Ultrafast Light-Induced Processes

Researchers from Graz University of Technology and the University of Vienna have better described the energy flow between strongly interacting molecular states. [43]

Manish Garg and Klaus Kern, researchers at the Max Planck Institute for Solid State Research in Stuttgart, have developed a microscope for the extremely fast processes that take place on the quantum scale. [42]

Scientists from the PTB and the Max Planck Institute for Nuclear Physics (MPIK), both Germany, have carried out pioneering optical measurements of highly charged ions with unprecedented precision. [41]

Scientists from Argonne National Laboratory and the University of Chicago launched a new testbed for quantum communication experiments from Argonne last week. [40]

Physicists at The City College of New York have used atomically thin two-dimensional materials to realize an array of quantum emitters operating at room temperature that can be integrated into next generation quantum communication systems. [39]

Research in the quantum optics lab of Prof. Barak Dayan in the Weizmann Institute of Science may be bringing the development of such computers one step closer by providing the "quantum gates" that are required for communication within and between such quantum computers. [38]

Calculations of a quantum system's behavior can spiral out of control when they involve more than a handful of particles. [37]

Researchers from the University of North Carolina at Chapel Hill have reached a new milestone on the way to optical computing, or the use of light instead of electricity for computing. [36]

The key technical novelty of this work is the creation of semantic embeddings out of structured event data. [35]

The researchers have focussed on a complex quantum property known as entanglement, which is a vital ingredient in the quest to protect sensitive data. [34]

Cryptography is a science of data encryption providing its confidentiality and integrity. [33]

Researchers at the University of Sheffield have solved a key puzzle in quantum physics that could help to make data transfer totally secure. [32]

"The realization of such all-optical single-photon devices will be a large step towards deterministic multi-mode entanglement generation as well as high-fidelity photonic quantum gates that are crucial for all-optical quantum information processing," says Tanji-Suzuki. [31]

Researchers at ETH have now used attosecond laser pulses to measure the time evolution of this effect in molecules. [30]

A new benchmark quantum chemical calculation of C_2, Si_2, and their hydrides reveals a qualitative difference in the topologies of core electron orbitals of organic molecules and their silicon analogues. [29]

A University of Central Florida team has designed a nanostructured optical sensor that for the first time can efficiently detect molecular chirality—a property of molecular spatial twist that defines its biochemical properties. [28]

UCLA scientists and engineers have developed a new process for assembling semiconductor devices. [27]

A new experiment that tests the limit of how large an object can be before it ceases to behave quantum mechanically has been proposed by physicists in the UK and India. [26]

Phonons are discrete units of vibrational energy predicted by quantum mechanics that correspond to collective oscillations of atoms inside a molecule or a crystal. [25]

This achievement is considered as an important landmark for the realization of practical application of photon upconversion technology. [24]
Considerable interest in new single-photon detector technologies has been scaling in this past decade. [23]

Engineers develop key mathematical formula for driving quantum experiments. [22]

Physicists are developing quantum simulators, to help solve problems that are beyond the reach of conventional computers. [21]

Engineers at Australia's University of New South Wales have invented a radical new architecture for quantum computing, based on novel 'flip-flop qubits', that promises to make the large-scale manufacture of quantum chips dramatically cheaper - and easier - than thought possible. [20]

A team of researchers from the U.S. and Italy has built a quantum memory device that is approximately 1000 times smaller than similar devices— small enough to install on a chip. [19]

The cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation. [18]

This is an important clue for our theoretical understanding of optically controlled magnetic data storage media. [17]

A crystalline material that changes shape in response to light could form the heart of novel light-activated devices. [16]

Now a team of Penn State electrical engineers have a way to simultaneously control diverse optical properties of dielectric waveguides by using a two-layer coating, each layer with a near zero thickness and weight. [15]

Just like in normal road traffic, crossings are indispensable in optical signal processing. In order to avoid collisions, a clear traffic rule is required. A new method has now been developed at TU Wien to provide such a rule for light signals. [14]

Researchers have developed a way to use commercial inkjet printers and readily available ink to print hidden images that are only visible when illuminated with appropriately polarized waves in the terahertz region of the electromagnetic spectrum. [13]

That is, until now, thanks to the new solution devised at TU Wien: for the first time ever, permanent magnets can be produced using a 3D printer. This allows magnets to be produced in complex forms and precisely customised magnetic fields, required, for example, in magnetic sensors. [12]

For physicists, loss of magnetisation in permanent magnets can be a real concern. In response, the Japanese company Sumitomo created the strongest available magnet—one offering ten times more magnetic energy than previous versions—in 1983. [11]

New method of superstrong magnetic fields' generation proposed by Russian scientists in collaboration with foreign colleagues. [10]

By showing that a phenomenon dubbed the "inverse spin Hall effect" works in several organic semiconductors - including carbon-60 buckyballs - University of Utah physicists changed magnetic "spin current" into electric current. The efficiency of this new power conversion method isn't yet known, but it might find use in future electronic devices including batteries, solar cells and computers. [9]

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

This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories.

The changing acceleration of the electrons explains the created negative electric field of the magnetic induction, the changing relativistic mass and the Gravitational Force, giving a Unified Theory of the physical forces. Taking into account the Planck Distribution Law of the electromagnetic oscillators also, we can explain the electron/proton mass rate and the Weak and Strong Interactions.

Contents

Author: George Rajna

Preface

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

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

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

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

Simulation experiment allows deeper insights into ultrafast light-induced processes

Researchers from Graz University of Technology and the University of Vienna have better described the energy flow between strongly interacting molecular states. Since the 1990s, femtochemistry has been researching ultrafast processes at the molecular level. In the last few years, the research group Femtosecond Dynamics at TU Graz's Institute of Experimental Physics has been able to achieve a number of successes in the area of light-matter interaction.

"A precise understanding of the processes triggered by photoexcitation in molecules is, for example, a prerequisite for the development of sustainable technologies that enable an energy supply based on solar energy," says Markus Koch, the head of the working group.

As an example, he cites photocatalysis, which helps to convert sunlight into chemical energy with advantages in terms of long-term storage and energy density when compared to the generation of electrical energy via photovoltaics.

One method for such molecular dynamic investigations makes use of so-called pump-probe measurements applying an ultrashort laser pulse to excite ("pump") a molecular system into a desired state. After an adjustable delay time, a second ("probe") laser interrogates the population of the excited state by ionizing the molecule.

The energy of the emitted photoelectrons is measured and by varying the pump-probe delay time, conclusions can be drawn about the energy flow in the molecule.

Heisenberg's energy-time uncertainty principle prevents exact results

An exact description of light-induced processes on their real time scale has so far failed for some polyatomic molecules that may take different decay or fragmentation routes after excitation, depending on the choice between closely spaced energy states.

As a result of Heisenberg's energy-time uncertainty principle, laser pulses of only femtosecond (10-15 seconds) time duration cannot selectively excite closely neighbouring molecular states. However, short pulses are a prerequisite for the observation of extremely fast processes.

New approach combines theory and experiment

In collaboration with researchers of the Institute of Theoretical Chemistry at the Faculty of Chemistry of the University of Vienna under the direction of Prof. Leticia González, the experimental physicists in Graz have now overcome this hurdle.

By combining experiments with ultrashort laser pulses and theoretical simulations of light-induced processes, the energy flow in acetone—a molecule that has already been well studied—could now be observed for the first time at a key energy window between three closely related states.

Even for the Vienna group, a driving force in the field of the theoretical description of molecules after light excitation, the system under investigation presented a challenge. "For these simulations, new developments in our local software package SHARC were necessary, without which the correct description of acetone dynamics would not have been possible," emphasizes González.

Synergy effects yield new insights

Both methods in themselves are widely used, but "while the energy-time-blur relation in femtosecond spectroscopy prevents precise results, real-time simulations provide deeper insights into molecular dynamics, which in turn require the experimental results to be verified," explains Koch.

The combination of these two techniques now provides researchers with a deeper insight into acetone dynamics and is a further milestone in the study of light-matter interactions. The results were published in The *Journal of Physical Chemistry Letters*. [43]

An ultrafast microscope for the quantum world

The operation of components for future computers can now be filmed in HD quality, so to speak. Manish Garg and Klaus Kern, researchers at the Max Planck Institute for Solid State Research in Stuttgart, have developed a microscope for the extremely fast processes that take place on the quantum scale. This microscope—a sort of HD camera for the quantum world—allows the precise tracking of electron movements down to the individual atom. It should therefore provide useful insights when it comes to developing extremely fast and extremely small electronic components, for example.

The processes taking place in the quantum world represent a challenge for even the most experienced of physicists. For example, the things taking place inside the increasingly powerful components of computers or smartphones not only happen extremely quickly but also within an ever-smaller space. When it comes to analysing these processes and optimising transistors, for example, videos of the electrons would be of great benefit to physicists. To achieve this, researchers need a high-speed camera that exposes each frame of this "electron video" for just a few hundred attoseconds. An attosecond is a billionth of a billionth of a second; in that time, light can only travel the length of a water molecule. For a number of years, physicists have used laser pulses of a sufficiently short length as an attosecond camera.

In the past, however, an attosecond image delivered only a snapshot of an electron against what was essentially a blurred background. Now, thanks to the work of Klaus Kern, Director at the Max Planck Institute for Solid State Research, and Manish Garg, a scientist in Kern's Department, researchers can now also identify precisely where the filmed electron is located down to the individual atom.

Ultrashort laser pulses combined with a scanning tunnelling microscope

To do this, the two physicists use ultrashort laser pulses in conjunction with a scanning tunnelling microscope. The latter achieves atomic-scale resolution by scanning a surface with a tip that itself is ideally made up of just a single atom. Electrons tunnel between the tip and the surface—that is, they cross the intervening space even though they actually don't have enough energy to do so. As the effectiveness of this tunnelling process depends strongly on the distance the electrons have to travel, it can be used to measure the space between the tip and a sample and therefore to depict even individual atoms and molecules on a surface. Until now, however, scanning tunnelling microscopes did not achieve sufficient temporal resolution to track electrons.

"By combining a scanning tunnelling microscope with ultrafast pulses, it was easy to use the advantages of the two methods to compensate for their respective disadvantages," says Manish Garg. The researchers fire these extremely short pulses of light at the microscope tip—which is positioned with atomic precision—to trigger the tunnelling process. As a result, this high-speed camera for the quantum world can now also achieve HD resolution.

Paving the way for light-wave electronics, which is millions of times faster

With the new technique, physicists can now measure exactly where electrons are at a specific time down to the individual atom and to an accuracy of a few hundred attoseconds. For example, this can be used in molecules that have had an electron catapulted out of them by a high-energy pulse of light, leading the remaining negative charge carriers to rearrange themselves and possibly causing the molecule to enter into a chemical reaction with another molecule. "Filming electrons in molecules live, and on their natural spatial and temporal scale, is vital in order to understand chemical reactivity, for example, and the conversion of light energy within charged particles, such as electrons or ions," says Klaus Kern, Director at the Max Planck Institute for Solid State Research.

Moreover, the technique not only allows researchers to track the path of electrons through the processors and chips of the future, but can also lead to a dramatic acceleration of the charge carriers: "In today's computers, electrons oscillate at a frequency of a billion hertz," says Klaus Kern. "Using ultrashort light pulses, it may be possible to increase their frequency to a trillion hertz." With this turbo booster for light waves, researchers could clear the way for light-wave electronics, which is millions of times faster than current computers. Therefore, the ultrafast microscope not only films processes in the quantum world, but also acts as the Director by interfering with these processes. [42]

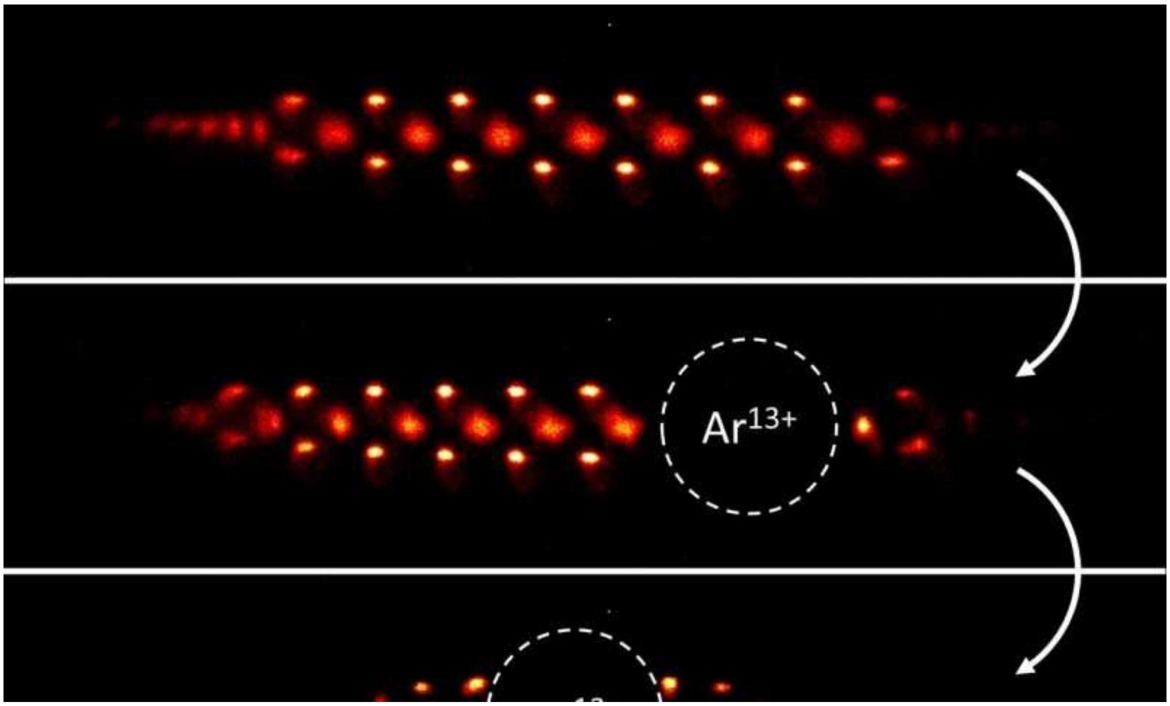
Quantum logic spectroscopy unlocks potential of highly charged ions

Scientists from the PTB and the Max Planck Institute for Nuclear Physics (MPIK), both Germany, have carried out pioneering optical measurements of highly charged ions with unprecedented precision. To do this, they isolated a single Ar13 + ion from an extremely hot plasma and brought it practically to rest inside an ion trap together with a laser-cooled, singly charged ion. Employing quantum logic spectroscopy on the ion pair, they have increased the relative precision by a factor of a hundred million over previous methods.

This opens up the multitude of highly charged ions for novel atomic clocks and further avenues in the search for new physics.

Highly charged ions are—although seemingly exotic—a very natural form of visible matter. All the matter in our sun and in all other stars is highly ionized, for example. In many ways, however, highly charged ions are more extreme than neutral atoms or singly charged ions. Due to their high positive charge, the outer electrons of the atomic shell are more strongly bound to the atomic nucleus. They are therefore less sensitive to perturbations by external electromagnetic fields. On the other hand, compared to neutral and singly charged atoms, the effects of special relativity and quantum electrodynamics as well as the interaction with the atomic nucleus are considerably enhanced. Highly charged ions are therefore ideal systems for accurate atomic clocks that can be used to test fundamental physics. The outer electrons in these systems serve as sensitive "quantum sensors" for effects such as previously unknown forces and fields. Since every single element of the periodic table provides as many charge states as there are electrons in the atomic shell, there exists a vast variety of atomic systems to choose from.

To date, however, established measurement techniques as used in optical atomic clocks could not be applied to highly charged ions. The main obstacle manifests already in the process of their production: a large amount of energy is required in order to remove a significant number of electrons from the atoms, and the ions then exist in the form of a plasma as hot as the Sun itself. However, the most precise and accurate experiments require the exact opposite: the lowest possible temperatures and well-controlled ambient conditions in order to reduce shifts and broadening of the spectral lines to be measured. This is hindered by the fact that highly charged ions cannot be directly laser-cooled, and conventional detection methods cannot be applied due to their atomic structure.



Implantation of the Ar13+ ion into the laser-cooled Be+ ion crystal and step-wise reduction to the quantum logic configuration of an ion pair. Credit: PTB

Physicists from the Physikalisch-Technische Bundesanstalt and the Max Planck Institute for Nuclear Physics in Heidelberg have now combined individual solutions to each of these problems in a worldwide unique experiment at the QUEST Institute for Experimental Quantum Metrology in Braunschweig. They isolated a single highly charged ion (Ar_{13}^+) from a hot plasma ion source and stored it together with a singly charged beryllium ion in an ion trap. The latter can be laser-cooled very efficiently and through the mutual electrical interaction the temperature of the entire ion pair can be reduced. Eventually, this so-called "sympathetic cooling" forms a two-ion crystal that completely "freezes" into the quantum mechanical ground state of motion at an equivalent temperature of only a few millionths of a degree above absolute zero.

Using an ultrastable laser the scientists precisely resolved the spectral structure of the Ar_{13}^+ ion in a measurement procedure similar to that used in state-of-the-art clocks. For this, they applied the concept of quantum logic, in which the spectroscopy signal is coherently transferred from the highly charged ion to the beryllium ion by means of two laser pulses. The quantum state of the beryllium ion is much easier to determine via laser excitation. "Descriptively, the beryllium ion 'eavesdrops' on the state of the less communicative highly charged ion and reports to us about its state," explains Piet Schmidt, head of the collaboration. "Here, we have improved the relative precision for highly charged ions by a factor of one hundred million compared to traditional spectroscopy," adds Peter Micke, research assistant at the QUEST Institute and first author of the paper.

Combining all these methods establishes a very general concept that can be applied to most highly charged ions. The beryllium ion can always be used as a so-called logic ion and the production process of the highly charged ions in the plasma with subsequent isolation of a single ion is independent of the choice of the atomic type and the charge state.

José Crespo, head of the group at the Max Planck Institute for Nuclear Physics, emphasizes: "This experiment opens up an unprecedented, extremely extensive area of atomic systems to be used in precision spectroscopy as well as for future clocks with special properties." For basic research, the great variety of these new, tailored "quantum sensors" enables a promising investigation of fundamental questions: Is our standard model of particle physics complete? What is dark matter? Are fundamental constants really constant?

The study is reported in *Nature*. [41]

New quantum loop provides testbed for quantum communication technology

Scientists from Argonne National Laboratory and the University of Chicago launched a new testbed for quantum communication experiments from Argonne last week.

The quantum loop consists of a pair of connected 26-mile fiber-optic cables that wind circuitously between Argonne to the Illinois Tollway near suburban Bolingbrook and back. At 52 total miles, it is among the longest ground-based quantum communication channels in the country.

The loop will serve as a testbed for researchers interested in leveraging the principles of quantum physics to send unhackable information across long distances. Researchers at Argonne and UChicago plan to use the testbed to explore science underlying quantum engineering systems and to harness the properties of quantum entanglement—a phenomenon Albert Einstein famously characterized as "spooky action at a distance." Quantum entanglement links two (or more) particles so that they are in a shared state—such that whatever happens to one immediately affects the other, no matter how far they have traveled apart.

"Inaugurating this quantum loop is a significant step for Chicago and the nation in building a large-scale quantum network that can enable secure data transmissions over long distances," said principal investigator David Awschalom, senior scientist in the Materials Science Division at Argonne, the Liew Family Professor in Molecular Engineering at the University of Chicago and director of the Chicago Quantum Exchange. "The loop will enable us to identify and address challenges in operating a quantum network and can be scaled to test and demonstrate communication across even greater distances to help lay the foundation for a quantum internet."

Argonne scientists Joe Heremans, Alan Dibos and Gary Wolfowicz, who worked on the quantum loop project, demonstrated the operation of the testbed by generating and transmitting optical pulses through one and then both fiber loops. They witnessed a delay of 200 microseconds for the transit time of the laser pulse along one fiber loop, which is consistent with the speed of light in the glass fiber.

They also began to use the loop for a series of experiments, including transmitting signals from photons emitted from ensembles of ions. These ions can be used as a quantum memory for the network. A functional quantum memory, which entails the storage and retrieval of quantum states, is a key technological advance needed for quantum communication and a quantum internet.

"We will need many of these quantum memories spaced out over about 100 kilometers to relay the quantum signal through a network. The quantum loop enables us to test and refine this quantum memory technology before deploying it in large scale," said Tian Zhong, scientist in the Nanoscience and Technology Division at Argonne and assistant professor of molecular engineering at the University of Chicago.

"Research leading to science infrastructure such as the quantum loop will ensure that America remains a world leader in this pivotal, rapidly evolving field, which will open up important new avenues of investigation in areas like quantum data transfer and secure communications," said Department of Energy Under Secretary of Science Paul Dabbar. "We look forward to continued increased support and accomplishment for this and other areas of quantum information science."

"This quantum loop is a significant capability for the scientific communities in quantum physics, communications and computing," said Paul Kearns, Argonne National Laboratory director. "These experiments demonstrate how Argonne's world-leading scientists and engineers help ensure U.S. leadership in essential quantum information science."

In addition to the quantum loop, Argonne plans to develop a two-way quantum link network with Fermi National Accelerator Laboratory. When the two projects are connected, the quantum link, also supported by the Department of Energy, is expected to be among the longest links in the world to send secure information using quantum physics. [40]

On-demand room-temperature single photon array—a quantum communication breakthrough

Physicists at The City College of New York have used atomically thin two-dimensional materials to realize an array of quantum emitters operating at room temperature that can be integrated into next generation quantum communication systems.

Researchers from the groups of City College Professors Carlos Meriles and Vinod Menon developed for the first time an array of on-demand single photon emitters that operate at room temperature.

Using an atomically thin material, hexagonal boron nitride (hBN), placed on nanopillars, the researchers demonstrated single photon emission at the pillar locations. In simplest terms, the breakthrough allows one to know where the single photon emitters are located. Single photon emitters are essential building blocks for next generation quantum communication and computing protocols as they can be used as a quantum bit (qubit). The secure communication comes about because of the quantum property of the single photon making eavesdropping impossible. The current breakthrough has solved a long-standing and practical hurdle of realizing deterministic single photon emitters at room temperature. Previously, very low temperatures were necessary or the photons were hard to extract using other materials such as diamond, noted Menon. And, if single photon emission did occur at room temperature, it happened at random locations.

The work was carried out by graduate student Nicholas Proscia, post-doctoral researchers, Zav Shotan and Harishankar Jayakumar, and undergraduate students Michael Dollar and Charles Cohen, in collaboration with theory groups from the Australian National University (Marcus Doherty and Prithvi Reddy) and the Center for Physical Science and Technology, Lithuania (Audrius Alkauskas). [39]

A quantum gate between atoms and photons may help in scaling up quantum computers

The quantum computers of the future will be able to perform computations that cannot be done on today's computers. These may likely include the ability to crack the encryption that is currently used for secure electronic transactions, as well as the means to efficiently solve unwieldy problems in which the number of possible solutions increases exponentially. Research in the quantum optics lab of Prof. Barak Dayan in the Weizmann Institute of Science may be bringing the development of such computers one step closer by providing the "quantum gates" that are required for communication within and between such quantum computers.

In contrast with today's electronic bits that can only exist in one of two states—zero or one—quantum bits known as qubits can also be in states that correspond to both zero and one at the same time. This is called quantum superposition, and it gives qubits an edge as a computer made of them could perform numerous computations in parallel.

There is just one catch: The state of quantum superposition state can exist only as long as it is not observed or measured in any way by the outside world; otherwise all the possible states collapse into a single one. This leads to contradicting requirements: For the qubits to exist in several states at once they need to be well isolated, yet at the same time they need to interact and communicate with many other qubits. That is why, although several labs and companies around the world have already demonstrated small-scale quantum computers with a few dozen qubits, the challenge of scaling up these to the desired scale of millions of qubits remains a major scientific and technological hurdle.

One promising solution is using isolated modules with small, manageable numbers of qubits, which can communicate between them when needed with optical links. The information stored in a material qubit (e.g. a single atom or ion) would then be transferred to a "flying qubit—a single particle of light called a photon. This photon can be sent through optical fibers to a distant material qubit and transfer its information without letting the environment sense the nature of that information. The challenge in creating such a system is that single photons carry extremely small amounts of energy, and the minuscule systems comprising material qubits generally do not interact strongly with such weak light.

Dayan's quantum optics lab in the Weizmann Institute of Science is one of the few groups worldwide that are focused entirely on attacking this scientific challenge. Their experimental setup has single atoms coupled to unique micron-scale silica resonators on chips; and photons are sent directly to these through special optical fibers. In previous experiments Dayan and his group had demonstrated the ability of their system to function as a single-photon activated switch, and also a way to "pluck" a single photon from a flash of light. In the present study, reported in *Nature Physics*, Dayan and his team succeeded—for the first time—to create a logic gate in which a photon and an atom automatically exchange the information they carry.

"The photon carries one qubit, and the atom is a second qubit," says Dayan. "Each time the photon and the atom meet they exchange the qubits between them automatically and simultaneously, and the photon then continues on its way with the new bit of information. In quantum mechanics, in which information cannot be copied or erased, this swapping of information is in fact the basic unit of reading and writing—the "native" gate of quantum communication."

This type of logic gate—a SWAP gate—can be used to exchange qubits both within and between quantum computers. As this gate needs no external control fields or management system, it can enable the construction of the quantum equivalent of very large-scale integration (VLSI) networks. "The SWAP gate we demonstrated is applicable to photonic communication between all types of matter-based qubits—not only atoms," says Dayan. "We therefore believe that it will become an essential building-block in the next generation of quantum computing systems." [38]

Synopsis: Making Quantum Computations Behave

Calculations of a quantum system's behavior can spiral out of control when they involve more than a handful of particles. So for just about anything more complicated than the hydrogen atom, physicists forget about finding an exact solution to the Schrödinger equation and rely instead on approximation methods. Dean Lee of Michigan State University, East Lansing, and colleagues have now proposed an alternative method for when even the best approximation schemes fail. Their approach should be applicable to a variety of many-particle problems in atomic, nuclear, and particle physics.

The researchers considered the popular Bose-Hubbard model to illustrate their idea. In the model, which has been used to describe atoms in an optical lattice and in superconductors, bosons hop from point to point on a cubic grid, but they interact with one another only when they sit on the same site. Physicists are interested in how the particles behave as the strength of this interaction, UU, varies. Using the so-called perturbative approach, the particles' wave function can be calculated for a simple case ($U=0U=0$) and then approximated at greater interaction strengths in terms of a power series in UU. But this formula blows up when UU is too large.

Instead, the team's approach was to track the wave function's changing shape at a few values of UU where the functions can be accurately calculated. They then used this shape "trajectory" to predict the ground-state wave function at values of UU that perturbation theory can't reach, demonstrating the accuracy of their method for four bosons on a $4\times4\times44\times4\times4$grid.

Lee says the technique, which he and his colleagues have dubbed "eigenvector continuation," should work well for calculations that involve a smoothly varying parameter, like interaction strength, but it might struggle with a discretely varying parameter, like particle number. The researchers are now planning to dive into some computations that are known to defy conventional methods, such as simulations involving large nuclei.

This research is published in ***Physical Review Letters***. [37]

Researchers enable transmission of specific colors of light over long distances

Researchers from the University of North Carolina at Chapel Hill have reached a new milestone on the way to optical computing, or the use of light instead of electricity for computing. They explored a new way to select and send light of a specific color using long silicon wires that are several hundred nanometers in diameter (about 1,000 times smaller than a human hair) and their work enabled a new type of nanoscale "light switch" that can turn on and off the transmission of one color of light over very long distances.

The research paper, written by chemistry professor James Cahoon and graduate student Seokhyoung Kim at the University of North Carolina at Chapel Hill, along with collaborators at Korea University, was published in the journal *Nature Communications* on July 17.

Optical computing technology promises many benefits. Swapping electrons for light-based technology would mean that the computers of the future won't overheat and will run much faster.

"In the past there hasn't been a controlled method for selectively sending light down nanoscale wires, so optical technology has either used much larger structures or wasted a lot of light in the process," said James Cahoon, senior corresponding author and associate professor of chemistry in the College of Arts and Sciences at UNC-Chapel Hill. "We found a way to turn on and off the transmission of a specific color of light, and it represents an important step towards the more controlled, effective use of light that would enable optical computing."

The research team developed the Encoded Nanowire Growth and Appearance through VLS and Etching (ENGRAVE) technique, which can create complex shapes in nanowires. They then achieved selective light transmission through precise diameter modulation with the ENGRAVE technique. This was the first report of direct use of a Mie resonance, a light scattering property of nanowires, for guiding light in a nanowire.

This work is a step forward for optical computing and will help enable further advances in the technology. The team's findings can enable downsizing of the optical components needed to develop computers based on light instead of on electricity. By miniaturizing these components, they can be more easily integrated with the existing electronic components in computers. Additionally, the color of light conducted by the wires in this study is sensitive, with the color changing as the environment changes. Thus, these structures can be used as a new type of sensor, in which the color of the conducted light senses the environment of the wire. [36]

Semantic concept discovery over event databases

At IBM Research AI, we built an AI-based solution to assist analysts in preparing reports. The paper describing this work recently won the best paper award at the "In-Use" Track of the 2018 Extended Semantic Web Conference (ESWC).

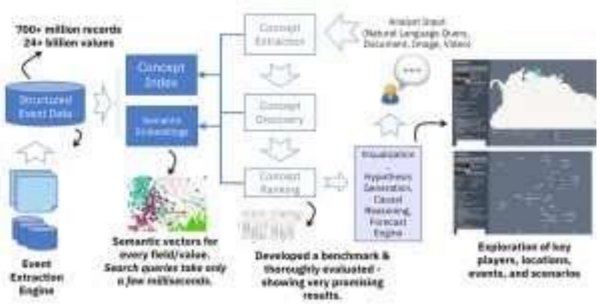
Analysts are often tasked with preparing comprehensive and accurate reports on given topics or high-level questions, which may be used by organizations, enterprises, or government agencies to make informed decisions, reducing the risk associated with their future plans. To prepare such reports, analysts need to identify topics, people, organizations, and events related to the questions. As an example, in order to prepare a report on the consequences of Brexit on London's financial markets, an analyst needs to be aware of the key related topics (e.g., financial markets, economy, Brexit, Brexit Divorce Bill), people and organizations (e.g., The European Union, decision makers in the EU & UK, people involved in Brexit negotiations), and events (e.g., Negotiation meetings, Parliamentary elections within the EU, etc.). An AI-assisted solution can help analysts to prepare complete reports and also avoid bias based on past experience. For example, an analyst could miss an important source of information if it has not been used effectively in the past.

The knowledge induction team at IBM Research AI built the solution using deep learning and structured event data. The team, led by Alfio Gliozzo, also won the prestigious Semantic Web Challenge award last year.

Semantic embeddings from event databases

The key technical novelty of this work is the creation of semantic embeddings out of structured event data. The input to our semantic embeddings engine is a large structured data source (e.g., database tables with millions of rows) and the output is a large collection of vectors with a constant size (e.g., 300) where each vector represents the semantic context of a value in the structured data. The core idea is similar to the popular and widely used idea of word embeddings in natural language processing, but instead of words, we represent values in the structured data. The result is a powerful solution enabling fast and effective semantic search across different fields in the database. A single search query takes only a few milliseconds but retrieves results based on mining hundreds of millions of records and billions of values.

While we experimented with various neural network models for building embeddings, we obtained very promising results using a simple adaptation of the original skip-gram word2vec model. This is an efficient shallow neural network model based on an architecture that predicts the context (surrounding words) given a word in a document. In our work, we are dealing not with text documents but with structured database records. For this, we no longer need to use a sliding window of a fixed or random size to capture the context. In structured data, the context is defined by all the values in the same row regardless of the column position, since two adjacent columns in a database are as related as any other two columns. The other difference in our settings is the need to capture different fields (or columns) in the database. Our engine needs to enable both general semantic queries (i.e., return any database value related to the given value) and field-specific values (i.e., return values from a given field related to the input value). For this, we assign a type to the vectors built out of each field and build an index that supports type-specific or generic queries.



Credit: IBM

For the work described in our paper, we used three publicly available event databases as input: GDELT, ICEWS, and EventRegistry. Overall, these databases consist of hundreds of millions of records (JSON objects or database rows) and billions of values across various fields (attributes). Using our embeddings engine, each value turns into a vector representing the context in the data.

A simple retrieval query

One can see how well the context is captured by our engine using a simple retrieval query. For example, when querying for value "Hilary Clinton" (misspelled) in field "person" in GDELT GKG, the first hit or most similar vector is "Hilary Clinton" (misspelled) under field "name" and the next most similar vectors are "Hillary Clinton" (correct spelling) under fields "person" and "name". This is due to the very similar context of the misspelled value and the correct spelling, and also the values across the fields "name" and "person". The rest of the hits for the above query include U.S. politicians, particularly those active during the last presidential elections, as well as related organizations, persons with similar job roles in the past, and family members.

Similarity search on combined queries

Of course, our solution is capable of achieving much more than a simple retrieval query. In particular, one can combine these queries to turn a set of values extracted from a natural language query into a vector and perform similarity search. We evaluated the outcome of this approach using a benchmark built from reports written by human experts, and examined the ability of our engine to return the concepts described in the reports using the title of the report as the only input. The results clearly showed the superiority of our semantic embeddings–based concept discovery approach compared with a baseline approach relying only on the co-occurrence of the values.

New applications in concept discovery

A very interesting aspect of our framework is that any value and any field is assigned a vector representing its context, which enables new interesting applications. For example, we embedded latitude and longitude coordinates from events in the databases into the same semantic space of concepts, and worked with the Visual AI Lab led by Mauro Martino to build a visualization framework that highlights related locations on a geographic map given a question in natural language. Another interesting application we are currently investigating is using the retrieved concepts and their semantic embeddings as features for a machine learning model that the analyst needs to build. This can be used in an automated machine learning and data science (AutoML) engine, and support analysts in another important aspect of their jobs. We are planning to integrate this solution in IBM's Scenario Planning Advisor, a decision support system for risk analysts. [35]

New study could hold key to hack-proof systems

Major data breaches have made worldwide headlines of late but an international consortium of scientists—including a professor from Heriot-Watt—have developed a new technique that could result in hack-proof systems.

The researchers have focussed on a complex quantum property known as entanglement, which is a vital ingredient in the quest to protect sensitive data.

In a new paper published today in *Nature Physics*, the team of scientists from Austria, the Czech Republic, and the UK, reveal a more advanced and noise-robust way to measure the entanglement of high-dimensional quantum systems.

Entangled particles of light behave in an identical manner, irrespective of how far apart they may be. Measurements made on a pair of entangled light particles would always result in correlated outcomes, even if they were physically on different planets. The outcomes of these measurements represent different quantum levels, which can be used as a "quantum alphabet" for encoding information.

As such, entangled states can be used to generate shared strings of random information across large distances, which form an essential part of data encryption. Any attempts to hack this communication would destroy the sensitive entanglement between the two particles and reveal the presence of the attacker.

Titled "Measurements in two bases are sufficient for certifying high-dimensional entanglement," the research has been led by the Institute of Quantum Optics and Quantum Information (IQOQI) in Vienna.

Professor Mehul Malik from Heriot-Watt's School of Engineering and Physical Sciences, who led the experimental aspect of this new research, said on the discovery: "The most surprising thing about our method is that it requires only two measurements to work, irrespective of how large or complex the entangled state may be!"

Applying their newly developed technique to photons entangled in their spatial structure, the group was able to conclude the structure of entanglement can be unveiled and proven to be truly high-dimensional. They achieved a world record for the highest unconditional dimensionality of entanglement in an experiment of this kind—nine dimensions.

The group is currently looking into a more direct use of this technique in actual quantum cryptography protocols, and expect their technique to be widely applied in other quantum systems such as atoms and superconducting circuits. [34]

Researcher develops algorithm to improve information security tools

Cryptography is a science of data encryption providing its confidentiality and integrity. After cryptographic transformations (the basis of encryption algorithms) are applied, only users that possess a relevant key can have access to the initial text.

Transformations based on elliptical curves have been widely used for data protection recently. They provide the same security levels as other types of cryptographic algorithms but require substantially shorter keys. These transformations are in high demand due to the fact that modern technologies aim at the reduction of memory and computational power consumption.

Mobile devices, blockchain technologies, and the Internet of things require new safety measures, raising the demand for new cryptographic transformation algorithms with lower computational power consumption. The Internet of things is a concept according to which devices communicate not only with the users, but also with each other. Blockchain technologies also cover the Internet of things, and personal mobile devices and are based on digital signature technology.

The main mathematical operation in transformations based on elliptical curves is scalar multiplication, in which a point on an elliptical curve is multiplied by a parameter (scalar). The main disadvantage of scalar multiplication is its high calculational complexity, which may be reduced by using efficient algorithms with lower complexity and therefore lower computational power consumption.

"In the course of the study we found an algorithm and identified different parameters of its operation. When these parameters are used, and depending on available memory volumes and the value of the scalar, the algorithm allows us to perform scalar multiplication—the main operation on the elliptical curve—with minimum computational power consumption," said Denis Khleborodov, the author of the article, Ph.D., CCIE Security, and a researcher at MSU.

The new algorithm is based on window non-adjacent form of scalar representation that is classified as an algorithm with a precomputation step. Precomputations are single-time calculations that are performed before the main part of the work, and their results are saved in the memory. The main advantage of algorithms with precomputations is the division of calculation into two parts: the precomputations themselves followed by the new calculations reusing their results. Therefore, the computational complexity of consecutive scalar multiplication operations is reduced.

The author also performed comparative analysis of the obtained result with another effective algorithm based on the same method. The scientist managed to reduce the average computational complexity of the precomputation stage by 5 percent to 46 percent, and of the main stage—by 4 percent to 22 percent depending on the input data.

The new algorithm may be used on blockchain platforms for digital signing of transactions and authentication, as well as on the Internet of things for the authentication of its devices, in session keys development protocols for the encryption of transferred data, and to secure the integrity of transmitted information.

"We expect to develop an improved algorithm based on the sliding window non-adjacent form of scalar representation, i.e. with changeable parameters of precomputations. We also want to adapt the algorithms for simultaneous calculations. The results may be used in security features of the Internet of things and blockchain platforms," concluded the scientist. [33]

Faster photons could enable total data security

Researchers at the University of Sheffield have solved a key puzzle in quantum physics that could help to make data transfer totally secure.

The team have developed a way of generating very rapid single-photon light pulses. Each photon, or particle of light, represents a bit of binary code—the fundamental language of computing. These photons cannot be intercepted without disturbing them in a way that would alert the sender that something was amiss.

Transferring data using light passed along fibre optic cables has become increasingly common over the past decades, but each pulse currently contains millions of photons. That means that, in principle, a portion of these could be intercepted without detection.

Secure data is already encrypted, but if an 'eavesdropper' was able to intercept the signals containing details of the code then—in theory—they could access and decode the rest of the message.

Single photon pulses offer total security, because any eavesdropping is immediately detected, but scientists have struggled to produce them rapidly enough to carry data at sufficient speeds to transfer high volumes of data.

In a new study, published in *Nature Nanotechnology*, the Sheffield team have employed a phenomenon called the Purcell Effect to produce the photons very rapidly. A nanocrystal called a quantum dot is placed inside a cavity within a larger crystal—the semiconductor chip. The dot is then bombarded with light from a laser which makes it absorb energy. This energy is then emitted in the form of a photon.

Placing the nanocrystal inside a very small cavity makes the laser light bounce around inside the walls. This speeds up the photon production by the Purcell Effect. One problem is that the photons carrying data information can easily become confused with the laser light. The Sheffield researchers have overcome this by funnelling the photons away from the cavity and inside the chip to separate the two different types of pulse.

In this way, the team have succeeded in making the photon emission rate about 50 times faster than would be possible without using the Purcell Effect. Although this isn't the fastest photon light pulse yet developed, it has a crucial advantage because the photons produced are all identical—an essential quality for many quantum computing applications.

Mark Fox, Professor of Optical Physics at the University of Sheffield, explains: "Using photons to transmit data enables us to use the fundamental laws of physics to guarantee security. It's impossible to measure or 'read' the particle in any way without changing its properties. Interfering with it would therefore spoil the data and sound an alarm."

He added: "Our method also solves a problem that has puzzled scientists for about 20 years—how to use this Purcell Effect to speed up photon production in an efficient way.

"This technology could be used within secure fibre optic telecoms systems, although it would be most useful initially in environments where security is paramount, including governments and national security headquarters." [32]

Controlling photons with a photon

Photons are considered to be ideal information carriers and expected to play important roles in quantum communication and information processing, where quantum mechanics allows for absolutely secure cryptographic key distribution as well as computation much faster than conventional computers. In order to take full advantage of quantum information carried by photons, it is important to make them directly interact with each other for information processing.

However, photons generally do not interact with one another. So it is necessary to mediate such interactions with matter to realize effective photon-photon interaction, but light-matter interaction is usually extremely weak in normal media.

Haruka Tanji-Suzuki and colleagues at the Institute for Laser Science, the University of Electro-Communications, Tokyo, are currently working to develop all-optical quantum devices that are sensitive to a single photon input, such as a single photon switch in which an incoming photon switches the state of another photon.

In order to realize the strong light-matter interaction that is necessary for such devices, Tanji-Suzuki uses a laser-cooled ensemble of 87Rb atoms (~10 uK) trapped within a high-finesse optical resonator (finesse ~50000) in an ultrahigh-vacuum chamber. Notably, in order to switch a photon with a photon in such a system, the researchers use an effect known as 'vacuum-induced transparency' observed recently by Tanji-Suzuki et al., in which an electromagnetic field as weak as a vacuum field (light with no photons) is shown to alter the optical properties of atoms.

"The realization of such all-optical single-photon devices will be a large step towards deterministic multi-mode entanglement generation as well as high-fidelity photonic quantum gates that are crucial for all-optical quantum information processing," says Tanji-Suzuki. [31]

The photoelectric effect in stereo

In the photoelectric effect, a photon ejects an electron from a material. Researchers at ETH have now used attosecond laser pulses to measure the time evolution of this effect in molecules. From their results they can deduce the exact location of a photoionization event.

When a photon hits a material, it can eject an electron from it provided it has enough energy. Albert Einstein found the theoretical explanation of this phenomenon, which is known as the photoelectric effect, in Bern during his "year of wonders" 1905. That explanation was a crucial contribution to the development of quantum mechanics, which was under way at the time, and it earned him the Nobel Prize in Physics in 1921. An international team of physicists led by Ursula Keller at the Institute for Quantum Electronics of the ETH Zurich has now added a new dimension to the experimental investigation of this important effect. Using attosecond laser pulses they were able to measure a tiny time difference in the ejection of the electron from a molecule depending on the position of the electron inside the molecule.

"For quite some time, people have studied the time evolution of the photoelectric effect in atoms", says Ph.D. student Jannie Vos, "but very little has so far been published on molecules." That is mainly due to the fact that molecules are considerably more complex than single atoms. In an atom, the outermost electron moving around the atomic nucleus is essentially catapulted out of its orbit. In a molecule, by contrast, two or more nuclei share the same electron. Where it is located depends on the interplay between the different attractive potentials. Exactly how the photoelectric effect happens under such conditions could only now be studied in detail.

To do so, Keller and her co-workers used carbon monoxide molecules, which consist of two atoms – one carbon and one oxygen atom. Those molecules were exposed to an extreme ultraviolet laser pulse that only lasted for a few attoseconds. (An attosecond is the billionth part of a billionth of a second). The energy of the ultraviolet photons ripped an electron out of the molecules, which subsequently broke up into their constituent atoms. One of those atoms turned into a positively charged ion in the process. Using a special instrument, the researchers then measured the directions in which the electrons and ions flew away. A second laser pulse, which acted as a kind of measuring stick, also allowed them to determine the precise instant at which the electron left the molecule.

"In this way we were able, for the first time, to measure the so-called Stereo Wigner time delay," explains Laura Cattaneo, who works as a postdoctoral researcher in Keller's group. The stereo Wigner time delay measures how much earlier or later an electron leaves the molecule if it is located close to the oxygen atom or to the carbon atom when photoionization occurs. The extremely short laser pulses make it possible to measure that instant to within a few attoseconds. From that information, in turn, it is possible to determine the location of the ionization event inside the molecule to within a tenth of a nanometre. The experimental results agree well with theoretical predictions that describe the most likely position of an electron at the time of photoionization.

Next, the ETH researchers want to take a closer look at larger molecules, starting with the laughing gas N2O. The extra atom in that molecule already makes the theoretical description quite a bit more difficult, but at the same time the physicists hope to obtain new insights, for example into the so-called charge migration inside molecules, which plays an important role in chemical process.

In principle it should even be possible to use attosecond laser pulses not just to study those processes, but also to deliberately steer them and thus to control chemical reactions in detail. Right now, however, such atto-chemistry is still a long way off, as Jannie Vos points out: "In theory that's all very exciting, but a lot remains to be done before we get there." [30]

Core electron topologies in chemical bonding

YNU researchers have solved the age-old mystery of why silicon cannot replace carbon in organic compounds. A new benchmark quantum chemical calculation of C_2, Si_2, and their hydrides reveals a qualitative difference in the topologies of core electron orbitals of organic molecules and their silicon analogues. The researchers propose other elements with carbon's propensity to reshape their core electron nodal structures upon chemical bonding.

Since the discovery of silicon and Wöhler's success in the mid-19th century with synthesizing organic compounds, Wöhler himself was among the first to suggest replacing carbon by silicon in organic compounds. It became clear in the early 20th century that silicon does not have a chemistry similar to carbon, and dreams of silicon-based life only survive in science fiction. We know empirically that carbon has the capability to form a variety of unsaturated compounds, which silicon does not. However, the root cause of why only carbon has this capability has remained a mystery.

Quantum chemical calculations of unprecedented accuracy carried out at YNU reveal that core electrons (which were not supposed to participate in chemical bonding) have a very different role in the unsaturated compounds of carbon and silicon. Carbon has the propensity to alter the topology (nodal structure) of its core electrons, which, for C_2, results in the formation of a torus-like ring in the 1σg orbital formed of C1s electrons (see Figure). Si_2, however, maintains the spherical like core orbitals centered at each atomic site in all its molecules. This flexibility of carbon's core orbitals allows carbon to form a cornucopia of different valence bond structures, whereas silicon is restricted to bond structures orthogonal to the atomic like spherical core orbitals.

The impact of this discovery is far-reaching. Core electrons have thus far been assumed more or less inert, but perhaps it becomes necessary to reassess their contribution to chemical bonding—at least in the case of unsaturated bonds. Finally, the study suggests that other elements, such as nitrogen, phosphorous, and fluorine, exhibit similar flexibility to modify their core electron topologies, and thus, exhibit similarly rich chemistries.

The paper, "Core Electron Topologies in Chemical Compounds: Case Study of Carbon versus Silicon," is published in *Angewandte Chemie International Edition* vol 57(24) on June 6th, 2018. [29]

New optical sensor can determine if molecules are left or right 'handed'

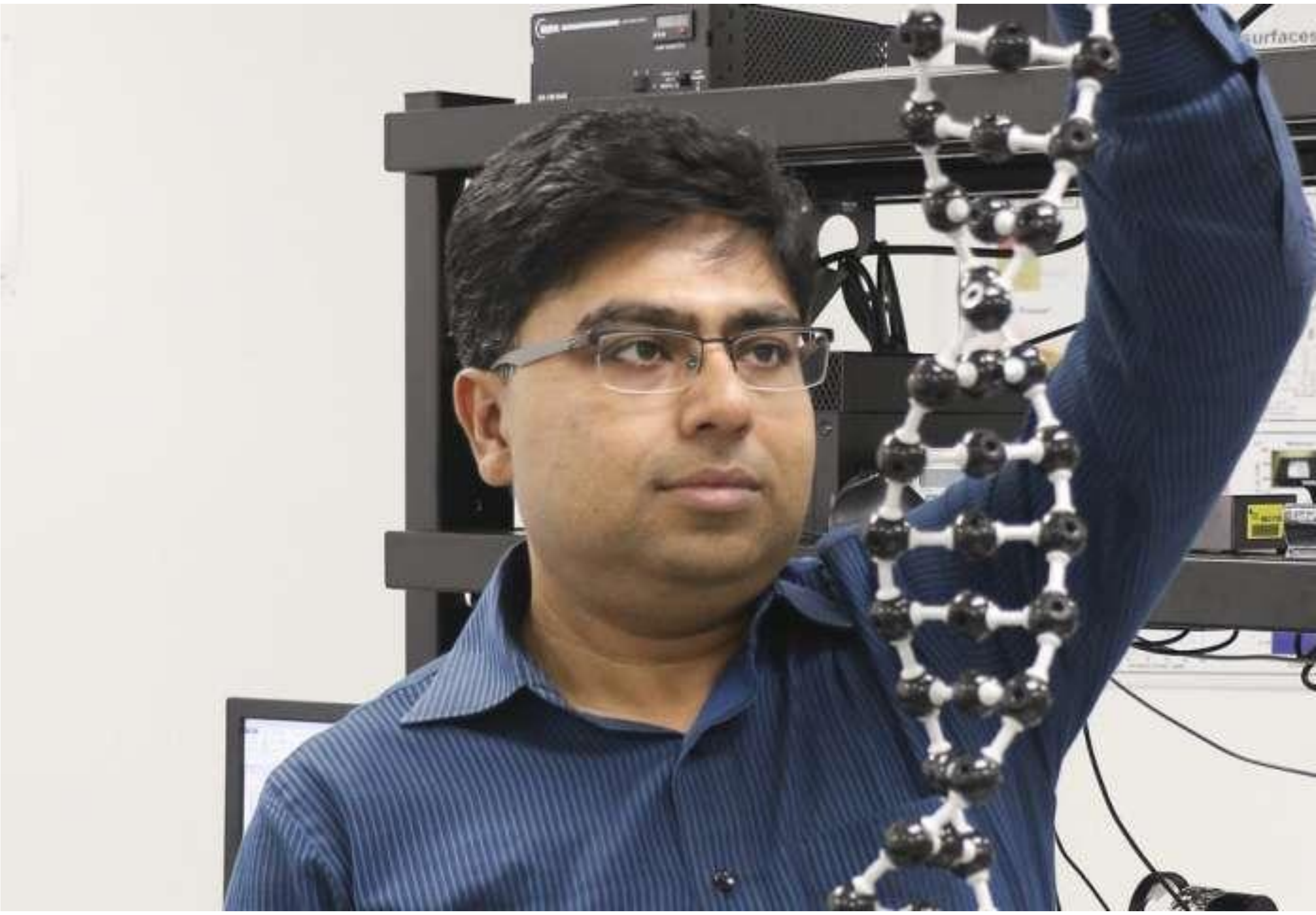
A University of Central Florida team has designed a nanostructured optical sensor that for the first time can efficiently detect molecular chirality—a property of molecular spatial twist that defines its biochemical properties.

Determining chirality is critical for new drug development.

Think of molecules as having little hands. They are not identical, but they serve almost undistinguishable functions. You can grip, pinch, punch and open your hands, regardless of whether you use your left or right hand. But when you get to some functions, such as writing, it matters if you are right-handed or left-handed.

Scientists have struggled to determine if molecules have unique left- or right-hand functions because their physical attributes such as length, weight, density, elasticity, etc. appear to be identical.

UCF's NanoScience Technology Center Associate Professor Debashis Chanda and Ph.D. student Abraham Vazquez-Guardado have figured out a unique way to do it. The interaction between light and the specially designed nanostructure they built creates a strong chiral light field—called superchiral light. Such a nanostructure does not have geometrical chirality yet it creates two opposite light chirality (left or right) on demand. When light and matter's chirality match, just as hand-shaking with our right hand, successful identification happens. Therefore, this rotating light field has the ability to probe and identify any chiral molecule like drugs, proteins or DNAs. The light field lets scientist see the tiny hands, so to speak.



UCF's NanoScience Technology Center Associate Professor Debashis Chanda. Credit: University of Central Florida: Karen Norum

Their findings were recently published in the *Physical Review Letters* journal.

"Chirality detection is vital in the drug-development industry, where newly synthesized chiral drugs also have two-handed strands and always form with the same likeliness during the synthesis process," Chanda said. "But while one chiral strand constitutes the active element in the drug, its opposite can turn out to be toxic or render detrimental side effects. Consequently, pharmacological and toxicological characterization of chirality plays a crucial role in the pharmaceutical drug industry and FDA approval process."

By being able to detect chirality at this level, scientists will have a better way to identify what may be causing bad side effects or perhaps finding places to upload life-saving drugs.

In this preliminary study, the UCF team demonstrated chiral molecule-detection sensitivity that is four times higher compared to the conventional technique, but without the extensive and tedious sample preparation and at much lower sample volume.

The single optical element thin-film chirality sensor, when fabricated based on low cost and large-area nanoimprinting technique, will immensely benefit drug design and protein-conformation identification, both of paramount importance in treating and understanding several diseases, Chanda added. [28]

Tiny defects in semiconductors created 'speed bumps' for electrons—researchers cleared the path

UCLA scientists and engineers have developed a new process for assembling semiconductor devices. The advance could lead to much more energy-efficient transistors for electronics and computer chips, diodes for solar cells and light-emitting diodes, and other semiconductor-based devices.

A paper about the research was published in *Nature*. The study was led by Xiangfeng Duan, professor of chemistry and biochemistry in the UCLA College, and Yu Huang, professor of materials science and engineering at the UCLA Samueli School of Engineering. The lead author is Yuan Liu, a UCLA postdoctoral fellow.

Their method joins a semiconductor layer and a metal electrode layer without the atomic-level defects that typically occur when other processes are used to build semiconductor-based devices. Even though those defects are minuscule, they can trap electrons traveling between the semiconductor and the adjacent metal electrodes, which makes the devices less efficient than they could be. The electrodes in semiconductor-based devices are what enable electrons to travel to and from the semiconductor; the electrons can carry computing information or energy to power a device.

Generally, metal electrodes in semiconductor devices are built using a process called physical vapor deposition. In this process, metallic materials are vaporized into atoms or atomic clusters that then condense onto the semiconductor, which can be silicon or another similar material. The metal atoms stick to the semiconductor through strong chemical bonds, eventually forming a thin film of electrodes atop the semiconductor.

One issue with that process is that the metal atoms are usually different sizes or shapes from the atoms in the semiconductor materials that they're bonding to. As a result, the layers cannot form perfect one-to-one atomic connections, which is why small gaps or defects occur.

"It is like trying to fit one layer of Lego brand blocks onto those of a competitor brand," Huang said. "You can force the two different blocks together, but the fit will not be perfect. With semiconductors, those imperfect chemical bonds lead to gaps where the two layers join, and those gaps could extend as defects beyond the interface and into the materials."

Those defects trap electrons traveling across them, and the electrons need extra energy to get through those spots.

The UCLA method prevents the defects from forming, by joining a thin sheet of metal atop the semiconductor layer through a simple lamination process. And instead of using chemical bonds to hold the two components together, the new procedure uses van der Waals forces—weak electrostatic connections that are activated when atoms are very close to each other—to keep the molecules "attached" to each other. Van der Waals forces are weaker than chemical bonds, but they're strong enough to hold the materials together because of how thin they are—each layer is around 10 nanometers thick or less.

"Even though they are different in their geometry, the two layers join without defects and stay in place due to the van der Waals forces," Huang said.

The research is also the first work to validate a scientific theory that originated in the 1930s. The Schottky-Mott rule proposed the minimum amount of energy electrons need to travel between metal and a semiconductor under ideal conditions.

Using the theory, engineers should be able to select the metal that allows electrons to move across the junction between metal and semiconductor with the smallest amount of energy. But because of those tiny defects that have always occurred during manufacturing, semiconductor devices have always needed electrons with more energy than the theoretical minimum.

The UCLA team is the first to verify the theory in experiments with different combinations of metals and semiconductors. Because the electrons didn't have to overcome the usual defects, they were able to travel with the minimum amount of energy predicted by the Schottky-Mott rule.

"Our study for the first time validates these fundamental limits of metal–semiconductor interfaces," Duan said. "It shows a new way to integrate metals onto other surfaces without introducing defects. Broadly, this can be applied to the fabrication of any delicate material with interfaces that were previously plagued by defects."

For example, besides electrode contacts on semiconductors, it could be used to assemble ultra–energy-efficient nanoscale electronic components, or optoelectronic devices such as solar cells.

The paper's other UCLA authors are graduate students Jian Guo, Enbo Zhu and Sung-Joon Lee, and postdoctoral scholar Mengning Ding. Researchers from Hunan University, China; King Saud University, Saudia Arabia; and Northrop Grumman Corporation also contributed to the study.

The study builds off of nearly a decade of work by Duan and Huang on using van der Waals forces to integrate materials. A study they led, published in *Nature* in March 2018, described their use of van der Waals forces to create a new class of 2-D materials called monolayer atomic crystal molecular superlattices. In an earlier study, which was published in *Nature* in 2010, they described their use of van der Waals forces to build high-speed transistors using graphene. [27]

How to measure quantum behaviour in nanocrystals

A new experiment that tests the limit of how large an object can be before it ceases to behave quantum mechanically has been proposed by physicists in the UK and India. The measurement involves trapping a nanocrystal with light and then measuring its position to see if its behaviour violates the Leggett-Garg inequality – which is a test of the quantum nature of a system. While the team is keen to have their proposal tested in the lab, not all physicists believe that it could be implemented.

A crucial important feature of quantum mechanics is Heisenberg's uncertainty principle. Whereas in classical mechanics, both the position and momentum of an object can be determined at arbitrarily high precision at the same time, the principle states that it is impossible to measure both position and momentum in quantum mechanics beyond a certain degree of accuracy. Furthermore, the more you know about one measurement, the more uncertain the other becomes.

The proposed experiment tests how large an object can be before the rules of quantum measurement do not apply. Sougato Bose of University College London and colleagues at the Bose Institute and the SN Bose National Centre for Basic Sciences in Kolkata studied the behaviour of a quantum linear harmonic oscillator, which bears a strong resemblance to its classical counterpart. "The uncertainties in position and momentum are both as low as they can get," explains Bose.

Caught in a trap

Bose and colleagues have done an analysis of a hypothetical experiment involving a cooled nanocrystal oscillating in a trap that is created by an optical harmonic potential. The experiment can detect which side of the trap is occupied by the nanocrystal at any instant by focusing a beam of light on one side of the trap. The light causes fluorescence in the nanocrystal, and if fluorescent light is not detected it can be concluded that the nanocrystal is in the other side of the trap – a procedure called negative result measurement.

The experiment begins with a position measurement and then the system evolves for about a microsecond before the position is measured again. If the nanocrystal is a purely classical object, the researchers reasoned, a negative result in the first measurement would not affect the nanocrystal's position in the second measurement. This is because the nanocrystal would have been in the other half of the trap, and therefore would not have interacted with the beam. If there were quantum uncertainty in the position and momentum of the nanocrystal, however, the null result at the start of the experimental run could still affect its measured position at the second measurement. This is because the nanocrystal's position would not be well defined until it was actually measured. Therefore, the nanocrystal could have interacted with the light beam in one half of the trap despite not being detected there.

The team calculated the Leggett-Garg inequality for the systems. This is analogous to Bell's inequality, which is famously used to rule out hidden variable explanations of quantum mechanics. Bell's inequality quantifies the maximum statistical correlation that is possible between properties of independent particles separated by distances so great that information could not pass between them without travelling faster than light.

The Leggett-Garg inequality uses similar reasoning to calculate the maximum statistical correlation between two results that had not influenced each other. Violation of the inequality, therefore, would show that the nanocrystal's state could be influenced by the earlier negative result, and therefore that the nanocrystal is a quantum, rather than a classical, object. Crunching the numbers, the researchers calculated that it should be feasible to detect non-classical behaviour in objects with masses up to around 10^{10} amu or about 10^{-14} g. Bose says experimentalists are planning to test this.

"That's pretty tricky"

Bose and colleagues report their results in *Physical Review Letters*. Theoretical physicist Clive Emary of Newcastle University in the UK says "if someone goes on to do these experiments, we'll all look back and say it was a significant paper". He cautions, however, that: "it looks like it needs very high time resolution to do the proposed measurements and in my experience that looks like the kind of thing you propose to experimentalists and they come back and say 'that's pretty tricky'." Quantum information theorist Renato Renner of ETH Zurich is more optimistic: "We can now do experiments in quantum technologies that, five or ten years ago, people would have said were not possible," he says, "I'm optimistic that most quantum experiments we can think of will at some point be feasible."

Emary and Renner agree, however, that, whereas in Bell's inequality, the two measurements are isolated classically by the fact that nothing that can travel faster than the speed of light, the Leggett-Garg inequality relies on proving there can be no classical explanation for the earlier measurement disturbing the later one. "That's just not possible," says Emary, "There's always a loophole: you could disturb the air molecules in the lab next door and they could come back and disturb your system, for example." [26]

Detecting the birth and death of a phonon

Phonons are discrete units of vibrational energy predicted by quantum mechanics that correspond to collective oscillations of atoms inside a molecule or a crystal. When such vibrations are produced by light interacting with a material, the vibrational energy can be transferred back and forth between individual phonons and individual packets of light energy, the photons. This process is called the Raman effect.

In a new study, the lab of Christophe Galland at EPFL's Institute of Physics has developed a technique for measuring, in real time and at room-temperature, the creation and destruction of individual phonons, opening up exciting possibilities in various fields such as spectroscopy and quantum technologies.

The technique uses ultra-short laser pulses, which are bursts of light that last less than 10^{-13} seconds (a fraction of a trillionth of a second). First, one such pulse is shot onto a diamond crystal to excite a single phonon inside it. When this happens, a partner photon is created at a new wavelength through the Raman effect and is observed with a specialized detector, heralding the success of the preparation step.

Second, to interrogate the crystal and probe the newly created phonon, the scientists fire another laser pulse into the diamond. Thanks to another detector, they now record photons that have reabsorbed the energy of the vibration. These photons are witnesses that the phonon was still alive, meaning that the crystal was still vibrating with exactly the same energy.

This is in strong contradiction with our intuition: we are used to seeing vibrating objects progressively lose their energy over time, like a guitar string whose sound fades away. But in quantum mechanics this is "all or nothing": the crystal either vibrates with a specific energy or it is in its resting state; there is no state allowed in between. The decay of the phonon over time is therefore observed as a decrease of the probability of finding it in the excited state instead of having jumped down to the rest state.

Through this approach, the scientists could reconstruct the birth and death of a single phonon by analyzing the output of the two photon detectors. "In the language of quantum mechanics, the act of measuring the system after the first pulse creates a well-defined quantum state of the phonon, which is probed by the second pulse," says Christophe Galland. "We can therefore map the phonon decay with very fine time resolution by changing the time delay between the pulses from zero to a few trillionths of a second (10^{-12} seconds or picoseconds)."

The new technique can be applied to many different types of materials, from bulk crystals down to single molecules. It can also be refined to create more exotic vibrational quantum states, such as entangled states where energy is "delocalized" over two vibrational modes. And all this can be performed in ambient conditions, highlighting that exotic quantum phenomena may occur in our daily life—we just need to watch very fast. [25]

Sustainable solvent platform for photon upconversion increases solar utilization efficiency

The conversion of solar energy into electricity is currently restricted by a concept known as the Shockley-Quesser limit. This limitation allows only photons that have higher energies than those of the bandgap to be used, while those with lower energies are wasted. In an effort to obtain a solution to this problem and make solar energy conversion more efficient, researchers have developed a process of converting photons with lower energies into ones with higher energies, called photon upconversion.

In the past decade, a method of photon upconversion that uses triplet-triplet annihilation (TTA) of organic molecules has drawn attention because it is presently the only method applicable to weak light such as sunlight. This method combines two kinds of organic molecules or chromophores, a sensitizer and an emitter. The sensitizer will absorb a photon and convert it to its excited triplet state. The excitation energy is then transferred to the emitter. When two emitters with excitation energy collide, one will convert to its lowest excited singlet state and release an upconverted photon that can be harvested for energy conversion.

While many studies into photon upconversion have been carried out in organic solvents, their practical use is limited due to the high vapor pressures, vapor toxicity, flammability, and lack of thermal stability of the solvent mixtures. Multiple approaches have been proposed to overcome these limitations, including the use of viscous fluidic media like ionic liquids that have low vapor pressures and high thermal stability. Ionic liquids are also limited in practicality, however, due to the relatively high costs of starting materials and synthetic processes, as well as their poor biodegradability.

To fundamentally resolve these previous problems, scientists at Tokyo Tech developed a TTA photon upconversion using a new class of liquids known as deep eutectic solvents (DESs). DESs are a potential alternative to ionic fluids, because they possess desirable properties similar to those of ionic fluids and can be created through a simple mixing of two substances, a hydrogen bond donor and a hydrogen bond acceptor, without the need for synthetic processes. The starting substances for the generation of DESs are also generally much cheaper, safer and more biodegradable than those needed for the creation of ionic liquids, making them an ideal alternative.

Photographs of the DESs and photon upconverters are shown in Fig. 1. The prepared DES was optically transparent and colorless and used as the solvent for the sensitizer and emitter chromophores. The sample converts weak incident green light (wavelength: 532 nm; power: 2-3 mW) into blue emission (wavelength: ~440 nm). The expected high thermal stability was confirmed by the absence of ignition and fuming during exposure to a burner flame for 1 min.

Notably, the photon upconversion quantum yield of the samples reached 0.21 (where the maximum quantum yield is defined as 0.5; one higher-energy photon is created by using two lower-energy photons at maximum in photon upconversion). This corresponds to the upconversion quantum efficiency of 42 percent (whose maximum is defined as 100 percent). This is a relatively high efficiency.

The scientists developed a novel material platform for TTA photon upconversion using cheaper, less toxic, and thermally stable DESs. This achievement is considered as an important landmark for the realization of practical application of photon upconversion technology. [24]

Graphene single photon detectors

Considerable interest in new single-photon detector technologies has been scaling in this past decade. Nowadays, quantum optics and quantum information applications are, among others, one of the main precursors for the accelerated development of single-photon detectors. Capable of sensing an increase in temperature of an individual absorbed photon, they can be used to help us study and understand, for example, galaxy formation through the cosmic infrared background, observe entanglement of superconducting qubits or improve quantum key distribution methods for ultra-secure communications.

Current detectors are efficient at detecting incoming photons that have relatively high energies, but their sensitivity drastically decreases for low frequency, low energy photons. In recent years, graphene has shown to be an exceptionally efficient photo-detector for a wide range of the electromagnetic spectrum, enabling new types of applications for this field.

Thus, in a recent paper published in the journal Physical Review Applied, and highlighted in APS Physics, ICFO researcher and group leader Prof. Dmitri Efetov, in collaboration with researchers from Harvard University, MIT, Raytheon BBN Technologies and Pohang University of Science and Technology, have proposed the use of graphene-based Josephson junctions (GJJs) to detect single photons in a wide electromagnetic spectrum, ranging from the visible down to the low end of radio frequencies, in the gigahertz range.

In their study, the scientists envisioned a sheet of graphene that is placed in between two superconducting layers. The so created Josephson junction allows a supercurrent to flow across the graphene when it is cooled down to 25 mK. Under these conditions, the heat capacity of the graphene is so low, that when a single photon hits the graphene layer, it is capable of heating up the electron bath so significantly, that the supercurrent becomes resistive – overall giving rise to an easily detectable voltage spike across the device. In addition, they also found that this effect would occur almost instantaneously, thus enabling the ultrafast conversion of absorbed light into electrical signals, allowing for a rapid reset and readout.

The results of the study confirm that we can expect a rapid progress in integrating graphene and other 2-D materials with conventional electronics platforms, such as in CMOS-chips, and shows a promising path towards single-photon-resolving imaging arrays, quantum information processing applications of optical and microwave photons, and other applications that would benefit from the quantum-limited detection of low-energy photons. [23]

Engineers develop key mathematical formula for driving quantum experiments

Since he was a graduate student, Washington University in St. Louis systems engineer Jr-Shin Li has provided specific mathematical information to experimentalists and clinicians who need it to perform high-resolution magnetic resonance applications, such as body MRIs for medical diagnosis or spectroscopy for uncovering protein structures. Now, after more than a decade of work, he has developed a formula that researchers can use to generate that information themselves.

Li, the Das Family Career Development Distinguished Associate Professor in the School of Engineering & Applied Science, and his collaborators have derived a mathematical formula to design broadband pulse sequences to excite a population of nuclear spins over a wide band of frequencies. Such a broadband excitation leads to enhanced signal or sensitivity in diverse quantum experiments across fields from protein spectroscopy to quantum optics.

The research, the first to find that designing the pulse can be done analytically, was published in Nature Communications Sept. 5.

"This design problem is traditionally done by purely numerical optimization," Li said. "Because one has to design a common input—a magnetic field to excite many, many particles—the problem is challenging. In many cases in numerical optimization, the algorithms fail to converge or take enormous amounts of time to get a feasible solution."

For more than a decade, Li has sought a better way for pulse design using the similarity between spins and springs by applying numerical experiments. Spin is a form of angular momentum carried by elementary particles. Spin systems are nonlinear and difficult to work with, Li said, while spring systems, or harmonic oscillators, are linear and easier to work with. While a doctoral student at Harvard University, Li found a solution by projecting the nonlinear spin system onto the linear spring system, but was unable to prove it mathematically until recently.

"We have very rigorous proof that such a projection from nonlinear to linear is valid, and we also have done a lot of numerical simulations to demonstrate the discovery," Li said. "My collaborator, Steffan Glaser (of the Technische Universität Munich), has been in this field of NMR spectroscopy for more than 20 years, and he is confident that if the quantum pulses perform well in computer simulations, they may perform the same in experimental systems."

The team plans to conduct various experiments in magnetic resonance to verify the analytical invention.

The theoretical work opens up new avenues for pulse sequence design in quantum control. Li plans to create a website where collaborators can enter their parameter values to generate the pulse formula they will need in their quantum experiments. [22]

New tool for characterizing quantum simulators

Physicists are developing quantum simulators, to help solve problems that are beyond the reach of conventional computers. However, they first need new tools to ensure that the simulators work properly. Innsbruck researchers around Rainer Blatt and Christian Roos, together with researchers from the Universities of Ulm and Strathclyde, have now implemented a new technique in the laboratory that can be used to efficiently characterize the complex states of quantum simulators. The technique, called matrix product state tomography, could become a new standard tool for characterizing quantum simulators.

Many phenomena in the quantum world cannot be investigated directly in the laboratory, and even supercomputers fail when trying to simulate them. However, scientists are now able to control various quantum systems in the laboratory very precisely and these systems can be used to simulate other quantum systems. Such Quantum Simulators are therefore considered to be one of the first concrete applications of the second quantum revolution.

However, the characterization of large quantum states, which is necessary to guide the development of large-scale quantum simulators, proves to be difficult. The current gold standard for quantum-state characterization in the laboratory - quantum-state tomography - is only suitable for small quantum systems composed of a handful of quantum particles. Researchers from the Institute of Experimental Physics at the University of Innsbruck and the Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences have now established a new method in the laboratory that can be used to efficiently characterize large quantum states.

A collaborative effort

In ion traps, charged atoms (ions) are cooled to temperatures close to absolute zero and manipulated with the aid of lasers. Such systems represent a promising approach to performing quantum simulations that can go beyond the capabilities of modern supercomputers. The Innsbruck quantum physicists are amongst the world leaders in this field and can currently entangle 20 or more ions in their traps. In order to fully characterize such large quantum systems, they need new methods. For this, theorists around Martin Plenio from the University of Ulm, Germany, came to their aid. In 2010, the Plenio team proposed a new method for the characterization of complex quantum states called matrix-product-state tomography. Using this method, the state of a group of entangled quantum particles can be estimated precisely without the effort increasing dramatically as the number of particles in the group is increased. In collaboration with the teams around Martin Plenio from Ulm and Andrew Daley from the University of Strathclyde in Scotland, the Innsbruck experimental physicists around Christian Roos, Ben Lanyon and Christine Maier have now implemented this procedure in the laboratory.

More efficient measurements

As a test case, the physicists built a quantum simulator with up to 14 quantum bits (atoms), that was first prepared in a simple initial state without quantum correlations. Next, the researchers entangled the atoms with laser light and observed the dynamical propagation of entanglement in the system. "With the new method, we can determine the quantum state of the whole system by measuring only a small fraction of the system properties," says START prize winner Ben Lanyon. The theorists around Martin Plenio took the characterization of the global quantum state from the measured data: "The method is based on the fact that we can theoretically describe locally-distributed entanglement well and can now also measure it in the laboratory."

When the work group of Rainer Blatt realized the first quantum byte in 2005, more than 6,000 measurements were required for the characterization of the quantum state, taken over a period of ten hours. The new method requires only 27 measurements to characterise the same size system, taken over around 10 minutes. "We were able to show that this method can be used to identify large and complex quantum states efficiently," says Christine Maier, a team member from Innsbruck. Now the scientists want to further develop the algorithms so that they can also be used flexibly by other research groups.

New gold standard

The new method allows the complete characterization of systems containing large numbers of correlated quantum particles and thus provides a comparison option for quantum simulations. "We can use the new technique to calibrate quantum simulators, by comparing the states that we find in the lab with the ones expected from analytical calculations," explains Christian Roos. "Then we know if the simulator does what we want." The new method offers physicians a tool for many applications and could become a new standard for quantum simulations. [21]

Flip-flop qubits: Radical new quantum computing design invented

Engineers at Australia's University of New South Wales have invented a radical new architecture for quantum computing, based on novel 'flip-flop qubits', that promises to make the large-scale manufacture of quantum chips dramatically cheaper - and easier - than thought possible.

The new chip design, detailed in the journal Nature Communications, allows for a silicon quantum processor that can be scaled up without the precise placement of atoms required in other approaches. Importantly, it allows quantum bits (or 'qubits') - the basic unit of information in a quantum computer - to be placed hundreds of nanometres apart and still remain coupled.

The design was conceived by a team led by Andrea Morello, Program Manager in UNSW-based ARC Centre of Excellence for Quantum Computation and Communication Technology (CQC2T) in Sydney, who said fabrication of the new design should be easily within reach of today's technology.

Lead author Guilherme Tosi, a Research Fellow at CQC2T, developed the pioneering concept along with Morello and co-authors Fahd Mohiyaddin, Vivien Schmitt and Stefanie Tenberg of CQC2T, with collaborators Rajib Rahman and Gerhard Klimeck of Purdue University in the USA.

"It's a brilliant design, and like many such conceptual leaps, it's amazing no-one had thought of it before," said Morello.

"What Guilherme and the team have invented is a new way to define a 'spin qubit' that uses both the electron and the nucleus of the atom. Crucially, this new qubit can be controlled using electric signals, instead of magnetic ones. Electric signals are significantly easier to distribute and localise within an electronic chip."

Tosi said the design sidesteps a challenge that all spin-based silicon qubits were expected to face as teams begin building larger and larger arrays of qubits: the need to space them at a distance of only 10-20 nanometres, or just 50 atoms apart.

"If they're too close, or too far apart, the 'entanglement' between quantum bits - which is what makes quantum computers so special - doesn't occur," Tosi said.

Researchers at UNSW already lead the world in making spin qubits at this scale, said Morello. "But if we want to make an array of thousands or millions of qubits so close together, it means that all the control lines, the control electronics and the readout devices must also be fabricated at that nanometric scale, and with that pitch and that density of electrodes. This new concept suggests another pathway."

At the other end of the spectrum are superconducting circuits - pursued for instance by IBM and Google - and ion traps. These systems are large and easier to fabricate, and are currently leading the way in the number of qubits that can be operated. However, due to their larger dimensions, in the long run they may face challenges when trying to assemble and operate millions of qubits, as required by the most useful quantum algorithms.

"Our new silicon-based approach sits right at the sweet spot," said Morello, a professor of quantum engineering at UNSW. "It's easier to fabricate than atomic-scale devices, but still allows us to place a million qubits on a square millimetre."

In the single-atom qubit used by Morello's team, and which Tosi's new design applies, a silicon chip is covered with a layer of insulating silicon oxide, on top of which rests a pattern of metallic electrodes that operate at temperatures near absolute zero and in the presence of a very strong magnetic field.

At the core is a phosphorus atom, from which Morello's team has previously built two functional qubits using an electron and the nucleus of the atom. These qubits, taken individually, have demonstrated world-record coherence times.

Tosi's conceptual breakthrough is the creation of an entirely new type of qubit, using both the nucleus and the electron. In this approach, a qubit '0' state is defined when the spin of the electron is down and the nucleus spin is up, while the '1' state is when the electron spin is up, and the nuclear spin is down.

"We call it the 'flip-flop' qubit," said Tosi. "To operate this qubit, you need to pull the electron a little bit away from the nucleus, using the electrodes at the top. By doing so, you also create an electric dipole."

"This is the crucial point," adds Morello. "These electric dipoles interact with each other over fairly large distances, a good fraction of a micron, or 1,000 nanometres.

"This means we can now place the single-atom qubits much further apart than previously thought possible," he continued. "So there is plenty of space to intersperse the key classical components such as interconnects, control electrodes and readout devices, while retaining the precise atom-like nature of the quantum bit."

Morello called Tosi's concept as significant as Bruce Kane seminal 1998 paper in Nature. Kane, then a senior research associate at UNSW, hit upon a new architecture that could make a silicon-based quantum computer a reality - triggering Australia's race to build a quantum computer.

"Like Kane's paper, this is a theory, a proposal - the qubit has yet to be built," said Morello. "We have some preliminary experimental data that suggests it's entirely feasible, so we're working to fully demonstrate this. But I think this is as visionary as Kane's original paper."

Building a quantum computer has been called the 'space race of the 21st century' - a difficult and ambitious challenge with the potential to deliver revolutionary tools for tackling otherwise impossible calculations, with a plethora of useful applications in healthcare, defence, finance, chemistry and materials development, software debugging, aerospace and transport. Its speed and power lie in the fact that quantum systems can host multiple 'superpositions' of different initial states, and in the spooky 'entanglement' that only occurs at the quantum level the fundamental particles.

"It will take great engineering to bring quantum computing to commercial reality, and the work we see from this extraordinary team puts Australia in the driver's seat," said Mark Hoffman, UNSW's Dean of Engineering. "It's a great example of how UNSW, like many of the world's leading research universities, is today at the heart of a sophisticated global knowledge system that is shaping our future."

The UNSW team has struck a A$83 million deal between UNSW, telco giant Telstra, Australia's Commonwealth Bank and the Australian and New South Wales governments to develop, by 2022, a 10-qubit prototype silicon quantum integrated circuit - the first step in building the world's first quantum computer in silicon.

In August, the partners launched Silicon Quantum Computing Pty Ltd, Australia's first quantum computing company, to advance the development and commercialisation of the team's unique technologies. The NSW Government pledged A$8.7 million, UNSW A$25 million, the Commonwealth Bank A$14 million, Telstra A$10 million and the Federal Government A$25 million. [20]

New quantum memory device small enough to fit on a chip

A team of researchers from the U.S. and Italy has built a quantum memory device that is approximately 1000 times smaller than similar devices—small enough to install on a chip. In their paper published in the journal Science, the team describes building the memory device and their plans for adding to its functionality.

Scientists have been working steadily toward building quantum computers and networks, and have made strides in both areas in recent years. But one inhibiting factor is the construction of quantum memory devices. Such devices have been built, but until now, they have been too large to put on a chip, a requirement for practical applications. In this new effort, the researchers report developing a quantum memory device that is not only small enough to fit on a chip, but is also able to retrieve data on demand.

The device is very small, approximately 10 by 0.7 micrometers and has an odd shape, like a Toblerone candy bar—long and thin with a notched triangular shape, with mirrors on either end. It is made of yttrium orthovanadate with small amounts of neodymium, which form a cavity. These cavities in turn hold a crystal cavity that traps single photons encoding data information (zero, one or both).

To operate the device, the researchers fired laser pulses at it, causing photons to assemble in the comb, which forced them to be absorbed—the configuration also caused the photons to emerge from the comb after 75 nanoseconds. During the time period when the photons were absorbed, the researchers fired dual laser pulses at the comb to delay the reemergence of the photons for 10 nanoseconds, which allowed for on-demand retrieval of data. During the time period when the photons were held, they existed as dual pulses—early and late.

To show that the device was actually storing data information, the team compared the wavefunction of the photons both before and after storage and found them to be virtually unchanged, meaning they still held their zero, one or both state—it had not been destroyed, which meant the device was truly a quantum memory device. [19]

How to store data on magnets the size of a single atom

The cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation.

Magnetism is useful in many ways, and the magnetic memory effect appears even at the atomic level.

There is an adage that says that data will expand to fill all available capacity. Perhaps ten or 20 years ago, it was common to stockpile software programs, MP3 music, films and other files, which may have taken years to collect. In the days when hard disk drives offered a few tens of gigabytes of storage, running out of space was almost inevitable.

Now that we have fast broadband internet and think nothing of downloading a 4.7 gigabyte DVD, we can amass data even more quickly. Estimates of the total amount of data held worldwide are to rise from 4.4 trillion gigabytes in 2013 to 44 trillion gigabytes by 2020. This means that we are generating an average of 15m gigabytes per day. Even though hard disk drives are now measured in thousands of gigabytes rather than tens, we still have a storage problem.

Research and development is focused on developing new means of data storage that are more dense and so can store greater amounts of data, and do so in a more energy efficient way. Sometimes this involves updating established techniques: recently IBM announced a new magnetic tape technology that can store 25 gigabytes per square inch, a new world record for the 60-year-old technology. While current magnetic or solid-state consumer hard drives are more dense at around 200 gigabytes per square inch, magnetic tapes are still frequently used for data back-up.

However, the cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation.

The quest for atomic magnets

Current magnetic data storage technologies – those used in traditional hard disks with spinning platters, the standard until a few years ago and still common today – are built using "top-down" methods. This involves making thin layers from a large piece of ferromagnetic material, each containing the many magnetic domains that are used to hold data. Each of these magnetic domains is made of a large collection of magnetised atoms, whose magnetic polarity is set by the hard disk's read/write head to represent data as either a binary one or zero.

An alternative "bottom-up" method would involve constructing storage devices by placing individual atoms or molecules one by one, each capable of storing a single bit of information. Magnetic domains retain their magnetic memory due to communication between groups of neighbouring magnetised atoms.

Single-atom or single-molecule magnets on the other hand do not require this communication with their neighbours to retain their magnetic memory. Instead, the memory effect arises from quantum mechanics. So because atoms or molecules are much, much smaller than the magnetic domains currently used, and can be used individually rather than in groups, they can be packed more closely together which could result in an enormous increase in data density.

Working with atoms and molecules like this is not science fiction. Magnetic memory effects in single-molecule magnets (SMMs) were first demonstrated in 1993, and similar effects for singleatom magnets were shown in 2016.

Raising the temperature

The main problem standing in the way of moving these technologies out of the lab and into the mainstream is that they do not yet work at ambient temperatures. Both single atoms and SMMs require cooling with liquid helium (at a temperature of –269°C), an expensive and limited resource. So research effort over the last 25 years has concentrated on raising the temperature at which magnetic hysteresis – a demonstration of the magnetic memory effect – can be observed. An important target is –196°C, because this is the temperature that can be achieved with liquid nitrogen, which is abundant and cheap.

It took 18 years for the first substantive step towards raising the temperature in which magnetic memory is possible in SMMs – an increase of 10°C achieved by researchers in California. But now our research team at the University of Manchester’s School of Chemistry have achieved magnetic hysteresis in a SMM at –213 °C using a new molecule based on the rare earth element dysprosocenium, as reported in a letter to the journal Nature. With a leap of 56°C, this is only 17°C away from the temperature of liquid nitrogen.

Future uses

There are other challenges, however. In order to practically store individual bits of data, molecules must be fixed to surfaces. This has been demonstrated with SMMs in the past, but not for this latest generation of high-temperature SMMs. On the other hand, magnetic memory in single atoms has already been demonstrated on a surface.

Optical control of magnetic memory—New insights into fundamental mechanisms

This is an important clue for our theoretical understanding of optically controlled magnetic data storage media. The findings are published at August 25th in the journal Scientific Reports.

The demands placed on digital storage media are continuously increasing. Rapidly increasing quantities of data and new technological applications demand memory that can store large amounts of information in very little space and permit this information to be utilised dependably with high access speeds.

Re-writeable magnetic data storage devices using laser light appear to have especially good prospects. Researchers have been working on this new technology for several years. "However, there are still unresolved questions about the fundamental mechanisms and the exact manner in which optically controlled magnetic storage devices operate", says Dr. Florian Kronast, assistant head of the Materials for Green Spintronics department at the Helmholtz-Zentrum Berlin (HZB).

A research team led by him has now succeeded in making an important step toward better understanding of this very promising storage technology. The scientists were able to empirically establish for the first time that the warming of the storage material by the energy of the laser light plays an instrumental role when toggling the magnetisation alignments and that the change in the material only takes place under certain conditions.

Making precise measurements in tiny laser spots

The HZB scientists together with those of Freie Universität Berlin and Universität Regensburg studied the microscopic processes at extremely high resolution while irradiating a thin layer of magnetic material using circularly polarised laser light. To do this, they directed the light of an infrared laser onto a nanometre-thick layer of alloy made from the metals terbium and iron (TbFe). What was special about the experimental set-up was that the narrowly focussed spot of laser light had a diameter of only three microns. "That is far less than was usual in prior experiments", says HZB scientist Ashima Arora, first author of the study. And it provided the researchers with unsurpassed detail resolution for studying the phenomena. The images of the magnetic domains in the alloy that the team created with the help of X-rays from the BESSY II synchrotron radiation source revealed fine features that themselves were only 30 nanometres in size.

The crucial thing occurs in the boundary ring

The results of the measurements prove that a ring-shaped region forms around the tiny laser spot and separates the two magnetically contrasting domains from one another. The extant magnetisation pattern inside the ring is completely erased by the thermal energy of the laser light. Outside the ring, however, it remains in its original state. Within the boundary zone itself, a temperature distribution arises that facilitates a change in magnetisation by displacing the domain boundaries. "It is only there that the toggling of magnetic properties can proceed, permitting a device to store re-writeable data", explains Arora.

Surprising influence of the layer thickness

"These new insights will assist in the development of optically controlled magnetic storage devices having the best possible properties," in the view of Kronast. An additional effect contributes to better understanding the physical processes that are important in this phenomenon, which researchers at HZB unexpectedly observed for the first time. The way the toggling of the magnetisations happens is highly dependent on the layer thickness of the material irradiated by the laser. It changes over an interval of 10 to 20 nanometres thickness.

"This is a clear indication that two contrasting mechanisms are involved and compete with one another", Kronast explains. He and his team suspect two complex physical effects for this. To confirm their suspicions, though, further empirical and theoretical studies are necessary. [17]

Photosensitive perovskites change shape when exposed to light

A crystalline material that changes shape in response to light could form the heart of novel lightactivated devices. Perovskite crystals have received a lot of attention for their efficiency at converting sunlight into electricity, but new work by scientists at KAUST shows their potential uses extend far beyond the light-harvesting layer of solar panels.

Photostriction is the property of certain materials to undergo a change in internal strain, and therefore shape, with exposure to light. Organic photostrictive materials offer the greatest shape change so far reported in response to light—a parameter known as their photostrictive coefficient—but their response is slow and unstable under ambient conditions.

KAUST electrical engineer Jr-Hau He and his colleagues have looked for photostriction in a new family of materials, the perovskites. "Perovskites are one of the hottest optical materials," says He. His work now shows there's more to their interesting optical properties than solar energy harvesting. The researchers tested a perovskite called MAPbBr3 and revealed it had strong and robust photostriction behavior.

To extensively test the material's photostriction capabilities, the team developed a new method. They used Raman spectroscopy, which probes the molecular vibrations within the structure. When bathed in light, photostriction alters the internal strain in the material, which then shifts the internal pattern of vibrations. By measuring the shift in the Raman signal when the material was placed under mechanical pressure, the team could calibrate the technique and so use it to quantify the effect of photostriction.

"We demonstrated that in situ Raman spectroscopy with confocal microscopy is a powerful characterization tool for conveniently measuring intrinsic photoinduced lattice deformation," says Tzu-Chiao Wei, a member of the team. "The same approach could be applied to measure photostriction in other materials," he adds.

The perovskite material proved to have a significant photostriction coefficient of 1.25%. The researchers also showed that the perovskite's photostriction was partly due to the photovoltaic effect—the phenomenon at the heart of most solar cell operation. The spontaneous generation of positive and negative charges when the perovskite is bathed in light polarizes the material, which induces a movement in the ions the material is made from.

The robust and stable photostriction of perovskite makes it useful for a range of possible devices, says Wei. "We will use this material to fabricate next-generation optoelectronic devices, including wireless remote switchable devices and other light-controlled applications," he says. [16]

Conformal metasurface coating eliminates crosstalk and shrinks waveguides

The properties of materials can behave in funny ways. Tweak one aspect to make a device smaller or less leaky, for example, and something else might change in an undesirable way, so that engineers play a game of balancing one characteristic against another. Now a team of Penn State electrical engineers have a way to simultaneously control diverse optical properties of dielectric waveguides by using a two-layer coating, each layer with a near zero thickness and weight.

"Imagine the water faucet in your home, which is an essential every-day device," said Douglas H. Werner, John L. and Genevieve H. McCain Chair Professor of Electrical Engineering. "Without pipes to carry the water from its source to the faucet, the device is worthless. It is the same with 'waveguides.' They carry electromagnetic or optical signals from the source to the device—an antenna or other microwave, millimeter-wave or terahertz device. Waveguides are an essential component in any electromagnetic or optical system, but they are often overlooked because much of the focus has been on the devices themselves and not the waveguides."

According to Zhi Hao Jiang, former postdoctoral fellow at Penn State and now a professor at Southeast University, Nanjing, China, metasurface coatings allow researchers to shrink the diameter of waveguides and control the waveguiding characteristics with unprecedented flexibility.

The researchers developed a material that is so thin it is almost 2-dimensional, with characteristics that manipulate and enhance properties of the waveguide.

They developed and tested two conformal coatings, one for guiding the signal and one to cloak the waveguide. They created the coatings by judiciously engineering the patterning on the surfaces to enable new and transformative waveguide functionality. The coatings are applied to a rod-shaped, Teflon waveguide with the guiding layer touching the Teflon and the cloaking layer on the outside.

This quasi 2-dimensional conformal coating that is configured as a cloaking material can solve the crosstalk and blockage problem. Dielectric waveguides are not usually used singly, but in bundles. Unfortunately, conventional waveguides leak, allowing the signal from one waveguide to interfere with those located nearby.

The researchers also note in today's (Aug. 25) issue of Nature Communications that "the effectiveness of the artificial coating can be well maintained for waveguide bends by properly matching the dispersion properties of the metasurface unit cells." Although the coating can be applied to a bend in the waveguide, the waveguide cannot be bent after the coating is applied.

Improving the properties of the waveguide to carefully control polarization and other attributes allows the waveguides to be smaller, and alleviating crosstalk allows these smaller waveguides to be more closely bundled. Smaller waveguides more closely bundled could lead to increased miniaturization.

"In terms of applications these would include millimeter-wave/terahertz/infrared systems for sensing, communications, and imaging that need to manipulate polarization, squeeze signals through waveguides with a smaller cross-section, and/or require dense deployment of interconnected components," said Jiang.

Also working on this project was Lei Kang, research associate in electrical engineering, Penn State. [15]

A nano-roundabout for light

Just like in normal road traffic, crossings are indispensable in optical signal processing. In order to avoid collisions, a clear traffic rule is required. A new method has now been developed at TU Wien to provide such a rule for light signals. For this purpose, the two glass fibers were coupled at their intersection point to an optical resonator, in which the light circulates and behaves as in a roundabout. The direction of circulation is defined by a single atom coupled to the resonator. The atom also ensures that the light always leaves the roundabout at the next exit. This rule is still valid even if the light consists merely of individual photons. Such a roundabout will consequently be installed in integrated optical chips - an important step for optical signal processing.

Signal processing using light instead of electronics

The term "optical circulators" refers to elements at the intersection point of two mutually perpendicular optical fibers which direct light signals from one fiber to the other, so that the direction of the light always changes, for example, by 90° clockwise.

"These components have long been used for freely propagating light beams," says Arno Rauschenbeutel from the Vienna Center for Quantum Science and Technology at the Institute of Atomic and Subatomic Physics of TU Wien. "Such optical circulators are mostly based on the socalled Faraday effect: a strong magnetic field is applied to a transparent material, which is located between two polarization beam splitters which are rotated with respect to each other. The direction of the magnetic field breaks the symmetry and determines in which direction the light is redirected."

However, for technical reasons, components that make use of the Faraday effect cannot be realized on the small scales of nanotechnology. This is unfortunate as such components are important for future technological applications. "Today, we are trying to build optical integrated circuits with similar functions as they are known from electronics," says Rauschenbeutel. Other methods to break the symmetry of the light function only at very high light intensities or suffer from high optical losses. However, in nanotechnology one would like to be able to process very small light signals, ideally light pulses that consist solely of individual photons.

Two glass fibers and a bottle for light

The team of Arno Rauschenbeutel chooses a completely different way: they couple a single rubidium atom to the light field of a so-called "bottle resonator" - a microscopic bulbous glass object on the surface of which the light circulates. If such a resonator is placed in the vicinity of two ultrathin glass fibers, the two systems couple to one another. Without an atom, the light changes from one glass fiber to the other via the bottle resonator. In this way, however, no sense of circulation is defined for the circulator: light, which is deflected by 90° in the clockwise direction, can also travel backwards via the same route, i.e. counter-clockwise.

In order to break this forward/backward symmetry, Arno Rauschenbeutel's team additionally couples an atom to the resonator, which prevents the coupling of the light into the resonator, and thus the overcoupling into the other glass fiber for one of the two directions of circulation. For this trick, a special property of the light is used at TU Wien: the direction of oscillation of the light wave, also known as its polarization.

The interaction between the light wave and the bottle resonator results in an unusual oscillation state. "The polarization rotates like the rotor of a helicopter," Arno Rauschenbeutel explains. The direction of rotation depends on whether the light in the resonator travels clockwise or counter-clockwise: in one case the polarization rotates counter-clockwise, while in the other case it rotates clockwise. The direction of circulation and the polarization of the light are therefore locked together.

If the rubidium atom is correctly prepared and coupled to the resonator, one can make its interaction with the light differ for the two directions of circulation. "The clockwise circulating light is not affected by the atom. The light in the opposite direction, on the other hand, strongly couples to the atom and therefore cannot enter the resonator," says Arno Rauschenbeutel. This asymmetry of the light-atom coupling with respect to the propagation direction of the light in the resonator allows control over the circulator operation: the desired sense of circulation can be adjusted via the internal state of the atom.

"Because we use only a single atom, we can subtly control the process," says Rauschenbeutel. "The atom can be prepared in a state in which both traffic rules apply at the same time: all light particles then travel together through the circulator in both clockwise and counterclockwise direction." Luckily, this is impossible according to the rules of classical physics, as it would result in chaos in road traffic. In quantum physics however, such superpositions of different states are permitted which opens up entirely new and exciting possibilities for the optical processing of quantum information. [14]

Researchers create hidden images with commercial inkjet printers

Researchers have developed a way to use commercial inkjet printers and readily available ink to print hidden images that are only visible when illuminated with appropriately polarized waves in the terahertz region of the electromagnetic spectrum. The inexpensive method could be used as a type of invisible ink to hide information in otherwise normal-looking images, making it possible to distinguish between authentic and counterfeit items, for example.

"We used silver and carbon ink to print an image consisting of small rods that are about a millimeter long and a couple of hundred microns wide," said Ajay Nahata from the University of Utah, leader of the research team. "We found that changing the fraction of silver and carbon in each rod changes the conductivity in each rod just slightly, but visually, you can't see this modification. Passing terahertz radiation at the correct frequency and polarization through the array allows extraction of information encoded into the conductivity."

In The Optical Society's journal for high impact research, Optica, the researchers demonstrated their new method to hide image information in an array of printed rods that all look nearly identical. They used the technique to conceal both grayscale and 64-color QR codes, and even embedded two QR codes into a single image, with each code viewable using a different polarization. To the naked eye the images look like an array of identical looking lines, but when viewed with terahertz radiation, the embedded QR code image becomes apparent.

"Our very easy-to-use method can print complex patterns of rods with varying conductivity," said Nahata. "This cannot easily be done even using a multimillion dollar nanofabrication facility. An added benefit to our technique is that it can performed very inexpensively."

Printing metamaterials

The new technique allows printing of different shapes that form a type of metamaterial - synthetic materials that exhibit properties that don't usually exist in nature. Although there is a great deal of interest in manipulating metamaterials to better control the propagation of light, most techniques require expensive lithography equipment found in nanofabrication facilities to pattern the material in a way that produces desired properties.

Nahata and his colleagues previously developed a simple method to use an off-the-shelf inkjet printer to apply inks made with silver and carbon, which can be purchased from specialty stores online. They wanted to see if their ink-jet printing technique could create various conductivities, a parameter that is typically difficult to modify because it requires changing the type of metal applied at each spatial location. To do this using standard lithography would be time consuming and expensive because each metal would have to be applied in a separate process.

"As we were printing these rods we saw that, in many cases, we couldn't visually tell the difference between different conductivities," said Nahata. "That led to the idea of using this to encode an image without the need for standard encryption approaches."

Creating hidden images

To see if they could use the method to encode information, the researchers printed three types of QR codes, each 72 by 72 pixels. For one QR code they used arrays of rods to create nine different conductivities, each coding for one gray level. When they imaged this QR code with terahertz illumination, only 2.7 percent of the rods gave values that were different from what was designed. The researchers also used rods printed in a cross formation to create two separate QR codes that could each be read with a different polarization of terahertz radiation.

The team then created a color QR code by using non-overlapping rods of three different lengths to create each pixel. Each pixel in the image contained the same pattern of rods but varied in conductivity. By arranging the rods in a way that minimized errors, the researchers created three overlapping QR codes corresponding to RGB color channels. Because each pixel contained four different conductivities that could each correspond to a color, a total of 64 colors was observed in the final image. The researchers said they could likely achieve even more than 64 colors with improvements in the printing process.

"We have created the capability to fabricate structures that can have adjacent cells, or pixels, with very different conductivities and shown that the conductivity can be read with high fidelity," said Nahata. "That means that when we print a QR code, we see the QR code and not any blurring or bleeding of colors."

With the very inexpensive (under $60) printers used in the paper, the technique can produce images with a resolution of about 100 microns. With somewhat more expensive but still commercially available printers, 20-micron resolution should be achievable. Although the researchers used QR codes that are relatively simple and small, the technique could be used to embed information into more complex and detailed images using a larger canvas.

Nahata's team used terahertz radiation to read the coded information because the wavelengths in this region are best suited for imaging the resolution available from commercial inkjet printers. The researchers are now working to expand their technique so the images can be interrogated with visible, rather than terahertz, wavelengths. This challenging endeavor will require the researchers to build new printers that can produce smaller rods to form images with higher resolutions.

The researchers are also exploring the possibility of developing additional capabilities that could make the embedded information even more secure. For example, they could make inks that might have to be heated or exposed to light of a certain wavelength before the information would be visible using the appropriate terahertz radiation. [13]

For the first time, magnets are be made with a 3-D printer

Today, manufacturing strong magnets is no problem from a technical perspective. It is, however, difficult to produce a permanent magnet with a magnetic field of a specific pre-determined shape. That is, until now, thanks to the new solution devised at TU Wien: for the first time ever, permanent magnets can be produced using a 3D printer. This allows magnets to be produced in complex forms and precisely customised magnetic fields, required, for example, in magnetic sensors.

Designed on a computer

"The strength of a magnetic field is not the only factor," says Dieter Süss, Head of the ChristianDoppler Advanced Magnetic Sensing and Materials laboratory at TU Wien. "We often require special magnetic fields, with field lines arranged in a very specific way - such as a magnetic field that is relatively constant in one direction, but which varies in strength in another direction."

In order to achieve such requirements, magnets must be produced with a sophisticated geometric form. "A magnet can be designed on a computer, adjusting its shape until all requirements for its magnetic field are met," explains Christian Huber, a doctoral student in Dieter Süss' team.

But once you have the desired geometric shape, how do you go about implementing the design? The injection moulding process is one solution, but this requires the creation of a mould, which is time-consuming and expensive, rendering this method barely worthwhile for producing small quantities.

Tiny magnetic particles in the polymer matrix

Now, there is a much simpler method: the first-ever 3D printer which can be used to produce magnetic materials, created at TU Wien. 3D printers which generate plastic structures have existed for some time, and the magnet printer functions in much the same way. The difference is that the magnet printer uses specially produced filaments of magnetic micro granulate, which is held together by a polymer binding material. The printer heats the material and applies it point by point in the desired locations using a nozzle. The result is a three-dimensional object composed of roughly 90% magnetic material and 10% plastic.

The end product is not yet magnetic, however, because the granulate is deployed in an unmagnetised state. At the very end of the process, the finished article is exposed to a strong external magnetic field, converting it into a permanent magnet.

"This method allows us to process various magnetic materials, such as the exceptionally strong neodymium iron boron magnets," explains Dieter Süss. "Magnet designs created using a computer can now be quickly and precisely implemented - at a size ranging from just a few centimetres through to decimetres, with an accuracy of well under a single millimetre."

A whole world of new possibilities

Not only is this new process fast and cost-effective, it also opens up new possibilities which would be inconceivable with other techniques: you can use different materials within a single magnet to create a smooth transition between strong and weak magnetism, for instance. "Now we will test the limits of how far we can go - but for now it is certain that 3D printing brings something to magnet design which we could previously only dream of," declares Dieter Süss. [12]

New method to make permanent magnets more stable over time

For physicists, loss of magnetisation in permanent magnets can be a real concern. In response, the Japanese company Sumitomo created the strongest available magnet—one offering ten times more magnetic energy than previous versions—in 1983. These magnets are a combination of materials including rare-earth metal and so-called transition metals, and are accordingly referred to as RE-TM-B magnets. A Russian team has now been pushing the boundaries of magnet design, as published in a recent study in EPJ Plus.

They have developed methods to counter the spontaneous loss of magnetisation, based on their understanding of the underlying physical phenomenon. Roman Morgunov from the Institute of Problems of Chemical Physics at the Russian Academy of Sciences and colleagues have now developed a simple additive-based method for ensuring the stability of permanent magnets over time, with no loss to their main magnetic characteristics.

To design magnets that retain their magnetic stability, the authors altered the chemical composition of a RE-TM-B magnet. Their method consists in inserting small amounts of Samarium atoms at random places within the crystalline sub-lattice of the magnet's rare-earth component. They observed a multi-fold increase in the magnet's stability over time with as little as 1% Samarium. The advantage of using such low quantity of additives to stabilise the magnet is that it does not alter the magnetic properties.

The authors believe this result is linked to Samarium's symmetry. It differs from the crystalline structure of Dysprosium atoms, which enter the composition of the magnet's rare-earth component. As a result, spontaneous magnetisation no longer takes place. This is because the potential barriers separating the magnetisation states of different energies are enhanced by the disrupted symmetry.

Further developments of this research will most likely focus on identifying the discrete magnetisation jumps—elementary events that initiate the reversible magnetisation, leading to a loss in stability. [11]

New method for generating superstrong magnetic fields

Researchers of MEPhI (Russia), the University of Rostock (Germany) and the University of Pisa (Italy) suggest a new method for generating extremely strong magnetic fields of several gigaGauss in the lab. Currently available techniques produce fields of one order of magnitude less than the new method. In nature, such superstrong fields exist only in the space. Therefore, generation of such fields in laboratory conditions provides new opportunities for the modeling of astrophysical processes. The results will contribute to the new research field of laboratory astrophysics.

The Faraday effect has been known for a long time. It refers to the polarization plane of an electromagnetic wave propagating through a non-magnetic medium, which is rotating in the presence of a constant magnetic field. There is also an inverse process of the generation of a magnetic field during the propagation of a circularly polarized wave through a crystal or plasma. It was considered theoretically in the 1960s by Soviet theorist Lew Pitaevsky, a famous representative of Landau's school. The stronger the wave, the higher the magnetic field it can generate when propagating through a medium. However, a peculiarity of the effect is that it requires absorption for its very existence—it does not occur in entirely transparent media. In highly intense electromagnetic fields, electrons become ultrarelativistic, which considerably reduces their collisions, suppressing conventional absorption. The researchers demonstrate that at very high laser wave intensities, the absorption can be effectively provided by radiation friction instead of binary collisions. This specific friction leads to the generation of a superstrong magnetic field.

According to physicist Sergey Popruzhenko, it will be possible to check the calculations in the near future. Several new laser facilities of record power will be completed in the next several years. Three such lasers are now under construction within the European project Extreme Light Infrastructure (ELI) in the Czech Republic, Romania and Hungary. The Exawatt Center for Extreme Light Studies – XCELS is under the development at the Applied Physics Institute RAS at Nizhny Novgorod. These laser facilities will be capable of the intensities required for the generation of superstrong magnetic fields due to radiation friction and also for the observation of many other fundamental strong-field effects. [10]

Inverse spin Hall effect: A new way to get electricity from magnetism

By showing that a phenomenon dubbed the "inverse spin Hall effect" works in several organic semiconductors - including carbon-60 buckyballs - University of Utah physicists changed magnetic "spin current" into electric current. The efficiency of this new power conversion method isn't yet known, but it might find use in future electronic devices including batteries, solar cells and computers.

"This paper is the first to demonstrate the inverse spin Hall effect in a range of organic semiconductors with unprecedented sensitivity," although a 2013 study by other researchers demonstrated it with less sensitivity in one such material, says Christoph Boehme, a senior author of the study published April 18 in the journal Nature Materials.

"The inverse spin Hall effect is a remarkable phenomenon that turns so-called spin current into an electric current. The effect is so odd that nobody really knows what this will be used for eventually, but many technical applications are conceivable, including very odd new powerconversion schemes," says Boehme, a physics professor.

His fellow senior author, distinguished professor Z. Valy Vardeny, says that by using pulses of microwaves, the inverse spin Hall effect and organic semiconductors to convert spin current into electricity, this new electromotive force generates electrical current in a way different than existing sources.

Coal, gas, hydroelectric, wind and nuclear plants all use dynamos to convert mechanical force into magnetic-field changes and then electricity. Chemical reactions power modern batteries and solar cells convert light to electrical current. Converting spin current into electrical current is another method.

Scientists already are developing such devices, such as a thermoelectric generator, using traditional inorganic semiconductors. Vardeny says organic semiconductors are promising because they are cheap, easily processed and environmentally friendly. He notes that both organic solar cells and organic LED (light-emitting diode) TV displays were developed even though silicon solar cells and nonorganic LEDs were widely used.

A new way to get electricity from magnetism

Vardeny and Boehme stressed that the efficiency at which organic semiconductors convert spin current to electric current remains unknown, so it is too early to predict the extent to which it might one day be used for new power conversion techniques in batteries, solar cells, computers, phones and other consumer electronics.

"I want to invoke a degree of caution," Boehme says. "This is a power conversion effect that is new and mostly unstudied."

Boehme notes that the experiments in the new study converted more spin current to electrical current than in the 2013 study, but Vardeny cautioned the effect still "would have to be scaled up many times to produce voltages equivalent to household batteries."

The new study was funded by the National Science Foundation and the University of Utah-NSF Materials Research Science and Engineering Center. Study co-authors with Vardeny and Boehme were these University of Utah physicists: research assistant professors Dali Sun and Hans Malissa, postdoctoral researchers Kipp van Schooten and Chuang Zhang, and graduate students Marzieh Kavand and Matthew Groesbeck.

From spin current to electric current

Just as atomic nuclei and the electrons that orbit them carry electrical charges, they also have another inherent property: spin, which makes them behave like tiny bar magnets that can point north or south.

Electronic devices store and transmit information using the flow of electricity in the form of electrons, which are negatively charged subatomic particles. The zeroes and ones of computer binary code are represented by the absence or presence of electrons within silicon or other nonorganic semiconductors.

Spin electronics - spintronics - holds promise for faster, cheaper computers, better electronics and LEDs for displays, and smaller sensors to detect everything from radiation to magnetic fields.

The inverse spin Hall effect first was demonstrated in metals in 2008, and then in nonorganic semiconductors, Vardeny says. In 2013, researchers elsewhere showed it occurred in an organic semiconductor named PEDOT:PSS when it was exposed to continuous microwaves that were relatively weak to avoid frying the semiconductor. [9]

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Simple Experiment

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

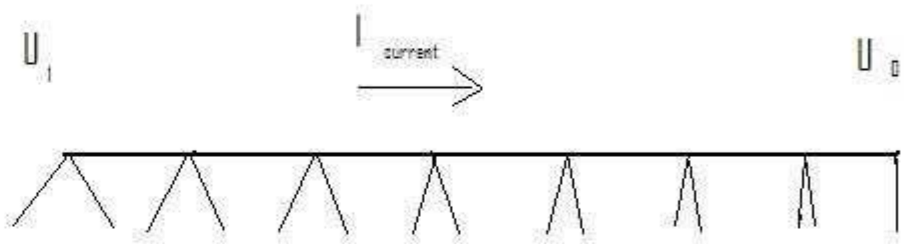


Figure 1.) Aluminium folios shows the charge distribution on the electric wire

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

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

Uniformly accelerated electrons of the steady current

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

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

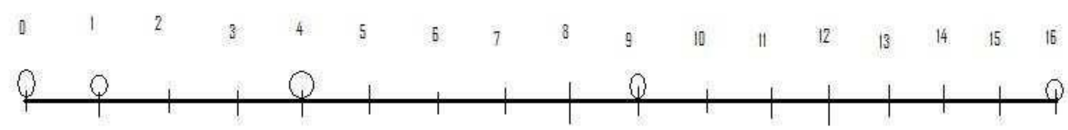


Figure 2.) The accelerating electrons created charge distribution on the electric wire

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

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

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

Magnetic effect of the decreasing U electric potential

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

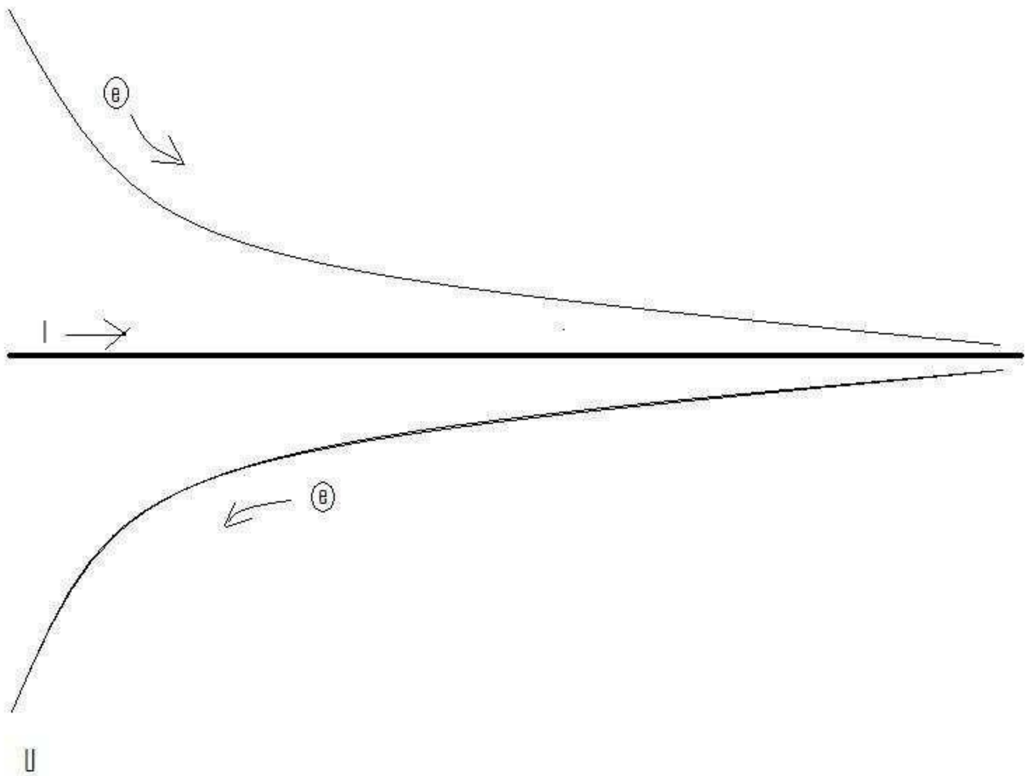


Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

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

Getting the magnetic force from the $\underline{\mathbf{F}} = \mathbf{d\underline{p}/dt}$ 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 **A** magnetic vector potential gives the radial parabolic electric potential change of the charge distribution due to the acceleration of electric charges in the electric current.

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

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

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

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

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

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

The Constant Force of the Magnetic Vector Potential

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

Electromagnetic four-potential

The electromagnetic four-potential defined as:

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

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

Magnetic induction

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

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

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

E = - dA/dt - dU/dr

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

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

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

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

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

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

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

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

Or

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

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

Lorentz transformation of the Special Relativity

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

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

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

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

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

Heisenberg Uncertainty Relation

In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass.

This means that the electron and proton are not point like particles, but has a real charge distribution.

Wave – Particle Duality

The accelerating electrons explains the wave – particle duality of the electrons and photons, since the elementary charges are distributed on delta x position with delta p impulse and creating a wave packet of the electron. The photon gives the electromagnetic particle of the

mediating force of the electrons electromagnetic field with the same distribution of wavelengths.

Atomic model

The constantly accelerating electron in the Hydrogen atom is moving on the equipotential line of the proton and it's kinetic and potential energy will be constant. Its energy will change only when it is changing its way to another equipotential line with another value of potential energy or getting free with enough kinetic energy. This means that the Rutherford-Bohr atomic model is right and only the changing acceleration of the electric charge causes radiation, not the steady acceleration. The steady acceleration of the charges only creates a centric parabolic steady electric field around the charge, the magnetic field. This gives the magnetic moment of the atoms, summing up the proton and electron magnetic moments caused by their circular motions and spins.

Fermions' spin

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

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

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

Fine structure constant

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

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

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

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

Since this is the source of the Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths, since **E = mc²**.

The expression of the fine-structure constant becomes the abbreviated

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

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

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

Planck Distribution Law

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

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

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

Electromagnetic inertia and Gravitational attraction

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

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

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

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

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

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

Conclusions

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

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

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

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

References

[1] 3 Dimensional String Theory

Author: George Rajna

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

[2] Magnetic forces on moving charges

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

[3] Equipotential surface http://en.wikipedia.org/wiki/Equipotential_surface

[4] Hamilton Principle http://en.wikipedia.org/wiki/Hamilton%27s_principle

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

[6] Electromagnetic four-potential http://en.wikipedia.org/wiki/Electromagnetic_four-potential

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

[8] New electron spin secrets revealed: Discovery of a novel link between magnetism and electricity http://phys.org/news/2014-11-electron-secrets-revealed-discovery-link.html

[9] Inverse spin Hall effect: A new way to get electricity from magnetism

http://phys.org/news/2016-04-inverse-hall-effect-electricity-magnetism.html

[10] New method for generating superstrong magnetic fields http://phys.org/news/2016-08-method-superstrong-magnetic-fields.html [11] New method to make permanent magnets more stable over time http://phys.org/news/2016-10-method-permanent-magnets-stable.html [12] For the first time, magnets are be made with a 3-D printer http://phys.org/news/2016-10-magnets-d-printer.html

[13] Researchers create hidden images with commercial inkjet printers

http://phys.org/news/2016-12-hidden-images-commercial-inkjet-printers.html

[14] A nano-roundabout for light http://phys.org/news/2016-12-nano-roundabout.html

[15] Conformal metasurface coating eliminates crosstalk and shrinks waveguides

https://phys.org/news/2017-08-conformal-metasurface-coating-crosstalk-waveguides.html

[16] Photosensitive perovskites change shape when exposed to light

https://phys.org/news/2017-08-photosensitive-perovskites-exposed.html

[17] Optical control of magnetic memory—New insights into fundamental mechanisms

https://phys.org/news/2017-08-optical-magnetic-memorynew-insights-fundamental.html

[18] How to store data on magnets the size of a single atom

https://cosmosmagazine.com/technology/how-to-store-data-on-magnets-the-size-of-a-singleatom

[19] New quantum memory device small enough to fit on a chip https://phys.org/news/2017-09-quantum-memory-device-small-chip.html [20] Flip-flop qubits: Radical new quantum computing design invented https://phys.org/news/2017-09-flip-flop-qubits-radical-quantum.html

[21] New tool for characterizing quantum simulators https://phys.org/news/2017-09-tool-characterizing-quantum-simulators.html [22] Engineers develop key mathematical formula for driving quantum experiments

https://phys.org/news/2017-09-key-mathematical-formula-quantum.html

[23] Graphene single photon detectors https://phys.org/news/2017-09-graphene-photon-detectors.html

[24] Sustainable solvent platform for photon upconversion increases solar utilization efficiency

https://phys.org/news/2017-12-sustainable-solvent-platform-photon-upconversion.html

[25] Detecting the birth and death of a phonon

https://phys.org/news/2018-06-birth-death-phonon.html

[26] How to measure quantum behaviour in nanocrystals

https://physicsworld.com/a/how-to-measure-quantum-behaviour-in-nanocrystals/

[27] Tiny defects in semiconductors created 'speed bumps' for electrons—researchers cleared the path

https://phys.org/news/2018-06-tiny-defects-semiconductors-electronsresearchers-path.html

[28] New optical sensor can determine if molecules are left or right 'handed'

https://phys.org/news/2018-06-optical-sensor-molecules-left.html

[29] Core electron topologies in chemical bonding

https://phys.org/news/2018-06-core-electron-topologies-chemical-bonding.html

[30] The photoelectric effect in stereo

https://phys.org/news/2018-06-photoelectric-effect-stereo.html

[31] Controlling photons with a photon

https://phys.org/news/2018-06-photons-photon.html

[32] Faster photons could enable total data security

https://phys.org/news/2018-07-faster-photons-enable-total.html

[33] Researcher develops algorithm to improve information security tools

https://phys.org/news/2018-07-algorithm-tools.html

[34] New study could hold key to hack-proof systems

https://phys.org/news/2018-07-key-hack-proof.html

[35] Semantic concept discovery over event databases

https://phys.org/news/2018-07-semantic-concept-discovery-event-databases.html

[36] Researchers enable transmission of specific colors of light over long distances

https://phys.org/news/2018-07-enable-transmission-specific-distances.html#nRlv

[37] Synopsis: Making Quantum Computations Behave

https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.121.032501

[38] A quantum gate between atoms and photons may help in scaling up quantum computers

https://phys.org/news/2018-09-quantum-gate-atoms-photons-scaling.html

[39] On-demand room-temperature single photon array—a quantum communication breakthrough

https://phys.org/news/2018-09-on-demand-room-temperature-photon-arraya-quantum.html

[40] New quantum loop provides testbed for quantum communication technology

https://phys.org/news/2020-01-quantum-loop-testbed-technology.html

[41] Quantum logic spectroscopy unlocks potential of highly charged ions

https://phys.org/news/2020-01-quantum-logic-spectroscopy-potential-highly.html

[42] An ultrafast microscope for the quantum world

https://phys.org/news/2020-01-ultrafast-microscope-quantum-world.html

[43] Simulation experiment allows deeper insights into ultrafast light-induced processes

https://phys.org/news/2020-02-simulation-deeper-insights-ultrafast-light-induced.html