

Metamaterials Reprogram Themselves

Materials scientists aim to engineer intelligence into the fabric of materials or metamaterials for programmable functions. [15]

Researchers at Aalto University have developed new metasurfaces for the arbitrary manipulation of reflected waves, essentially breaking the law to engineer the reflection of a surface at will. [14]

In new research, scientists at the University of Minnesota used a first-of-its-kind device to demonstrate a way to control the direction of the photocurrent without deploying an electric voltage. [13]

Brown University researchers have demonstrated for the first time a method of substantially changing the spatial coherence of light. [12]

Researchers at the University of Central Florida have generated what is being deemed the fastest light pulse ever developed. [11]

Physicists at Chalmers University of Technology and Free University of Brussels have now found a method to significantly enhance optical force. [10]

Nature Communications today published research by a team comprising Scottish and South African researchers, demonstrating entanglement swapping and teleportation of orbital angular momentum 'patterns' of light. [9]

While physicists are continually looking for ways to unify the theory of relativity, which describes large-scale phenomena, with quantum theory, which describes small-scale phenomena, computer scientists are searching for technologies to build the quantum computer using Quantum Information.

In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods.

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 Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate and the Weak and Strong Interactions by the diffraction patterns. The Weak Interaction changes the diffraction patterns by moving the electric

charge from one side to the other side of the diffraction pattern, which violates the CP and Time reversal symmetry.

The diffraction patterns and the locality of the self-maintaining electromagnetic potential explains also the Quantum Entanglement, giving it as a natural part of the Relativistic Quantum Theory and making possible to build the Quantum Computer with the help of Quantum Information.

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Author: George Rajna

Preface

While physicists are continually looking for ways to unify the theory of relativity, which describes large-scale phenomena, with quantum theory, which describes small-scale phenomena, computer scientists are searching for technologies to build the quantum computer.

Australian engineers detect in real-time the quantum spin properties of a pair of atoms inside a silicon chip, and disclose new method to perform quantum logic operations between two atoms. [5]

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently – instead, a quantum state may be given for the system as a whole. [4]

I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

Smart metamaterials that sense and reprogram themselves

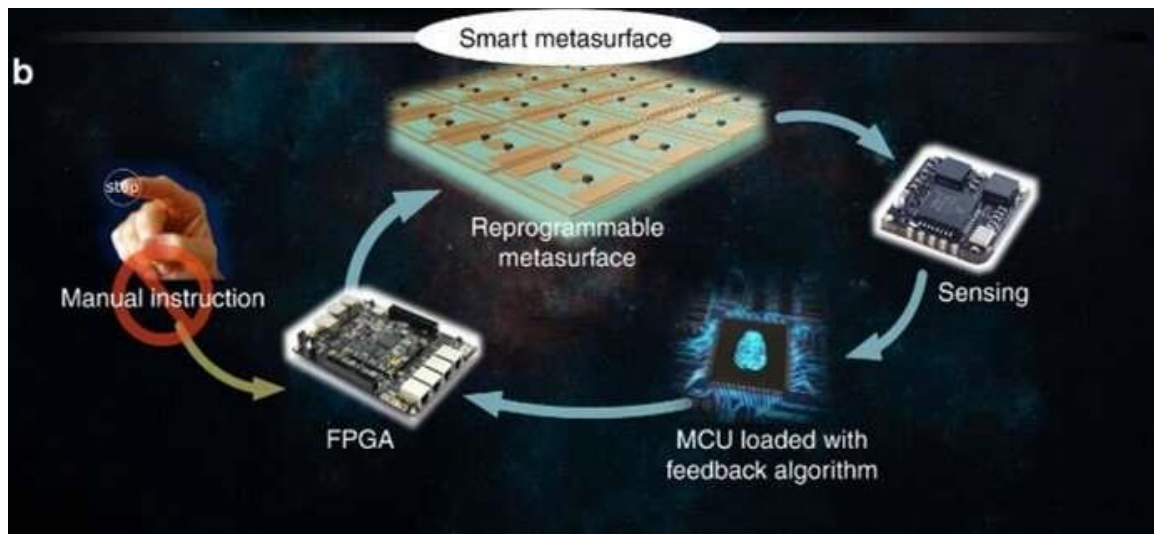
Materials scientists aim to engineer intelligence into the fabric of materials

or [metamaterials](#) for programmable functions. Engineering efforts can vary from passive to

active forms to develop programmable metasurfaces using dynamic and arbitrary [electromagnetic](#) (EM) wavefields. Such metasurfaces, however, require manual control to switch between functions. In a new study now published on *Light: Science & Applications*, Qian Ma and an interdisciplinary research team in the State Key Laboratory, Cyberspace Science and Technology, and the Department of Electronics in China engineered a smart metasurface for self-adaptive programmability.

Using an unmanned feedback sensing system, the smart metasurface detailed ambient environments with additional sensors, alongside adaptive adjustment of its EM operational functionality. As proof of concept, the team experimentally developed a motion-sensitive smart metasurface integrated into a three-axis [gyroscope](#) (to measure or maintain rotational motion) with ability to self-adjust the EM radiation beams by rotating the metasurface. Ma et al. developed an online feedback algorithm within the control software to steer the smart metasurfaces and perform adaptive dynamic reactions. They extended the proposed metasurfaces to physical sensors to program humidity detection, temperature or light illumination. The materials engineering strategy will open a new avenue to develop programmable devices without human participation to sense and detect motion in an ambient environment.

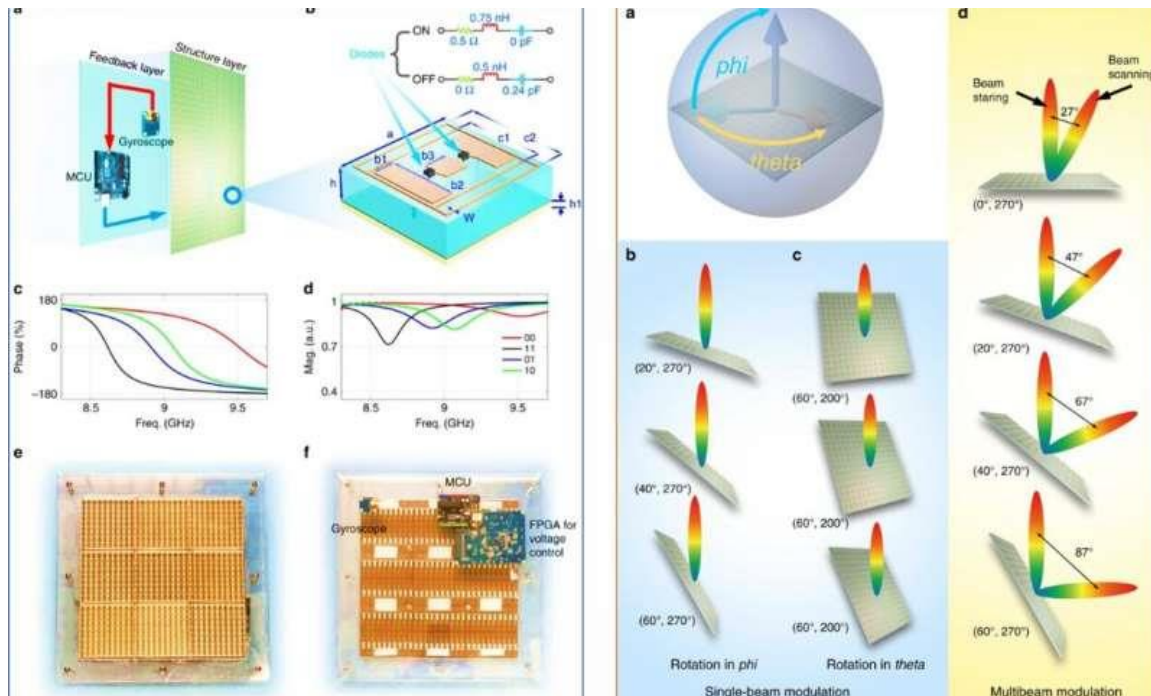
Metamaterials have [remarkable electromagnetic properties](#) introduced by their subwavelength structures and functional arrangement. Metasurfaces can overcome challenges typically encountered in bulk metamaterials to strongly manipulate EM waves for [wavefront shaping](#), [radiation control](#) and [polarization conversion](#). Due to the versatility of metasurfaces, research teams proposed a variety of applications including [imaging](#), [invisibility and illusion](#), as well as [anomalous reflection and refraction](#); mainly focused on [continuous modulations](#) on metasurfaces. To explore new perspectives of metasurfaces, research teams [proposed to link metasurface physics](#) and digital information science. To explore the new capabilities of metasurfaces, researchers proposed digital-coding metasurfaces to include physics, information science and digital signal processing. However, [such systems](#) remain under human (manual) control.



The schematic of a smart metasurface and the proposed method of study. The closed-loop system of the smart metasurface, which includes a digital-coding metasurface, an FPGA, a sensor, and a microcontroller unit (MCU) loaded with the fast feedback algorithm. Credit: Light: Science & Applications, doi: 10.1038/s41377-019-0205-3

In the present work, Ma et al. proposed and developed a smart digital-coding metasurface with self-adaptive capacity for reprogrammable functionality; implemented by the material surface itself. The metasurface independently used specific feedback modulations for spatial positions and other alterations. The team included a gyroscope sensor, an intelligent control system and fast feedback algorithm into the experimental setup to realize self-adaptive reprogrammable functions—without human aid. The open metasurface platform applied to diverse sensors and their inclusion to achieve elegant sensing-feedback mechanisms. Ma et al. envision the preliminary work will pave the way towards developing intelligent and cognitive metasurfaces in the future.

In the experimental setup, they used a sensor on the metasurface to detect specific features surrounding the construct in the environment and deliver them to a [microcontroller unit](#) (MCU). The MCU independently determined reactions to these variations and then instructed the [field programmable gate array](#) (FPGA) via coding patterns, to change the metasurface configuration in real time. The smart metasurfaces achieved self-adaptive reprogrammable functionality automatically based on the surface-installed sensing-feedback system and calculation software. The excellent surface compatibility of the MCU allowed Ma et al. to integrate a variety of sensors to the smart metasurface to sense with more degrees of freedom.

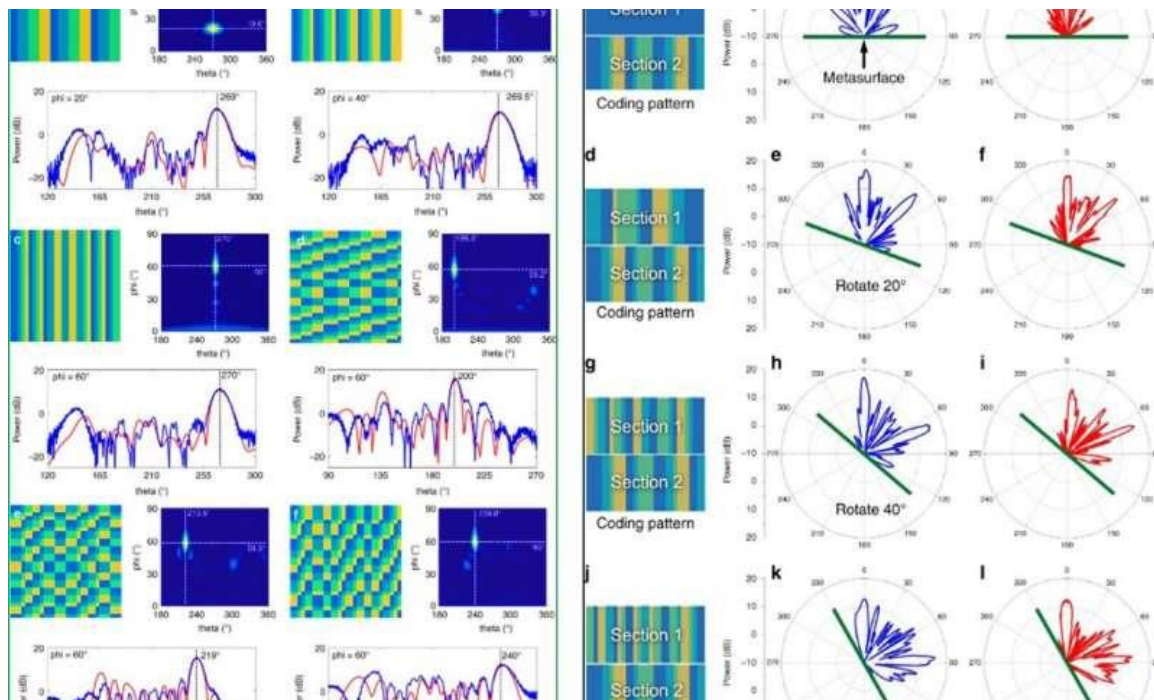


LEFT: The structure and performance of the designed 2-bit reprogrammable metasurface. (a) The configuration of the proposed smart metasurface. (b) The detailed unit structure of the 2-bit digital coding metasurface. (c and d) The phase and amplitude responses of the 2-bit digital coding metasurface, with different colors used to indicate four digital states. (e and f) The front and back views of the fabricated metasurface. RIGHT: The illustration of two schemes for the spatial self-adaptive principle. (a) The illustration for Scheme A: beam steering. (b) The situations where the metasurface rotates by different elevation angles (ϕ), namely, 20° , 40° , and 60° , in which the azimuth angle is fixed at 270° . (c) The situations where the metasurface rotates by different azimuth angles (θ), namely, 200° , 220° , and 240° , in which the elevation angle is fixed at 60° . (d) The situations for multibeam modulation. When the metasurface rotates, one beam stares at 0° , and the other beam rotates with respect to the metasurface from 0° to 60° . Credit: Light: Science & Applications, doi: 10.1038/s41377-019-0205-3.

To demonstrate the working principles of smart beam manipulation, the team studied a specific situation in satellite communication with a flying airplane. They replaced the traditional devices with a simple, smart metasurface containing a gyroscope sensor and an MCU. During the design, they included the sensor and microcontroller written with the fast inverse design algorithm into the back of a programmable metasurface. They proposed the use of a [two-bit digital element](#) containing two PIN diodes to construct the programmable metasurface. The researchers used the equivalent circuits of the PIN diode in the "on" and "off" states within field circuit joint simulations. To understand the performance of adaptive controls, the team presented two (A and B) representative schemes.

For simulations and experimental demonstrations, Ma et al. designed and developed a smart digital-coding metasurface containing 30×30 elements. They observed deviations between simulations and measurements in scheme A due to imperfectly printed board manufacturing processes, manual operations errors in the measurement setup, and nonideal plane-wave

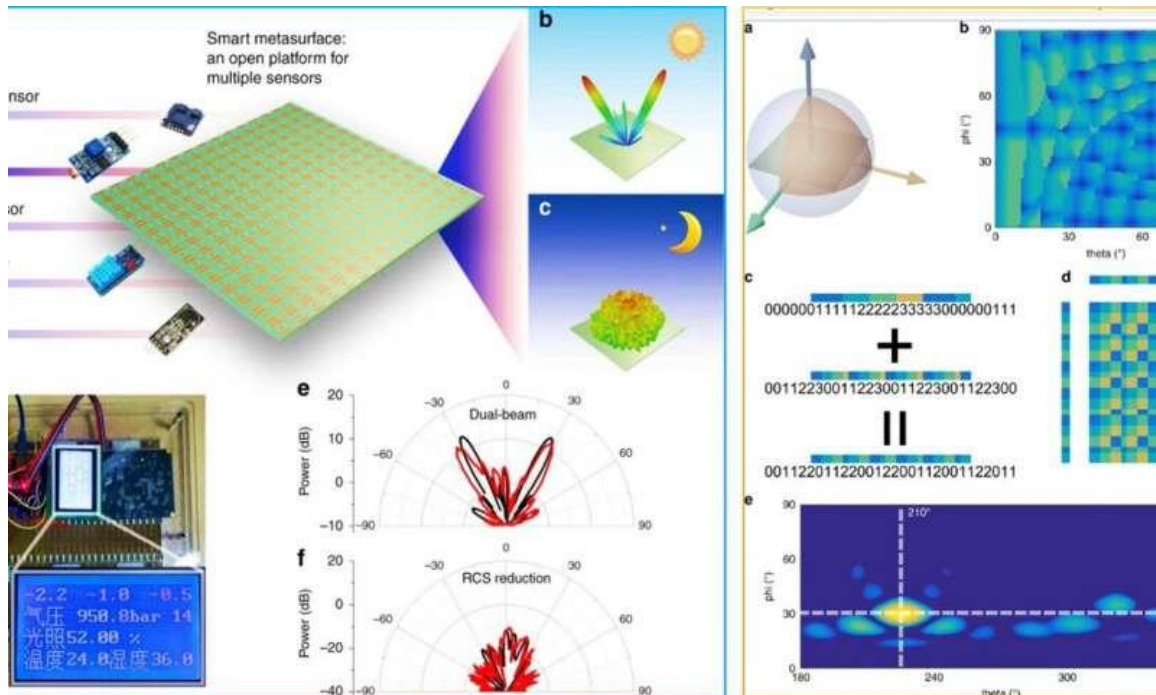
illumination. For scheme B multibeam modulations, the scientists observed consistency between the simulations and measurements, while the slight error rate between them resulted from non-ideal fabrication and manual operations.



LEFT: The designed digital-coding patterns and the simulated and experimental results for Scheme A, in which the simulated far-field results of the upper half space for the six situations are listed next to the coding patterns; the comparisons between the simulated and experimental far-field results for the six situations are listed below the coding patterns. Here, the simulated and experimental far-field results are marked with red and blue, respectively. (a–c) The three states of rotation in ϕ , with the deflecting beams at elevation angles of 20° , 40° , and 60° , in which the azimuth angle is fixed at 270° . (d–f) The three states of rotation in θ , with the deflecting beams at azimuth angles of 200° , 220° , and 240° , in which the elevation angle is fixed at 60° . RIGHT: The multiple-beam smart manipulation. (a, d, g, and j) The calculated coding patterns for different rotation states. (b, e, h, and k) The simulated far-field results when the metasurface rotates from 0° to 60° . (c, f, i, and l) The measured far-field results when the metasurface rotates from 0° to 60° . Credit: Light: Science & Applications, doi: 10.1038/s41377-019-0205-3.

The smart metasurface showed capacity for extended sensing functions and the ability to include multiple sensors. For example, diverse sensors on the smart metasurface could detect and react to a variety of stimuli. The research team showed the capacity for embedded light sensors to detect the intensity of visible light to produce an intensity percentage. Ma et al. used the sensors to combine visible-optical stimuli with microwave radiation. To validate their design experimentally, the research team developed five sensors including a gyroscope, light sensor, humidity sensor, height sensor and heat sensor on an assembled metasurface. They then demonstrated the light sensing reaction process by simulating and measuring two radiation patterns marked by red and blue lines; in good agreement between the simulations and experiments.

In this way, Ma et al. studied automatic single beam and multiple-beam modulations using the smart metasurface. They precalculated the coding patterns and stored them in the MCU (microcontroller unit) to realize required programmable functions independently of real-time manipulation. Structurally, the metasurface architecture included three main parts; programmable units, an FPGA (field programmable gate array) and sensors. The scientists calculated the coding patterns corresponding to the rotation angles to setup a database stored in the MCU to achieve the required functions in real time. As a result, they developed diverse functions by programming multiple algorithms in the MCU for numerical simulations and experimental verifications.



LEFT: An illustration of the smart metasurface platform. (a) The smart metasurface integrated with multiple sensors. (b and c) The distinct reactions according to the light sensor: dual-beam radiation for the light state and RCS reduction for the dark state. (d) A photograph of the assembled smart metasurface. (e and f) The simulated and measured results for dual-beam radiation and RCS reduction. RIGHT: The coding pattern calculation process and its design error analysis. (a) The illustration for beam deflections in the first quadrant. (b) The error angle distribution for beam deflections in the first quadrant (θ and ϕ vary from 1° to 90°). (c) The calculation process for the digital-coding sequence. (d) The calculated digital-coding pattern. (e) The simulated far-field result in the upper half space. Credit: Light: Science & Applications, doi: 10.1038/s41377-019-0205-3.

The proposed self-adaptive, digital-coding metasurface contains a complete sensing and feedback mechanism realized as a smart [metasurface](#), without human control. Additional sensors succeeded to connect optical stimuli and microwave modulations. The experimental results agreed well with numerical simulations to validate the adaptive sensing-feedback mechanisms. The research team established a variety of smart metasurfaces in the study, equipped with relevant [sensors](#) for expected applications. The proposed concept will offer a new definition for metasurfaces and pave the way towards the development of cognitive and intelligent metamaterials constructs. [15]

Engineered metasurfaces reflect waves in unusual directions

In our daily lives, we can find many examples of manipulation of reflected waves, such as mirrors, or reflective surfaces for sound that improve auditorium acoustics. When a wave impinges on a reflective surface with a certain angle of incidence and the energy is sent back, the angle of reflection is equal to the angle of incidence. This classical reflection law is valid for any homogenous surface. Researchers at Aalto University have developed new metasurfaces for the arbitrary manipulation of reflected waves, essentially breaking the law to engineer the reflection of a surface at will.

Metasurfaces are artificial structures, composed of periodic arranged of meta-atoms at subwavelength scale. Meta-atoms are made of traditional materials, but if they are placed in a periodic manner, the surface can have many unusual effects that cannot be realized by natural materials. In their article published 15 February 2019 in *Science Advances*, the researchers used power-flow conformal metasurfaces to engineer the direction of reflected waves.

"Existing solutions for controlling reflection of waves have low efficiency or difficult implementation," says Ana Díaz-Rubio, postdoctoral researcher at Aalto University. "We solved both of those problems. Not only did we figure out a way to design high efficient metasurfaces, we can also adapt the design for different functionalities. These metasurfaces are a versatile platform for arbitrary control of reflection. This is really an exciting result. We have figured out a way to design such a device and we test it for controlling sound waves. Moreover, this idea can be applied to electromagnetic fields." [12]

Researchers steer the flow of electrical current with spinning light

Light can generate an electrical current in semiconductor materials. This is how solar cells generate electricity from sunlight and how smart phone cameras can take photographs. To collect the generated electrical current, called photocurrent, an electric voltage is needed to force the current to flow in only one direction.

In new research, scientists at the University of Minnesota used a first-of-its-kind device to demonstrate a way to control the direction of the photocurrent without deploying an electric voltage. The new study was recently published in the scientific journal *Nature Communications*.

The study reveals that control is effected by the direction in which the particles of light, called photons, are spinning—clockwise or counterclockwise. The photocurrent generated by the spinning light is also spin-polarized, which means there are more electrons with spin in one direction than in the other. This new device holds significant potential for use in the next generation of microelectronics using electron spin as the fundamental unit of information. It could also be used for energy efficient optical communication in data centers.

"The observed effect is very strong and robust in our devices, even at room temperature and in open air," said Mo Li, a University of Minnesota electrical and computer engineering associate

professor and a lead author of the study. "Therefore, the device we demonstrate has great potential for being implemented in next-generation computation and communication systems."

Optical spin and topological insulators

Light is a form of electromagnetic wave. The way the electric field oscillates, either in a straight line or rotating, is called polarization. (Your polarized sunglasses block part of the unpleasant reflected light that is polarized along a straight line.) In circularly polarized light, the electric field can spin in the clockwise or counterclockwise direction. In such a state, the particle of light (photon) is said to have positive or negative optical spin angular momentum. This optical spin is analogous to the spin of electrons, and endows magnetic properties to [materials](#).

Recently, a new category of materials, called [topological insulators](#) (TI), was discovered to have an intriguing property not found in common [semiconductor materials](#). Imagine a road on which red cars only drive on the left lane, and blue cars only in the right lane. Similarly, on the surface of a TI, the electrons with their spins pointing one way always flow in one direction. This effect is called spin-momentum locking—the spin of the electrons is locked in the direction they travel.

Interestingly, shining a [circularly polarized light](#) on a TI can free electrons from its inside to flow on its surface in a selective way, for example, clockwise light for spin-up electrons and counterclockwise for spin-down electrons. Because of this effect, the generated photocurrent on the surface of the TI material spontaneously flows in one direction, requiring no electric voltage. This particular feature is significant for controlling the direction of a photocurrent. Because most of the electrons in this current have their spins pointing in a single direction, this current is spin-polarized.

Controlling direction and polarization

To fabricate their unique [device](#) that can change the direction of a photocurrent without the use of an [electric voltage](#), the University's research team integrated a thin film of a TI material, bismuth selenide, on an optical waveguide made of silicon. Light flows through the waveguide (a tiny wire measuring 1.5 microns wide and 0.22 micron high) just like electrical current flows through a copper wire. Because light is tightly squeezed in the waveguide, it tends to be circularly polarized along a direction normal to the direction in which it flows. This is akin to the spin-momentum locking effect of the electrons in a TI material.

The scientists supposed that integrating a TI material with the [optical waveguide](#) will induce strong coupling between the light in the waveguide and the [electrons](#) in the TI material, both having the same, intriguing spin-momentum locking effect. The coupling will result in a unique optoelectronic effect—light flowing along one direction in the waveguide generates an electrical current flowing in the same direction with electron spin polarized.

Reversing the light direction reverses both the [direction](#) of the current and its spin polarization. And this is exactly what the team observed in their devices. Other possible causes of the observed effect, such as heat generated by the light, have been ruled out through careful experiments.

Future prospects

The outcome of the research is exciting for the researchers. It bears enormous potential for possible applications.

"Our devices generate a spin-polarized current flowing on the surface of a topological insulator. They can be used as a current source for spintronic devices, which use electron spin to transmit and process information with very low energy cost," said Li He, a University of Minnesota physics graduate student and an author of the paper.

"Our research bridges two important fields of nanotechnology: spintronics and nanophotonics. It is fully integrated with a silicon photonic circuit that can be manufactured on a large scale and has already been widely used in optical communication in data centers," He added.

Research demonstrates method to alter coherence of light

Brown University researchers have demonstrated for the first time a method of substantially changing the spatial coherence of light.

In a paper published in the journal *Science Advances*, the researchers show that they can use surface plasmon polaritons—propagating electromagnetic waves confined at a metal-dielectric interface—to transform light from completely incoherent to almost fully coherent and vice versa. The ability to modulate coherence could be useful in a wide variety of applications from structural coloration and optical communication to beam shaping and microscopic imaging.

"There had been some theoretical work suggesting that coherence modulation was possible, and some experimental results showing small amounts of modulation," said Dongfang Li, a postdoctoral researcher in Brown's School of Engineering and the study's lead author. "But this is the first time very strong modulation of coherence has been realized experimentally."

Coherence deals with the extent to which propagating electromagnetic waves are correlated with each other. Lasers, for example, emit light that's highly coherent, meaning the waves are strongly correlated. The sun and incandescent light bulbs emit weakly correlated waves, which are generally said to be "incoherent", although, more precisely, they are characterized by low yet measurable degrees of coherence.

"Coherence, like color and polarization, is a fundamental property of light," said Domenico Pacifici, an associate professor of engineering and physics at Brown and coauthor of the research. "We have filters that can manipulate the color of light and we have things like polarizing sunglasses that can manipulate polarization. The goal with this work was to find a way to manipulate coherence like we can these other properties."

To do that, Li and Pacifici took a classic experiment used to measure coherence, Young's double slit, and turned it into a device that can modulate coherence of light by controlling and finely tuning the interactions between light and electrons in metal films.

In the classic double-slit experiment, an opaque barrier is placed between a light source and a detector. The light passes through two parallel slits in the barrier to reach the detector on the other side. If the light shown on the barrier is coherent, the rays emanating from the slits will interfere with each other, creating an interference pattern on the detector—a series of bright and

dark bands called interference fringes. The extent to which the light is coherent can be measured by the intensity of bands. If the light is incoherent, no bands will be visible.

"As this is normally done, the double-slit experiment simply measures the coherence of light rather than changing it," Pacifici said. "But by introducing surface plasmon polaritons, Young's double slits become a tool not just for measurement but also modulation."

To do that, the researchers used a thin metal film as the barrier in the double slit experiment. When the light strikes the film, surface plasmon polaritons—ripples of electron density created when the electrons are excited by light—are generated at each slit and propagate toward the opposite slit.

"The surface plasmon polaritons open up a channel for the light at each slit to talk to each other," Li said. "By connecting the two, we're able to change the mutual correlations between them and therefore change the coherence of light."

In essence, surface plasmon polaritons are able to create correlation where there was none, or to cancel any existing correlation that was there, depending on the nature of the light coming in and the distance between the slits.

One of the study's key results is the strength of the modulation they achieved. The technique is able to modulate coherence across a range from 0 percent (totally incoherent) to 80 percent (nearly full coherent). Modulation of such strength has never been achieved before, the researchers say, and it was made possible by using nanofabrication methods that allowed to maximize the generation efficiencies of surface plasmon polaritons existing on both surfaces of the slitted screen.

This initial proof-of-concept work was done at the micrometer scale, but Pacifici and Li say there's no reason why this couldn't be scaled up for use in a variety of settings.

"We've broken a barrier in showing that it's possible to do this," Pacifici said. "This clears the way for new two-dimensional beam shapers, filters and lenses that can manipulate entire optical beams by using the coherence of light as a powerful tuning knob." [12]

53 attoseconds: Research produces shortest light pulse ever developed

Researchers at the University of Central Florida have generated what is being deemed the fastest light pulse ever developed.

The 53-attosecond pulse, obtained by Professor Zhenhu Chang, UCF trustee chair and professor in the Center for Research and Education in Optics and Lasers, College of Optics and Photonics, and Department of Physics, and his group at the university, was funded by the U.S. Army Research Laboratory's Army Research Office.

Specifically, it was funded by ARO's Multidisciplinary University Research Initiative titled "Post-BornOppenheimer Dynamics Using Isolated Attosecond Pulses," headed by ARO's Jim Parker and Rich Hammond.

This beats the team's record of a 67-attosecond extreme ultraviolet light pulse set in 2012.

Attosecond light pulses allow scientists to capture images of fast-moving electrons in atoms and molecules with unprecedented sharpness, enabling advancements in solar panel technology, logic and memory chips for mobile phones and computers, and in the military in terms of increasing the speed of electronics and sensors, as well as threat identification.

"This is the shortest laser pulse ever produced," Hammond said. "It opens new doors in spectroscopy, allowing the identification of pernicious substances and explosive residue."

Hammond noted that this achievement is also a new and very effective tool to understand the dynamics of atoms and molecules, allowing observations of how molecules form and how electrons in atoms and molecules behave.

"This can also be extended to condensed matter systems, allowing unprecedented accuracy and detail of atomic, molecular, and even phase, changes," Hammond said. "This sets the stage for many new kinds of experiments, and pushes physics forward with the ability to understand matter better than ever before."

Chang echoed Hammond's sentiments about this achievement being a game-changer for continued research in this field.

"The photon energy of the attosecond X-ray pulses is two times higher than previous attosecond light sources and reached the carbon K-edge (284 eV), which makes it possible to probe and control core electron dynamics such as Auger processes," Chang said. "In condensed matter physics, the ultrafast electronic process in carbon containing materials, such as graphene and diamond, can be studied via core to valence transitions. In chemistry, electron dynamics in carbon containing molecules, such as carbon dioxide, Acetylene, Methane, etc., may now be studied by attosecond transient absorption, taking advantage of the element specificity."

This development is the culmination of years of ARO funding of attosecond science.

It all started with an ARO MURI about eight years ago titled "Attosecond Optical Technology Based on Recollision and Gating" from the Physics Division. This was followed by single investigator awards, Defense University Research Instrumentation Programs and finally an ARO MURI titled "Attosecond Electron Dynamics" from the Chemistry Division.

From the ARL/ARO perspective, Hammond said that this achievement, which included researchers from around the globe, shows how continued funding into fundamental research using several instruments, such as MURIs, DURIPS, and single investigator awards, can be used in a coherent and meaningful way to push the forward the frontiers of science.

Chang's team includes Jie Li, Xiaoming Ren, Yanchun Yin, Andrew Chew, Yan Cheng, Eric Cunningham, Yang Wang, Shuyuan Hu, and Yi Wu, who are all affiliated with the Institute for the Frontier of Attosecond Science and Technology, or iFAST; Kun Zhao, who is also affiliated with the Chinese Academy of Sciences, and Michael Chini with the UCF Department of Physics. [11]

Method to significantly enhance optical force

Light consists of a flow of photons. If two waveguides – cables for light – are side by side, they attract or repel each other. The interaction is due to the optical force, but the effect is usually extremely small. Physicists at Chalmers University of Technology and Free University of Brussels have now found a method to significantly enhance optical force. The method opens new possibilities within sensor technology and nanoscience. The results were recently published in Physical Review Letters.

To make light behave in a completely new way, the scientists have studied waveguides made of an artificial material to trick the photons. The specially designed material makes all the photons move to one side of the waveguide. When the photons in a nearby waveguide do the same, a collection of photons suddenly gather very closely. This enhances the force between the waveguides up to 10 times.

"We have found a way to trick the photons so that they cluster together at the inner sides of the waveguides. Photons normally don't prefer left or right, but our metamaterial creates exactly that effect," says Philippe Tassin, Associate Professor at the Department of Physics at Chalmers University of Technology.

Philippe Tassin and Sophie Viaene at Chalmers and Lana Descheemaeker and Vincent Ginis at Free University of Brussels have developed a method to use the optical force in a completely new way. It can, for example, be used in sensors or to drive nanomotors. In the future, such motors might be used to sort cells or separate particles in medical technology.

"Our method opens up new opportunities for the use of waveguides in a range of technical applications. It is really exciting that man-made materials can change the basic characteristics of light propagation so dramatically," says Vincent Ginis, assistant professor at the Department of Physics at Free University of Brussels. [10]

Researchers demonstrate quantum teleportation of patterns of light

Nature Communications today published research by a team comprising Scottish and South African researchers, demonstrating entanglement swapping and teleportation of orbital angular momentum 'patterns' of light. This is a crucial step towards realizing a quantum repeater for high-dimensional entangled states.

Quantum communication over long distances is integral to information security and has been demonstrated in free space and fibre with two-dimensional states, recently over distances exceeding 1200 km between satellites. But using only two states reduces the information capacity of the photons, so the link is secure but slow. To make it secure and fast requires a higher-dimensional alphabet, for example, using patterns of light, of which there are an infinite number. One such pattern set is the orbital angular momentum (OAM) of light. Increased bit rates can be achieved by using OAM as the carrier of information. However, such photon states decay when transmitted over long distances, for example, due to mode coupling in fibre or turbulence in free space, thus requiring a way to amplify the signal. Unfortunately such "amplification" is not allowed in the quantum world, but it is possible to create an analogy, called a quantum repeater, akin to optical fibre repeaters in classical optical networks.

An integral part of a quantum repeater is the ability to entangle two photons that have never interacted - a process referred to as "entanglement swapping". This is accomplished by interfering two photons from independent entangled pairs, resulting in the remaining two photons becoming entangled. This allows the establishment of entanglement between two distant points without requiring one photon to travel the entire distance, thus reducing the effects of decay and loss. It also means that you don't have to have a line of sight between the two places.

An outcome of this is that the information of one photon can be transferred to the other, a process called teleportation. Like in the science fiction series, Star Trek, where people are "beamed" from one place to another, information is "teleported" from one place to another. If two photons are entangled and you change a value on one of them, then other one automatically changes too. This happens even though the two photons are never connected and, in fact, are in two completely different places.

In this latest work, the team performed the first experimental demonstration of entanglement swapping and teleportation for orbital angular momentum (OAM) states of light. They showed that quantum correlations could be established between previously independent photons, and that this could be used to send information across a virtual link. Importantly, the scheme is scalable to higher dimensions, paving the way for long-distance quantum communication with high information capacity.

Background

Present communication systems are very fast, but not fundamentally secure. To make them secure researchers use the laws of Nature for the encoding by exploiting the quirky properties of the quantum world. One such property is entanglement. When two particles are entangled they are connected in a spooky sense: a measurement on one immediately changes the state of the other no matter how far apart they are. Entanglement is one of the core resources needed to realise a quantum network.

Yet a secure quantum communication link over long distance is very challenging: Quantum links using patterns of light languish at short distances precisely because there is no way to protect the link against noise without detecting the photons, yet once they are detected their usefulness is destroyed. To overcome this one can have a repeating station at intermediate distances - this allows one to share information across a much longer distance without the need for the information to physically flow over that link. The core ingredient is to get independent photons to become entangled. While this has been demonstrated previously with two-dimensional states, in this work the team showed the first demonstration with OAM and in high-dimensional spaces. [9]

How to Win at Bridge Using Quantum Physics

Contract bridge is the chess of card games. You might know it as some stuffy old game your grandparents play, but it requires major brainpower, and preferably an obsession with rules and strategy. So how to make it even geekier? Throw in some quantum mechanics to try to gain a competitive advantage. The idea here is to use the quantum magic of entangled photons—which are essentially twins, sharing every property—to transmit two bits of information to your bridge partner for the price of one. Understanding how to do this is not an easy task, but it will help

elucidate some basic building blocks of quantum information theory. It's also kind of fun to consider whether or not such tactics could ever be allowed in professional sports. [6]

Quantum Information

In quantum mechanics, quantum information is physical information that is held in the "state" of a quantum system. The most popular unit of quantum information is the qubit, a two-level quantum system. However, unlike classical digital states (which are discrete), a two-state quantum system can actually be in a superposition of the two states at any given time.

Quantum information differs from classical information in several respects, among which we note the following:

However, despite this, the amount of information that can be retrieved in a single qubit is equal to one bit. It is in the processing of information (quantum computation) that a difference occurs.

The ability to manipulate quantum information enables us to perform tasks that would be unachievable in a classical context, such as unconditionally secure transmission of information. Quantum information processing is the most general field that is concerned with quantum information. There are certain tasks which classical computers cannot perform "efficiently" (that is, in polynomial time) according to any known algorithm. However, a quantum computer can compute the answer to some of these problems in polynomial time; one well-known example of this is Shor's factoring algorithm. Other algorithms can speed up a task less dramatically - for example, Grover's search algorithm which gives a quadratic speed-up over the best possible classical algorithm.

Quantum information, and changes in quantum information, can be quantitatively measured by using an analogue of Shannon entropy. Given a statistical ensemble of quantum mechanical systems with the density matrix S , it is given by.

Many of the same entropy measures in classical information theory can also be generalized to the quantum case, such as the conditional quantum entropy. [7]

Quantum Teleportation

Quantum teleportation is a process by which quantum information (e.g. the exact state of an atom or photon) can be transmitted (exactly, in principle) from one location to another, with the help of classical communication and previously shared quantum entanglement between the sending and receiving location. Because it depends on classical communication, which can proceed no faster than the speed of light, it cannot be used for superluminal transport or communication of classical bits. It also cannot be used to make copies of a system, as this violates the no-cloning theorem. Although the name is inspired by the teleportation commonly used in fiction, current technology provides no possibility of anything resembling the fictional form of teleportation. While it is possible to teleport one or more qubits of information between two (entangled) atoms, this has not yet been achieved between molecules or anything larger. One may think of teleportation either

as a kind of transportation, or as a kind of communication; it provides a way of transporting a qubit from one location to another, without having to move a physical particle along with it.

The seminal paper first expounding the idea was published by C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres and W. K. Wootters in 1993. Since then, quantum teleportation has been realized in various physical systems. Presently, the record distance for quantum teleportation is 143 km (89 mi) with photons, and 21 m with material systems. In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]

Quantum Computing

A team of electrical engineers at UNSW Australia has observed the unique quantum behavior of a pair of spins in silicon and designed a new method to use them for "2-bit" quantum logic operations.

These milestones bring researchers a step closer to building a quantum computer, which promises dramatic data processing improvements.

Quantum bits, or qubits, are the building blocks of quantum computers. While many ways to create a qubits exist, the Australian team has focused on the use of single atoms of phosphorus, embedded inside a silicon chip similar to those used in normal computers.

The first author on the experimental work, PhD student Juan Pablo Dehollain, recalls the first time he realized what he was looking at.

"We clearly saw these two distinct quantum states, but they behaved very differently from what we were used to with a single atom. We had a real 'Eureka!' moment when we realized what was happening – we were seeing in real time the 'entangled' quantum states of a pair of atoms." [5]

Quantum Entanglement

Measurements of physical properties such as position, momentum, spin, polarization, etc. performed on entangled particles are found to be appropriately correlated. For example, if a pair of particles is generated in such a way that their total spin is known to be zero, and one particle is found to have clockwise spin on a certain axis, then the spin of the other particle, measured on the same axis, will be found to be counterclockwise. Because of the nature of quantum measurement, however, this behavior gives rise to effects that can appear paradoxical: any measurement of a property of a particle can be seen as acting on that particle (e.g. by collapsing a number of superimposed states); and in the case of entangled particles, such action must be on the entangled system as a whole. It thus appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances. [4]

The Bridge

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. [1]

Accelerating charges

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field. In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion. The same thing happens on the atomic scale giving a dp impulse difference and a dx way difference between the different part of the not point like particles.

Relativistic effect

Another bridge between the classical and quantum mechanics in the realm of relativity is that the charge distribution is lowering in the reference frame of the accelerating charges linearly: $ds/dt = at$ (time coordinate), but in the reference frame of the current it is parabolic: $s = a/2 t^2$ (geometric coordinate).

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 Δx position difference and with a Δp momentum difference such a way that they product is about the half Planck reduced constant. For the proton this Δx much less in the nucleon, than in the orbit of the electron in the atom, the Δp 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 Δx position with Δp 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 that 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.

The Relativistic Bridge

Commonly accepted idea that the relativistic effect on the particle physics is the fermions' spin - another unresolved problem in the classical concepts. If the electric charges can move only with accelerated motions in the self maintaining electromagnetic field, once upon a time they would reach the velocity of the electromagnetic field. The resolution of this problem is the spinning particle, constantly accelerating and not reaching the velocity of light because the acceleration is radial. One origin of the Quantum Physics is the Planck Distribution Law of the electromagnetic oscillators, giving equal intensity for 2 different wavelengths on any temperature. Any of these two wavelengths will give equal intensity diffraction patterns, building different asymmetric constructions, for example proton - electron structures (atoms), molecules, etc. Since the particles are centers of diffraction patterns they also have particle - wave duality as the electromagnetic waves have. [2]

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry. The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

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

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

The neutrino is a $1/2$ spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with $1/2$ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction

intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

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

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

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

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

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

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

The General Weak Interaction

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

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

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater than subatomic matter structures as an electric dipole change. There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

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

Fermions and Bosons

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

Van Der Waals force

Named after the Dutch scientist Johannes Diderik van der Waals – who first proposed it in 1873 to explain the behaviour of gases – it is a very weak force that only becomes relevant when atoms and molecules are very close together. Fluctuations in the electronic cloud of an atom mean that it will have an instantaneous dipole moment. This can induce a dipole moment in a nearby atom, the result being an attractive dipole–dipole interaction.

Electromagnetic inertia and mass

Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

Relativistic change of mass

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.

The frequency dependence of mass

Since $E = h\nu$ and $E = mc^2$, $m = h\nu/c^2$ that is the m depends only on the ν frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_0 inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the

proton, their masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron – Proton mass ratio

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different λ wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force. [2]

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

Gravity from the point of view of quantum physics

The Gravitational force

The gravitational attractive force is basically a magnetic force.

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

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

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

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

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

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

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

The Higgs boson

By March 2013, the particle had been proven to behave, interact and decay in many of the expected ways predicted by the Standard Model, and was also tentatively confirmed to have + parity and zero spin, two fundamental criteria of a Higgs boson, making it also the first known scalar particle to be discovered in nature, although a number of other properties were not fully proven and some partial results do not yet precisely match those expected; in some cases data is also still awaited or being analyzed.

Since the Higgs boson is necessary to the W and Z bosons, the dipole change of the Weak interaction and the change in the magnetic effect caused gravitation must be conducted. The Wien law is also important to explain the Weak interaction, since it describes the T_{\max} change and the diffraction patterns change. [2]

Higgs mechanism and Quantum Gravity

The magnetic induction creates a negative electric field, causing an electromagnetic inertia. Probably it is the mysterious Higgs field giving mass to the charged particles? We can think about the photon as an electron-positron pair, they have mass. The neutral particles are built from negative and positive charges, for example the neutron, decaying to proton and electron. The wave – particle duality makes sure that the particles are oscillating and creating magnetic induction as an inertial mass, explaining also the relativistic mass change. Higher frequency creates stronger magnetic induction, smaller frequency results lesser magnetic induction. It seems to me that the magnetic induction is the secret of the Higgs field.

In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge bosons in a gauge theory with mass through absorption of Nambu–Goldstone bosons arising in spontaneous symmetry breaking.

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other

fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the W^\pm , and Z weak gauge bosons through electroweak symmetry breaking. The Large Hadron Collider at CERN announced results consistent with the Higgs particle on July 4, 2012 but stressed that further testing is needed to confirm the Standard Model.

What is the Spin?

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

The Graviton

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

Conclusions

In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]

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 accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]

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. The Secret of Quantum Entanglement that the particles are diffraction patterns of the

electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]

The key breakthrough to arrive at this new idea to build qubits was to exploit the ability to control the nuclear spin of each atom. With that insight, the team has now conceived a unique way to use the nuclei as facilitators for the quantum logic operation between the electrons. [5]

Basing the gravitational force on the accelerating Universe caused 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 also.

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