Electron's Trip Across a Border

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A team of physicists headed by Professor Sebastian Reineke of TU Dresden has developed a new method of storing information in fully transparent plastic foils. [15]

A new electron microscopy technique that detects the subtle changes in the weight of proteins at the nanoscale—while keeping the sample intact—could open a new pathway for deeper, more comprehensive studies of the basic building blocks of life. [14]

Researchers use a cavity-coupled double quantum dot to study electron-phonon interactions in a nanowire. [13]

Quantum behavior plays a crucial role in novel and emergent material properties, such as superconductivity and magnetism. [12]

A source of single photons that meets three important criteria for use in quantum-information systems has been unveiled in China by an international team of physicists. Based on a quantum dot, the device is an efficient source of photons that emerge as solo particles that are indistinguishable from each other. The researchers are now trying to use the source to create a quantum computer based on "boson sampling". [11]

With the help of a semiconductor quantum dot, physicists at the University of Basel have developed a new type of light source that emits single photons. For the first time, the researchers have managed to create a stream of identical photons. [10]

Optical photons would be ideal carriers to transfer quantum information over large distances. Researchers envisage a network where information is processed in certain nodes and transferred between them via photons. [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.

First direct view of an electron's short, speedy trip across a border

Electrons flowing across the boundary between two materials are the foundation of many key technologies, from flash memories to batteries and solar cells. Now researchers have directly observed and clocked these tiny cross-border movements for the first time, watching as electrons raced seven-tenths of a nanometer – about the width of seven hydrogen atoms – in 100 millionths of a billionth of a second.

Led by scientists at the Department of Energy's SLAC National Accelerator Laboratory and Stanford University, the team made these observations by measuring tiny bursts of electromagnetic waves given off by the traveling electrons – a phenomenon described more than a century ago by Maxwell's equations, but only now applied to this important measurement.

"To make something useful, generally you need to put different materials together and transfer charge or heat or light between them," said Eric Yue Ma, a postdoctoral researcher in the laboratory of SLAC/Stanford Professor Tony Heinz and lead author of a report in *Science Advances*.

"This opens up a new way to measure how charge – in this case, electrons and holes – travels across the abrupt interface between two materials," he said. "It doesn't just apply to layered materials. For instance, it can also be used to look at electrons flowing between a solid surface and molecules that are attached to it, or even, in principle, between a liquid and a solid."

Too short, too fast – or were they?

The materials used in this experiment are transition metal dichalcogenides, or TMDCs – an emerging class of semiconducting materials that consist of layers just a few atoms thick. There's been an explosion of interest in TMDCs over the past few years as scientists explore their fundamental properties and potential uses in nanoelectronics and photonics.

When two types of TMDC are stacked in alternating layers, electrons can flow from one layer to the next in a controllable way that people would like to harness for various applications.

But until now, researchers who wanted to observe and study that flow had only been able to do it indirectly, by probing the material before and after the electrons had moved. The distances involved were just too short, and the electron speeds too fast, for today's instruments to catch the flow of charge directly.

At least that's what they thought.

Maxwell leads the way

According to a famous set of equations named after physicist James Clerk Maxwell, pulses of current give off electromagnetic waves, which can vary from radio waves and microwaves to visible light and X-rays. In this case, the team realized that an electron's journey from one TMDC layer to another should generate blips of terahertz waves – which fall between microwaves and infrared light on the electromagnetic spectrum – and that those blips could be detected with today's state-of-the-art tools.

"People had probably thought of this before, but dismissed the idea because they thought there was no way you could measure the current from electrons traveling such a small distance in such a small amount of material," Ma said. "But if you do a back-of-the-envelope calculation, you see that if a current is really that fast you should be able to measure the emitted light, so we just tried."

Nudges from a laser

The researchers, all investigators with the Stanford Institute for Materials and Energy Sciences (SIMES) at SLAC, tested their idea on a TMDC material made of molybdenum disulfide and tungsten disulfide.

Working with SLAC/Stanford Professor Aaron Lindenberg, Ma and fellow postdoc Burak Guzelturk hit the material with ultrashort pulses of optical laser light to get the electrons moving and recorded the terahertz waves they gave off with a technique called time-domain terahertz emission spectroscopy. Those measurements not only revealed how far and fast the electric current traveled between layers, Ma said, but also the direction it traveled in. When the same two materials were stacked in reverse order, the current flowed in exactly the same way but in the opposite direction.

"With the demonstration of this new technique, many exciting problems can now be addressed," said Heinz, who led the team's investigation. "For example, rotating one of the two crystal layers with respect to the other is known to dramatically change the electronic and optical properties of the combined layers. This method will allow us to directly follow the rapid motion of electrons from one layer to the other and see how this motion is affected by the relative positioning of the atoms." [17]

Physicists uncover the topological origin of surface electromagnetic waves

In work that provides insights for several areas of wave physics, including Maxwell electromagnetism, topological quantum states, and plasmonics/metamaterials, scientists have shown that the well-known surface electromagnetic waves at interfaces between homogeneous isotropic media, obtained within classical Maxwell's electromagnetism, also have a purely topological origin, similar to quantum topological states.

Maxwell's electromagnetic theory, which was formulated 150 years ago, was one of the greatest breakthroughs in physics. It united electricity and magnetism, provided an ultimate description of electromagnetic waves, including light, and anticipated relativity and the field theories of the 20th century. More recently, more than 60 years ago, scientists found that electromagnetic radiation can not only propagate in free space but can also form surface waves at interfaces between media, such as between metals and air or glass. This resulted in the development of plasmonics and metamaterials, where surface electromagnetic waves underpin a number of phenomena and useful applications.

Another area of modern physics where surface waves play a crucial role is topological quantum systems, which are very robust against small perturbations and continuous deformations. The discovery of nontrivial topological phases in condensed-matter quantum systems and the existence of topological surface modes at interfaces between topologically-different materials resulted in the Nobel Prize in physics in 2016.

Now, in a paper published in *Nature Communications*, scientists from the RIKEN Cluster for Pioneering Research in Japan have demonstrated that the well-known surface electromagnetic waves at interfaces between homogeneous isotropic media, obtained within classical Maxwell's electromagnetism, also have a purely topological origin, similar to quantum topological states.

This new approach illuminates the origin of surface electromagnetic waves and explains why these waves appear at interfaces where one of the medium parameters (dielectric permittivity or magnetic permeability) changes its sign. Moreover, the number of surface modes is determined by the number of the bulk-medium parameters changing their signs at the interface, which is called "bulk-boundary correspondence" in the topological formalism.

Konstantin Bliokh says, "There is a crucial difference between the topological description of surface Maxwell waves and that of previously known topological surface modes. So far, topological properties and classification of various wave systems have relied on mathematical properties of the Hamiltonian (i.e., energy) operator characterizing the system. In contrast, the topological properties of Maxwell's waves are described by the so-called helicity operator, which characterizes the chirality—or handedness—of circularly-polarized electromagnetic waves. Thus, our theory also extends the range of applicability of the topological approach to other wave systems. It shows that the topological classification can be associated not only with the Hamiltonian but also with other operators corresponding to conserved physical quantities."

Franco Nori says, "Our work provides a new twist and insights for several areas of wave physics: Maxwell electromagnetism, topological quantum states, and plasmonics/metamaterials." [16]

Invisible tags: Physicists write, read and erase using light

A team of physicists headed by Professor Sebastian Reineke of TU Dresden has developed a new method of storing information in fully transparent plastic foils. Their innovative idea has been published in *Science Advances*.

Prof. Reineke and his LEXOS team work with simple plastic foils with a thickness of less than 50 µm, which is thinner than a human hair. In these transparent plastic foils, they introduce organic luminescent molecules. In the beginning, these molecules are in an inactive, dark state. By locally using ultraviolet irradiation, it is possible to turn this dark state into an active, luminescent one. By mask illumination or laser writing, activated patterns can be printed onto the foil with a resolution that is comparable to common laser printers. Similar to glow-in-the-dark stickers, the patterns can be made to shine and the imprinted information can be read. By illuminating with infrared light, the tag is erased completely and new data can be written into it.

The working principle of these programmable transparent tags is based on the well-known oxygen molecule. Oxygen is present in the plastic foil and steals the light energy from the glowing molecules. Ultraviolet radiation induces a chemical reaction which efficiently removes the oxygen from the layer. As a result, the luminescent molecules are activated and are able to emit light. The deactivation process using infrared light is based on a temperature rise of the foil, leading to an increased oxygen permeability and therefore a refilling of the layer with oxygen.

These novel tags can be manufactured in any size. The low material costs of less than €2 per square meter promise a wide range of possible applications, including barcodes, serial numbers or addresses that can be hidden for on-demand readout only. Also, these invisible tags could propel document security and anti-counterfeiting to a whole new level.

Prof. Reineke is already thinking further ahead: "Those invisible and re-writable tags can be used in a multitude of ways. We can manufacture such tags thinner than conventional barcode stickers. These tags can become a versatile alternative to many frequently technology-laden solutions for information exchange in our daily life. These luminescent tags make electronics obsolete at the location where the information is stored. The development and optimisation of such systems open a broad research field bringing together material development, process engineering, and fundamental research in an interdisciplinary fashion. [15]

Novel electron microscopy offers nanoscale, damage-free isotope tracking in amino acids

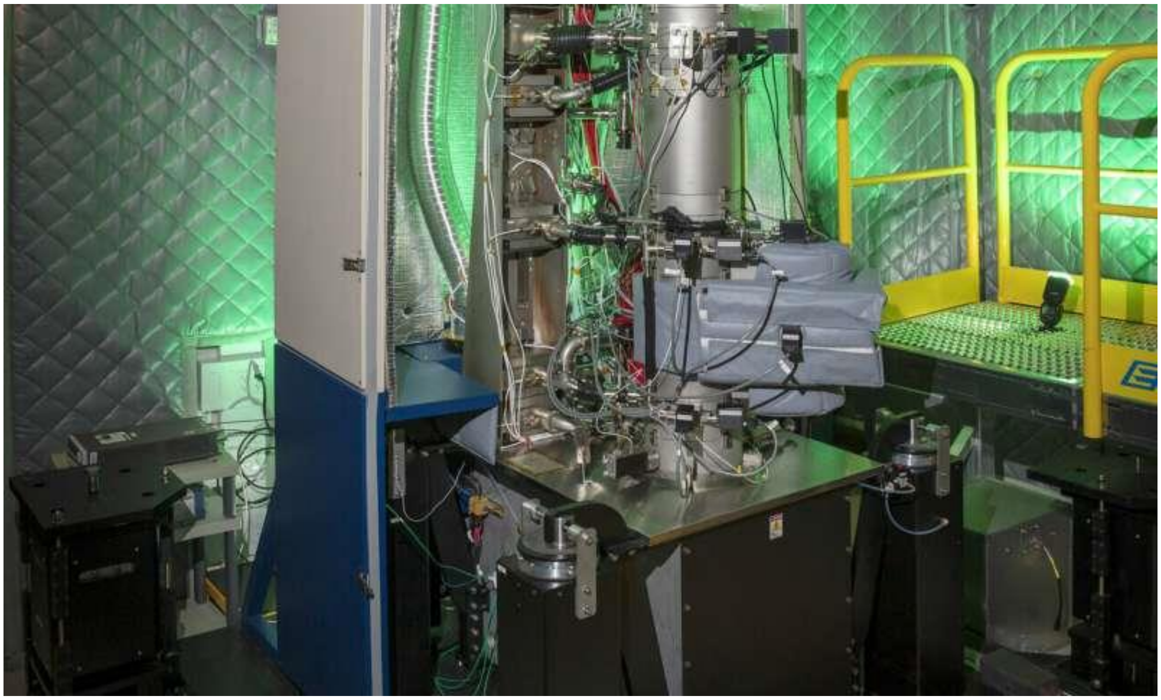
A new electron microscopy technique that detects the subtle changes in the weight of proteins at the nanoscale—while keeping the sample intact—could open a new pathway for deeper, more comprehensive studies of the basic building blocks of life.

Scientists at the Department of Energy's Oak Ridge National Laboratory described in the journal *Science* the first use of an electron microscope to directly identify isotopes in amino acids at the nanoscale without damaging the samples.

Isotopes are commonly used to label molecules and proteins. By measuring the variations in the vibrational signatures of the molecule, the electron microscope can track isotopes with unprecedented spectral precision and spatial resolution.

The technique does not destroy the amino acids, allowing for real-space observation of dynamic chemistry and creating a foundation for a host of scientific discoveries from simple to complex biological structures across the life sciences.

"The way we understand the progression of diseases, human metabolism and other complicated biological phenomena is based on interactions between proteins," said Jordan Hachtel, ORNL postdoctoral fellow and lead author. "We study these interactions by labeling specific proteins with an isotope and then tracking it through a chemical reaction to see where it went and what it did."



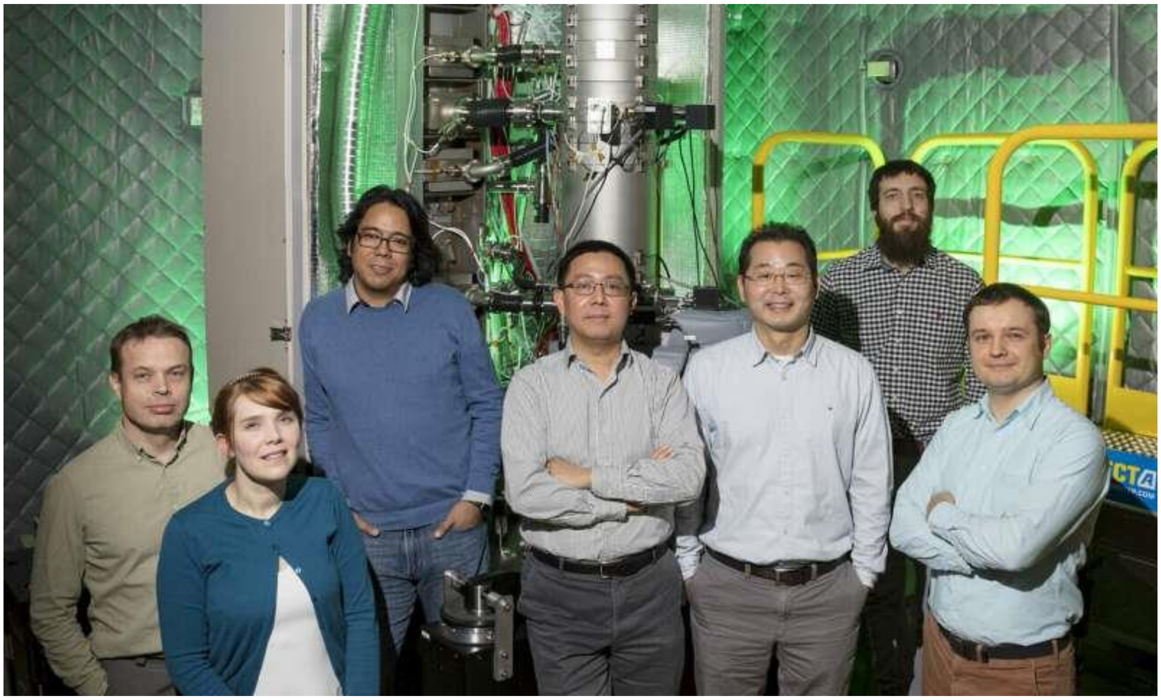
Oak Ridge National Laboratory scientists used a monochromated, aberration-corrected scanning transmission electron microscope, or MAC-STEM, technique that detects the subtle changes in the weight of proteins at the nanoscale--while keeping …more"Now, we can track isotopic labels directly with the electron microscope, meaning we can do it with a spatial resolution comparable to the actual size of the proteins," Hachtel added.

Their novel experiment, which took place at ORNL's Center for Nanophase Materials Sciences, used monochromated electron energy-loss spectroscopy, or EELS, in a scanning transmission electron microscope, or STEM. The technique the scientists used is sensitive enough to distinguish between molecules that differ by a single neutron on a single atom. EELS was used to capture the minute vibrations in the molecular structure of an amino acid.

"Isotopic labels are typically seen on the macroscopic level using mass spectrometry, a scientific tool that reveals a sample's atomic weight and isotopic composition," said Juan Carlos Idrobo, ORNL staff scientist and corresponding author. "Mass spectrometry has incredible mass resolution, but it typically doesn't have nanometer spatial resolution. It's a destructive technique."

A mass spectrometer uses an electron beam to break a molecule apart into charged fragments that are then characterized by their mass-to-charge ratio. Observing the sample at the macroscale, scientists can only infer statistically what chemical bonds were likely to have existed in the sample. The sample gets destroyed during the experiment, leaving valuable information undiscovered.

The new electron microscopy technique, as applied by the ORNL team, offers a gentler approach. By positioning the electron beam extremely close to the sample, but without directly touching it, the electrons can excite and detect the vibrations without destroying the sample, allowing observations of biological samples at room temperature over longer periods of time.



The interdisciplinary ORNL research team that brought damage-free isotopic labeling to the nanoscale in the electron microscope include, from left, Jacek Jakowski, Santa Jansone-Popova, Juan Carlos Idrobo, Jingsong Huang, Jong Keum, Jordan …more

Their result constitutes a breakthrough for electron microscopy, since the negatively charged electron beam is typically sensitive only to the protons, and not the neutrons. "However, the frequency of the molecular vibrations is dependent on the atomic weight, and the accurate measurement of these vibrational frequencies opens the first direct channel to measure isotopes in the electron microscope," said Idrobo.

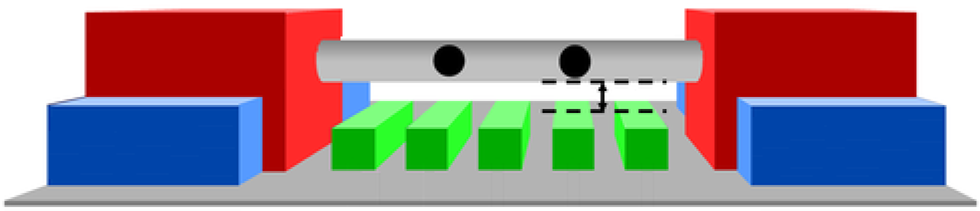
The ORNL-led research team expects their potentially game-changing technology would not replace but rather complement mass spectrometry and other conventional optical and neutron-based techniques currently used to detect isotopic labels.

"Our technique is the perfect complement to a macroscale mass spectrometry experiment," Hachtel said. "With the pre-knowledge of the mass spectrometry, we can go in and spatially resolve where the isotopic labels are ending up in a real-space sample."

Beyond the life sciences the technique could be applied to other soft matter such as polymers, and potentially in quantum materials where isotopic substitution can play a key role in controlling superconductivity. [14]

Device to Probe Electron-Phonon Interactions

Researchers use a cavity-coupled double quantum dot to study electron-phonon interactions in a nanowire.



T. R. Hartke *et al.*, Phys. Rev. Lett. (2018)

Interactions between phonons—vibrational quanta—and electrons can reduce the cooling rate of a computer chip or limit the amount of electrical current that can squeeze through a nanotube. But researchers don't understand the details of electron-phonon interactions or why they lead to these unwanted effects. Now Thomas Hartke and colleagues at Princeton University, New Jersey, take a step toward solving this problem by demonstrating a new method to study electron-phonon interactions in a nanowire. Their method, which uses a double quantum dot (DQD) and a microwave cavity, could pick up the faint signals associated with these interactions, allowing researchers to probe the missing details of electron-phonon interactions.

The team's device resembles a tiny bridge. The DQD—a 50-nm-thick wire—is suspended between two pedestals, a design that makes the DQD sensitive to 60-μμeV phonons. One end of the bridge is connected to a nearby microwave cavity, and a sinusoidal electromagnetic wave is applied to the cavity to fill it with photons. Electrons tunneling from one end of the bridge to the other cause the wire to vibrate, creating phonons; the electrons also emit photons into the cavity. Detection of electron-phonon interaction is made by tracking the wire's current as it vibrates and by monitoring the cavity photons.

In a proof-of-principle demonstration of the device, Hartke and his co-workers varied the potential across the bridge and measured changes in the wire's current and in the amplitude and phase of the cavity photons. They observed well-defined oscillations in all three variables as the potential changed, with peaks appearing as the energy within the DQD passed through multiples of 60 μμeV, a sign that phonons were emitted. The team also found that photons emitted by the tunneling electrons altered the natural frequency of the cavity, a critical insight for interpreting future experiments.

This research is published in ***Physical Review Letters***. [13]

Simulating the quantum world with electron traps

This story was prepared by the Delft University of Technology (TU Delft) (link is external) and adapted with permission. The experiments described were performed at TU Delft, with theoretical and numerical contributions from JQI Fellow and Condensed Matter Theory Center Director Sankar Das Sarma and JQI postdoctoral researcher Xiao Li.

Quantum behavior plays a crucial role in novel and emergent material properties, such as superconductivity and magnetism. Unfortunately, it is still impossible to calculate the underlying quantum behavior, let alone fully understand it. Scientists of QuTech, the Kavli Institute of Nanoscience in Delft and TNO, in collaboration with ETH Zurich and the University of Maryland, have now succeeded in building an "artificial material" that mimics this type of quantum behavior on a small scale. In doing so, they have laid the foundations for new insights and potential applications. Their work is published today in Nature (link is external).

Over the past century, an increased understanding of semiconductor materials has led to many technological improvements, such as computer chips becoming ever faster and smaller. We are, however, gradually reaching the limits of Moore's Law, the trend that predicts a doubling in computing power for half the price every two years. But this prediction ignores the possibility that computers might harness quantum physics.

"There is so much physics left to discover if we truly want to understand materials on the very smallest scale," says Lieven Vandersypen, a professor at TU Delft in the Netherlands and the lead experimentalist on the new paper. And that new physics is set to bring even more new technology with it. "The difficulty is that, at this scale, quantum theory determines the behavior of electrons and it is virtually impossible to calculate this behavior accurately even for just a handful of electrons, using even the most powerful supercomputers," Vandersypen says.

Scientists are now combining the power of the semiconductor industry with their knowledge of quantum technology in order to mimic the behavior of electrons in materials—a technique known as quantum simulation. "I hope that, in the near future, this will enable us to learn so much about materials that we can open some important doors in technology, such as the design of superconductors at room temperature, to make possible loss-free energy transport over long distances, for example," Vandersypen says.

Mimicking nature

It has long been known that individual electrons can be confined to small regions on a chip, known as quantum dots. There are, in principle, suitable for researching the behavior and interactions of electrons in materials. The captured electrons can move, or tunnel, between the quantum dots in a controlled way, while they interact through the repulsion of their negative charges. "Processes like these in quantum dots, cooled to a fraction of a degree above absolute zero, are perfectly suitable for simulating the electronic properties of new materials," says Toivo Hensgens, a graduate student at TU Delft and the lead author of the paper.

In practice, it is a major challenge to control the electrons in quantum dots so precisely that the underlying physics becomes visible. Imperfections in the quantum chips and inefficient methods of controlling the electrons in the dots have made this a particularly hard nut to crack.

Quantum equipment

Researchers have now demonstrated a method that is both effective and can be scaled up to larger numbers of quantum dots. The number of electrons in each quantum dot can be set from 0 to 4 and the chance of tunnelling between neighbouring dots can be varied from negligible to the point at which neighbouring dots actually become one large dot. "We use voltages to distort the (potential) landscape that the electrons sense," explains Hensgens. "That voltage determines the number of electrons in the dots and the relative interactions between them."

In a quantum chip with three quantum dots, the QuTech team has demonstrated that they are capable of simulating a series of material processes experimentally. But the most important result is the method that they have demonstrated. "We are now easily able to add more quantum dots with electrons and control the potential landscape in such a way that we can ultimately simulate very large and interesting quantum processes," Hensgens says.

The Vandersypen team aims to progress towards more quantum dots as soon as possible. To achieve that, he and his colleagues have entered a close collaboration with chipmaker Intel. "Their knowledge and expertise in semiconductor manufacturing combined with our deep understanding of quantum control offers opportunities that are now set to bear fruit," he says. [12]

Single-photon source is efficient and indistinguishable

Devices that emit one – and only one – photon on demand play a central role in light-based quantum-information systems. Each photon must also be emitted in the same quantum state, which makes each photon indistinguishable from all the others. This is important because the quantum state of the photon is used to carry a quantum bit (qubit) of information.

Quantum dots are tiny pieces of semiconductor that show great promise as single-photon sources. When a laser pulse is fired at a quantum dot, an electron is excited between two distinct energy levels. The excited state then decays to create a single photon with a very specific energy. However, this process can involve other electron excitations that result in the emission of photons with a wide range of energies – photons that are therefore not indistinguishable.

Exciting dots

This problem can be solved by exciting the quantum dot with a pulse of light at the same energy as the emitted photon. This is called resonance fluorescence, and has been used to create devices that are very good at producing indistinguishable single photons. However, this process is inefficient, and only produces a photon about 6% of the time.

Now, Chaoyang Lu, Jian-Wei Pan and colleagues at the University of Science and Technology of China have joined forces with researchers in Denmark, Germany and the UK to create a resonancefluorescence-based source that emits a photon 66% of the time when it is prompted by a laser pulse. Of these photons, 99.1% are solo and 98.5% are in indistinguishable quantum states – with both figures of merit being suitable for applications in quantum-information systems.

Lu told physicsworld.com that nearly all of the laser pulses that strike the source produce a photon, but about 34% of these photons are unable to escape the device. The device was operated at a laser-pulse frequency of 81 MHz and a pulse power of 24 nW, which is a much lower power requirement than other quantum-dot-based sources.

Quantum sandwich

The factor-of-ten improvement in efficiency was achieved by sandwiching a quantum dot in the centre of a "micropillar" created by stacking 40 disc-like layers (see figure). Each layer is a "distributed Bragg reflector", which is a pair of mirrors that together have a thickness of one quarter the wavelength of the emitted photons.

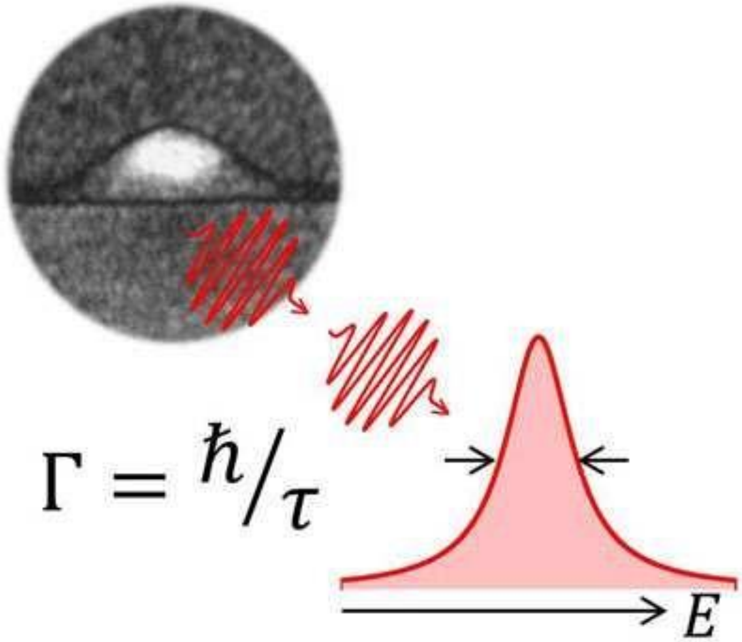
The micropillar is about 2.5 µm in diameter and about 10 µm tall, and it allowed the team to harness the "Purcell effect", whereby the rate of fluorescence is increased significantly when the emitter is placed in a resonant cavity.

Lu says that the team is already thinking about how the photon sources could be used to perform boson sampling (see "'Boson sampling' offers shortcut to quantum computing"). This involves a network of beam splitters that converts one set of photons arriving at a number of parallel input ports into a second set leaving via a number of parallel outputs. The "result" of the computation is the probability that a certain input configuration will lead to a certain output. This result cannot be easily calculated using a conventional computer, and this has led some physicists to suggest that boson sampling could be used to solve practical problems that would take classical computers vast amounts of time to solve.

Other possible applications for the source are the quantum teleportation of three properties of a quantum system – the current record is two properties and is held by Lu and Pan – or quantum cryptography.

The research is described in Physical Review Letters. [11]

Semiconductor quantum dots as ideal single-photon source



A single-photon source never emits two or more photons at the same time. Single photons are important in the field of quantum information technology where, for example, they are used in quantum computers. Alongside the brightness and robustness of the light source, the indistinguishability of the photons is especially crucial. In particular, this means that all photons must be the same color. Creating such a source of identical single photons has proven very difficult in the past.

However, quantum dots made of semiconductor materials are offering new hope. A quantum dot is a collection of a few hundred thousand atoms that can form itself into a semiconductor under certain conditions. Single electrons can be captured in these quantum dots and locked into a very small area. An individual photon is emitted when an engineered quantum state collapses.

Noise in the semiconductor

A team of scientists led by Dr. Andreas Kuhlmann and Prof. Richard J. Warburton from the University of Basel have already shown in past publications that the indistinguishability of the photons is reduced by the fluctuating nuclear spin of the quantum dot atoms. For the first time ever, the scientists have managed to control the nuclear spin to such an extent that even photons sent out at very large intervals are the same color.

Quantum cryptography and quantum communication are two potential areas of application for single-photon sources. These technologies could make it possible to perform calculations that are far beyond the capabilities of today's computers. [10]

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]

Heralded Qubit Transfer

Optical photons would be ideal carriers to transfer quantum information over large distances. Researchers envisage a network where information is processed in certain nodes and transferred between them via photons. However, inherent losses in long-distance networks mean that the information transfer is subject to probabilistic errors, making it hard to know whether the transfer of a qubit of information has been successful. Now Gerhard Rempe and colleagues from the Max Planck Institute for Quantum Optics in Germany have developed a new protocol that solves this problem through a strategy that “heralds” the accurate transfer of quantum information at a network node.

The method developed by the researchers involves transferring a photonic qubit to an atomic qubit trapped inside an optical cavity. The photon-atom quantum information transfer is initiated via a quantum “logic-gate” operation, performed by reflecting the photon from the atom-cavity system, which creates an entangled atom-photon state. The detection of the reflected photon then collapses the atom into a definite state. This state can be one of two possibilities, depending on the photonic state detected: Either the atom is in the initial qubit state encoded in the photon and the transfer process is complete, or the atom is in a rotated version of this state. The authors were able to show that the roles of the atom and photon could be reversed. Their method could thus be used as a quantum memory that stores (photon-to-atom state transfer) and recreates (atom-to-photon state transfer) a single-photon polarization qubit. [9]

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 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 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 it 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 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ 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 ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

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

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

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

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

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

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 $E = hv$ 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.

Electron – Proton mass rate

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 a gravitational force. [2]

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.

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 Bing 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 rate Mp=1840 Me. 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

The method developed by the researchers involves transferring a photonic qubit to an atomic qubit trapped inside an optical cavity. The photon-atom quantum information transfer is initiated via a quantum "logic-gate" operation, performed by reflecting the photon from the atom-cavity system, which creates an entangled atom-photon state. [9]

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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