Glimpse of Flat Physics

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Researchers from the Moscow Institute of Physics and Technology, ETH Zurich, and Argonne National Laboratory, U.S, have described an extended quantum Maxwell's demon, a device locally violating the second law of thermodynamics in a system located one to five meters away from the demon. [20]

"We've experimentally confirmed the connection between information in the classical case and the quantum case," Murch said, "and we're seeing this new effect of information loss." [19]

It's well-known that when a quantum system is continuously measured, it freezes, i.e., it stops changing, which is due to a phenomenon called the quantum Zeno effect. [18]

Physicists have extended one of the most prominent fluctuation theorems of classical stochastic thermodynamics, the Jarzynski equality, to quantum field theory. [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.

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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.

Cold atoms offer a glimpse of flat physics

These days, movies and video games render increasingly realistic 3-D images on 2-D screens, giving viewers the illusion of gazing into another world. For many physicists, though, keeping things flat is far more interesting.

One reason is that flat landscapes can unlock new movement patterns in the quantum world of atoms and electrons. For instance, shedding the third dimension enables an entirely new class of particles to emerge—particles that that don't fit neatly into the two classes, bosons and fermions, provided by nature. These new particles, known as anyons, change in novel ways when they swap places, a feat that could one day power a special breed of quantum computer.

But anyons and the conditions that produce them have been exceedingly hard to spot in experiments. In a pair of papers published this week in *Physical Review Letters*, JQI Fellow Alexey Gorshkov and several collaborators proposed new ways of studying this unusual flat physics, suggesting that small numbers of constrained atoms could act as stand-ins for the finicky electrons first predicted to exhibit low-dimensional quirks.

"These two papers add to the growing literature demonstrating the promise of cold atoms for studying exotic physics in general and anyons in particular," Gorshkov says. "Coupled with recent advances in cold atom experiments—including by the group of Ian Spielman at JQI—this work hints at exciting experimental demonstrations that might be just around the corner."

In the first paper, which was selected as an Editors' Suggestion, Gorshkov and colleagues proposed looking for a new experimental signature of anyons—one that might be visible in a small collection of atoms hopping around in a 1-D grid. Previous work suggested that such systems might simulate the swapping behavior of anyons, but researchers only knew of ways to spot the effects at extremely cold temperatures. Instead, Fangli Liu, a graduate student at JQI, along with Gorshkov and other collaborators, found a way to detect the presence of anyons without needing such frigid climes.

Ordinarily, atoms spread out symmetrically over time in a 1-D grid, but anyons will generally favor the left over the right or vice versa. The researchers argued that straightforward changes to the laser used to create the grid would make the atoms hop less like themselves and more like anyons. By measuring the way that the number of atoms at different locations changes over time, it would then be possible to spot the asymmetry expected from anyons. Furthermore, adjusting the laser would make it easy to switch the favored direction in the experiment.

"The motivation was to use something that didn't require extremely cold temperatures to probe the anyons," says Liu, the lead author of the paper. "The hope is that maybe some similar ideas can be used in more general settings, like looking for related asymmetries in two dimensions."

In the second paper, Gorshkov and a separate group of collaborators found theoretical evidence for a new state of matter closely related to a Laughlin liquid, the prototypical example of a substance with topological order. In a Laughlin liquid, particles—originally electrons—find elaborate ways of avoiding one another, leading to the emergence of anyons that carry only a fraction of the electric charge held by an electron.

"Anyons are pretty much still theoretical constructs," says Tobias Grass, a postdoctoral researcher at JQI and the lead author of the second paper, "and experiments have yet to conclusively demonstrate them."

Although fractional charges have been observed in experiments with electrons, many of their other predicted properties have remained unmeasurable. This makes it hard to search for other interesting behavior or to study Laughlin liquids more closely. Grass, Gorshkov and their colleagues suggested a way to manipulate the interactions between a handful of atoms and discovered a new state of matter that mixes characteristics of the Laughlin liquid and a less exotic crystal phase.

The atoms in this new state avoid one another in a similar way as electrons in a Laughlin liquid, and they also fall into a regular pattern like in a crystal—albeit in a strange way, with only half of an atom occupying each crystal site. It's a unique mix of crystal symmetry and more complex topological order—a combination that has received little prior study.

"The idea that you have a bosonic or fermionic system, and then from interactions there emerges completely different physics—that's only possible in lower dimensions," Grass says. "Having an experimental demonstration of any of these phases is just interesting from a fundamental perspective." [25]

The coolest experiment in the universe

What's the coldest place you can think of? Temperatures on a winter day in Antarctica dip as low as -120ºF (-85ºC). On the dark side of the Moon, they hit -280ºF (-173ºC). But inside NASA's Cold Atom Laboratory on the International Space Station, scientists are creating something even colder.

The Cold Atom Lab (CAL) is the first facility in orbit to produce clouds of "ultracold" atoms, which can reach a fraction of a degree above absolute zero: -459ºF (-273ºC), the absolute coldest temperature that matter can reach. Nothing in nature is known to hit the temperatures achieved in laboratories like CAL, which means the orbiting facility is regularly the coldest known spot in the universe.

NASA's Cold Atom Laboratory on the International Space Station is regularly the coldest known spot in the universe. But why are scientists producing clouds of atoms a fraction of a degree above absolute zero? And why do they need to do it in space? Quantum physics, of course.

Seven months after its May 21, 2018, launch to the space station from NASA's Wallops Flight Facility in Virginia, CAL is producing ultracold atoms daily. Five teams of scientists will carry out experiments on CAL during its first year, and three experiments are already underway.

Why cool atoms to such an extreme low? Room-temperature atoms typically zip around like hyperactive hummingbirds, but ultracold atoms move much slower than even a snail. Specifics vary, but ultracold atoms can be more than 200,000 times slower than room-temperature atoms. This opens up new ways to study atoms as well as new ways to use them for investigations of other physical phenomena. CAL's primary science objective is to conduct fundamental physics research—to try to understand the workings of nature at the most fundamental levels.

The Cold Atom Laboratory (CAL) consists of two standardized containers that will be installed on the International Space Station. The larger container holds CAL's physics package, or the compartment where CAL will produce clouds of ultracold atoms. Credit: NASA/JPL-Caltech"With CAL we're starting to get a really thorough understanding of how the atoms behave in microgravity, how to manipulate them, how the system is different than the ones we use on Earth," said Rob Thompson, a cold atom physicist at NASA's Jet Propulsion Laboratory in Pasadena, California, and the mission scientist for CAL. "This is all knowledge that is going to build a foundation for what I hope is a long future of cold atom science in space."

Laboratories on Earth can produce ultracold atoms, but on the ground, gravity pulls on the chilled atom clouds and they fall quickly, giving scientists only fractions of a second to observe them. Magnetic fields can be used to "trap" the atoms and hold them still, but that restricts their natural movement. In microgravity, the cold atom clouds float for much longer, giving scientists an extended view of their behavior.

The process to create the cold atom clouds starts with lasers that begin to lower the temperature by slowing the atoms down. Radio waves cut away the warmest members of the group, further lowering the average temperature. Finally, the atoms are released from a magnetic trap and allowed to expand. This causes a drop in pressure that, in turn, naturally causes another drop in the cloud's temperature (the same phenomenon that causes a can of compressed air to feel cold after use). In space, the cloud has longer to expand and thus reach even lower temperatures than what can be achieved on Earth—down to about one ten billionth of a degree above absolute zero, perhaps even lower.

The Cold Atom Laboratory (CAL), packaged in a protective layer, is loaded onto a Northrop Grumman (formerly Orbital ATK) Cygnus spacecraft for its trip to the International Space Station. The facility launched in May 2018 from NASA's …more

Ultracold atom facilities on Earth typically occupy an entire room, and in most, the hardware is left exposed so that scientists can adjust the apparatus if need be. Building a cold atom laboratory for space posed several design challenges, some of which change the fundamental nature of these facilities. First, there was the matter of size: CAL flew to the station in two pieces—a metal box a little larger than a minifridge and a second one about the size of a carry-on suitcase. Second, CAL was designed to be operated remotely from Earth, so it was built as a fully enclosed facility.

CAL also features a number of technologies that have never been flown in space before, such as specialized vacuum cells that contain the atoms, which have to be sealed so tightly that almost no stray atoms can leak in. The lab needed to be able to withstand the shaking of launch and extreme forces experienced during the flight to the space station. It took the teams several years to develop unique hardware that could meet the precise needs for cooling atoms in space.

Credit: NASA"Several parts of the system required redesigning, and some parts broke in ways we'd never seen before," said Robert Shotwell, chief engineer for JPL's Astronomy, Physics and Space Technology Directorate and CAL project manager. "The facility had to be completely torn apart and reassembled three times."

All the hard work and problem solving since the mission's inception in 2012 turned the CAL team's vision into reality this past May. CAL team members talked via live video with astronauts Ricky Arnold and Drew Feustel aboard the International Space Station for the installation of the

Cold Atom Laboratory, the second ultracold atom facility ever operated in space, the first to reach Earth orbit and the first to remain in space for more than a few minutes. Along the way, CAL has also met the minimum requirements NASA set to deem the mission a success and is providing a unique tool for probing nature's mysteries. [24]

'Kondo metamagnet' is first in a family of eccentric quantum crystals

There's an oddball in most families, but Rice University physicist Emilia Morosan has discovered an entire clan of eccentric compounds that could help explain the mysterious electronic and magnetic workings of other quantum materials engineers are eying for next-generation computers and electronics.

Morosan and 30 co-authors describe the first family member—a "semimetallic Kondo lattice" made from ytterbium, rhodium and silicon in a ratio of 1-to-3-to-7—in a study this week in the American Physical Society journal *Physical Review X* (*PRX*). The paper describes two properties of $YbRh_3Si_7$—"metamagnetism" and "low-carrier Kondo" effects—that have rarely previously been measured in the same material.

Morosan, whose lab specializes in the design, discovery and synthesis of quantum materials, created the new family of 1-3-7's with support from the Gordon and Betty Moore Foundation's Emergent Phenomena in Quantum Systems Initiative (EPiQS). She said few 1-3-7's had been described in the scientific literature prior to her Moore-funded research. Of the several compounds in the 1-3-7 family discovered by her group, four are magnetic, three are ytterbium-based and "each is more surprising than the last," she said.

"First, this gives us an opportunity to understand all of these, by themselves, and then to understand them in relationship to each other," said Morosan, who was named a Moore Foundation EPiQS Materials Synthesis Investigator in 2014. "For example, the structural and chemical differences between these are very small. The lattice parameters are almost identical. One would expect that the physical changes would therefore be minimal in these related compounds, but we're finding dramatically different magnetic and transport properties. If we can understand why that happens in this family, it might allow us to search for compounds with the properties we want."

In $YbRh_3Si_7$ and all other crystals, atoms are arranged in an orderly way. Each crystal has its own signature structural pattern, or lattice. In crystals containing magnetic elements like iron or ytterbium, the orderly arrangement of atoms in a lattice often goes hand in hand with magnetic order.

For example, every electron acts like a tiny spinning bar magnet, with a positive and negative magnetic pole at either end of its spin axis. The electron's magnetic moment refers to the direction in which the spin axis points, and in elements like iron and ytterbium, which each contain many electrons, atoms can have a strong collective magnetic moment. In ferromagnets—the materials stuck to countless refrigerators and automobiles—these magnetic moments all point in one direction. In antiferromagnets, like $YbRh_3Si_7$, half of the moments point one way and half point the opposite way.

Tech companies are increasingly interested in using spin in solid-state devices. Spintronics, a growing movement, is dedicated to creating spin-based technologies for data transfer, data storage and computation, including fundamentally new kinds of chips for quantum computers.

For those studying new magnetic materials, like $YbRh_3Si_7$, one way to probe magnetic order is by coaxing the moments to point in another direction in response to an external magnetic field. By measuring the amount of field energy needed to change the direction that the magnetic moments point, physicists can learn much about the role that the crystal lattice plays in how the magnetic moments express themselves.

In most materials, the magnetic moments of atoms gradually rotate towards the direction of the external field as intensity increases. In metamagnets, the forces of the crystal field exert such a pull that the moments stay locked in place, even as an external field is applied. But when the field energy reaches a critical level, the moments all snap instantly into a new arrangement that's more closely aligned to the field. If the field intensity is increased enough, the moments can be made to align with the field, but "only through this progression of stepwise changes that are reminiscent of a devil's staircase," Morosan said.

The finding of the metamagnetic transitions was the first clue that something strange was at work in the crystallographic structure of $YbRh_3Si_7$.

"There are very few examples of metamagnetism in ytterbium-based compounds," said study co-author Macy Stavinoha, a graduate student in Morosan's group. "That transition clued us into looking at the underlying magnetic structure, which was quite complicated. We had to use a manifold of techniques to confirm what was involved."

The eight-year experimental odyssey to decipher the material's magnetic order was led by former Ph.D. student and co-author Binod Rai and included trips to Tennessee's Oak Ridge National Laboratory, Maryland's National Institute of Standards and Technology, the United Kingdom's Rutherford Appleton Laboratory, Florida's National High Magnetic Field Laboratory and New Mexico's Los Alamos National Laboratory.

Morosan said the experiments helped her team decipher the confusing competition of forces—structural, electronic and magnetic—at play in $YbRh_3Si_7$.

"There was nothing simple, in the sense that you could sit down, look at the data from an experiment and immediately tell what was going on," she said.

For example, experiments showed that the metamagnetic transitions in $YbRh_3Si_7$ occurred at lower fields when the magnetic field is applied perpendicular to the zero-field moment direction. This contrasts with metamagnetic transitions in almost all other ytterbium-based compounds, which occur when the applied field is parallel to the moment direction. Morosan said this points to a delicate balance between the different energy scales in $YbRh_3Si_7$.

Another example of competing energy scales in the material can be seen in the enhanced interaction between magnetic moments and conduction electrons. This interaction, known as "Kondo screening," arises when carrier electrons—the flowing particles in electric current—interact with magnetically aligned electrons in the ytterbium atoms. Stavinoha said it's puzzling because $YbRh_3Si_7$ has a lower density of carrier electrons than most known Kondo materials.

"You rarely find multiple Kondo systems in one family of isostructural compounds," Stavinoha said. "In the 1-3-7 family, we discovered three such Kondo systems with distinct magnetic and electronic properties. That combination of structural similarity and physical property dissimilarity present a great opportunity for comparative studies." [23]

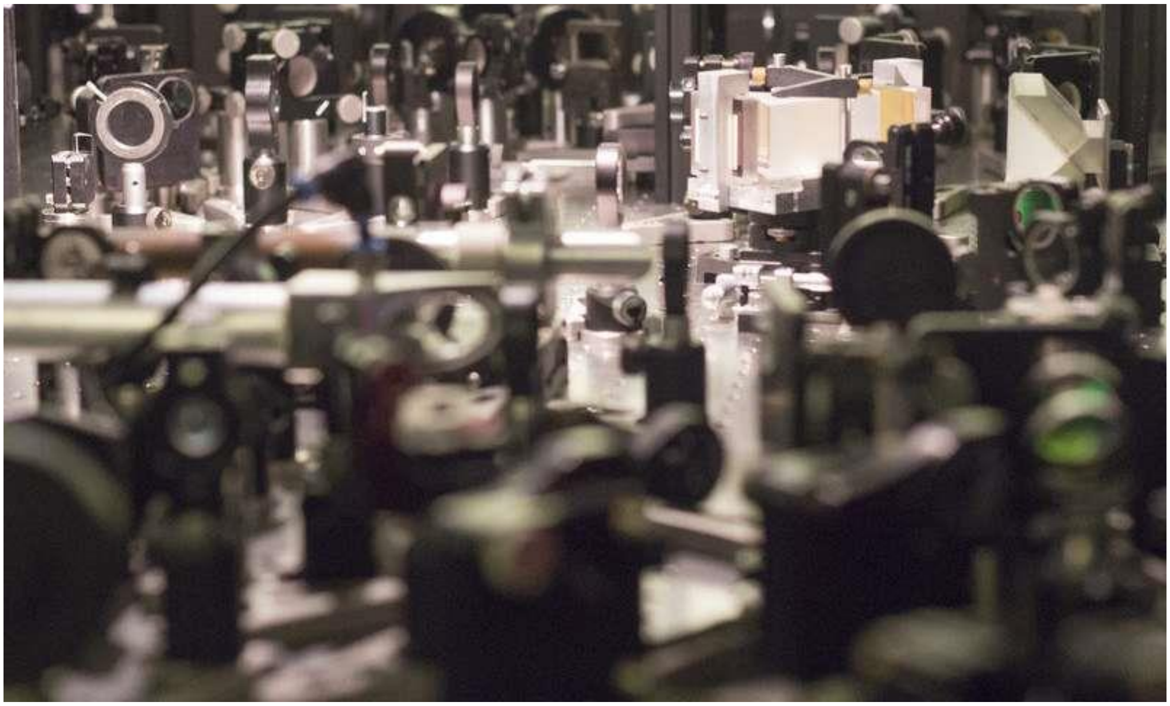
Quantum tricks to unveil the secrets of topological materials

Electrons are not just little spheres, bouncing through a material like a rubber ball. The laws of quantum physics tell us that electrons behave like waves. In some materials, these electron waves can take on rather complicated shapes. The so-called "topological materials" produce electron states that can be very interesting for technical applications, but it is extremely difficult to identify these materials and their associated electronic states.

TU Wien (Vienna) and several research groups from China have now developed new ideas and implemented them in an experiment. A "crystal " made of light waves is created to hold atoms in a very special geometric pattern. These "light crystals", which have been used in different ways for the manipulation of atoms, can now be used to deliberately drive the system out of equilibrium. By switching between simple and complicated states, the system reveals whether or not it has topologically interesting states. These findings have now been published in the journal *Physical Review Letters*.

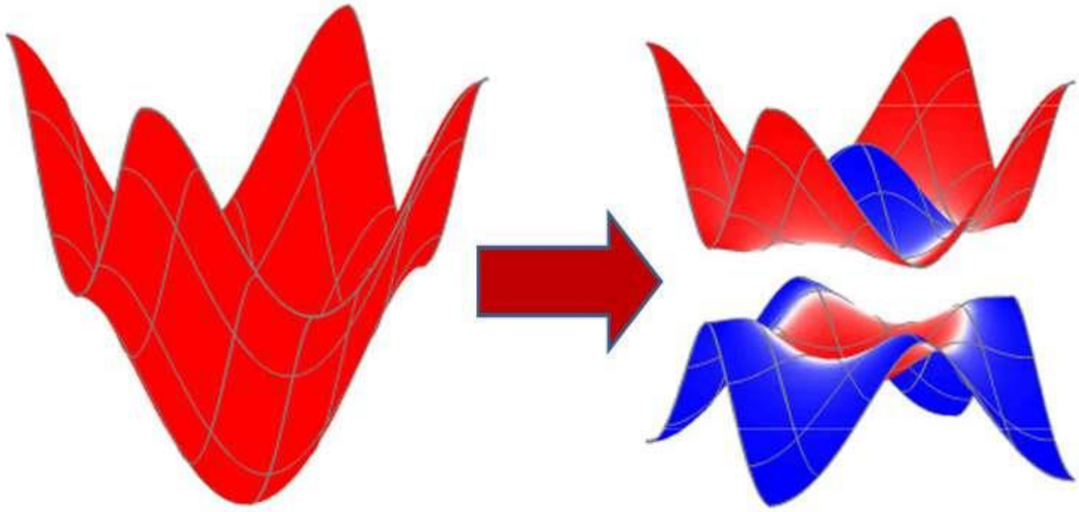
Bread Rolls and Donuts

The importance of topology can easily be seen if we pack too many things into a shopping bag: a bread roll may be slightly crushed and squeezed into a shape similar to a banana. Bread rolls and bananas have the same basic geometric structure, topologically they are the same. On the other hand, a donut has a hole in the middle—its topology is different. Even if it is slightly squeezed, its shape can still be easily distinguished from that of the bread roll.



Optical instruments at TU Wien. Credit: Vienna University of Technology"It is similar with quantum states," explains Prof. Jörg Schmiedmayer from Vienna Center for Quantum Science and Technology (VCQ) at TU Wien. "Quantum states can have a nontrivial topology which protects them with respect to certain perturbations. That's what makes them so interesting for technology, because you always have to deal with perturbations in every experiment and in every real world technological application." In 2016, the Nobel Prize in Physics for research was awarded for research on topological states of matter, but it is still considered extremely difficult to determine whether or not a certain material allows topologically interesting quantum states.

"Quantum states that are not in equilibrium, are changing rapidly," says Jörg Schmiedmayer. "This dynamics is notoriously difficult to understand, but as we have shown, it is a great way to obtain extremely interesting information about the system." Schmiedmayer cooperated with research teams from China. "The experiment was led by Prof. Shuai Chen, in the research group of Prof. Jian-Wei Pan. Both were once collaborators in my group in Heidelberg, and ever since their return to China, we have been work closely together," says Schmiedmayer. The TU Vienna and the Chinese University of Science and Technology (USTC, Heifei, China) signed a cooperation agreement in 2016, which strengthened research cooperation, especially in the field of physics.



A topologically trivial bandstructure (left), much like a valley, in which a rolling ball approaches the lowest point. The structure on the right is more complex. Credit: Vienna University of Technology

An Imbalance Revealing Material Properties

With the help of interfering light waves, atoms can be held in pre-defined places, creating a regular grid of atoms, similar to a crystal, the atoms taking the roles of the electrons in a solid state crystal. By changing the light, the geometry of the atomic arrangement can be switched, in order to examine how the electron states would behave in a real solid state material.

"With this change, a massive imbalance is suddenly being generated," says Jörg Schmiedmayer. "The quantum states must rearrange and approach a new equilibrium, much like balls rolling down a hill until they find equilibrium in the valley. And during this process we can see clear signatures that tell us whether topologically interesting states are to be found or not. "

This is an important new insight for research on topological materials. One could even adapt the artificial light crystals to simulate certain crystal structures and in order to find new topological materials. [22]

Strong interactions produce a dance between light and sound

Light and high-frequency acoustic sound waves in a tiny glass structure can strongly couple to one another and perform a dance in step.

A team of researchers from Imperial College London, the University of Oxford, and the National Physical Laboratory have experimentally achieved a long-standing goal to demonstrate the so-called "strong-coupling regime" between light and high-frequency acoustic vibrations.

The team's research will have impact for classical- and quantum-information processing and even testing quantum mechanics at large scales. The details of their research are published today in the prestigious journal *Optica*.

Central to the team's research are 'whispering-gallery-mode resonances' where light bounces many times around the surface of a tiny round glass structure shown in the figure above.

This phenomenon is named after an effect that was observed in St Paul's cathedral in the nineteenth century, where one could whisper along the wall of the round gallery building and be heard on the other side.

"It is fascinating that these glass ring resonators can store excessive amounts of light, which can 'shake' the molecules in the material and generate acoustic waves," said project co-author Dr. Pascal Del'Haye of the National Physical Laboratory.

As the light circulates around the circumference of the glass structure it interacts with an 11 GHz acoustic vibration that causes light to be scattered in the reverse direction. This interaction allows energy to be swapped between the light and sound at a certain rate. However, both the light- and the sound-fields will decay due to friction-like processes, preventing the two from dancing in step.

The team overcame this challenge by utilizing two such whispering-gallery-mode resonances and achieved a coupling rate that is larger than these friction-like processes, allowing the signatures of the light-sound dance to be observed.

Lead author of the project, Georg Enzian at the University of Oxford, said: "Achieving this strong-coupling regime was a thrilling moment for us." Professor Ian Walmsley, co-author of the project, and Provost of Imperial College London, said: "I'm excited about the near- and longer-term-prospects for this new experimental platform."

Looking ahead, the team are now preparing the next generation of these experiments that will operate at temperatures close to absolute zero. "This will allow highly sensitive quantum mechanical behaviour to be explored and utilized for the development of quantum technologies," said principal investigator of the project, Dr. Michael Vanner from the Quantum Measurement Lab at Imperial College London. [21]

Quantum Maxwell's demon 'teleports' entropy out of a qubit

Researchers from the Moscow Institute of Physics and Technology, ETH Zurich, and Argonne National Laboratory, U.S, have described an extended quantum Maxwell's demon, a device locally violating the second law of thermodynamics in a system located one to five meters away from the demon. The device could find applications in quantum computers and microscopic refrigerators that cool down tiny objects with pinpoint accuracy. The research was published Dec. 4 in *Physical Review B*.

The second law of thermodynamics says that in an isolated system, entropy, the degree of disorder or randomness, never decreases.

"Our demon causes a device called a qubit to transition into a more orderly state," explained the study's lead author, Andrey Lebedev of MIPT and ETH Zurich. "Importantly, the demon does not alter the qubit's energy and acts over a distance that is huge for quantum mechanics."

All quantum Maxwell's demons described or created so far by the authors or other researchers have had a very limited range of action—they were situated near the object on which they operated.

Because the demon needs to be "initialized," or prepared, prior to each interaction with the qubit, some energy is inevitably spent at the location of the demon. This means that globally, the second law still holds.

Demonic 'purity'

The study proposes the qubit be implemented as a superconducting artificial atom, a microscopic device like the one the researchers previously proposed for use as a quantum magnetometer. Such a qubit would be made of thin aluminum films deposited on a silicon chip. The reason this system is called an artificial atom is that at temperatures close to absolute zero, it behaves like an atom with two basis states: the ground and the excited states.

A qubit can simultaneously exhibit mixed "pure" and "impure" states. If a qubit is in one of the two basis states, but it is not known for sure which, its state is referred to as "impure." If that is the case, a classical probability for finding the artificial atom in one of the two states may be calculated.

However, just like a real atom, the qubit may be in a quantum superposition of the ground and the excited states. A quantum superposition is a special state that can be reduced to neither of the basis states. This so-called pure state, which defies the classical notion of probability, is associated with more order, and therefore less entropy. It can only exist for a fraction of a second before degenerating back into an impure state.

The demon described in the paper is another qubit connected to the first one by a coaxial cable carrying microwave signals. A consequence of the Heisenberg uncertainty principle is that once connected by a transmission line, the qubits start exchanging virtual photons, portions of microwave radiation. This photon exchange enables the qubits to swap their states.

If a pure state is artificially induced in the demon, it can then swap states with the target qubit, endowing it with "purity" in return for an impure state of the same energy. By purifying the target qubit, its entropy is reduced but its energy is not affected. The result is that the demon channels entropy away from a system isolated in terms of energy—namely, the target qubit. This results in the apparent violation of the second law if the target qubit is considered locally.

Quantum nanorefrigerator

Being able to purify a target qubit over a macroscopic distance is important from a practical standpoint. Unlike the impure state, the pure one can be switched into the ground or the excited state in a relatively straightforward and predictable way using an electromagnetic field. This operation may be useful in a quantum computer, whose qubits need to be switched into the ground state upon launch. Doing this from a distance is important, since the presence of a demon close to the quantum computer would affect the latter in adverse ways.

Another possible application of the demon has to do with the following: Switching the target qubit into the pure and subsequently into the ground state makes its immediate environment slightly colder. This turns the proposed system into a nanosized refrigerator capable of cooling parts of molecules with pinpoint accuracy.

"A conventional refrigerator cools its entire volume, while the qubit 'nanofridge' would target a particular spot. This might well be more effective in some cases," explained the paper's co-author Gordey Lesovik, who heads MIPT's Laboratory of the Physics of Quantum Information Technology. "For example, you could implement what's known as algorithmic cooling. This would involve supplying the code of a primary, 'quantum' program with a subprogram designed to target-cool specifically the hottest qubits.

"A further twist is that with any 'heat machine,' you can run it in reverse, turning a heat engine into a refrigerator or vice versa," added the physicist. "This lands us with a highly selective heater, as well. To turn it on, we would switch the target qubit into the excited rather than the ground state, making the qubit's whereabouts hotter."

This cooling or heating cycle could be run repeatedly, since the target qubit retains its pure state for a brief time, after which it enters the impure state, consuming or emitting the thermal energy of the environment. With every iteration, the location of the qubit becomes progressively cooler or warmer, respectively.

Besides the range of the demon, the authors have estimated the maximum temperature of the coaxial cable running between the qubits. Above this temperature, the quantum properties of the system are lost and the demon no longer works. Although the cable temperature may not exceed a few degrees above the absolute zero, this is nevertheless about 100 times hotter than the working temperature of the qubits. This makes it considerably easier to implement the proposed setup experimentally.

The team is already working on implementing the experiment. [20]

Researchers find quantum 'Maxwell's demon' may give up information to extract work

Thermodynamics is one of the most human of scientific enterprises, according to Kater Murch, associate professor of physics in Arts & Sciences at Washington University in St. Louis.

"It has to do with our fascination of fire and our laziness," he said. "How can we get fire"—or heat—"to do work for us?"

Now, Murch and colleagues have taken that most human enterprise down to the intangible quantum scale—that of ultra low temperatures and microscopic systems—and discovered that, as in the macroscopic world, it is possible to use information to extract work.

There is a catch, though: Some information may be lost in the process.

"We've experimentally confirmed the connection between information in the classical case and the quantum case," Murch said, "and we're seeing this new effect of information loss."

The results were published in the July 20 issue of *Physical Review Letters*.

The international team included Eric Lutz of the University of Stuttgart; J. J. Alonzo of the University of Erlangen-Nuremberg; Alessandro Romito of Lancaster University; and Mahdi Naghiloo, a Washington University graduate research assistant in physics.

Credit: Washington University in St. Louis

That we can get energy from information on a macroscopic scale was most famously illustrated in a thought experiment known as Maxwell's Demon. The "demon" presides over a box filled with molecules. The box is divided in half by a wall with a door. If the demon knows the speed and direction of all of the molecules, it can open the door when a fast-moving molecule is moving from the left half of the box to the right side, allowing it to pass. It can do the same for slow particles moving in the opposite direction, opening the door when a slow-moving molecule is approaching from the right, headed left.

After a while, all of the quickly-moving molecules are on the right side of the box. Faster motion corresponds to higher temperature. In this way, the demon has created a temperature imbalance, where one side of the box is hotter. That temperature imbalance can be turned into work—to push on a piston as in a steam engine, for instance. At first the thought experiment seemed to show that it was possible create a temperature difference without doing any work, and since temperature differences allow you to extract work, one could build a perpetual motion machine—a violation of the second law of thermodynamics.

"Eventually, scientists realized that there's something about the information that the demon has about the molecules," Murch said. "It has a physical quality like heat and work and energy."

His team wanted to know if it would be possible to use information to extract work in this way on a quantum scale, too, but not by sorting fast and slow molecules. If a particle is in an excited state, they could extract work by moving it to a ground state. (If it was in a ground state, they wouldn't do anything and wouldn't expend any work).

But they wanted to know what would happen if the quantum particles were in an excited state and a ground state at the same time, analogous to being fast and slow at the same time. In quantum physics, this is known as a superposition.

"Can you get work from information about a superposition of energy states?" Murch asked. "That's what we wanted to find out."

There's a problem, though. On a quantum scale, getting information about particles can be a bit … tricky.

"Every time you measure the system, it changes that system," Murch said. And if they measured the particle to find out exactly what state it was in, it would revert to one of two states: excited, or ground.

This effect is called quantum backaction. To get around it, when looking at the system, researchers (who were the "demons") didn't take a long, hard look at their particle. Instead, they took what was called a "weak observation." It still influenced the state of the superposition, but not enough to move it all the way to an excited state or a ground state; it was still in a superposition of energy states. This observation was enough, though, to allow the researchers track with fairly high accuracy, exactly what superposition the particle was in—and this is important, because the way the work is extracted from the particle depends on what superposition state it is in.

To get information, even using the weak observation method, the researchers still had to take a peek at the particle, which meant they needed light. So they sent some photons in, and observed the photons that came back.

"But the demon misses some photons," Murch said. "It only gets about half. The other half are lost." But—and this is the key—even though the researchers didn't see the other half of the photons, those photons still interacted with the system, which means they still had an effect on it. The researchers had no way of knowing what that effect was.

They took a weak measurement and got some information, but because of quantum backaction, they might end up knowing less than they did before the measurement. On the balance, that's negative information.

And that's weird.

"Do the rules of thermodynamics for a macroscopic, classical world still apply when we talk about quantum superposition?" Murch asked. "We found that yes, they hold, except there's this weird thing. The information can be negative.

"I think this research highlights how difficult it is to build a quantum computer," Murch said.

"For a normal computer, it just gets hot and we need to cool it. In the quantum computer you are always at risk of losing information." [19]

Maxwell's demon in the quantum Zeno regime

In the original Maxwell's demon thought experiment, a demon makes continuous measurements on a system of hot and cold reservoirs, building up a thermal gradient that can later be used to perform work. As the demon's measurements do not consume energy, it appears that the demon violates the second law of thermodynamics, although this paradox can be resolved by considering that the demon uses information to perform its sorting tasks.

It's well-known that when a quantum system is continuously measured, it freezes, i.e., it stops changing, which is due to a phenomenon called the quantum Zeno effect. This leads to the question: what might happen when Maxwell's demon enters the quantum Zeno regime? Will the demon's continuous measurements cause the quantum system to freeze and prevent work extraction, or will the demon still be able to influence the system's dynamics?

In a paper published in the *New Journal of Physics*, physicists Georg Engelhardt and Gernot Schaller at the Technical University of Berlin have theoretically implemented Maxwell's demon in a single-electron transistor in order to investigate the actions of the demon in the quantum Zeno regime.

In their model, the single-electron transistor consists of two electron reservoirs coupled by a quantum dot, with a demon making continuous measurements on the system. The researchers demonstrated that, as predicted by the quantum Zeno effect, the demon's continuous measurements block the flow of current between the two reservoirs. As a result, the demon cannot extract work.

However, the researchers also investigated what happens when the demon's measurements are not quite continuous. They found that there is an optimal measurement rate at which the measurements do not cause the system to freeze, but where a chemical gradient builds up between the two reservoirs and work can be extracted.

"The key significance of our findings is that it is necessary to investigate the transient short-time dynamics of thermoelectric devices, in order to find the optimal performance," Engelhardt told *Phys.org*. "This could be important for improving nanoscale technological devices."

The physicists explain that this intermediate regime lies between the quantum regime in which genuine quantum effects occur and the classical regime. What's especially attractive about this regime is that, due to the demon's measurements, the total energy of the system decreases so that no external energy needs to be invested to make the demon work.

"Due to the applied non-Markovian method, we have been able to find a working mode of the demon, at which—besides the build-up of the chemical gradient—it also gains work due the measurement," Engelhardt explained.

Going forward, it may be possible to extract work from the chemical gradient and use it, for example, to charge a battery. The researchers plan to address this possibility and others in the future.

"In our future research, we aim to investigate potential applications," Engelhardt said. "Feedback processes are important, for example, in many biological processes. We hope to identify and analyze quantum transport processes from a feedback viewpoint.

"Furthermore, we are interested in feedback control of topological band structures. As topological effects strongly rely on coherent dynamics, measurements seem to be an obstacle for feedback control. However, for an appropriate weak measurement, which only partly destroys the coherent quantum state, a feedback manipulation might be reasonable." [18]

Physicists extend stochastic thermodynamics deeper into quantum territory

Physicists have extended one of the most prominent fluctuation theorems of classical stochastic thermodynamics, the Jarzynski equality, to quantum field theory. As quantum field theory is considered to be the most fundamental theory in physics, the results allow the knowledge of stochastic thermodynamics to be applied, for the first time, across the full range of energy and length scales.

The physicists, Anthony Bartolotta, a graduate student at Caltech, and Sebastian Deffner, Physics Professor at the University of Maryland Baltimore County, have written a paper on the Jarzynski equality for quantum field theories that will be published in an upcoming issue of *Physical Review X*.

The work address one of the biggest challenges in fundamental physics, which is to determine how the laws of classical thermodynamics can be extended to the quantum scale. Understanding work and heat flow at the level of subatomic particles would benefit a wide range of areas, from designing nanoscale materials to understanding the evolution of the early universe.

As Bartolotta and Deffner explain in their paper, in contrast to the large leaps made in the "microscopic theories" of classical and quantum mechanics during the past century, the development of thermodynamics has been rather stagnant over that time.

Although thermodynamics was originally developed to describe the relation between energy and work, the theory traditionally applies only to systems that change infinitely slowly. In 1997, physicist Christopher Jarzynski at the University of Maryland College Park introduced a way to extend thermodynamics to systems in which heat and energy transfer processes occur at any rate. The fluctuation theorems, the most prominent of which is now called the Jarzynski equality, have made it possible to understand the thermodynamics of a wider range of smaller, yet still classical, systems.

"Thermodynamics is a phenomenological theory to describe the average behavior of heat and work," Deffner told *Phys.org*. "Originally designed to improve big, stinky heat engines, it was not capable of describing small systems and systems that operate far from equilibrium. The Jarzynski equality dramatically broadened the scope of thermodynamics and laid the groundwork for stochastic thermodynamics, which is a new and very active branch of research."

Stochastic thermodynamics deals with classical thermodynamic concepts such as work, heat, and entropy, but on the level of fluctuating trajectories of atoms and molecules. This more detailed picture is particularly important for understanding thermodynamics in small-scale systems, which is also the realm of various emerging applications.

It wasn't for another decade, however, until the Jarzynski equality and other fluctuation theorems were extended to the quantum scale, at least up to a point. In 2007, researchers determined how quantum effects modify the usual interpretation of work. However, many questions still remain and overall, the area of quantum stochastic thermodynamics is still incomplete. Against this backdrop, the results of the new study represent a significant advance.

"Now, in 2018 we have taken the next big step forward," Deffner said. "We have generalized stochastic thermodynamics to quantum field theories (QFT). In a certain sense we have extended stochastic thermodynamics to its ultimate range of validity, since QFT is designed to be the most fundamental theory in physics."

One of the keys to the achievement was to develop a completely novel graph theoretic approach, which allowed the researchers to classify and combine the Feynman diagrams used to describe particle behavior in a new way. More specifically, the approach makes it possible to precisely calculate infinite sums of all the possible permutations (or arrangements) of disconnected subdiagrams describing the particle trajectories.

"The quantity we were interested in, the work, is different than the quantities usually calculated by particle theorists and thus required a different approach," Bartolotta said.

The physicists expect that the results will allow other scientists to apply the fluctuation theorems to a wide variety of problems at the forefront of physics, such as in particle physics, cosmology, and condensed matter physics. This includes studying things like quantum engines, the thermodynamic properties of graphene, and the quark gluon plasma produced in heavy ion colliders—some of the most extreme conditions found in nature.

In the future, the physicists plan to generalize their approach to a wider variety of quantum field theories, which will open up even further possibilities. [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.

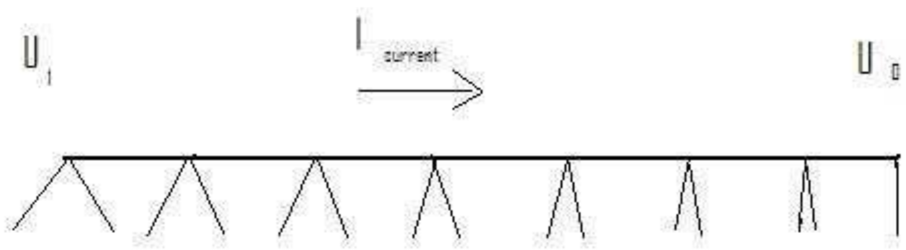


Figure 1.) Aluminium folios shows the charge distribution on the electric wire

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 **$x = 1/2\ at^2$** 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**.

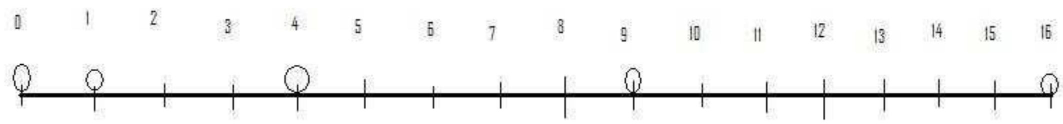


Figure 2.) The accelerating electrons created charge distribution on the electric wire

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.

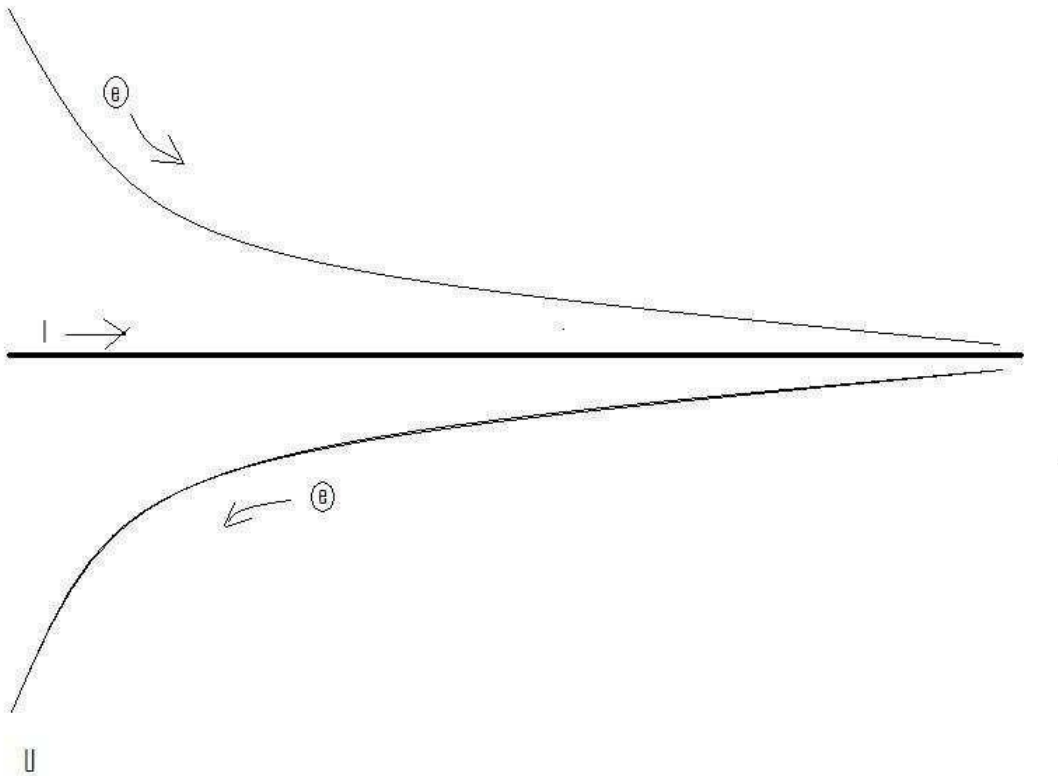


Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

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 **<u>A</u>** 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 **<u>A</u>** magnetic vector potential is proportional with <u>a</u>, the acceleration of the charges in the electric current although this is not the only parameter.

The **<u>A</u>** 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 **<u>A</u>**. [7] This means that the bigger potential differences with smaller cross-section can give the same **I** current and **<u>A</u>** vector potential, explaining the gauge transformation.

Since the magnetic field B is defined as the curl of **<u>A</u>**, 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 ϕ 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 = mc²**.

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 ν 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.

References

[1] 3 Dimensional String Theory

Author: George Rajna

Publisher: academia.edu
http://www.academia.edu/3834454/3_Dimensional_String_Theory

[2] Magnetic forces on moving charges

http://theory.uwinnipeg.ca/mod_tech/node93.html

[3] Equipotential surface

http://en.wikipedia.org/wiki/Equipotential_surface

[4] Hamilton Principle

http://en.wikipedia.org/wiki/Hamilton%27s_principle

[5] Magnetic Vector Potential http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magvec.html

[6] Electromagnetic four-potential

http://en.wikipedia.org/wiki/Electromagnetic_four-potential

[7] http://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity

[8] New electron spin secrets revealed: Discovery of a novel link between magnetism and electricity http://phys.org/news/2014-11-electron-secrets-revealed-discovery-link.html [9] Entanglement of Spin-12 Heisenberg Antiferromagnetic Quantum Spin Chains http://arxiv.org/pdf/1605.04373v1.pdf

[10] Scientists find surprising magnetic excitations in a metallic compound http://phys.org/news/2016-06-scientists-magnetic-metallic-compound.html

[11] Using lasers to make data storage faster than ever http://phys.org/news/2016-06-lasers-storage-faster.html [12] New device lengthens the life of quantum information http://phys.org/news/2016-07-yale-developed-device-lengthens-life-quantum.html

[13] Researchers blur the line between classical and quantum physics by connecting chaos and entanglement http://phys.org/news/2016-07-blur-line-classical-quantum-physics.html [14] Physicists retrieve 'lost' information from quantum measurements http://phys.org/news/2016-09-physicists-lost-quantum.html

[15] A single photon reveals quantum entanglement of 16 million atoms

https://phys.org/news/2017-10-photon-reveals-quantum-entanglement-million.html

[16] Generalized Hardy's paradox shows an even stronger conflict between quantum and classical physics

https://phys.org/news/2018-02-hardy-paradox-stronger-conflict-quantum.html

[17] Physicists extend stochastic thermodynamics deeper into quantum territory

https://phys.org/news/2018-02-physicists-stochastic-thermodynamics-deeper-quantum.html

[18] Maxwell's demon in the quantum Zeno regime

https://phys.org/news/2018-03-maxwell-demon-quantum-zeno-regime.html

[19] Researchers find quantum 'Maxwell's demon' may give up information to extract work

https://phys.org/news/2018-07-quantum-maxwell-demon.html

[20] Quantum Maxwell's demon 'teleports' entropy out of a qubit

https://phys.org/news/2018-12-quantum-maxwell-demon-teleports-entropy.html

[21] Strong interactions produce a dance between light and sound

https://phys.org/news/2018-12-strong-interactions.html

[22] Quantum tricks to unveil the secrets of topological materials

https://phys.org/news/2018-12-quantum-unveil-secrets-topological-materials.html

[23] 'Kondo metamagnet' is first in a family of eccentric quantum crystals

https://phys.org/news/2018-12-kondo-metamagnet-family-eccentric-quantum.html

[24] The coolest experiment in the universe

https://phys.org/news/2018-12-coolest-universe.html

[25] Cold atoms offer a glimpse of flat physics

https://phys.org/news/2018-12-cold-atoms-glimpse-flat-physics.html