

# Magnetoelectric RAM

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*Concepts for information storage and logical processing based on magnetic domain walls have great potential for implementation in future information and communications technologies." [21]*

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*Los Alamos National Laboratory has produced the first known material capable of single-photon emission at room temperature and at telecommunications wavelengths. [19]*

*In their paper published in Nature, the team demonstrates that photons can become an accessible and powerful quantum resource when generated in the form of colour-entangled quDits. [18]*

*But in the latest issue of Physical Review Letters, MIT researchers describe a new technique for enabling photon-photon interactions at room temperature, using a silicon crystal with distinctive patterns etched into it. [17]*

*Kater Murch's group at Washington University in St. Louis has been exploring these questions with an artificial atom called a qubit. [16]*

*Researchers have studied how light can be used to observe the quantum nature of an electronic material. [15]*

*An international team of researchers led by the National Physical Laboratory (NPL) and the University of Bern has revealed a new way to tune the functionality of next-generation molecular electronic devices using graphene. [14]*

*Researchers at the Department of Physics, University of Jyväskylä, Finland, have created a theory that predicts the properties of nanomagnets manipulated with electric currents. This theory is useful for future quantum technologies. [13]*

*Quantum magnetism, in which – unlike magnetism in macroscopic-scale materials, where electron spin orientation is random – atomic spins self-organize into one-dimensional rows that can be simulated using cold atoms*

*trapped along a physical structure that guides optical spectrum electromagnetic waves known as a photonic crystal waveguide. [12]*

*Scientists have achieved the ultimate speed limit of the control of spins in a solid state magnetic material. The rise of the digital information era posed a daunting challenge to develop ever faster and smaller devices for data storage and processing. An approach which relies on the magnetic moment of electrons (i.e. the spin) rather than the charge, has recently turned into major research fields, called spintronics and magnonics. [11]*

*A team of researchers with members from Germany, the U.S. and Russia has found a way to measure the time it takes for an electron in an atom to respond to a pulse of light. [10]*

*As an elementary particle, the electron cannot be broken down into smaller particles, at least as far as is currently known. However, in a phenomenon called electron fractionalization, in certain materials an electron can be broken down into smaller "charge pulses," each of which carries a fraction of the electron's charge. Although electron fractionalization has many interesting implications, its origins are not well understood. [9]*

*New ideas for interactions and particles: This paper examines the possibility to origin the Spontaneously Broken Symmetries from the Planck Distribution Law. This way we get a Unification of the Strong, Electromagnetic, and Weak Interactions from the interference occurrences of oscillators. Understanding that the relativistic mass change is the result of the magnetic induction we arrive to the conclusion that the Gravitational Force is also based on the electromagnetic forces, getting a Unified Relativistic Quantum Theory of all 4 Interactions.*

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## Researchers create magnetic RAM

MIPT researchers teamed up with collaborators for a successful demonstration of magnetoelectric random access memory (MELRAM). A transition to magnetoelectric memory could enable substantial energy savings, as well as the instantaneous startup of devices. Their paper was published in Applied Physics Letters.

Random access memory, or RAM, is one of the principal components of any computer or smartphone. The most common type of RAM is known as dynamic random access memory, or DRAM for short. It is a semiconductor memory based on a simple principle. In DRAM, each memory cell consists of one capacitor and one transistor. The transistor is used to admit current into the condenser, allowing it to be charged and discharged. The electrical charge of the capacitor stores binary information, which is conventionally represented as zeros (uncharged) and ones (charged).

"RAM technology has been rapidly advancing, with memory modules becoming ever faster. However, this type of memory has one major limitation that cannot be overcome: its low energy efficiency," says principal investigator Sergei Nikitov of MIPT. "In this paper, we present the magnetoelectric memory cell. It will reduce bit reading and writing energy consumption by a factor of 10,000 or more."

A MELRAM cell consists of two components with remarkable properties. The first is a piezoelectric material. Piezoelectricity is a property of certain materials that are deformed in response to applied voltage and, conversely, generate voltage under mechanical stress. The other MELRAM component is a layered structure characterized by a high magnetoelasticity—the dependence of magnetization on the elastic strain. Because the structure is anisotropic—that is, it is organized differently along different axes,—it can be magnetized along two directions that correspond to the logical zero and one in binary code. In contrast to dynamic RAM, magnetoelectric memory cells are capable of maintaining their state: They need not be continually rewritten and do not lose information when power is cut off.

"We built a test piece about one millimeter across and showed that it works," says Anton Churbanov, a Ph.D. student at the Department of Physical and Quantum Electronics, MIPT. "It is worth noting that the structures we used could serve as the basis of nano-sized memory cells, whose dimensions are similar to those of regular RAM cells."

At the heart of the study is a novel data reading mechanism, providing an alternative to the sophisticated magnetic field sensors used in earlier MELRAM cells, which do not allow for easy downscaling. The researchers found a simpler way to read information, which does not require such complicated arrangements. When a voltage is applied to the memory cell, the piezoelectric layer of the structure is deformed. Depending on the nature of the strain, magnetization assumes a particular orientation, storing information. The changing orientation of the magnetic field gives rise to increased voltage in the sample. By detecting this voltage, the state of the memory cell can be determined. But the reading operation might affect magnetization; therefore, it is necessary to recommit the value that has been read to the memory cell.

The authors of the paper say their solution can be scaled down without any adverse effect on its efficiency. This makes MELRAM promising for computing hardware applications mandating low energy consumption. [22]

## **Surprise discovery in the search for energy efficient information storage**

Today almost all information stored on hard disc drives or cloud servers is recorded in magnetic media, because it is non-volatile (i.e. it retains the information when power is switched off) and cheap. For portable devices such as mobile phones and tablets, other forms of non-magnetic memory are used because the technology based on magnetism is impractical and is not energy efficient. In an age of mass data storage and portable devices which collect and process information, the search is on to find smaller, faster, cheaper and more energy efficient ways, of both processing and storing increasing amounts of data.

In the course of their research into the use of magnetic domain walls (local regions of magnetic "charge" usually driven by magnetic fields) to increase our capacity for information storage and logical processing, physicists at the University of Nottingham have discovered a phenomenon which has allowed them to 'manipulate' the structure of a magnetic domain wall.

The research carried out by researchers in the Spintronics Group in the School of Physics and Astronomy, in collaboration with York University, has been published in the open access journal Scientific Reports (Scientific Reports 7, Article number: 7613 (2017) DOI: 10.1038/s41598-017-07944-9). It could provide a route to creating a new class of highly efficient, non-volatile information processing and storage technology.

Dr Andrew Rushforth, from the School of Physics and Astronomy, said: "In the drive towards increasingly miniaturised, portable devices, the need to store and process information with low power consumption is becoming a critical issue. Concepts for information storage and logical processing based on magnetic domain walls have great potential for implementation in future information and communications technologies."

## ***Magnetic media***

The main benefit of using magnetism is the fact that the magnetic state remains stable when power is removed from the device, enabling non-volatile storage of information. By contrast, most processors and random access memory (RAM) chips store information using electrical charge which is fast, but dissipates when the device is powered down.

Magnetic random access memory (MRAM) is a promising form of non-volatile RAM based on magnetism which has recently found applications in some niche markets. In MRAM information is written using electrical current which generates heat and stray magnetic fields.

To date there are no technologies which use magnetism to process information.

Harnessing magnetism to process and store information

A solution to these problems may lie in the use of magnetic domain walls. A magnetic domain wall forms in a magnetic wire and separates regions where the magnetisation points in opposite directions. Under certain conditions it consists of a region in which the magnetisation rotates around a central vortex core, which points into or out of the wire.

An analogy would be the way in which water rotates around a vortex core as it drains down a plug hole. The sense of rotation of the magnetisation in the vortex wall—its chirality—can be clockwise or anticlockwise. There have been proposals to use the chirality to both store and process information. The problem is finding a way to manipulate the vortex domain wall.

Previously it has been shown that the chirality can be manipulated by applying magnetic fields to complicated nanowire geometries, but the use of magnetic fields is wasteful of energy and limits the ability to address individual domain walls selectively.

## ***A surprising discovery***

The researchers have discovered a way to control the chirality of the vortex domain wall using an electric field.

Dr Rushforth said: "We didn't set out to switch the chirality of the domain walls. We were actually trying to see if we could make them move. When we noticed that the chirality was switching, we were rather surprised, but we realised that it was an interesting and novel effect that could potentially have important applications. We then had to go back to the office and perform micromagnetic calculations to understand why and how the phenomenon occurs."

The team used the strain induced by an electric field applied to a piezoelectric material (which deforms mechanically in response to an electric field) to manipulate the chirality of the domain wall.

The knowledge is at an early stage. Until now it hasn't been obvious how one could control magnetic domain walls reversibly and predictably using electric fields. This research helps to solve that issue, but there remain practical issues to be addressed.

The next stage in the work will be to investigate how the chirality switching depends upon the material properties and the geometry and dimensions of the magnetic wire.

The University of Nottingham has filed a patent application for a memory device based on the effect. [21]

## **With a gentle touch, scientists push us closer to flash memory successor**

Sometimes a light touch is best: When you're telling a joke or hammering a tiny finishing nail into a wall, a gentle delivery often succeeds most effectively. Research at the National Institute of Standards and Technology (NIST) suggests it also may be true in the microscopic world of computer memory, where a team of scientists may have found that subtlety solves some of the issues with a novel memory switch.

This technology, resistive random access memory (RRAM), could form the basis of a better kind of nonvolatile computer memory, where data is retained even when the power is off. Nonvolatile memory is already familiar as the basis for flash memory in thumb drives, but flash technology has essentially reached its size and performance limits. For several years, the industry has been hunting for a replacement.

RRAM could surpass flash in many key respects: It is potentially faster and less energy-intensive. It also could pack far more memory into a given space—its switches are so small that a terabyte could be packed into a space the size of a postage stamp. But RRAM has yet to be broadly commercialized because of technical hurdles that need addressing.

One hurdle is its variability. A practical memory switch needs two distinct states, representing either a one or a zero, and component designers need a predictable way to make the switch flip. Conventional memory switches flip reliably when they receive a pulse of electricity, but we're not there yet with RRAM switches, which are still flighty.

"You can tell them to flip and they won't," said NIST guest researcher David Nminibapiel. "The amount needed to flip one this time may not be enough the next time around, but if you use too much energy and overshoot it, you can make the variability problem even worse. And even if you flip it successfully, the two memory states can overlap, making it unclear whether the switch has a one or a zero stored."

This randomness cuts into the technology's advantages, but in two recent papers, the research team has found a potential solution. The key lies in controlling the energy delivered to the switch by using multiple, short pulses instead of one long pulse.

Typically, chip designers have used relatively strong pulses of about a nanosecond in duration. The NIST team, however, decided to try a lighter touch—using less energetic pulses of 100 picoseconds, about a tenth as long. They found that sending a few of these gentler signals was useful for exploring the behavior of RRAM switches as well as for flipping them.

"Shorter pulses reduce the variability," Nminibapiel said. "The issue still exists, but if you tap the switch a few times with a lighter 'hammer,' you can move it gradually, while simultaneously giving you a way to check it each time to see if it flipped successfully."

Because the lighter touch does not push the switch significantly from its two target states, the overlapping issue can be significantly reduced, meaning one and zero can be clearly distinguished. Nminibapiel added that the use of shorter pulses also proved instrumental to uncovering the next serious challenge for RRAM switches—their instability.

"We achieved high endurance, good stability and uniformity comparable to using longer pulse widths," he said. "Instability affects our ability to maintain the memory state, though. Eliminating this instability is a problem for another day, but at least we've clarified the problem for the next round of research." [20]

### **Single-photon emitter has promise for quantum info-processing**

Los Alamos National Laboratory has produced the first known material capable of single-photon emission at room temperature and at telecommunications wavelengths. These carbon nanotube quantum light emitters may be important for optically-based quantum information processing and information security, while also being of significant interest for ultrasensitive sensing, metrology and imaging needs and as photon sources for fundamental advances in quantum optics studies. The research was reported today in the journal *Nature Photonics*.

"By chemically modifying the nanotube surface to controllably introduce light-emitting defects, we have developed carbon nanotubes as a single photon source, working toward implementing defect-state quantum emitters operating at room temperature and demonstrating their function in technologically useful wavelengths," said Stephen Doorn, leader of the project at Los Alamos and a member of the Center for Integrated Nanotechnologies (CINT). "Ideally, a single photon emitter will provide both room-temperature operation and emission at telecom wavelengths, but this has remained an elusive goal. Up to now, materials that could act as single photon emitters in these wavelengths had to be cooled to liquid helium temperatures, rendering them much less useful for ultimate applications or scientific purposes," he said.

A critical breakthrough in the CINT nanotube work was the ability of the team to force the nanotube to emit light from a single point along the tube, only at a defect site. The key was to limit defect levels to one per tube. One tube, one defect, one photon. . . . By emitting light only one photon at a time, one can then control the photons' quantum properties for storage, manipulation and transmission of information.

The CINT researchers were able to attain this degree of control using diazonium-based chemistry, a process they used to bind an organic molecule to the nanotube's surface to serve as the defect. The diazonium reaction chemistry allowed a controllable introduction of benzene-based defects with reduced sensitivity to natural fluctuations in the surrounding environment. Importantly, the versatility of the diazonium chemistry also permitted the researchers to access the inherent tunability of nanotube emission wavelengths.

The wavelengths (or color) of the photons produced in most other approaches had been too short for telecommunications applications, where photons need to be efficiently manipulated and transported within optical circuits. The team found that by choosing a nanotube of appropriate diameter, the single photon emission could be tuned to the essential telecom wavelength region.



The functionalized carbon nanotubes have significant prospects for further development, Doorn noted, including advances in functionalization chemistry; integration into photonic, plasmonic and metamaterials structures for further control of quantum emission properties; and implementation into electrically driven devices and optical circuitry for diverse applications. [19]

## **The multi-colored photons that might change quantum information science**

With leading corporations now investing in highly expensive and complex infrastructures to unleash the power of quantum technologies, INRS researchers have achieved a breakthrough in a light-weight photonic system created using on-chip devices and off-the-shelf telecommunications components. In their paper published in *Nature*, the team demonstrates that photons can become an accessible and powerful quantum resource when generated in the form of colour-entangled quDits.

The system uses a small and cost-effective photonic chip fabricated through processes similar to those used for integrated electronics. With an on-chip micro-ring resonator excited by a laser, photons are emitted in pairs that share a complex quantum state. The photons are constructed in a state featuring a number of superimposed frequency components: The photons have several colours simultaneously, and the colours of each photon in a pair are linked (entangled), regardless of their separation distance.

With each frequency—or colour—representing a dimension, the photons are generated on-chip as a high-dimensional quantum state (quDit). Thus far, quantum information science has largely focused on the exploitation of qubits, based on two-dimensional systems where two states are superimposed (for example, 0 AND 1 at the same time, in contrast to classical bits, which are 0 OR 1 at any time). Working in the frequency domain allows the superposition of many more states (for example, a high-dimensional photon can be red AND yellow AND green AND blue, although the photons used here were infrared for telecommunications compatibility), enhancing the amount of information in a single photon.

To date, Professor Roberto Morandotti, who leads the INRS research team, confirms the realization of a quantum system with at least one hundred dimensions using this approach, and the technology developed is readily extendable to create two-quDit systems with more than 9,000 dimensions (corresponding to 12 qubits and beyond, comparable to the state of the art in significantly more expensive/complex platforms).

The use of the frequency domain for such quantum states enables their easy transmission and manipulation in optical fibre systems. "By merging the fields of quantum optics and ultrafast optical processing, we have shown that high-dimensional manipulation of these states is indeed possible using standard telecommunications elements like modulators and frequency filters," stresses telecommunications system expert Professor José Azaña, co-supervisor of the conducted research.

Until now, advances in established technologies for the telecommunications sector were targeted for the manipulation of classical signals. This research is a game-changer: The advances can be immediately transferred to quantum science and will directly enable fundamental investigations of high-dimensional quantum state characteristics, applications in large-alphabet fibre-based quantum

communications, and the future development of frequency-domain, high-dimensional quantum logic gates and other applications.

Leading authors Michael Kues and Christian Reimer note that a highlight of the demonstrated platform is its accessibility: It is easy to build and exploits components used in standard telecommunication systems that are commercially available everywhere. Thus, in the short term, researchers around the world will be able to incorporate and push this technology forward, enabling a leap in the development of practical quantum applications. [18]

## **Prototype device enables photon-photon interactions at room temperature for quantum computing**

Ordinarily, light particles—photons—don't interact. If two photons collide in a vacuum, they simply pass through each other.

An efficient way to make photons interact could open new prospects for both classical optics and quantum computing, an experimental technology that promises large speedups on some types of calculations.

In recent years, physicists have enabled photon-photon interactions using atoms of rare elements cooled to very low temperatures.

But in the latest issue of *Physical Review Letters*, MIT researchers describe a new technique for enabling photon-photon interactions at room temperature, using a silicon crystal with distinctive patterns etched into it. In physics jargon, the crystal introduces "nonlinearities" into the transmission of an optical signal.

"All of these approaches that had atoms or atom-like particles require low temperatures and work over a narrow frequency band," says Dirk Englund, an associate professor of electrical engineering and computer science at MIT and senior author on the new paper. "It's been a holy grail to come up with methods to realize single-photon-level nonlinearities at room temperature under ambient conditions."

Joining Englund on the paper are Hyeonrak Choi, a graduate student in electrical engineering and computer science, and Mikkel Heuck, who was a postdoc in Englund's lab when the work was done and is now at the Technical University of Denmark.

### ***Photonic independence***

Quantum computers harness a strange physical property called "superposition," in which a quantum particle can be said to inhabit two contradictory states at the same time. The spin, or magnetic orientation, of an electron, for instance, could be both up and down at the same time; the polarization of a photon could be both vertical and horizontal.

If a string of quantum bits—or qubits, the quantum analog of the bits in a classical computer—is in superposition, it can, in some sense, canvass multiple solutions to the same problem simultaneously, which is why quantum computers promise speedups.

Most experimental qubits use ions trapped in oscillating magnetic fields, superconducting circuits, or—like Englund's own research—defects in the crystal structure of diamonds. With all these technologies, however, superpositions are difficult to maintain.

Because photons aren't very susceptible to interactions with the environment, they're great at maintaining superposition; but for the same reason, they're difficult to control. And quantum computing depends on the ability to send control signals to the qubits.

That's where the MIT researchers' new work comes in. If a single photon enters their device, it will pass through unimpeded. But if two photons—in the right quantum states—try to enter the device, they'll be reflected back.

The quantum state of one of the photons can thus be thought of as controlling the quantum state of the other. And quantum information theory has established that simple quantum "gates" of this type are all that is necessary to build a universal quantum computer.

### ***Unsympathetic resonance***

The researchers' device consists of a long, narrow, rectangular silicon crystal with regularly spaced holes etched into it. The holes are widest at the ends of the rectangle, and they narrow toward its center. Connecting the two middle holes is an even narrower channel, and at its center, on opposite sides, are two sharp concentric tips. The pattern of holes temporarily traps light in the device, and the concentric tips concentrate the electric field of the trapped light.

The researchers prototyped the device and showed that it both confined light and concentrated the light's electric field to the degree predicted by their theoretical models. But turning the device into a quantum gate would require another component, a dielectric sandwiched between the tips. (A dielectric is a material that is ordinarily electrically insulating but will become polarized—all its positive and negative charges will align in the same direction—when exposed to an electric field.)

When a light wave passes close to a dielectric, its electric field will slightly displace the electrons of the dielectric's atoms. When the electrons spring back, they wobble, like a child's swing when it's pushed too hard. This is the nonlinearity that the researchers' system exploits.

The size and spacing of the holes in the device are tailored to a specific light frequency—the device's "resonance frequency." But the nonlinear wobbling of the dielectric's electrons should shift that frequency.

Ordinarily, that shift is mild enough to be negligible. But because the sharp tips in the researchers' device concentrate the electric fields of entering photons, they also exaggerate the shift. A single photon could still get through the device. But if two photons attempted to enter it, the shift would be so dramatic that they'd be repulsed.

### ***Practical potential***

The device can be configured so that the dramatic shift in resonance frequency occurs only if the photons attempting to enter it have particular quantum properties—specific combinations of polarization or phase, for instance. The quantum state of one photon could thus determine the way in which the other photon is handled, the basic requirement for a quantum gate.

Englund emphasizes that the new research will not yield a working quantum computer in the immediate future. Too often, light entering the prototype is still either scattered or absorbed, and the quantum states of the photons can become slightly distorted. But other applications may be more feasible in the near term. For instance, a version of the device could provide a reliable source of single photons, which would greatly abet a range of research in quantum information science and communications.

"This work is quite remarkable and unique because it shows strong light-matter interaction, localization of light, and relatively long-time storage of photons at such a tiny scale in a semiconductor," says Mohammad Soltani, a nanophotonics researcher in Raytheon BBN Technologies' Quantum Information Processing Group. "It can enable things that were questionable before, like nonlinear single-photon gates for quantum information. It works at room temperature, it's solid-state, and it's compatible with semiconductor manufacturing. This work is among the most promising to date for practical devices, such as quantum information devices." [17]

## **How the quantum Zeno effect impacts Schroedinger's cat**

You've probably heard about Schrödinger's cat, which famously is trapped in a box with a mechanism that is activated if a radioactive atom decays, releasing radiation. The act of looking in the box collapses the atom's wave function—the mathematical description of its state—from a "superposition" of states to a definite state, which either kills the cat or let's it live another day.

But did you know that if you peek into the cat box frequently—thousands of times a second—you can either delay the fateful choice or, conversely, accelerate it? The delay is known as the quantum Zeno effect and the acceleration as the quantum anti-Zeno effect.

The quantum Zeno effect was named by analogy with the arrow paradox conceived by the Greek philosopher Zeno: At any given instant of time, an arrow in flight is motionless; how then can it move? Similarly, if an atom could be continually measured to see if it is still in its initial state, it would always be found to be in that state.

Both the Zeno and an the anti-Zeno effects are real and happen to real atoms. But how does this work? How can measurement either delay or accelerate the decay of the radioactive atom? What is "measurement," anyway?

The physicist's answer is that in order to obtain information about a quantum system, the system must be strongly coupled to the environment for a brief period of time. So the goal of measurement is to obtain information, but the strong coupling to the environment means that the act of measurement also necessarily disturbs the quantum system.

But what if the system was disturbed but no information was passed to the outside world? What would happen then? Would the atom still exhibit the Zeno and anti-Zeno effects?

Kater Murch's group at Washington University in St. Louis has been exploring these questions with an artificial atom called a qubit. To test the role of measurement in the Zeno effects, they devised a new type of measurement interaction that disturbs the atom but learns nothing about its state, which they call a "quasimeasurement."

They report in the June 14, 2017, issue of Physical Review Letters that quasimeasurements, like measurements, cause Zeno effects. Potentially the new understanding of the nature of measurement in quantum mechanics could led to new ways of controlling quantum systems. [16]

## **Observing electrons surfing waves of light on graphene**

Researchers have studied how light can be used to observe the quantum nature of an electronic material. They captured light in graphene and slowed it down to the speed of the material's electrons. Then electrons and light started to move in concert, manifesting their quantum nature at such large scale that it could observed with a special type of microscope.

The experiments were performed with ultra-high-quality graphene. To excite and image the ultra-slow ripples of light in the graphene (also called plasmons), the researchers used a special antenna for light that scans the surface at a distance of a few nanometers. With this near-field nanoscope, they saw that the light ripples on the graphene moved more than 300 times more slowly than light, dramatically diverging from what is suggested by classical physics laws.

The work has been published in Science by ICFO researchers Dr. Mark Lundberg, Dr. Achim Woessner, led by ICREA Prof. at ICFO Frank Koppens, in collaboration with Prof. Hillenbrand from Nanogune, Prof. Polini from IIT and Prof. Hone from Columbia University.

In reference to the accomplished experiments, Prof. Koppens says, "Usually, it is very difficult to probe the quantum world, and to do so requires ultra-low temperatures; here we could observe it with light at room temperature."

This technique paves the way for exploring many new types quantum materials, including superconductors or topological materials that allow for quantum information processing with topological qubits. In addition, Prof. Hillenbrand states that "this could just be the beginning of a new era of near field nanoscopy."

Prof. Polini says, "This discovery may eventually lead to understanding in a truly microscopic fashion complex quantum phenomena that occur when matter is subject to ultra-low temperatures and very high magnetic fields, like the fractional quantum Hall effect." [15]

## **Graphene offers new functionalities in molecular electronics**

An international team of researchers led by the National Physical Laboratory (NPL) and the University of Bern has revealed a new way to tune the functionality of next-generation molecular electronic devices using graphene. The results could be exploited to develop smaller, higher-performance devices for use in a range of applications including molecular sensing, flexible electronics, and energy conversion and storage, as well as robust measurement setups for resistance standards.

The field of nanoscale molecular electronics aims to exploit individual molecules as the building blocks for electronic devices, to improve functionality and enable developers to achieve an unprecedented level of device miniaturization and control. The main obstacle hindering progress in

this field is the absence of stable contacts between the molecules and metals used that can both operate at room temperature and provide reproducible results.

Graphene possesses not only excellent mechanical stability, but also exceptionally high electronic and thermal conductive properties, making the emerging 2-D material very attractive for a range of possible applications in molecular electronics.

A team of experimentalists from the University of Bern and theoreticians from NPL (UK) and the University of the Basque Country (UPV/EHU, Spain), with the help of collaborators from Chuo University (Japan), have demonstrated the stability of multi-layer graphene-based molecular electronic devices down to the single molecule limit.

The findings, reported in the journal *Science Advances*, represent a major step change in the development of graphene-based molecular electronics, with the reproducible properties of covalent contacts between molecules and graphene (even at room temperature) overcoming the limitations of current state-of-the-art technologies based on coinage metals.

### ***Connecting single molecules***

Adsorption of specific molecules on graphene-based electronic devices allows device functionality to be tuned, mainly by modifying its electrical resistance. However, it is difficult to relate overall device properties to the properties of the individual molecules adsorbed, since averaged quantities cannot identify possibly large variations across the graphene's surface.

Dr Alexander Rudnev and Dr Veerabhadrarao Kaliginedi, from the Department of Chemistry and Biochemistry at the University of Bern, performed measurements of the electric current flowing through single molecules attached to graphite or multi-layered graphene electrodes using a unique low-noise experimental technique, which allowed them to resolve these molecule-to-molecule variations.

Guided by the theoretical calculations of Dr Ivan Rungger (NPL) and Dr Andrea Droghetti (UPV/EHU), they demonstrated that variations on the graphite surface are very small and that the nature of the chemical contact of a molecule to the top graphene layer dictates the functionality of single-molecule electronic devices.

"We find that by carefully designing the chemical contact of molecules to graphene-based materials, we can tune their functionality," said Dr Rungger. "Our single-molecule diodes showed that the rectification direction of electric current can be indeed switched by changing the nature of chemical contact of each molecule," added Dr Rudnev.

"We are confident that our findings represent a significant step towards the practical exploitation of molecular electronic devices, and we expect a significant change in the research field direction following our path of room-temperature stable chemical bonding," summarised Dr Kaliginedi.

The findings will also help researchers working in electro-catalysis and energy conversion research design graphene/molecule interfaces in their experimental systems to improve the efficiency of the catalyst or device. [14]

## Quantum theory for manipulating Nanomagnets

Researchers at the Department of Physics, University of Jyväskylä, Finland, have created a theory that predicts the properties of nanomagnets manipulated with electric currents. This theory is useful for future quantum technologies. The research was published in Physical Review Letters.

### *How to make faster magnetic memories?*

In computer hard drives the information is stored in the magnetic states of small nanomagnets as zeros and ones. "Zero" is thus coded as the south-north magnetization, and "one" as the "north-south" magnetization. Writing information thus requires turning the magnetization, whereas reading it means finding out the magnetization state. The speed of hard drives thus depends on how fast these processes can be realized. The reading process is based on electric currents and therefore can be made fast. On the other hand, writing usually has to be made via magnetic fields, which is much slower. For over 20 years physicists have known a process, spin transfer torque, with which also writing could be realized with the help of electric current. The problem hindering its use in commercial products is the heating this process causes. Because of this heating, the process is more prone to errors. Switching the magnetization state is a stochastic process, which means that the final outcome is not certain. The problem becomes harder as the temperature increases.

### *Random precession of magnetization*

The researchers managed to develop a theory with which to evaluate the probability of the changes in the magnetization in situations where it is manipulated by electric current. The same theory provides the probability of the reciprocal process, spin pumping, where the motion of the magnetization pumps current into the circuit. This latter process is used for radio frequency generation, and also it is stochastic, which means that the pumped current has random fluctuations, noise. In particular, the researchers managed to find out how this noise behaves in the quantum limit of magnetization precession, where the precession frequency is large. Earlier work had concentrated on low frequencies. Therefore, this work will be particularly useful for magnetism-based quantum technologies.

The result is very general and simple, but finding it required the use of complicated theory tools. "Finding the result required a lot of thinking and derivations, but I am very happy with the outcome", tells post-doctoral researcher Pauli Virtanen, now in Scuola Normale Superiore, Pisa, who took care of the detailed calculation. Professor Tero Heikkilä, who provided the idea of the work, continues: "This type of calculation requires a lot of deep intuition. Now our result can be generalized to more complex magnetic structures." [13]

## Simulated quantum magnetism can control spin interactions at arbitrary distances

Quantum magnetism, in which – unlike magnetism in macroscopic-scale materials, where electron spin orientation is random – atomic spins self-organize into one-dimensional rows that can be simulated using cold atoms trapped along a physical structure that guides optical spectrum electromagnetic waves known as a photonic crystal waveguide. Recently, scientists at Purdue University, Max-Planck-Institut für Quantenoptik, Germany, and California Institute of Technology, used this approach to devise a scheme for simulating quantum magnetism that provides full control

of interactions between pairs of spins at arbitrary distances in 1D and 2D lattices, and moreover demonstrated the scheme's wide utility by generating several well-known spin models. The researchers state that their results allow the introduction of geometric phases into the spin system that could generate topological models with long-range spin-spin interactions.

Dr. Chen-Lung Hung, Dr. Alejandro González-Tudela and Phys.org discussed the study, its challenges and the resulting paper that they have published with their colleagues in Proceedings of the National Academy of Sciences. These challenges included using a two-photon Raman addressing scheme to devise their proposed atom-nanophotonic system – a system that can achieve arbitrary and dynamic control on the strength, phase, and length scale of spin interactions, as well as simulate quantum magnetism with full control of interactions between pairs of spins at arbitrary distances in 1D and 2D lattices. Moreover, the researchers showed that it is possible to introduce geometric phases into the spin system – and thereby realizing topological models with long-range spin-spin interactions – by carefully arranging the propagation phases of Raman beams.

"Cold atoms are an ideal system for studying quantum many-body problems due to their high degree of controllability and reproducibility," González-Tudela and Hung tell Phys.org. "To study various lattice spin models, state-of-the-art experiments load cold atoms into the so-called optical lattices, formed by interfering laser beams in free space. Despite past experimental successes in realizing, for example, superfluid-Mott insulator quantum phase transitions with cold atoms in optical lattices, there are, however, several limitations that preclude cold atoms from emulating a large class of many-body problems involving strong or long-range interactions." This is due to cold atoms being neutral systems that interact very weakly via contact potentials, González-Tudela explains, adding that this small interaction strength makes it difficult to study, for example, important quantum magnetism problems, since these require interactions between atoms in, at least, the adjacent lattice sites. "Decoherence sources can kick in before these very small interaction effects manifest – and on the other hand, short-range interactions also limit the amount of entanglement in the system."

To overcome this challenge and to increase interaction strength, González-Tudela continues, the scientists recently proposed<sup>1</sup> to interface cold atoms with structured dielectrics, which with suitable engineering allows increased interaction strengths and range by letting the atoms talk through guided photons in the structure. "However," he points out, "the spatial dependence of the interactions is fixed by the spatial profile of the photon modes and so does not allow for full control in the interactions. This is why, in this paper, we combine our current and previous ideas, employing external magnetic fields and external multi-frequency laser beams to achieve full controllability of spin-spin interactions." In short, these two extra ingredients allow the researchers to achieve not only full control of pair-wise interactions, but also to introduce space-dependent phases through sideband engineering in the control laser beams – and this improved control has important consequences:

The ability to simulate long-range interactions with spatial dependence at will, not just fixed by the photon profile in the material. This has important consequences in the static properties of models that cannot be otherwise investigated, but also in the study of thermalization of closed systems with long-range interactions.



The possibility of introducing space-dependent phases allows the engineering of models with non-trivial topology with long-range interactions, something that is very difficult to obtain in other platforms.

The prospect of modifying boundary conditions at will allow exploration of non-trivial geometries that may give rise to exotic quantum states.

One of the key findings reported in the paper was the new avenues promised by the proposed platform for engineering a large class of spin Hamiltonians, including those exhibiting topological order or frustrated long-range magnetism (in which the atoms whose spin states are giving rise to quantum magnetism cannot settle into a state that minimizes each interaction). "Because the interactions can be engineered at will, many spin model that require long-range spin-exchange or direct spin-spin interactions can be engineered. Frustration phenomena due to competition between long-range spin-exchange and spin-spin interactions can be studied with great details. Moreover, by carefully controlling the optical phases of the external addressing laser beams, we can imprint a quantum mechanical phase on spins that hop along a closed contour. This gives us an opportunity to engineer the so-called geometrical phases in the spin model, which is responsible of inducing topological quantum phases such as quantum Hall states in 2D electron gases.

Another interesting result was showing that atom-nanophotonic systems present appealing platforms to engineer many-body quantum matter by using low-dimensional photons to mediate interaction between distant atom pairs. "Nanophotonic structures provide us a way to engineer the transport property of what we call effectively low-dimensional photons – that is, photons confined in a quasi-2D plane or a 1D wire. When used in nanophotonics, these low-dimensional photons are excellent force- or information-carrying mobile particles that can mediate interactions between distant atom pairs."

Relatedly, the study found that the proposed platform potentially allows for conducting detailed studies on quantum dynamics of long-range, strongly interacting spin systems that are driven out-of-equilibrium. "Dynamic control of interaction strengths is another important feature in our system," Hung points out. "In our Raman control scheme, long-range interaction can be dynamically adjusted via tuning either the amplitude or sidebands in the external control laser beam. Therefore, it will be very easy for the proposed platform to prepare a quantum system out-of-equilibrium and study the subsequent quantum spin dynamics."

On a more encompassing level, the paper states that the scientists expect that their platform may bring novel opportunities to the study of quantum thermalization in long-range many-body systems, or for further understanding of information propagation in a long-range quantum network. Specifically, not only could their platform allow the researchers to study dynamics of a quantum system driven out-of-equilibrium, as mentioned above, but also to investigate how quantum dynamics depends on the range of interactions. "This would provide information on how correlation or entanglement between atomic spins can propagate throughout the spin system, and whether the resulting spin state can still be analyzed as a pure state, or, rather, if it becomes indistinguishable from a statistical mixture," Hung says.

This would therefore provide an opportunity to study quantum thermalization in long-range systems. "Moreover," he continues, "by arbitrary, pairwise engineering of spin-spin interactions, we

could establish our model system as a 'miniature' long-range quantum network where atoms are viewed as quantum nodes interconnected via guided photons in the nanophotonic channels. Out-of-equilibrium studies in such systems could provide greater understanding of information propagation in a model quantum network."

Of significant importance to the future capabilities of quantum communications is the development of much more robust resistance to sudden decoherence than now exists. Phys.org therefore asked Hung if their scheme might be a factor in this effort. "Two conditions might lead to sudden decoherence between a pair of local quantum spins – namely, either through coupling to surrounding or distant spins via long-range interactions that we view as an environment, or through dissipative coupling to unwanted nanophotonic channels or to free space. There could be complex behaviors in the engineered spin system, so we may find new surprises."

The paper also discussed the possibility of engineering periodic boundary conditions, as explicitly shown in the 1D Haldane–Shastry model or in other global lattice topologies, by introducing long-range interactions between spins located at the boundaries of a finite system. "Long-range interaction allows us to connect distant spins located at the opposite end of the boundary in a finite system as well as to engineer the connectivity of a local spin to neighboring spins – thereby opening up ways to engineer the global topology of a lattice spin model."

A fascinating aspect of the study discussed in the paper was the possibility of creating previously-unavailable spin-lattice geometries, such as Möbius strip, torus, or lattice models with singular curvatures such as conic geometries that may lead to localized topological states with potential applications in quantum computations. "Boundary conditions and global lattice geometries can play an important role in lattice models exhibiting topological phases," Hung states. "In particular, topological properties manifest as spin transport at the boundaries or near special points with singular lattice curvatures – and these support topological excitations that are stable against local perturbations. Using the proposed platform, especially with arbitrary long-range interactions, we can engineer or even dynamically control the boundary conditions or lattice topologies that are unavailable in other experimental platforms such as cold atoms in optical lattices. This may open up new ways to engineer transport, localization, or even braiding operations of topological excitations," an abstract topological approach to determining quantum operations, "which may find significant applications in topological quantum computations."

In terms of their ongoing research, Hung tells Phys.org that the researchers had great initial successes in developing a prototype alligator photonic crystal<sup>2</sup>. "Our experimental groups at Caltech and Purdue University are currently developing new nanophotonic platforms with improved optical qualities and band structures that are capable of mediating stronger atom-photon interaction within a large array of trapped atoms to realize the proposed scheme. Another interesting avenue in atom-nanophotonic hybrid system," he continues, "is to use nanostructures and the resulting attractive vacuum forces to form nanoscale lattice potentials for cold atoms. The vacuum force-induced lattice potentials work just as optical lattices in free space for cold atoms, but the lattice spacing – as small as 50 nm – is much smaller than those of the optical lattices, which are limited by the wavelength of interfering lasers. Reduced lattice spacing leads to more than 100 times increased energy scale in the quantum lattice model, improving the low temperature limitation of cold atom experiments. In the long term," González-Tudela concludes, "the possibility of having a platform where long-range

interactions can be controlled at will may also impact the simulation of quantum chemistry problems." [12]

## **Femtosecond Laser pulses push Spintronics and Magnonics to the limit**

Scientists have achieved the ultimate speed limit of the control of spins in a solid state magnetic material. The rise of the digital information era posed a daunting challenge to develop ever faster and smaller devices for data storage and processing. An approach which relies on the magnetic moment of electrons (i.e. the spin) rather than the charge, has recently turned into major research fields, called spintronics and magnonics.

The researchers were able to induce spin oscillations of the intrinsically highest frequency by using femtosecond laser pulses (1 fs = 10<sup>-15</sup> sec). Furthermore, they demonstrated a complete and arbitrary manipulation of the phase and the amplitude of these magnetic oscillations – also called magnons. The length-scale of these magnons is on the order of 1 nanometre.

These results pave the way to the unprecedented frequency range of 20 THz for magnetic recording devices, which can be employed also at the nanometer scale.

The practical implementation of other schemes of magnetic control, based on the use of electric currents, is hampered by a significant heating which requires cooling systems. It is thus important to underline that the concept in the current publication does not involve any heating. This makes the study appealing from the point of view of future applications. However, the possibility to monitor the evolution of a magnet on such short time- and length- scales simultaneously is a major breakthrough also in terms of fundamental science. A new regime, defined by Dr. Bossini as femto-nanomagnonics, has been disclosed. [11]

## **Superfast light pulses able to measure response time of electrons to light**

A team of researchers with members from Germany, the U.S. and Russia has found a way to measure the time it takes for an electron in an atom to respond to a pulse of light. In their paper published in the journal Nature, the team describes their use of a light field synthesizer to create pulses of light so fast that they were able to reveal the time it took for electrons in an atom to respond when struck. Kyung Taec Kim with the Gwangju Institute of Science offers a News & Views piece on the work done by the team in the same journal issue, outlining their work and noting one issue that still needs to be addressed with such work.

As scientists have begun preparing for the day when photons will replace electrons in high speed computers, work is being done to better understand the link between the two. One important aspect of this is learning what happens when photons strike electrons that remain in their atom (rather than being knocked out of them), specifically, how long does it take them to respond.

To find this answer, the researchers used what has come to be known as a light-field synthesizer—it is a device that is able to produce pulses of light that are just half of a single wavelength long—something many had thought was impossible not too long ago. The pulses are of such short duration

that they only last for the time it takes to travel that half wavelength, which in this case, was approximately 380 attoseconds.

The light-field synthesizer works by combining several pulses of light brought together but slightly out of phase, allowing for canceling and ultimately, a single very short pulse. In their experiments, the researchers fired their super-short pulses at krypton atoms held inside of a vacuum. In so doing, they found that it took the electrons 115 attoseconds to respond—the first such measurement of the response time of an electron to a visible light pulse.

The team plans to continue their work by looking at how electrons behave in other materials, and as Kim notes, finding a way to characterize both the amplitude and phase of radiation from atoms driven by a light field. [10]

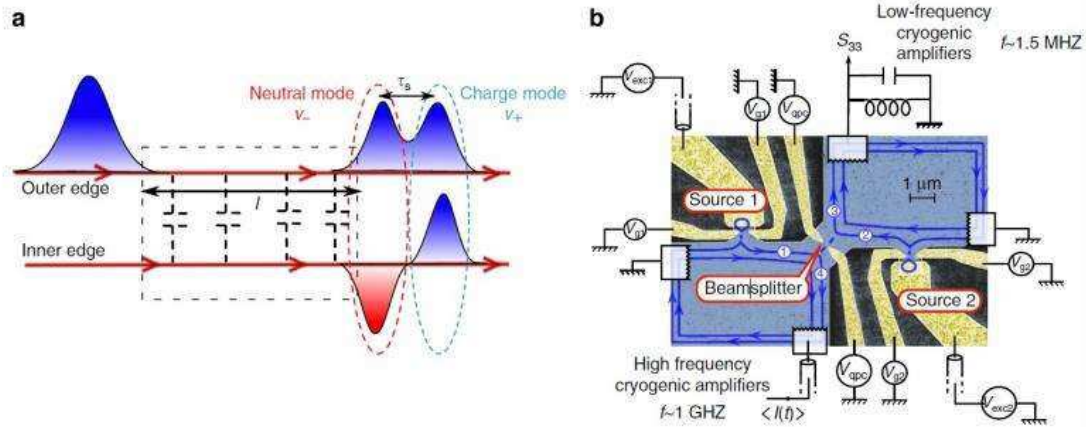
## When an electron splits in two

Now in a new paper published in *Nature Communications*, a team of physicists led by Gwendal Fève at the Ecole Normale Supérieure in Paris and the Laboratory for Photonics and Nanostructures in Marcoussis have applied an experiment typically used to study photons to investigate the underlying mechanisms of electron fractionalization. The method allows the researchers to observe single-electron fractionalization on the picosecond scale.

"We have been able to visualize the splitting of an electronic wavepacket into two fractionalized packets carrying half of the original electron charge," Fève told Phys.org. "Electron fractionalization has been studied in previous works, mainly during roughly the last five years. Our work is the first to combine single-electron resolution—which allows us to address the fractionalization process at the elementary scale—with time resolution to directly visualize the fractionalization process."

The technique that the researchers used is called the Hong-Ou-Mandel experiment, which can be used to measure the degree of resemblance between two photons, or in this case electron charge pulses, in an interferometer. This experiment also requires a single-electron emitter, which some of the same researchers, along with many others, have recently been developing.

The researchers first analyzed the propagation of a single electron in the interferometer's outer one-dimensional wire, and then when that electron fractionalized, they could observe the interaction between its two charge pulses in the inner one-dimensional wire. As the researchers explain, when the original electron travels along the outer wire, Coulomb interactions (interactions between charged particles) between excitations in the outer and inner wires produce two types of excitation pairs: two pulses of the same sign (carrying a net charge) and two pulses of opposite signs (which together are neutral). The two different excitation pairs travel at different velocities, again due to Coulomb interactions, which causes the original electron to split into two distinct charge pulses.



(a) An electron on the outer channel fractionalizes into two pulses. (b) A modified scanning electron microscope picture of the sample. Credit: Freulon, et al. ©2015 Nature

The experiment reveals that, when a single electron fractionalizes into two pulses, the final state cannot be described as a single-particle state, but rather as a collective state composed of several excitations. For this reason, the fractionalization process destroys the original electron particle. Electron destruction can be measured by the decoherence of the electron's wave packet.

Gaining a better understanding of electron fractionalization could have a variety of implications for research in condensed matter physics, such as controlling single-electron currents in one-dimensional wires.

"There has been, during the past years, strong efforts to control and manipulate the propagation of electrons in electronic conductors," Fève said. "It bears many analogies with the manipulations of the quantum states of photons performed in optics. For such control, one-dimensional conductors are useful, as they offer the possibility to guide the electrons along a one-dimensional trajectory. However, Coulomb interactions between electrons are also very strong in one-dimensional wires, so strong that electrons are destroyed: they fractionalize. Understanding fractionalization is understanding the destruction mechanism of an elementary electron in a one-dimensional wire. Such understanding is very important if one wants to control electronic currents at the elementary scale of a single electron."

In the future, the researchers plan to perform further experiments with the Hong-Ou-Mandel interferometer in order to better understand why fractionalization leads to electron destruction, and possibly how to suppress fractionalization.

"The Hong-Ou-Mandel interferometer can be used to picture the temporal extension (or shape) of the electronic wavepackets, which is what we used to visualize the fractionalization process," Fève said. "It can also be used to capture the phase relationship (or phase coherence) between two components of the electronic wavepacket."

"This combined information fully defines the single-electron state, offering the possibility to visualize the wavefunction of single electrons propagating in a one-dimensional conductor. This would first provide a complete understanding of the fractionalization mechanism and in particular how it leads

to the decoherence of single-electron states. It would also offer the possibility to test if single electrons can be protected from this decoherence induced by Coulomb interaction. Can we suppress (or reduce) the fractionalization process by reducing the strength of the Coulomb interaction? We would then be able to engineer and visualize pure single-electron states, preserved from Coulomb interaction.

"The next natural step is then to address few-particle states and electron entanglement in quantum conductors. Again, the question of the destruction of such states by Coulomb interaction effects will be a crucial one." [9]

## The Electromagnetic Interaction

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. [2]

## Asymmetry in the interference occurrences of oscillators

The asymmetrical configurations are stable objects of the real physical world, because they cannot annihilate. One of the most obvious asymmetry is the proton – electron mass rate  $M_p = 1840 M_e$  while they have equal charge. We explain this fact by the strong interaction of the proton, but how remember it his strong interaction ability for example in the H – atom where are only electromagnetic interactions among proton and electron.

This gives us the idea to origin the mass of proton from the electromagnetic interactions by the way interference occurrences of oscillators. The uncertainty relation of Heisenberg makes sure that the particles are oscillating.

The resultant intensity due to  $n$  equally spaced oscillators, all of equal amplitude but different from one another in phase, either because they are driven differently in phase or because we are looking at them an angle such that there is a difference in time delay:

$$(1) I = I_0 \frac{\sin^2 n \phi/2}{\sin^2 \phi/2}$$

If  $\phi$  is infinitesimal so that  $\sin \phi = \phi$ , than

$$(2) I = n^2 I_0$$

This gives us the idea of

$$(3) M_p = n^2 M_e$$

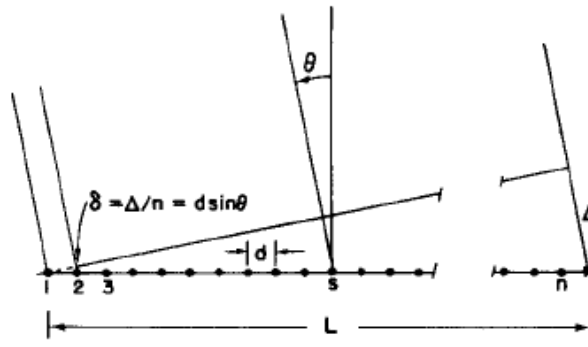


Fig. 30-3. A linear array of  $n$  equal oscillators, driven with phases  $\alpha_s = s\alpha$ .

Figure 1.) A linear array of  $n$  equal oscillators

There is an important feature about formula (1) which is that if the angle  $\phi$  is increased by the multiple of  $2\pi$ , it makes no difference to the formula.

So

$$(4) \quad d \sin \theta = m \lambda$$

and we get  $m$ -order beam if  $\lambda$  less than  $d$ . [6]

If  $d$  less than  $\lambda$  we get only zero-order one centered at  $\theta = 0$ . Of course, there is also a beam in the opposite direction. The right chooses of  $d$  and  $\lambda$  we can ensure the conservation of charge.

For example

$$(5) \quad 2(m+1) = n$$

Where  $2(m+1) = N_p$  number of protons and  $n = N_e$  number of electrons.

In this way we can see the  $H_2$  molecules so that  $2n$  electrons of  $n$  radiate to  $4(m+1)$  protons, because  $d_e > \lambda_e$  for electrons, while the two protons of one  $H_2$  molecule radiate to two electrons of them, because of  $d_e < \lambda_e$  for this two protons.

To support this idea we can turn to the Planck distribution law, that is equal with the Bose – Einstein statistics.

## Spontaneously broken symmetry in the Planck distribution law

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.

Max Planck found for the black body radiation

As a function of wavelength ( $\lambda$ ), Planck's law is written as:

$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

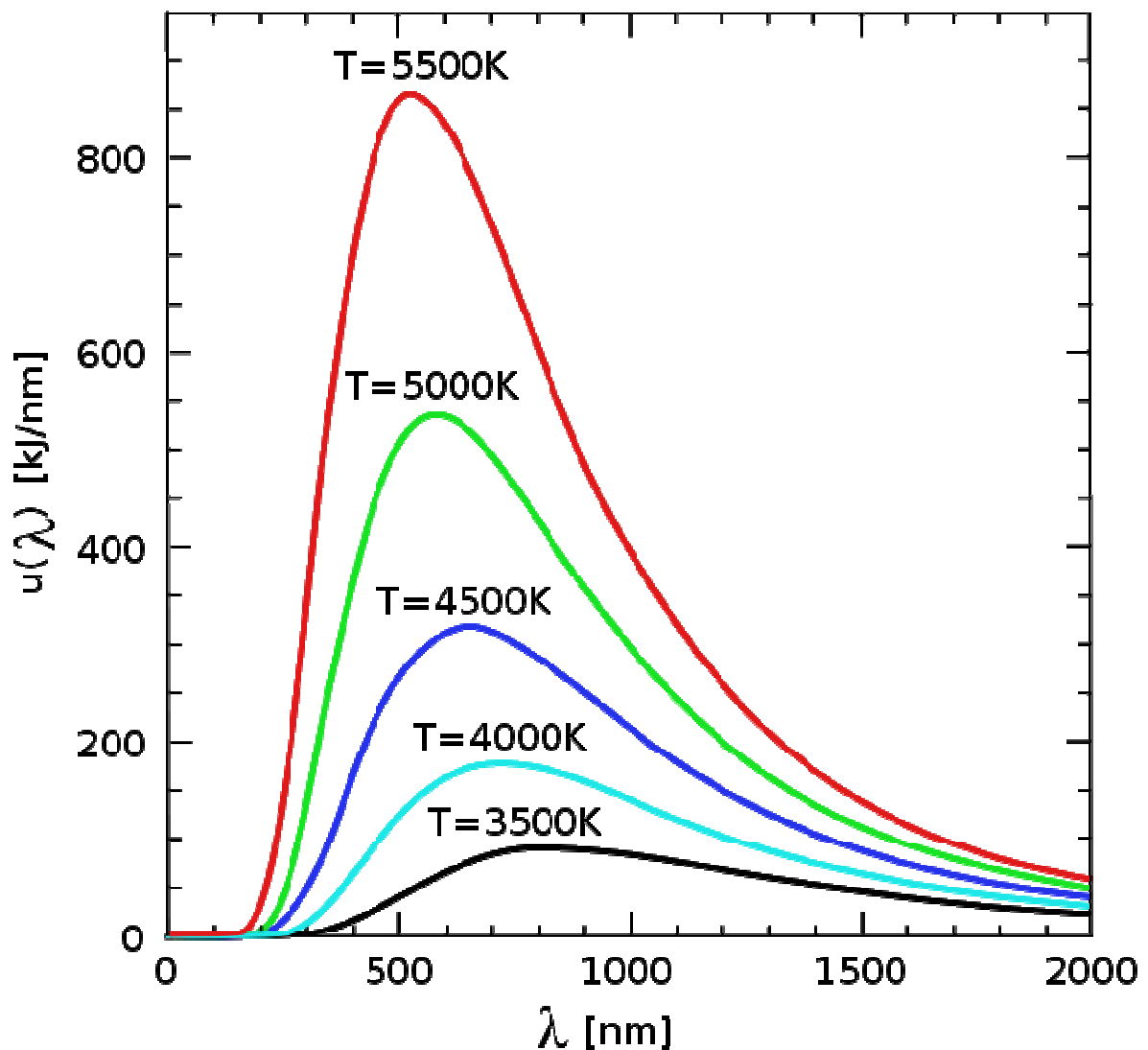


Figure 2. The distribution law for different T temperatures



We see there are two different  $\lambda_1$  and  $\lambda_2$  for each T and intensity, so we can find between them a d so that  $\lambda_1 < d < \lambda_2$ .

We have many possibilities for such asymmetrical reflections, so we have many stable oscillator configurations for any T temperature with equal exchange of intensity by radiation. All of these configurations can exist together. At the  $\lambda_{\max}$  is the annihilation point where the configurations are symmetrical. The  $\lambda_{\max}$  is changing by the Wien's displacement law in many textbooks.

$$(7) \quad \lambda_{\max} = \frac{b}{T}$$

where  $\lambda_{\max}$  is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to  $2.8977685(51) \times 10^{-3} \text{ m} \cdot \text{K}$  (2002 CODATA recommended value).

By the changing of T the asymmetrical configurations are changing too.

## The structure of the proton

We must move to the higher T temperature if we want look into the nucleus or nucleon arrive to  $d < 10^{-13} \text{ cm}$ . If an electron with  $\lambda_e < d$  move across the proton then by (5)  $2(m+1) = n$  with  $m = 0$  we get  $n = 2$  so we need two particles with negative and two particles with positive charges. If the proton can fraction to three parts, two with positive and one with negative charges, then the reflection of oscillators are right. Because this very strange reflection where one part of the proton with the electron together on the same side of the reflection, the all parts of the proton must be quasi lepton so  $d > \lambda_q$ . 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. The flavors of quarks are the possible oscillations differently by energy and if they are plane or linear oscillations. We know there is no possible reflecting two oscillations to each other which are completely orthogonal, so the quarks never can be free, however there is an asymptotic freedom while their energy are increasing to turn them to the orthogonally. If they will be completely orthogonal then they lose this reflection and take new partners from the vacuum. Keeping the symmetry of the vacuum the new oscillations are keeping all the conservation laws, like charge, number of baryons and leptons. The all features of gluons are coming from this model. The mathematics of reflecting oscillators show Fermi statistics.

Important to mention that in the Deuteron there are 3 quarks of  $+2/3$  and  $-1/3$  charge, that is three u and d quarks making the complete symmetry and because this its high stability.

The Pauli Exclusion Principle says that the diffraction points are exclusive!

## The Strong Interaction

### ***Confinement and Asymptotic Freedom***

For any theory to provide a successful description of strong interactions it should simultaneously exhibit the phenomena of confinement at large distances and asymptotic freedom at short distances. Lattice calculations support the hypothesis that for non-abelian gauge theories the two domains are analytically connected, and confinement and asymptotic freedom coexist. Similarly, one way to show that QCD is the correct theory of strong interactions is that the coupling extracted at various scales (using experimental data or lattice simulations) is unique in the sense that its variation with scale is given by the renormalization group. [4]  
Lattice QCD gives the same results as the diffraction theory of the electromagnetic oscillators, which is the explanation of the strong force and the quark confinement. [1]

### The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

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

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

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

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

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

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

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

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

Finally since the weak interaction is an electric dipole change with  $\frac{1}{2}$  spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

## The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of

Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.

The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change.

There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction. [5]

## Fermions and Bosons

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

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

## The 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:  $1/2 \hbar = \Delta x \Delta p$  or  $1/2 \hbar = \Delta t \Delta E$ , that is the value of the basic energy status.

What are the consequences of this in the weak interaction and how possible that the neutrinos' velocity greater than the speed of light?

The neutrino is the one and only particle doesn't participate in the electromagnetic interactions so we cannot expect that the velocity of the electromagnetic wave will give it any kind of limit.

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

## The source of the Maxwell equations

The electrons are accelerating also in a static electric current because of the electric force, caused by the potential difference. The magnetic field is the result of this acceleration, as you can see in [2].

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 matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

Also an interesting question, how the changing magnetic field creates a negative electric field? The answer also the accelerating electrons will give. When the magnetic field is increasing in time by

increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change.

In this way we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.

The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.

There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by weak interaction and can be understood by the Feynman graphs.

Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because 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 greatest proton mass.

## The Special Relativity

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 matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed. [8]

## The Heisenberg Uncertainty Principle

Moving faster needs stronger acceleration reducing the  $\Delta x$  and raising the  $\Delta p$ . It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass ratio since the  $\Delta x$  is much less requiring bigger  $\Delta p$  in the case of the proton, which is partly the result of a bigger mass  $m_p$  because of the higher electromagnetic induction of the bigger frequency (impulse).

## The Gravitational force

The changing magnetic field of the changing current causes electromagnetic mass change by the negative electric field caused by the changing acceleration of the electric charge.

The gravitational attractive force is basically a magnetic force.

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

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

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

The mass as seen before a result of the diffraction, for example the proton – electron mass ratio  $M_p = 1840 M_e$ . In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass. [1]

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.

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

## The Graviton

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

## What is the Spin?

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

## The Casimir effect

The Casimir effect is related to the Zero-point energy, which is fundamentally related to the Heisenberg uncertainty relation. The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin:  $1/2 \hbar = \Delta x \Delta p$  or  $1/2 \hbar = \Delta t \Delta E$ , that is the value of the basic energy status.

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. 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 is not a point like particle, but has a real charge distribution.

Electric charge and electromagnetic waves are two sides of the same thing; the electric charge is the diffraction center of the electromagnetic waves, quantified by the Planck constant  $h$ .

## The 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 Planck constant, the 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.

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, described in my diffraction theory.

## Path integral formulation of Quantum Mechanics

The path integral formulation of quantum mechanics is a description of quantum theory which generalizes the action principle of classical mechanics. It replaces the classical notion of a single, unique trajectory for a system with a sum, or functional integral, over an infinity of possible trajectories to compute a quantum amplitude. [7]

It shows that the particles are diffraction patterns of the electromagnetic waves.



## Conclusions

"The next natural step is then to address few-particle states and electron entanglement in quantum conductors. Again, the question of the destruction of such states by Coulomb interaction effects will be a crucial one." [9]

The magnetic induction creates a negative electric field, causing an electromagnetic inertia responsible for the relativistic mass change; it is the mysterious Higgs Field giving mass to the particles. The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass ratio by the diffraction patterns. The accelerating charges 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 Relativistic Quantum Theories. The self-maintained electric potential of the accelerating charges equivalent with the General Relativity space-time curvature, and since it is true on the quantum level also, gives the base of the Quantum Gravity. The electric currents causing self-maintaining electric potential is the source of the special and general relativistic effects. The Higgs Field is the result of the electromagnetic induction. The Graviton is two photons together.

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