = 1.

## Fine structure constant

The Planck constant was first described as the proportionality constant between the energy ***E*** of a photon and the frequency ***ν*** of its associated electromagnetic wave. This relation between the energy and frequency is called the Planck relation or the Planck–Einstein equation:

$$E = h\nu \, .$$

Since the frequency ***ν***, wavelength ***λ***, and speed of light ***c*** are related by ***λν* = *c***, the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda}.$$

Since this is the source of the Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths, since **$E = mc^2$**.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass rate is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law.

## Planck Distribution Law

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! 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 Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms, molecules, crystals, dark matter and energy.

One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order 1/3 **e** charge to each coordinates and 2/3 **e** charge to one plane oscillation, because the charge is scalar. In this way the proton has two +2/3 **e** plane oscillation and one linear oscillation with -1/3 **e** charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. [1]

## Electromagnetic inertia and Gravitational attraction

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

It looks clear that the growing acceleration results the relativistic growing mass - limited also with the velocity of the electromagnetic wave.

The negatively changing acceleration causes a positive electric field, working as a decreasing mass.

Since $E = h\nu$ and $E = mc^2$, $m = h\nu / c^2$ that is the $m$ depends only on the $\nu$ 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.

If the mass is electromagnetic, then the gravitation is also electromagnetic effect caused by the magnetic effect between the same charges, they would attract each other if they are moving parallel by the magnetic effect.

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 the measured effect of the force of the gravitation, since the magnetic effect depends on this closeness. This way the mass and the magnetic attraction depend equally on the wavelength of the electromagnetic waves.

## Conclusions

The generation and modulation of high-frequency currents are central wireless communication devices such as mobile phones, WLAN modules for personal computers, Bluetooth devices and future vehicle radars. [8]

Needless to say that the accelerating electrons of the steady stationary current are a simple demystification of the magnetic field, by creating a decreasing charge distribution along the wire, maintaining the decreasing U potential and creating the **A** vector potential experienced by the electrons moving by **v** velocity relative to the wire. This way it is easier to understand also the time dependent changes of the electric current and the electromagnetic waves as the resulting fields moving by c velocity.

There is a very important law of the nature behind the self maintaining **E** accelerating force by the accelerated electrons. The accelerated electrons created electromagnetic fields are so natural that they occur as electromagnetic waves traveling with velocity c. It shows that the electric charges are the result of the electromagnetic waves diffraction.

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 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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