Quantum Autoencoders

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A team of researchers has devised a simple way to tune a hallmark quantum effect in graphene—the material formed from a single layer of carbon atoms—by bathing it in light. [18]

Researchers from the University of Cambridge have taken a peek into the secretive domain of quantum mechanics. [17]

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.

Quantum autoencoders to denoise quantum measurements

Many research groups worldwide are currently trying to develop instruments to collect high-precision measurements, such as atomic clocks or gravimeters. Some of these researchers have tried to achieve this using entangled quantum states, which have a higher sensitivity to quantities than classical or non-entangled states.

Due to this high sensitivity, however, quantum entangled states are also more susceptible to picking up noise (i.e., unrelated signals) while collecting measurements. This can hinder the development of accurate and reliable quantum-enhanced metrological devices.

To overcome this limitation, two researchers at Leibniz Universität Hannover in Germany have recently developed quantum machine-learning algorithms that can be used to denoise quantum data. These algorithms, presented in a paper published in *Physical Review Letters*, could help to produce more reliable data using quantum clocks or other measurement tools based on entangled quantum states.

Dmytro Bondarenko, one of the researchers involved in the study, had already been working on a new algorithm based on quantum machine learning under the supervision of Professor Tobias Osborne at Leibniz Universität, Hannover. In this new study, Bondarenko and his colleague Polina Feldmann set out to investigate the feasibility of using this algorithm to denoise data collected by quantum-enhanced instruments.

"Quantum machine learning is a very promising topic, as it can combine the versatility of machine learning with the power of quantum algorithms," Bondarenko and Feldmann told Phys.org via email. "Machine learning is a ubiquitous method for data analysis."

Just like traditional machine-learning algorithms, quantum machine-learning algorithms depend on a series of variational parameters that need to be optimized before an algorithm can be used to analyze data. To learn the correct parameters, the algorithm needs first to be trained on data related to the task it is designed to complete (e.g., pattern recognition, image classification, etc.).

"When we say quantum machine learning, we mean that the input and the output of the algorithm are quantum states, for example, of some number of qubits (quantum bits), which can be realized, for instance, using superconductors," Bondarenko and Feldmann said. "The algorithm that maps the input state to the output state is meant to be implemented on a quantum computer. The variational parameters, which have to be optimized, are classical parameters of the transformations that are performed on the quantum computer."

The two researchers wanted to test whether the quantum machine leaning algorithm previously developed by Bondarenko, Osborne and their other colleagues could be used to clean up data collected using quantum-enhanced metrology tools. This ultimately led to the development of the quantum autoencoders introduced in their recent paper.

"Assume that you have a quantum experiment that gives you a number of noisy quantum states," Bondarenko and Feldmann explained. "Assume furthermore that you have a quantum computer which can process these states. Our autoencoder is an algorithm which tells the quantum computer how to transform the noisy quantum states from the experiment to denoise them."

As an initial step in their research, Bondarenko and Feldmann optimized their algorithms, training them to effectively denoise quantum data. As denoised reference states are hard to obtain or unavailable experimentally, the researchers used a trick that is often used when optimizing classical autoencoders, which are a type of unsupervised machine-learning algorithms.

"The trick is that the algorithm is written in such a way that it has to reduce the information on the way from the input to its output state," Bondarenko and Feldmann said. "Now, the figure of merit is defined as the similarity of the state processed by the autoencoder and another noisy state from your experiment. To make these states as similar as possible, the autoencoder has to keep the information which is equal for both states (their common noiseless origin), while discarding the noise, which, in every state coming from your experiment, is different."

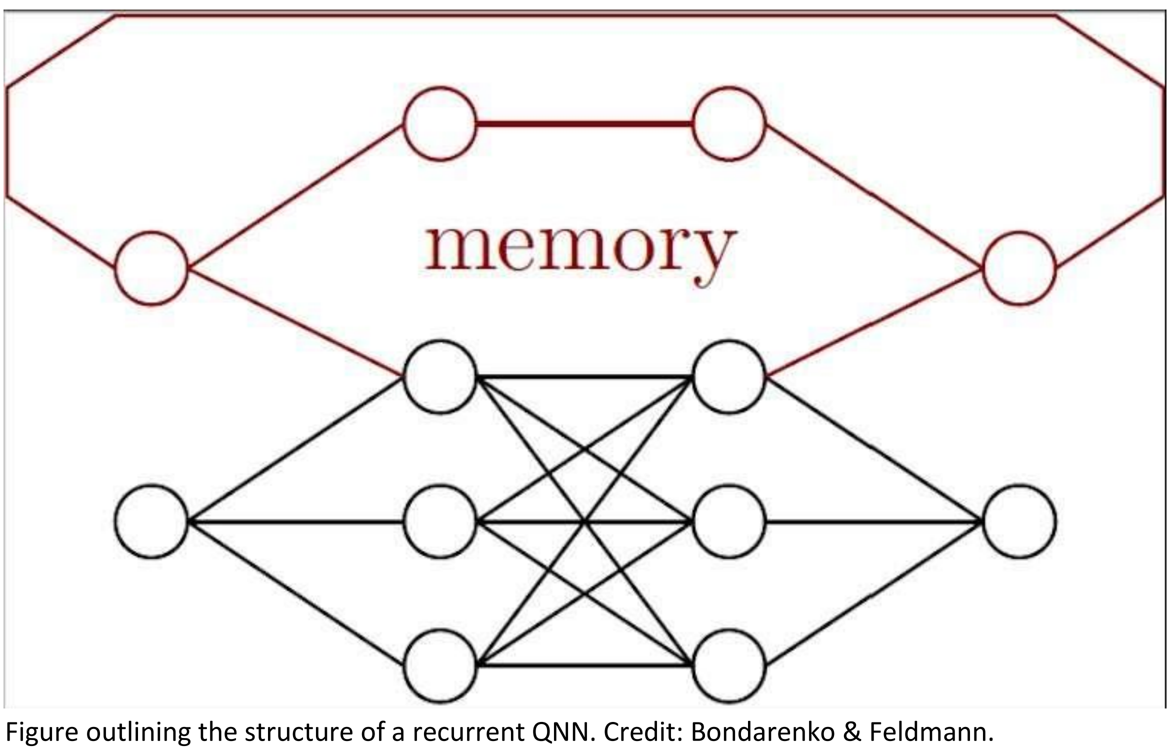

Figure outlining the structure of a recurrent QNN. Credit: Bondarenko & Feldmann.

The researchers have carried out numerous simulations in which they produced noisy entangled quantum states. First, they used these 'experimental' outputs to optimize the variational parameters of the autoencoder. Once this training phase was complete, they were able to evaluate their autoencoders' performance in denoising quantum measurements.

"The beauty of our approach is its generality," Bondarenko and Feldmann said. "You do not need to know beforehand what the output from your experiment looks like, nor do you have to characterize your noise sources. The denoising works even if your experimental output is not unique but depends on some experimental control parameter, which is crucial for metrological applications."

The goal of the numerical experiments was to denoise a number of highly entangled quantum states that are subject to spin-flip errors and random unitary noise. Their algorithms achieved remarkable results and could also be implemented on current quantum devices.

The algorithms require a quantum computer that can process the specific experimental output (i.e., quantum data). For instance, if a researcher is trying to use the autoencoders to denoise data based on trapped ions, but her quantum computer uses superconducting qubits, she will also need to use a technique that can map states from one physical platform to the other.

"Effectively training our autoencoders requires several trials, a considerable amount of experimental data, and the ability to measure the similarity between quantum states," Bondarenko and Feldmann said. "Nonetheless, our algorithm isn't too wasteful regarding these resources and our examples are small enough to easily fit, at least in terms of the number of qubits, into many existing quantum computers."

While quantum machine learning techniques and quantum computers have been found to perform well in a variety of tasks, researchers are still trying to identify the practical applications for which they could be of most use. The recent study carried out by Bondarenko and Feldmann offers a clear example of how quantum machine learning methods could ultimately be used in real-world scenarios.

"It was not at all obvious that our approach would work; and it does more than just work, at least in our small examples, it works extremely well," Bondarenko and Feldmann said.

In the future, the quantum autoencoders developed by these two researchers could be used to improve the reliability of measurements collected using quantum-enhanced tools, particularly those using many-body entangled states. In addition, they could serve as interfaces between different quantum architectures.

"Different quantum devices have different merits," Bondarenko and Feldmann said. "For example, it might be easier to use cold atoms to measure gravity, photons are great for communication and superconducting qubits are more useful for the quantum information processing. To convert information exchanged between these different platforms we need interfaces, which, by themselves, introduce errors. Our autoencoders can help to denoise this exchanged data."

Bondarenko and Feldmann are now trying to develop a different type of quantum algorithm: a recurrent quantum neural network. This new algorithm's recurrent architecture should allow it to store information it processed in the past and have a 'memory," which would allow the researchers to correct for drifts.

"This can make the quantum experiments simpler because drifts will be filtered away by post processing," Bondarenko and Feldmann said. "Another application of recurrent neural networks is the denoising in the case of slowly changing noise. For example, if one sends entangled photons via air, noise can differ between a snowy cloudy day and a hot day. However, the weather cannot change instantaneously, so an algorithm with memory can outperform one without." [22]

Quantum physics turned into tangible reality

ETH physicists have developed a silicon wafer that behaves like a topological insulator when stimulated using ultrasound. They have thereby succeeded in turning an abstract theoretical concept into a macroscopic product.

The usual procedure goes like this: you have a complex physical system and attempt to explain its behaviour through as simple a model as possible. Sebastian Huber, Assistant Professor at the Institute for Theoretical Physics, has shown that this procedure also works in reverse: he develops macroscopic systems that exhibit exactly the same properties predicted by theory, but which have not yet been observed at this level.

He succeeded in creating an illustrative example two and a half years ago. Together with his team, he built a mechanical device made of 270 pendulums connected by springs in such a way that the installation behaves like a topological insulator. This means that the pendulum and springs are positioned so that a vibrational excitation from the outside only moves the pendulums at the edges of the installation, but not the ones in the middle (as ETH News reported).

Vibration only in the corners

The new project, which will be published this week in the journal *Nature*, is also focused on a macroscopic system. This time, however, he created no large mechanical device, but a much more manageably-sized object. With his team, Huber created a 10 x 10 centimetre silicon wafer that consists of 100 small plates connected to each other via thin beams. The key aspect is that when the wafer is stimulated using ultrasound, only the plates in the corners vibrate; the other plates remain still, despite their connections.

Huber drew his inspiration for the new material from a work published around a year ago by groups from Urbana-Champaign and Princeton; the researchers presented a new theoretical approach for a second-order topological insulator. "In a conventional topological insulator, the vibrations only spread across the surface, but not inside," explains Huber. "The phenomenon is reduced by one dimension." In the case of the pendulum installation, this means that the two-dimensional arrangement led to a one-dimensional vibration pattern along the edges.

In a second-order topological insulator, however, the phenomenon is reduced by two dimensions. Accordingly, with a two-dimensional silicon wafer, the vibration no longer occurs along the edges, but only in the corners, at a zero-dimensional point. "We are the first to succeed in experimentally creating the predicted higher-order topological insulator," says Huber.

A new theoretical concept

Huber has again created something that behaves in exactly the way predicted by the theory. To solve this "inverse problem", he used a systematic process that he developed together with the group led by Chiara Daraio, now a professor at Caltech, and which he has published this week in the journal *Nature Materials*. Broadly speaking, Huber shows how a theoretically predicted functionality can be turned into concrete geometry. "In our example, we tested it using mechanical vibrations, by coupling elements with clearly defined modes of vibration using weak links," says Huber. "But the process can also be transferred to other applications, such as to optical or electrical systems."

Expansion to the third dimension

Huber already has clear plans for how to proceed: he wants to achieve a three-dimensional second-order topological insulator, in which the vibrations can be transmitted one-dimensionally. He recently received a Consolidator Grant from the European Research Council (ERC) for this project. Huber explains the basic idea: "We stack a number of these two-dimensional structures on top of each other, so that a three-dimensional form emerges. In this form, information or energy can be conducted from point A to point B through a one-dimensional channel."

Huber can think of a few possible applications. For example, such new topological insulators could be used to build robust and precise waveguides for communications networks. They could also be of use in the energy sector, for example for energy harvesting, in which energy from a diffuse surrounding source is focused for technological use.

Also of interest to theoreticians

Huber's results will not only be of interest to engineers and materials researchers, but also theoretical physicists. "The key finding from a theoretical viewpoint is that certain second-order topological insulators cannot be mathematically described as a dipole, as conventional topological insulators are, but as quadrupoles, which are far more complex," explains Huber. "The fact that we have been able to implement this experimentally in a macroscopic structure for the first time is therefore also a breakthrough for theoreticians." [21]

Physicists observe particles acting coherently as they undergo phase transitions

The common link between liquid-crystal TVs and the birth of the universe, when you look at the big picture, is that they are both characterized by the intriguing phenomenon in which matter abruptly changes states.

Scientists want to better understand and control the behavior of particles at the exact moment that these so-called phase transitions—a change in energy in a system, much like process in which water evaporates or turns to ice—occur.

A study published Dec. 18 in *Nature Physics* by University of Chicago scientists observed how particles behave as the change takes place in minute detail. In addition to shedding light on the fundamental rules that govern the universe, understanding such transitions could help design more useful technologies.

One of the questions was whether, as particles prepare to transition between quantum states, they can act as one coherent group that "knows" the states of the others, or whether different particles only act independently of one another, or incoherently.

Cheng Chin, professor in the Department of Physics, and his team looked at an experimental setup of tens of thousands of atoms cooled down to near absolute zero. As the system crossed a quantum phase transition, they measured its behavior with an extremely sensitive imaging system.

The conventional wisdom was that the atoms should evolve incoherently after the transition—a hallmark of older "classic" rather than quantum models of physics. "In contrast, we found strong evidence for coherent dynamics," said graduate student Lei Feng, the first author on the study. "In no moment do they become classical particles; they always behave as waves that evolve in synchrony with each other, which should give theorists a new ingredient to include in how they model such systems that are out of equilibrium."

This question gets at the fundamental rules that govern the way that matter interacts in our universe—but as always, it also has practical considerations. For example, engineers trying to build quantum computers are very interested in retaining the coherence of a group of interacting quantum bits, because they need to keep their system coherent in order to build faster computers. Cosmologists are interested in the physics of such transitions because they describe the earliest moments of the universe as it rapidly expanded and changed.

"Our observation sends us beyond the conventional picture of such transitions that scientists took for granted," Chin said. [20]

Groundbreaking experiment will test the limits of quantum theory

Scientists from three UK universities are to test one of the fundamental laws of physics as part of a major Europe-wide project awarded more than £3m in funding.

Experts from the University of Southampton, Queen's University Belfast and UCL have formed a consortium with European universities and British photonics technology company M Squared to test the limits of one of the core principles of quantum mechanics - the mind-boggling physical laws that allow microscopic particles such as atoms and electrons to be in two places at once.

Established at the beginning of the 20th century, quantum theory is a mathematical framework that provides, to date, the most accurate understanding of the results of experiments conducted on physical systems as small as single atoms, very small molecules and very faint light.

The consortium has devised an ambitious experiment to test the so-called quantum superposition principle (QSP) - the law that allows microscopic systems to appear in two different, perfectly distinguishable, configurations at the same time.

The validity of QSP at the microscopic level is accepted by scientists, and confirmed by an enormous amount of data. But what prevents it from applying to the 'large-scale' world around us? In other words, why do everyday objects such as cars, trees and people not behave in a quantum mechanical manner and exist in two places at once?

Unproven theories advanced since the 1980s suggest the existence of a universal background 'noise' that destroys QSP of larger objects, such as particles that can be seen using an optical microscope.

The 'Project TEQ' consortium, led by the University of Trieste, in Italy, will test the existence of this noise thanks to a €4.4m (£3.9m) award from the European Commission.

Its experiment will involve a tiny particle of glass, one-thousandth of the width of a human hair, being levitated by an electric field in a vacuum at a temperature close to absolute zero (-273C). A laser will be shot at the particle, and the scattering of the laser's light measured for signs of movement of the particle.

If there is no movement, it means that quantum mechanics still apply at this scale and there is no universal background noise.

However, if movement is detected, it indicates the existence of a noise that prevents QSP applying at this scale. This would represent the first observed failure of quantum theory, setting a limit on the scale at which quantum mechanics apply and having implications for large-scale applications of any physical system based on quantum principles.

Professor Hendrik Ulbricht, of the University of Southampton, said: "The vast majority of phenomena and events that occur in our daily lives can be accounted for by the laws of physics established by Isaac Newton, but the microscopic world obeys the rules of quantum mechanics, which are so strange that they can seem counter-intuitive.

"Whether it's possible to observe quantum behaviour in macroscopic objects is the great unanswered question in quantum physics. If it turns out we can, this could eventually open the way for us to use the amazing characteristics of quantum mechanics in a much larger set of physical systems beyond the microscopic world. We're about to embark on a very exciting journey."

Professor Mauro Paternostro, of Queen's University Belfast, said: "Our research programme could prove that we do not have to deal with extremely small systems in order to see quantum effects, which is currently the main limitation of quantum technology.

"If you can prove that quantum theory extends to larger systems, it will offer a much more robust way of processing information: all the chips and integrated systems in computers could be shrunk to a much smaller scale and we would be able to manage quantum for daily applications.

"This would mean larger data-processing rates, larger memories and larger transmission rates of data across these larger networks."

Dr Graeme Malcolm OBE, CEO and co-founder of M Squared, said: "This fund for TEQ is an excellent example of the EU's continued support of quantum research and allows established thinking behind quantum mechanics to be tested to its limits.

"If this work does prove that quantum effects can be seen on a larger scale, it widens the potential commercial applications of quantum technology - in particular, the areas of sensing and metrology will see significant commercial opportunities in the coming decades. It's an honour to be part of the team exploring the potential of technology operating at the very limits of physics.

If the experiment proves that quantum mechanics can be applied to larger-scale systems, it could make creating quantum technologies for use in space easier, with satellites being used to transmit quantum information rather than relying on fibres on the ground or under the sea."

Other potential applications include the development of ultra-sensitive measuring devices that could outperform existing sensors to measure the effects of gravity. [18]

Light may unlock a new quantum dance for electrons in graphene

A team of researchers has devised a simple way to tune a hallmark quantum effect in graphene—the material formed from a single layer of carbon atoms—by bathing it in light. Their theoretical work, which was published recently in *Physical Review Letters* , suggests a way to realize novel quantum behavior that was previously predicted but has so far remained inaccessible in experiments.

"Our idea is to use light to engineer these materials in place," says Tobias Grass, a postdoctoral researcher at the Joint Quantum Institute (JQI) and a co-author of the paper. "The big advantage of light is its flexibility. It's like having a knob that can change the physics in your sample."

The proposal suggests a method to alter a physical effect that occurs in flat materials held at very low temperatures and subjected to extremely strong magnets—at least a thousand times stronger than a fridge magnet. Under these circumstances, electrons zipping around on a two-dimensional landscape start to behave in an unusual way. Instead of continuously flowing through the material, they get locked into tight circular orbits of particular sizes and energies, barely straying from their spots. Only a certain number of electrons can occupy each orbit. When orbits are partially filled—which gives electrons some room to breathe—it activates new kinds of interactions between the charged particles and leads to a complex quantum dance.

Electrons carry out this choreography—known as the fractional quantum Hall effect—in graphene. Interestingly, tuning the interactions between electrons can coax them into different quantum Hall dance patterns, but it requires a stronger magnet or an entirely different sample—sometimes with two layers of graphene stacked together.

The new work, which is a collaboration between researchers at JQI and the City College of New York, proposes using laser light to circumvent some of these experimental challenges and even create novel quantum dances. The light can prod electrons into jumping between orbits of different energies. As a result, the interactions between the electrons change and lead to a different dance pattern, including some that have never been seen before in experiments. The intensity and frequency of the light alter the number of electrons in specific orbits, providing an easy way to control the electrons' performance. "Such a light-matter interaction results in some models that have previously been studied theoretically," says Mohammad Hafezi, a JQI Fellow and an author of the paper. "But no experimental scheme was proposed to implement them."

Unlocking those theoretical dances may reveal novel quantum behavior. Some may even spawn exotic quantum particles that could collaborate to remain protected from noise—a tantalizing idea that could be useful in the quest to build robust quantum computers. [18]

Researchers chart the 'secret' movement of quantum particles

Researchers from the University of Cambridge have taken a peek into the secretive domain of quantum mechanics. In a theoretical paper published in the journal *Physical Review A*, they have shown that the way that particles interact with their environment can be used to track quantum particles when they're not being observed, which had been thought to be impossible.

One of the fundamental ideas of quantum theory is that quantum objects can exist both as a wave and as a particle, and that they don't exist as one or the other until they are measured. This is the premise that Erwin Schrödinger was illustrating with his famous thought experiment involving a dead-or-maybe-not-dead cat in a box.

"This premise, commonly referred to as the wave function, has been used more as a mathematical tool than a representation of actual quantum particles," said David Arvidsson-Shukur, a Ph.D. student at Cambridge's Cavendish Laboratory, and the paper's first author. "That's why we took on the challenge of creating a way to track the secret movements of quantum particles."

Any particle will always interact with its environment, 'tagging' it along the way. Arvidsson-Shukur, working with his co-authors Professor Crispin Barnes from the Cavendish Laboratory and Axel Gottfries, a Ph.D. student from the Faculty of Economics, outlined a way for scientists to map these 'tagging' interactions without looking at them. The technique would be useful to scientists who make measurements at the end of an experiment but want to follow the movements of particles during the full experiment.

Some quantum scientists have suggested that information can be transmitted between two people – usually referred to as Alice and Bob – without any particles travelling between them. In a sense, Alice gets the message telepathically. This has been termed counterfactual communication because it goes against the accepted 'fact' that for information to be carried between sources, particles must move between them.

"To measure this phenomenon of counterfactual communication, we need a way to pin down where the particles between Alice and Bob are when we're not looking," said Arvidsson-Shukur. "Our 'tagging' method can do just that. Additionally, we can verify old predictions of quantum mechanics, for example that particles can exist in different locations at the same time."

The founders of modern physics devised formulas to calculate the probabilities of different results from quantum experiments. However, they did not provide any explanations of what a quantum particle is doing when it's not being observed. Earlier experiments have suggested that the particles might do non-classical things when not observed, like existing in two places at the same time. In their paper, the Cambridge researchers considered the fact that any particle travelling through space will interact with its surroundings. These interactions are what they call the 'tagging' of the particle. The interactions encode information in the particles that can then be decoded at the end of an experiment, when the particles are measured.

The researchers found that this information encoded in the particles is directly related to the wave function that Schrödinger postulated a century ago. Previously the wave function was thought of as an abstract computational tool to predict the outcomes of quantum experiments. "Our result suggests that the wave function is closely related to the actual state of particles," said Arvidsson-Shukur. "So, we have been able to explore the 'forbidden domain' of quantum mechanics: pinning down the path of quantum particles when no one is observing them." [17]

Neutrons track quantum entanglement in copper elpasolite mineral

A research team including Georgia Institute of Technology professor Martin Mourigal used neutron scattering at Oak Ridge National Laboratory to study copper elpasolite, a mineral that can be driven to an exotic magnetic state when subjected to very low temperatures and a high magnetic field.

A better understanding of the mineral's magnetic moments and the associated quantum coherence effects could lead to new applications in spintronic devices and quantum computing technologies.

"Studying the behavior of magnetic materials in extreme conditions such as very low temperatures and high magnetic fields is important to obtain a better fundamental understanding of quantum materials, and to write the basic dictionary relating their microscopic structure to human-scale properties," Mourigal said.

To reveal the material's magnetic structure, the team used the Neutron Powder Diffractometer and Polarized Triple Axis Spectrometer instruments at ORNL's High Flux Isotope Reactor—a DOE Office of Science User Facility.

Neutrons are well suited for investigating magnetic materials given their sensitivity to the organization and dynamics of electrons' spins at the microscopic scale.

"The goal of this experiment was to understand the magnetic structure of the material below its 700 mK [millikelvins] transition," Mourigal explained. "We know that spins talk to each other, but we don't know what organized pattern they collectively choose or why."

The researchers, led by project leader Art Ramirez at the University of California, Santa Cruz, recently published the results of their experiment in *Nature Physics*. The mineral sample was synthesized by Florida State University graduate student Lianyang Dong. [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.

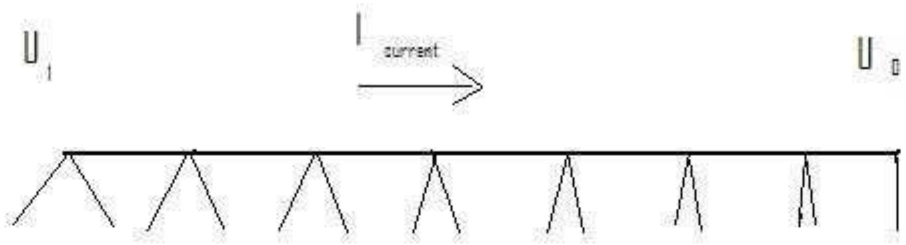

Figure 1.) Aluminium folios shows the charge distribution on the electric wire

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: **$-dU/dx = E = const$**.

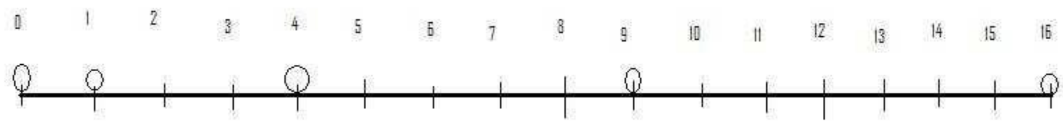

Figure 2.) The accelerating electrons created charge distribution on the electric wire

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.

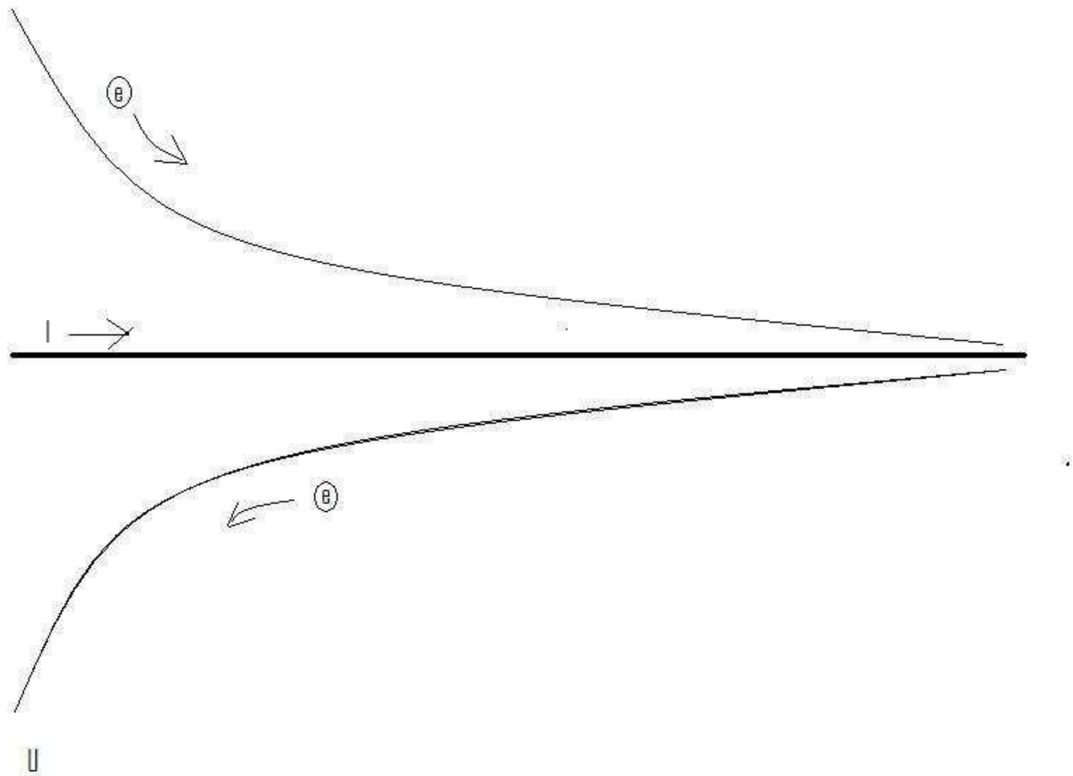

Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

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

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

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

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

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

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 I=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 $\mathbf{E = mc^2}$.

The expression of the fine-structure constant becomes the abbreviated

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

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

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

Planck Distribution Law

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms, molecules, crystals, dark matter and energy.

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

Electromagnetic inertia and Gravitational attraction

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

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

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

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

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

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths. Also since the particles are diffraction patterns they have some closeness to each other – can be seen as the measured effect of the force of the gravitation, since the magnetic effect depends on this closeness. This way the mass and the magnetic attraction depend equally on the wavelength of the electromagnetic waves.

Conclusions

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

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

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

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

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