QKD Transmission Distance Record

The sending-or-not-sending twin-field (SNS-TF) protocol has so far proved to be a highly promising strategy for achieving high rates over long distances in quantum key distribution (QKD) applications. [17]

EPFL physicist László Forró and his team pave the way for the future of data storage. [16]

Researchers from the University of Toronto Engineering and King Abdullah University of Science and Technology (KAUST) have overcome a key obstacle in combining the emerging solar-harvesting technology of perovskites with the commercial gold standard—silicon solar cells. [15]

Researchers from the Theory Department of the MPSD in Hamburg and North Carolina State University in the US have demonstrated that the long-sought magnetic Weyl semi-metallic state can be induced by ultrafast laser pulses in a three-dimensional class of magnetic materials dubbed pyrochlore iridates. [14]

At TU Wien recently, particles known as 'Weyl fermions' were discovered in materials with strong interaction between electrons. Just like light particles, they have no mass but nonetheless they move extremely slowly. [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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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.

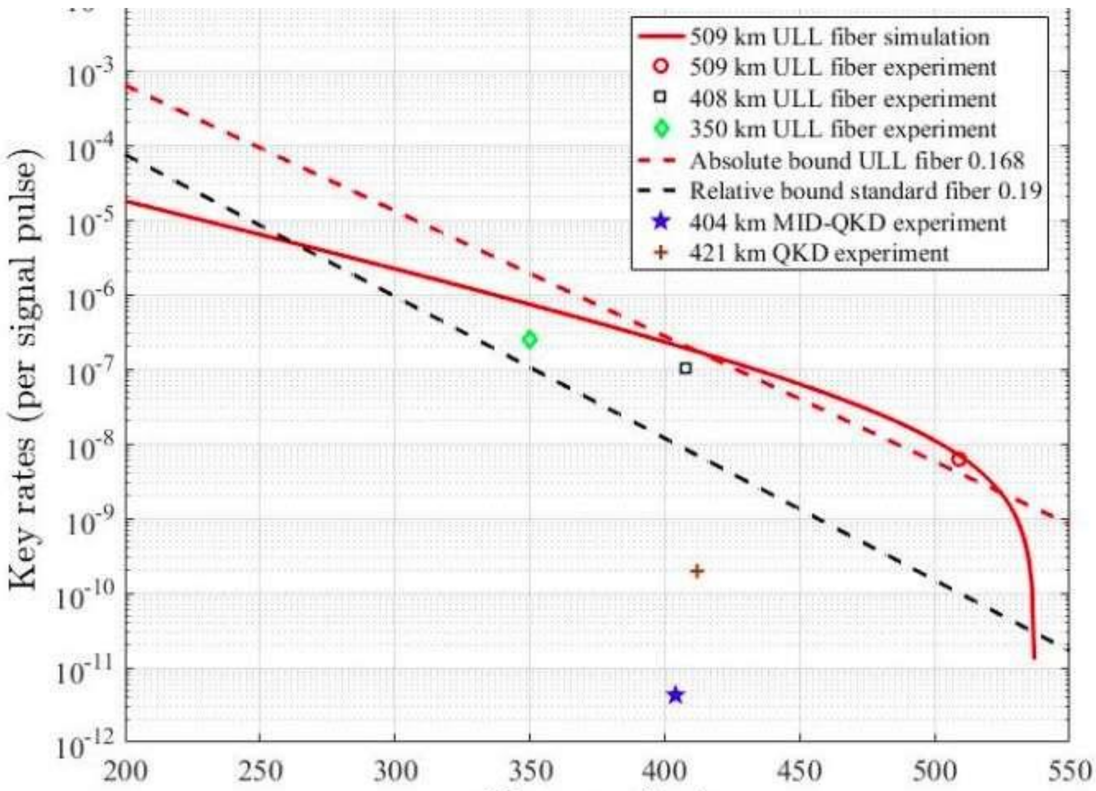
Study achieves a new record fiber QKD transmission distance of over 509 km

The sending-or-not-sending twin-field (SNS-TF) protocol has so far proved to be a highly promising strategy for achieving high rates over long distances in quantum key distribution (QKD) applications. In fact, by tolerating large misalignment errors, this protocol can surpass the repeaterless bound in more effective ways, which is a crucial factor in the realization of long-distance QKD.

Jian-Wei Pan, Qiang Zhang, Xiang-Bin Wang and other researchers at the University of Science and Technology of China and Tsinghua University have recently achieved an unprecedented QKD transmission distance using the SNS-TF protocol. Their paper, published in *Physical Review Letters*, reports QKD with a secure key distribution breaking the repeaterless bound over a 509-km-long optical fiber.

"Using the sending-or-not-sending twin-field (SNS-TF) protocol, we realized secure quantum key distribution (QKD) over 509 km, which is a new record secure distance in QKD over fiber," Qiang Zhang, one of the researchers who carried out the study, told Phys.org. "One of the important objectives of our study was to successfully break the absolute key-rate limit of repeater-less QKD, with any measurement device."

The SNS-TF protocol was developed and introduced in a previous research effort by some of the researchers who wrote the recent paper. In previous studies, the protocol proved to be highly advantageous for QKD applications, particularly for achieving long distance transmission.



Credit: Chen et al.

In their recent work, Zhang and his colleagues implemented the SNS-TF QKD protocol by eliciting a single-photon level, first-order interference between two independent lasers. These two independent lasers were combined with a remote frequency locking technique, ultimately enabling QKD transmission over unparalleled distances. In their experiments, the researchers also used superconducting single-photon detectors with high count rate and detection efficiencies.

"We adopted technology typically employed in time-frequency dissemination research and locked two independent lasers' frequency in an ultra-narrow laser cavity," Zhang said. "Then, we time-multiplexed strong laser light as phase reference with the quantum signal in one fiber. The strong light induced lots of noise counts, but we exploited many filtering methods to avoid this."

Using their SNS-TF approach, the researchers achieved a secure key rate at 509 km, over seven times higher than the relative repeaterless bound QKD, and with the same detection loss. Remarkably, the key rate they achieved is also higher than that achieved by more traditional QKD protocols running on a perfect repeaterless QKD device.

"We experimentally provided a new record for fiber QKD transmission distance and demonstrated that it breaks the absolute key-rate limit of repeaterless QKD," Zhang said. "In our future research, we plan to explore higher key rate and longer distance."

In their recent study, the researchers gathered new evidence confirming the potential of the SNS-TF QKD protocol and showed how this scheme can be combined with technological tools to achieve high secure key rates across long distribution distances. Their work could soon enable the large-scale implementation of QKD with relatively high key rates at 200-300 km, which could be particularly useful for the development of intra-city QKD networks. In fact, applying their technology to QKD main trunk lines could help to reduce trustful relays, resulting in more efficient QKD. [17]

Introducing the light-operated hard drives of tomorrow

What do you get when you place a thin film of perovkite material used in solar cells on top of a magnetic substrate? More efficient hard drive technology. EPFL physicist László Forró and his team pave the way for the future of data storage.

"The key was to get the technology to work at room temperature," explains László Forró, EPFL physicist. "We had already known that it was possible to rewrite magnetic spin using light, but you'd have to cool the apparatus to—180 degrees Celsius."

Forró, along with his colleagues Bálint Náfrádi and Endre Horváth, succeeded at tuning one ferromagnet at room temperature with visible light, a proof of concept that establishes the foundations of a new generation of hard drives that will be physically smaller, faster, and cheaper, requiring less energy compared to today's commercial hard drives. The results are published in *PNAS*.

A hard drive functions as a data storage device in a computer, where a large amount of data can be stored with an electromagnetically charged surface.

Nowadays, the demand for high capacity hard drives has increased more than ever. Computer users handle large files, databases, image or video files, using software, all of which require a large amount of memory in order to save and process the data as quickly as possible.

The EPFL scientists used a halide perovskite/oxide perovskite heterostructure in their new method for reversible, light-induced tuning of ferromagnetism at room temperature. Having a perovskite structure represents a novel class of light-absorbing materials.

As reported in the publication, "The rise of digitalization led to an exponential increase in demand for data storage. Mass-storage is resolved by hard-disk drives, HDDs, due to their relatively long lifespan and low price. HDDs use magnetic domains, which are rotated to store and retrieve information. However, an increase in capacity and speed is continuously demanded. We report a method to facilitate the writing of magnetic bits optically. We use a sandwich of a highly light sensitive ($MAPbI_3$) and a ferromagnetic material (LSMO), where illumination of MAPbI3 drives charge carriers into LSMO and decreases its magnetism. This is a viable alternative of the long-sought-after heat-assisted magnetic recording (HAMR) technology, which would heat up the disk material during the writing process."

The method is still experimental, but it may be used to build the next generation of memory-storage systems, with higher capacities and with low energy demands. The method provides a stand for the development of a new generation of magneto-optical hard drives. Forró concludes: " We are now looking for investors who would be interested in carrying on the patent application, and for industrial partners to implement this original idea and proof of principle into a product." [16]

Light to electricity: New multi-material solar cells set new efficiency standard

Researchers from the University of Toronto Engineering and King Abdullah University of Science and Technology (KAUST) have overcome a key obstacle in combining the emerging solar-harvesting technology of perovskites with the commercial gold standard—silicon solar cells. The result is a highly efficient and stable tandem solar cell, one of the best-performing reported to date.

"Today, silicon solar cells are more efficient and less costly than ever before," says Professor Ted Sargent, senior author on a new paper published today in *Science*. "But there are limits to how efficient silicon can be on its own. We're focused on overcoming these limits using a tandem (two-layer) approach."

Like silicon, perovskite crystals can absorb solar energy to excite electrons that can be channeled into a circuit. But unlike silicon, perovskites can be mixed with liquid to create a 'solar ink' that can be printed on surfaces.

The ink-based manufacturing approach—known as solution processing—is already well-established in the printing industry, and therefore has the potential to lower the cost of making solar cells.

"Adding a layer of perovskite crystals on top of textured silicon to create a tandem solar cell is a great way to enhance its performance," says Yi Hou, postdoctoral fellow and lead author of the new paper. "But the current industry standard is based on wafers—thin sheets of crystalline silicon—that were not designed with this approach in mind."

Though they may look smooth, standard silicon wafers used for solar cells feature tiny pyramidal structures about two micrometres high. The uneven surface minimizes the amount of light that reflects off the surface of the silicon and increases overall efficiency, but also makes it difficult to coat a uniform layer of perovskites on top.

"Most previous tandem cells have been made by first polishing the silicon surface to make it smooth, and then adding the perovskite layer," says Hou. "That works, but at additional costs."

Hou and the rest of the team—including Sargent and KAUST Professor Stefaan De Wolf—took a different approach. They increased the thickness of the perovskite layer, making it high enough to cover both the peaks and the valleys created by the pyramidal structures.

The team discovered that the perovskites in the valleys generated an electrical field that separates the electrons generated in the perovskite layer from those generated in the silicon layer. This type of charge separation is beneficial because it increases the chances that excited charges will flow into the circuit rather than other parts of the cell.

The team further enhanced charge separation by coating the perovskite crystals in a 'passivation layer' made of 1-butanethiol, a common industrial chemical.

The tandem solar cells achieved an efficiency of 25.7 per cent, as certified by an independent, external laboratory, the Fraunhofer Institute for Solar Energy in Freiburg, Germany. This is among the highest efficiencies ever reported for this type of design. They were also stable, withstanding temperatures of up to 85 degrees Celsius for more than 400 hours without a significant loss of performance.

"The fact that we can do all this without modifying the silicon makes it a drop-in solution," says Hou. "Industry can apply this without having to make costly changes to their existing processes."

Hou and the team are continuing to work on improvements to the design, including increasing stability up to 1,000 hours, one industry benchmark.

"We're very proud of the record-setting performance this collaboration was able to achieve, but this is just the beginning," says Hou. "By overcoming a key limitation in tandem solar cells, we've set the stage for even larger gains."

"Our approach opens a door for the silicon-photovoltaic industry to fully exploit the great advances perovskite technology has made so far," says De Wolf. "This can bring photovoltaic panels with higher performance at low cost to market." [15]

Shedding light on Weyl fermions

Researchers from the Theory Department of the MPSD in Hamburg and North Carolina State University in the US have demonstrated that the long-sought magnetic Weyl semi-metallic state can be induced by ultrafast laser pulses in a three-dimensional class of magnetic materials dubbed pyrochlore iridates. Their results, which have been published in *Nature Communications*, could enable high-speed magneto-optical topological switching devices for next-generation electronics.

All known elementary particles can be sorted into two categories: bosons and fermions. Bosons carry forces like the magnetic force or gravity, while fermions are the matter particles, like electrons. Theoretically it was predicted that fermions themselves can come in three species, named after the physicists Dirac, Weyl and Majorana.

Electrons in free space are Dirac fermions, but in solids, they can change their nature. In the atomically thin carbon material graphene, they become massless Dirac fermions. In other recently discovered and manufactured materials, they can also become Weyl and Majorana fermions, which makes such materials interesting for future technologies such as topological quantum computers and other novel electronic devices.

In combination with a wave of bosons, namely photons in a laser, fermions can be transformed from one type to another, as proposed by MPSD theorists in 2016. Now, a new study led by Ph.D. student Gabriel Topp in the Emmy Noether group of Michael Sentef suggests that electron spins can be manipulated by short light pulses to create a magnetic version of Weyl fermions from a magnetic insulator. Based on a prior study led by MPSD postdoctoral researcher Nicolas Tancogne-Déjean and Theory Director Angel Rubio, the scientists used the idea of laser-controlled electron-electron repulsion to suppress magnetism in a pyrochlore iridate material where electron spins are positioned on a lattice of tetrahedra.

On this lattice, electron spins, like little compass needles, point all-in to the center of the tetrahedron and all-out in the neighboring one. This all-in, all-out combination, together with the length of the compass needles, leads to insulating behavior in the material without light stimulation. However, modern computer simulations on large computing clusters revealed that when a short light pulse hits the material, the needles start to rotate in such a way that, on average, they look like shorter needles with less strong magnetic ordering. Done in just the right way, this reduction of magnetism leads to the material becoming semi-metallic with Weyl fermions emerging as the new carriers of electricity in it.

"This is a really nice step forward in learning how light can manipulate materials on ultrashort time scales," says Michael Sentef. Gabriel Topp says, "We were surprised by the fact that even a too-strong laser pulse that should lead to a complete suppression of magnetism and a standard metal without Weyl fermions could lead to a Weyl state. This is because on very short time scales, the material does not have enough time to find a thermal equilibrium. When everything is shaking back and forth, it takes some time until the extra energy from the laser pulse is distributed evenly among all the particles in the material."

The scientists are optimistic that their work will stimulate more theoretical and experimental work along these lines. "We are just at the beginning of learning to understand the many beautiful ways in which light and matter can combine to yield fantastic effects and we do not even know what they might be today," says Angel Rubio. "We are working very hard with a dedicated and highly motivated group of talented young scientists at the MPSD to explore these almost unlimited possibilities so that society will benefit from our discoveries." [14]

Weyl particles detected in strongly correlated electron systems

At TU Wien recently, particles known as 'Weyl fermions' were discovered in materials with strong interaction between electrons. Just like light particles, they have no mass but nonetheless they move extremely slowly.

There was great excitement back in 2015, when it was first possible to measure these 'Weyl fermions' – outlandish, massless particles that had been predicted almost 90 years earlier by German mathematician, physician and philosopher, Hermann Weyl. Now, once again, there has been a breakthrough in this field of research, with researchers at TU Wien being the first to successfully detect Weyl particles in strongly correlated electron systems – that is, materials where the electrons have a strong interaction with each other. In materials like this, the Weyl particles move extremely slowly, despite having no mass. The discovery should now open the door to an entirely new area of physics, and enable hitherto unimagined material-physical effects.

Quasiparticles: only possible in a solid state

After physician Paul Dirac had arrived at his Dirac equation in 1928, which can be used to describe the behaviour of relativistic electrons, Hermann Weyl found a particular solution for this equation – namely for particles with zero mass, or 'Weyl fermions'. The neutrino was originally thought to be such a massless Weyl particle, until it was discovered that it does indeed have mass. The mysterious Weyl fermions were, in fact, detected for the first time in 2015; they turned out not to be free particles like the neutrino, which can move through the universe independently from the rest of the world, but rather 'quasiparticles' in a solid state.

"Quasiparticles are not particles in the conventional sense, but rather excitations of a system consisting of many interacting particles," explains Prof. Silke Bühler-Paschen from the Institute of Solid State Physics at TU Wien. In some sense, they are similar to a wave in water. The wave is not a water molecule, rather it is based on the movement of many molecules. When the wave moves forward, this does not mean that the particles in the water are moving at that speed. It is not the water molecules themselves, but their excitation in wave form that spreads.

However, although the quasiparticles in a solid state are the result of an interplay between many particles, from a mathematical perspective they can be described similarly to a free particle in a vacuum.

The remarkable thing about the experiment, conducted by Sami Dzsaber and other members of the research group for quantum materials led by Silke Bühler-Paschen at TU Wien, is the fact that the Weyl particles were discovered in a strongly correlated electron system. This type of material is of particular interest for the field of solid state physics: their electrons cannot be described as separate from one another; they are strongly interconnected and it is precisely this that lends them extraordinary properties, from high-temperature superconductivity through to new kinds of phase transitions.

"The strong interactions in such materials usually lead, via the so-called Kondo effect, to particles behaving as if they had an extremely large mass," explains Sami Dzsaber. "So it was astonishing for us to detect Weyl fermions with a mass of zero in this particular type of material." According to the laws of relativity, free massless particles must always spread at light speed. This is, however, not the case in solid states: "Even though our Weyl fermions have no mass, their speed is extremely low," says Bühler-Paschen. The solid state lends them its own fixed 'light speed' to a certain extent. This is lower than 1000 m/s, i.e. only around three millionth of the speed of light in a vacuum. "As such, they are even slower than phonons, the analogue to the water wave in the solid state, and this makes them detectable in our experiment."

In search of new effects

At the same time as these measurements were being made at TU Wien, theoretical investigations were being carried out under the leadership of Qimiao Si at Rice University in Texas – BühlerPaschen was a visiting professor there at the time – which looked at the question of how these Weyl fermions could even exist in a strongly correlated material. This combination of experiment and theory thus produced a conclusive picture of the new effect, which is now enabling new research to be carried out.

The newly detected quasiparticles are interesting for a number of reasons: "Even if Weyl fermions were initially found in other materials, it is much easier to control the effect in our strongly correlated materials," says Silke Bühler-Paschen. "Due to their low energy, it is significantly easier to influence them using parameters such as pressure or an external magnetic field." This means the Weyl fermions can also be used for technological applications.

The Weyl fermions are only dispersed in the material to a minimal extent, meaning they can conduct electrical current almost without loss – this is of great significance for electronics. They are also likely to be extremely interesting to the field of spintronics, an advancement in electronics where not only the electrical charge of the particles but also their spin is used. Weyl fermions will be of interest here due to their particularly robust spin. The particle should also be especially well suited for use in quantum computers. "This is a really exciting development," says Bühler-Paschen. [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.

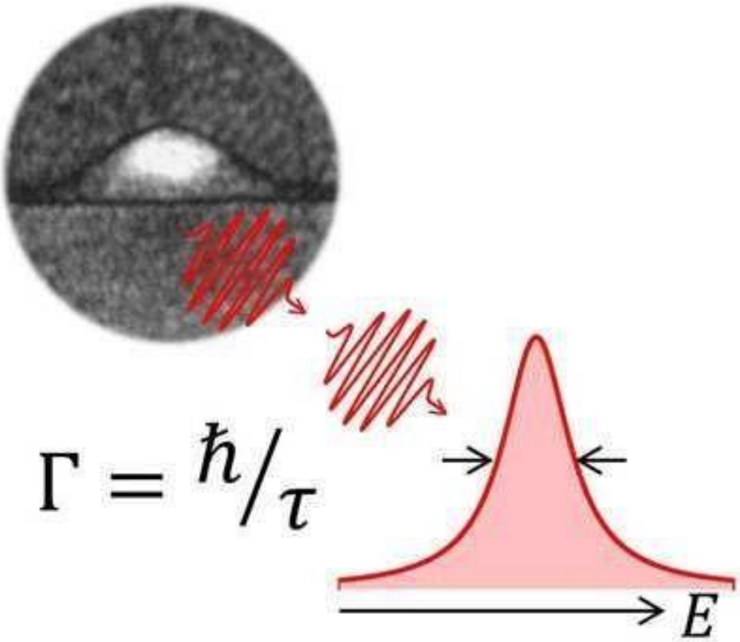
The micropillar is about 2.5 µm in diameter and about 10 µm tall, and it allowed the team to harness the "Purcell effect", whereby the rate of fluorescence is increased significantly when the emitter is placed in a resonant cavity.

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 $E = h\nu$ 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_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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