

# How Runny Liquid Can Be

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*Using a range of theoretical and simulation approaches, physicists from the University of Bristol have shown that liquids in contact with substrates can exhibit a finite number of classes of behaviour and identify the important new ones. [21]*

*Chains of atoms dash around at lightning speeds inside the solid material. [20]*

*A group of Michigan State University (MSU) researchers specializing in quantum calculations has proposed a radically new computational approach to solving the complex many-particle Schrödinger equation that holds the key to explaining the motion of electrons in atoms and molecules. [19]*

*This method, called atomic spin squeezing, works by redistributing the uncertainty unevenly between two components of spin in these measurements systems, which operate at the quantum scale. [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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## 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  $\underline{F} = q \underline{E}$ , imposed by the  $\underline{E}$  electric field along the wire as a result of the  $\underline{U}$  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  $\underline{A}$  magnetic potential is based on the real charge distribution of the electrons caused by their acceleration, maintaining the  $\underline{E}$  electric field and the  $\underline{A}$  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  $-\underline{E}$  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.

## Scientists discover just how runny a liquid can be

Scientists from Queen Mary University of London and the Russian Academy of Sciences have found a limit to how runny a liquid can be.

Viscosity, the measure of how runny a fluid is, is a property that we experience daily when we fill a kettle, take a shower, pour cooking oil or move through air.

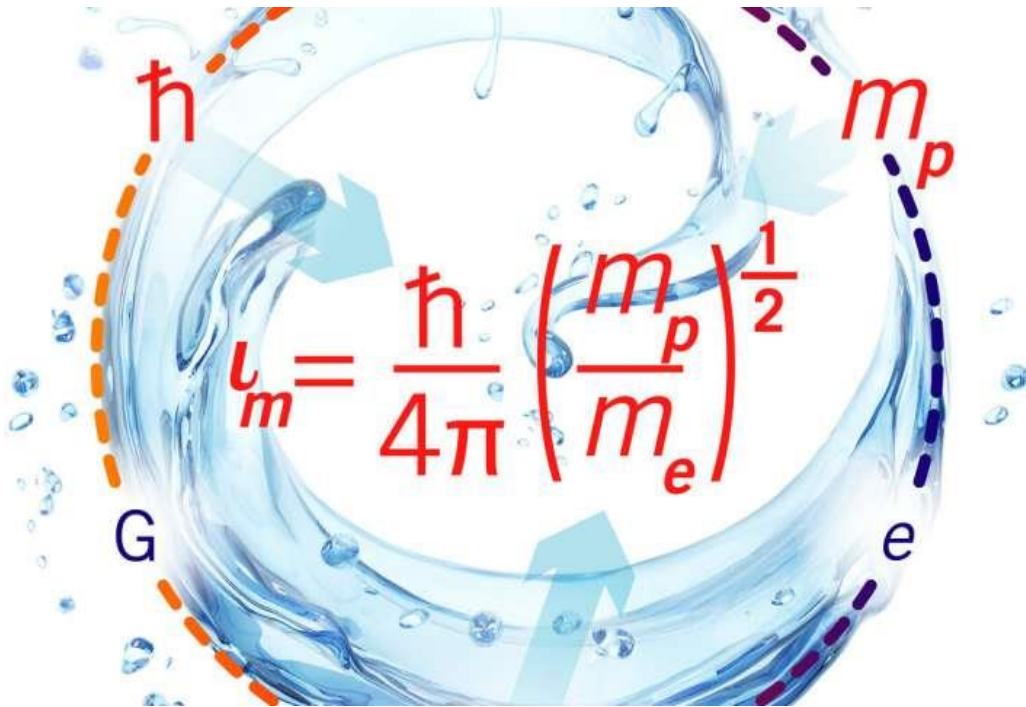
We know that liquids get thicker when cooled and runnier when heated, but how runny can a liquid ever get if we keep heating it?

Eventually, the liquid boils and becomes a gas or a dense gas-like substance if heated at high enough pressure. At the point where it transitions between the liquid-like and gas-like state is the minimum value of viscosity.

Viscosity is considered impossible to calculate from theory because it strongly depends on liquid structure, composition and interactions as well as external conditions in a complicated way. Nobel laureate Steven Weinberg compared the difficulty of calculating the viscosity of water to the problem of calculating fundamental physical constants, the constants which shape the fabric of our Universe.

Despite this difficulty, the researchers have developed an equation to do so.

In the study, published in *Science Advances*, they show that two fundamental physical constants govern how runny a liquid can be. Physical constants, or constants of Nature, are measurable properties of the physical universe that do not change.



The image shows how fundamental constants of Nature set the fundamental lower limit for liquid viscosity. Credit: thehackneycollective.com

Their equation relates the minimal value of elementary viscosity (the product of viscosity and volume per molecule) to the Planck constant, which governs the quantum world, and the dimensionless proton-to-electron mass ratio.

Professor Kostya Trachenko, lead author of the paper from Queen Mary University of London, said: "This result is startling. Viscosity is a complicated property varying strongly for different liquids and external conditions. Yet our results show that the minimal viscosity of all liquids turns out to be simple and universal."

There are practical implications of discovering this limit too. It could be applied where a new fluid for a chemical, industrial or biological process with a low viscosity is required. One example where this is important is the recent use of supercritical fluids for green and environmentally clean ways of treating and dissolving complex waste products.

In this instance, the discovered fundamental limit provides a useful theoretical guide of what to aim for. It also tells us that we should not waste resources trying to beat the fundamental limit because the constants of Nature will mould the viscosity at or above this point.

Fundamental physical constants and in particular dimensionless constants (fundamental constants that do not depend on the choice of physical units) are believed to define the Universe we live in. A finely-tuned balance between the proton-to-electron mass ratio and another dimensionless constant, the fine structure constant, governs nuclear reactions and nuclear synthesis in stars leading to essential biochemical elements including carbon.

This balance provides a narrow 'habitable zone' where stars and planets can form and life-supporting molecular structures can emerge. Change one of the dimensionless fundamental constants slightly, and the Universe becomes very different, with no stars, heavy elements, planets and life.

Professor Trachenko said: "The lower fundamental limit reminds us how fundamental constants of Nature affect us daily, starting from making a morning cup of tea by extending their overarching rule to specific, yet complex, properties such as liquid viscosity."

Vadim Brazhkin, co-lead author from the Russian Academy of Sciences, added: "There are indications that the fundamental lower limit of liquid viscosity may be related to very different areas of physics: black holes as well as the new state of matter, quark-gluon plasma, which appears at very high temperature and pressure. Exploring and appreciating these and other connections is what makes science ever so exciting." [22]

## Physicists shed new light on how liquids behave with other materials

Using a range of theoretical and simulation approaches, physicists from the University of Bristol have shown that liquids in contact with substrates can exhibit a finite number of classes of behaviour and identify the important new ones.

Their findings, published in the *Proceedings of the National Academy of Sciences (PNAS)*, challenge the accepted wisdom on wetting and drying phase behaviour.

The authors provide a firm conceptual framework for tailoring the properties of new materials, including finding super-repellant substrates, such as expelling water from windscreens, as well as understanding hydrophobic interactions at the length scale of biomolecules.

When a liquid such as water is repelled from a solid substrate, the drop created exhibits a large contact angle. This is known as a hydrophobic state, or superhydrophobic if the contact angle is very large, so that the drop forms a near spherical shape.

By contrast, if the substrate attracts the liquid sufficiently strongly—in other words, a hydrophilic substrate—this creates a small contact angle and the drop spreads over the surface.

Whether a surface is hydrophobic or hydrophilic is determined by the degree of molecular attraction between the substrate and the liquid.

Controlling the attraction is key to the wettability of substrates, which determines how many physical and biological systems function. For instance, plant leaves are often hydrophobic, allowing them to remain dry during rain so that gas exchange can occur through their pores. However, liquids such as paints, inks and lubricants are required to spread out to coat or 'wet' surfaces.

Building on early insights gained by former Bristol Ph.D. student Dr. Maria Stewart, Professor Bob Evans and Professor Nigel Wilding applied a number of theoretical and simulation techniques to realistic fluid models in order to study the properties of hydrophobic and hydrophilic substrates.

They discovered rich and unexpected behaviour such as divergent density fluctuations associated with the phenomenon of 'critical drying' at a superhydrophobic substrate.

Professor Evans said: "Clarifying the factors that control the contact angle of a liquid on a solid substrate is a long-standing scientific problem pertinent across physics, chemistry and materials science. Progress has been hampered by the lack of a comprehensive and unified understanding of the physics of wetting and drying phase transitions. Our results show the character of these transitions depends sensitively on both the range of fluid-fluid and substrate-fluid interactions and the temperature."

Professor Wilding added: "Our work has uncovered previously unrecognised classes of surface phase diagrams to which most experimental and simulation studies of liquids in contact with a substrate belong. A particularly interesting feature relates to water near superhydrophobic substrates where one observes the phenomenon of 'critical drying' as  $\theta \rightarrow 180^\circ$ . This is signalled by divergent density fluctuations which lead to rich structural properties including fractal arrangements of vapor bubbles near the substrate." [21]

## Chains of atoms move at lightning speed inside metals

A phenomenon that has previously been seen when researchers simulate the properties of planet cores at extreme pressures has now also been observed in pure titanium at atmospheric pressure. Chains of atoms dash around at lightning speeds inside the solid material.

"The phenomenon we have discovered changes the way we think about mass transport in metals. It explains properties of metals that we have, until now, not been able to understand. It's too early to say what this means in practical terms, but the more we know about how materials function in different conditions, the better possibilities we have to develop materials with new or improved properties," says Davide Sangiovanni, researcher in the Division of Theoretical Physics at LIU and principal author of an article that has been published in *Physical Review Letters*.

## Crystal structure

In solid materials such as metals, the atoms are arranged in a well-organized crystal structure, at definite distances from each other. Diffusion typically occurs as isolated "rare" hops of atoms into vacancies (crystal defects). However, for some materials—such as fast ion conductors at elevated temperatures, or water ("superionic ice") and iron at the extreme pressures found in planetary-cores—long chains of atoms/ions can suddenly start to move at surprisingly high speed as an entity. The process occurs on time scales of picoseconds or nanoseconds, and does not affect the crystal structure. The phenomenon is sometimes called "concerted diffusion," "superionic diffusion" or "liquid-like diffusion," and has been described in a number of theoretical papers.

The most exciting discovery that he has made, however, together with colleagues at Linköping University and universities in Germany and Russia, is that the same diffusion can take place in the cubic phase of pure titanium, at normal atmosphere pressure and at a temperature below the melting point.

## Concerted diffusion

Titanium, zirconium and hafnium, which are all in Group IVB of the periodic table, have several characteristic properties that researchers have not been able to explain—until now.



"In the article, we show that the anomalous properties of Group IVB metals in their cubic structure originate from concerted diffusion, in which the atomic chains wriggle through the solid crystal," says Davide Sangiovanni. [20]

## **Novel computational approach launches new paradigm in electronic structure theory**

A group of Michigan State University (MSU) researchers specializing in quantum calculations has proposed a radically new computational approach to solving the complex many-particle Schrödinger equation that holds the key to explaining the motion of electrons in atoms and molecules.

By understanding the details of this motion, one can determine the amount of energy needed to transform reactants into products in a chemical reaction, or the color of light absorbed by a molecule, and ultimately accelerate the design of new drugs and materials, better catalysts and more efficient energy sources.

The work, led by Piotr Piecuch, a University Distinguished Professor in the MSU Department of Chemistry and an adjunct professor in the Department of Physics and Astronomy in the College of Natural Science, was published in the Dec. 1 issue of *Physical Review Letters*. Also involved in the work are fourth-year graduate student J. Emiliano Deustua and senior postdoctoral associate Jun Shen. The group provides details for a new way of obtaining highly accurate electronic energies by merging the deterministic coupled-cluster and stochastic Quantum Monte Carlo approaches.

Although the general mathematical theory of the microscopic world of quantum mechanics is well established, the challenges have been centered on solving the complicated equations born of the exact application of the laws. The many-particle Schrödinger [equation](#) is at the heart of the problem.

"Instead of insisting on a single philosophy when solving the electronic Schrödinger equation, which has historically been either deterministic or stochastic, we have chosen a third way," Piecuch said. "As one of the reviewers noted, the essence of it is remarkably simple: use the stochastic approach to determine what is important and the deterministic approach to determine the important, while correcting for the information missed by stochastic sampling."

Their new method displays rapid convergence toward target molecular electronic energetics based on the information extracted from the early stages of the Monte Carlo wave function propagations, reducing computational costs by orders of magnitude.

Solving the Schrödinger equation for the many-electron wave function has been a key challenge in quantum chemistry for decades. Anything other than a one-electron problem, such as a hydrogen atom, requires resorting to numerical methods, converted into sophisticated computer

programs, such as those developed by Piecuch and his group. The main difficulty has been the intrinsic complexity of the electronic motion, which quantum chemists and physicists call "electron correlation."

The new idea is to use the stochastic methods, developed by Ali Alavi, professor of chemistry at the University of Cambridge and director of Electronic Structure Theory Group in the Max Planck Institute for Solid State Research in Stuttgart; George H. Booth, Royal Society Research Fellow in King's College London; and Alex J. W. Thom, Royal Society Research Fellow in the University of Cambridge, to identify the leading wave function components and the deterministic coupled-cluster computations, combined with suitable energy corrections, to provide the missing information.

"It's like playing chess and being able to predict the outcome of the game after the initial few moves," Deustua said.

The findings may profoundly impact quantum calculations for atoms and molecules, and other many-electron systems.

The merging of deterministic and stochastic approaches as a general method of solving the many-particle Schrödinger equation may also impact other areas, such as nuclear physics.

"In the case of nuclei, instead of being concerned with electrons, one would use our new approach to solve the Schrödinger equation for protons and neutrons," Piecuch said. "The mathematical and computational issues are similar. Just like chemists want to understand the electronic structure of a molecule, nuclear physicists want to unravel the structure of the atomic nucleus. Once again, solving the many-particle Schrödinger equation holds the key." [19]

## **Quantum noise reduction method for enhanced precision in atomic clocks**

Noise: it affects us all by distracting us. Noise also occurs at the quantum scale and can e.g. interfere with the measurements of atomic fountain clocks or with quantum information processing. This is because at that scale, there are effects that don't exist at larger scales. As such, finding ways to reduce quantum noise can enhance the precision of measurement in the examples given above. Now a team of physicists including Aranya Bhattacharjee from Jawaharlal Nehru University, New Delhi, India and colleagues are investigating ways of improving the analysis of quantum noise measurement in the case of spectroscopic investigations; their preliminary findings were released in a study in *EPJ D*.

This method, called atomic spin squeezing, works by redistributing the uncertainty unevenly between two components of spin in these measurements systems, which operate at

the [quantum scale](#). The spin represents a degree of freedom of the quantum particles involved. Thus, the spin component with reduced uncertainty becomes more precise in delivering its measurement - as the two are inversely correlated. Potential applications include the development of future quantum networks.

The quantum mechanical uncertainty of spin operators limits the measurement accuracy of spectroscopic investigations. Reducing the noise can help entangle two distant objects such as two atoms that are spatially separated. In this study, the authors develop a new approach that relies on spin squeezed states and is designed to accurately analyse the reduction of [quantum noise](#) in atomic systems associated with the spectroscopic measurements of atomic clocks.

Their method involves reducing the spin fluctuations in one spin component perpendicular to the mean spin direction below the [standard quantum limit](#). Until recently, accurately describing such complicated systems could only be done using numerical simulations. They demonstrate that this new method yields better results than the existing analytical methods and matches extremely well with exact numerical techniques. [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 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 ( $\text{Yb}_2\text{Pt}_2\text{Pb}$ ) 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 Tselik 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  $\text{Yb}_2\text{Pt}_2\text{Pb}$ .

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 spin-based 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-1/2 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 channel, 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.

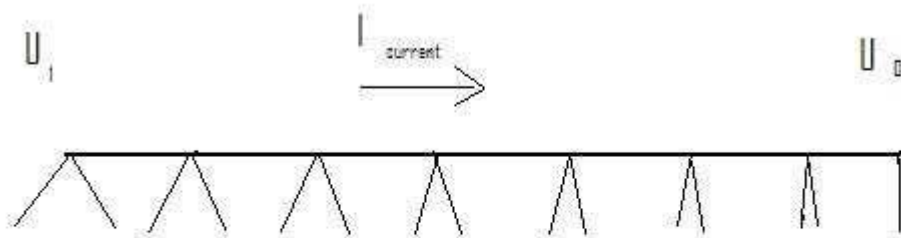


Figure 1.) Aluminium folios shows the charge distribution on the electric wire

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 be accelerating.

If the electrons are accelerating under the influence of the electric force, then they would arrive to the  $x = \frac{1}{2} at^2$  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 be found in the wire at  $x = 1, 4, 9, 16, 25 \dots$ , 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 is decreasing linearly and as a consequence of this the  $U$  field is decreasing linearly as expected:  $-dU/dx = E = \text{const}$ .

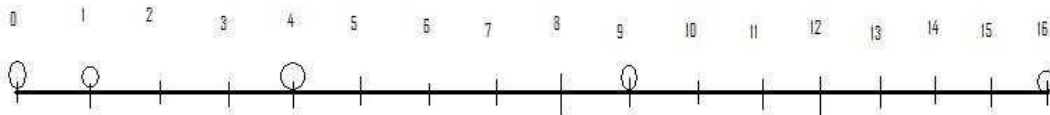


Figure 2.) The accelerating electrons created charge distribution on the electric wire

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.

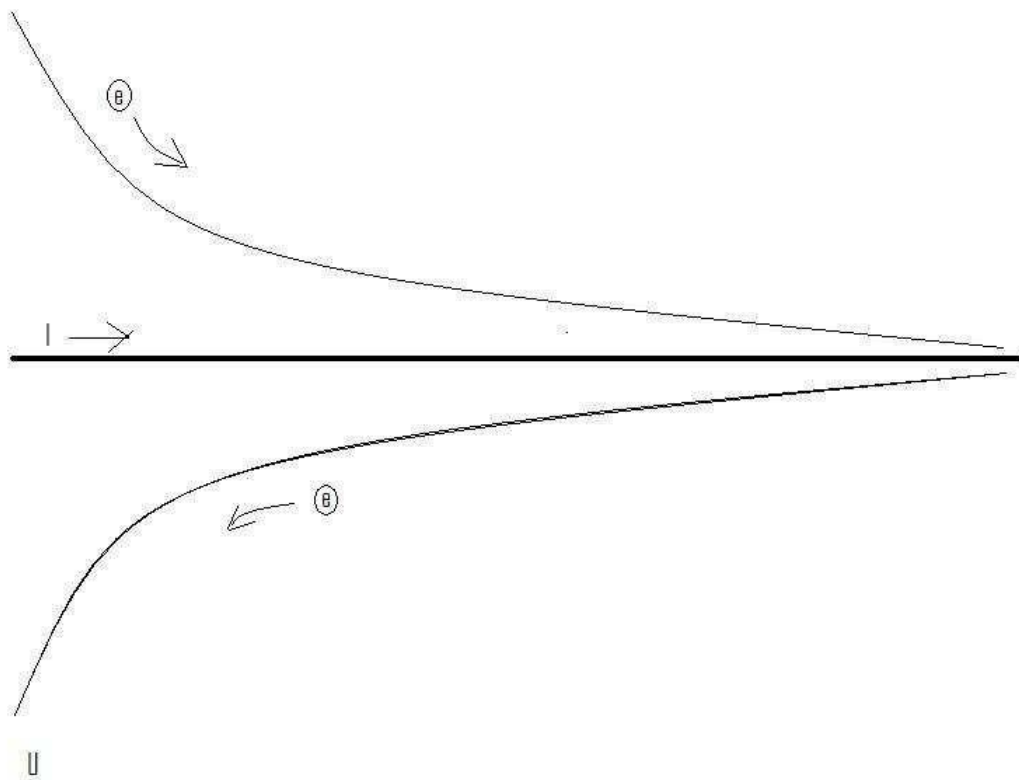


Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

Considering that the magnetic effect is  $\underline{F} = q \underline{v} \times \underline{B}$ , where the  $\underline{B}$  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  $\underline{v} \times \underline{B} = 0$ . 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  $\underline{v} \times \underline{B}$  magnetic force.

Getting the magnetic force from the  $\underline{F} = d\underline{p}/dt$  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  $\underline{A}$  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  $\underline{A}$  magnetic vector potential is proportional with  $\underline{a}$ , the acceleration of the charges in the electric current although this is not the only parameter.

The  $\underline{A}$  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  $\underline{A}$ . [7] This means that the bigger potential differences with smaller cross-section can give the same I current and  $\underline{A}$  vector potential, explaining the gauge transformation.

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

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

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

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

## The Constant Force of the Magnetic Vector Potential

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

## Electromagnetic four-potential

The electromagnetic four-potential defined as:

$$A^\alpha = (\phi/c, \mathbf{A}) \quad A^\alpha = (\phi, \mathbf{A})$$

SI units                      cgs units

in which  $\phi$  is the electric potential, and  $\mathbf{A}$  is the magnetic vector potential. [6] This is appropriate with the four-dimensional space-time vector (T,  $\mathbf{R}$ ) 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:

$$\underline{E} = - \underline{dA}/dt - dU/dr$$

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

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  $\underline{a}$  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:

$$\frac{1}{c^2} \frac{\partial^2 \varphi}{\partial t^2} - \nabla^2 \varphi = \frac{\rho}{\epsilon_0}$$

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

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 its 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:  $\frac{1}{2} \hbar = \Delta x \Delta p$  or  $\frac{1}{2} \hbar = \Delta t \Delta E$ , that is the value of the basic energy status, consequently related to the  $m_0$  inertial mass of the fermions.

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

## Fine structure constant

The Planck constant was first described as the proportionality constant between the energy  $E$  of a photon and the frequency  $\nu$  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  $\nu$ , wavelength  $\lambda$ , and speed of light  $c$  are related by  $\lambda\nu = c$ , the Planck relation can also be expressed as

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

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

The expression of the fine-structure constant becomes the abbreviated

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

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

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

## Planck Distribution Law

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

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

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



## Electromagnetic inertia and Gravitational attraction

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

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

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

Since  $E = h\nu$  and  $E = mc^2$ ,  $m = h\nu / c^2$  that is the  $m$  depends only on the  $\nu$  frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the  $m_0$  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  $\underline{A}$  vector potential experienced by the electrons moving by  $\underline{v}$  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  $\underline{E}$  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 their 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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