Satellite-Based Quantum Encryption Network

In a new study, researchers demonstrate ground-based measurements of quantum states sent by a laser aboard a satellite 38,000 kilometers above Earth. This is the first time that quantum states have been measured so carefully from so far away. [23]

For the first time, physicists have experimentally demonstrated a quantum secure direct communication (QSDC) protocol combined with quantum memory, which is essential for storing and controlling the transfer of information. [22]

Quantum encryption using single photons is a promising technique for boosting the security of communication systems and data networks, but there are challenges in applying the method over large distances due to transmission losses. [21]

Researchers in Delft and Oxford have now managed to distil a strong entangled link by combining multiple weaker quantum links into one. This method is essential to realize a trustworthy quantum network between several quantum nodes. [20]

Researchers in Canada have taken a significant step towards enabling secure quantum communication via moving satellites, as announced by the Canadian Government in April 2017. [19]

Particle-free quantum communication is achieved in the lab. [18]

In the non-intuitive quantum domain, the phenomenon of counterfactuality is defined as the transfer of a quantum state from one site to another without any quantum or classical particle transmitted between them. [17]

The quantum internet, which connects particles linked together by the principle of quantum entanglement, is like the early days of the classical internet – no one can yet imagine what uses it could have, according to Professor Ronald Hanson, from Delft University of Technology, the Netherlands, whose team was the first to prove that the phenomenon behind it was real. [16]

Through a collaboration between the University of Calgary, The City of Calgary and researchers in the United States, a group of physicists led by Wolfgang Tittel, professor in the Department of Physics and Astronomy at the University of Calgary have successfully demonstrated teleportation of a photon (an *elementary particle of light) over a straight-line distance of six kilometers using The City of Calgary's fiber optic cable infrastructure. [15]*

Optical quantum technologies are based on the interactions of atoms and photons at the single-particle level, and so require sources of single photons that are highly indistinguishable – that is, as identical as possible. Current single-photon sources using semiconductor quantum dots inserted into photonic structures produce photons that are ultrabright but have limited indistinguishability due to charge noise, which results in a fluctuating electric field. [14]

A method to produce significant amounts of semiconducting nanoparticles for light-emitting displays, sensors, solar panels and biomedical applications has gained momentum with a demonstration by researchers at the Department of Energy's Oak Ridge National Laboratory. [13]

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.

Researchers discover shortcut to satellite-based quantum encryption network

In a new study, researchers demonstrate ground-based measurements of quantum states sent by a laser aboard a satellite 38,000 kilometers above Earth. This is the first time that quantum states have been measured so carefully from so far away.

"We were quite surprised by how well the quantum states survived traveling through the atmospheric turbulence to a ground station," said Christoph Marquardt from the Max Planck Institute for the Science of Light, Germany. "The paper demonstrates that technology on satellites, already space-proof against severe environmental tests, can be used to achieve quantum-limited measurements, thus making a satellite quantum communication network possible. This greatly cuts down on development time, meaning it could be possible to have such a system as soon as five years from now."

A satellite-based quantum-based encryption network would provide an extremely secure way to encrypt data sent over long distances. Developing such a system in just five years is an extremely fast timeline since most satellites require around 10 years of development. Normally, every component—from computers to screws—must be tested and approved to work in the harsh environmental conditions of space and must survive the gravitational changes experienced during the launch.

Marquardt and his colleagues from the division of Gerd Leuchs at the Max Planck Institute in Erlangen report their new research in Optica, The Optical Society's journal for high impact research.

Using light to keep data safe

Today, text messages, banking transactions and health information are all encrypted with techniques based on mathematical algorithms. This approach works because it is extremely difficult to figure out the exact algorithm used to encrypt a given piece of data. However, experts believe that computers powerful enough to crack these encryption codes are likely to be available in the next 10 to 20 years.

The looming security threat has placed more attention on implementing stronger encryption techniques such as quantum key distribution. Rather than relying on math, quantum key distribution uses properties of light particles known as quantum states to encode and send the key needed to decrypt encoded data. If someone tries to measure the light particles to steal the key, it changes the particles' behavior in a way that alerts the intended communicating parties that the key has been compromised and should not be used. The fact that this system detects eavesdropping means that secure communication is guaranteed.

Although methods for quantum encryption have been in development for more than a decade, they don't work over long distances because residual light losses in optical fibers used for telecommunications networks on the ground degrade the sensitive quantum signals. Quantum signals cannot be also regenerated without altering their properties by suing optical amplifiers as it is done for classical optical data. For this reason, there has been a recent push to develop a satellite-based quantum communication network to link ground-based quantum encryption networks located in different metropolitan areas, countries and continents.

Although the new findings showed that quantum communication satellite networks do not need to be designed from scratch, Marquardt notes that it will still take 5 to 10 years to convert ground based systems to quantum-based encryption to communicate quantum states with the satellites.

Measuring quantum states

For the experiments, Marquardt's team worked closely with satellite telecommunications company Tesat-Spacecom GmbH and the German Space Administration. The German Space Administration previously contracted with Tesat-Spacecom on behalf of the German Ministry of Economics and Energy to develop an optical communications technology for satellites. This technology is now being used commercially in space by laser communication terminals onboard Copernicus—the European

Union's Earth Observation Programme—and by SpaceDataHighway, the European data relay satellite system.

It turned out that this satellite optical communications technology works much like the quantum key distribution method developed at the Max Planck Institute. Thus, the researchers decided to see if it was possible to measure quantum states encoded in a laser beam sent from one of the satellites already in space. In 2015 and the beginning of 2016, the team made these measurements from a ground-based station at the Teide Observatory in Tenerife, Spain. They created quantum states in a range where the satellite normally does not operate and were able to make quantum-limited measurements from the ground.

"From our measurements, we could deduce that the light traveling down to Earth is very well suited to be operated as a quantum key distribution network," Marquardt said. "We were surprised because the system was not built for this. The engineers had done an excellent job at optimizing the entire system."

The researchers are now working with Tesat-Spacecom and others in the space industry to design an upgraded system based on the hardware already used in space. This will require upgrading the laser communication design, incorporating a quantum-based random number generator to create the random keys and integrating post processing of the keys.

"There is serious interest from the space industry and other organizations to implement our scientific findings," said Marquardt. "We, as fundamental scientists, are now working with engineers to create the best system and ensure no detail is overlooked." [23]

Physicists use quantum memory to demonstrate quantum secure direct communication

For the first time, physicists have experimentally demonstrated a quantum secure direct communication (QSDC) protocol combined with quantum memory, which is essential for storing and controlling the transfer of information. Until now, QSDC protocols have used fiber delay lines as a substitute for quantum memory, but the use of quantum memory is necessary for future applications, such as long-distance communication over secure quantum networks.

The researchers, Wei Zhang et al., from the University of Science and Technology of China and Nanjing University of Posts and Telecommunications, have published a paper on their experimental demonstration in a recent issue of Physical Review Letters.

QSDC is one of several different types of quantum communication methods, and has the ability to directly transmit secret messages over a quantum channel. Unlike most other quantum communication methods, QSDC does not require that the two parties communicating share a private key in advance. Similar to other kinds of quantum communication, the security of the method relies on some of the basic principles of quantum mechanics, such as the uncertainty principle and the no-cloning theorem.

As the physicists explain, a quantum memory is necessary for QSDC protocols in order to effectively control the transfer of information in future quantum networks. However, experimentally realizing quantum memory with QSDC is challenging because it requires storing entangled single photons and establishing the entanglement between separated memories.

In their experiments, the researchers demonstrated most of the essential steps of the protocol, including entanglement generation; channel security; and the distribution, storage, and encoding of entangled photons. Due to the difficulty of decoding entangled photons in the optimal way (which requires distinguishing between four quantum states), the researchers used an alternative decoding method that is easier to implement.

In the future, the researchers expect that it will be possible to demonstrate QSDC across distances of 100 km or more in free space, similar to the recent demonstrations of quantum key distribution, quantum teleportation and entanglement distribution over these distances. Achieving this goal will mark an important step in realizing satellite-based long-distance and global-scale QSDC in the future. [22]

Physicists add amplifier to quantum communication toolbox

Quantum encryption using single photons is a promising technique for boosting the security of communication systems and data networks, but there are challenges in applying the method over large distances due to transmission losses. Using conventional optical amplification doesn't help as this disrupts the quantum link between sender and receiver, but physicists in Europe have found a solution – heralded photon amplification – and put it to the test.

The team, which includes researchers from the University of Geneva and Delft University of Technology, has demonstrated the technique over a simulated distance of 50 km, reporting its results in the journal Quantum Science and Technology. The work is published as part of a focus issue on the theme of quantum cryptography and quantum networking.

"In classical communication, amplifiers are used to regenerate the signal. However, in the quantum regime this adds too much noise and destroys the coherence of the quantum states," explained Robert Thew, who co-leads the Quantum Technologies Group at the University of Geneva. "In our experiments, we overcome this limitation by exploiting a teleportation-based approach, which can be thought of as a lossless channel."

Today, when we send sensitive information over the internet, we rely on hard-to-solve mathematical expressions to protect our data from eavesdroppers. However, this approach is vulnerable to attack in the future as computers become more capable of finding answers to these numerical problems.

To get around the issue, physicists have been busy developing alternative schemes for secure key generation based not on mathematical expressions, but on the quantum behaviour of single particles of light – photons. What's more, not only are these techniques impossible to crack through conventional means, they also warn of eavesdropping. These are so-called quantum keys.

As the researchers highlight, one of the major applications of heralded photon amplification is for so-called device-independent quantum key distribution – an approach aimed at certifying the security of a connection with minimal assumptions about the system itself and the technology that is exploited.

At the heart of the approach is the conceptually simple idea of sending a single photon on a 50/50 beam-splitter to generate entanglement. Repeating the process in succession and monitoring the output from single photon detectors provides the building blocks for studying quantum communication protocols.

Taking this a step further, it's possible to distribute the entanglement between two locations, generating a unique key for encrypting data transmission.

"The single photon, or path entangled, scheme we are using is also closely connected to quantum repeaters in terms of how entanglement is distributed in these long distance and fully-quantum network solutions," commented Thew. "Our next step is to develop compact and more efficient heralded photon sources that can be more easily deployed, allowing us to push these sorts of experiments into real-world networks." [21]

One step closer to the quantum internet by distillation

Scientists all over the world are working towards new methods to realize an unhackable internet, an internet based on quantum entanglement – an invisible quantum mechanical connection – as networking links. The greatest challenge is scaling to large networks that share entangled links with many particles and network nodes. Researchers in Delft and Oxford have now managed to distil a strong entangled link by combining multiple weaker quantum links into one. This method is essential to realize a trustworthy quantum network between several quantum nodes. This innovative new work has now been published in Science magazine.

Spooky internet

Safe communication is one of today's greatest digital challenges. There is a world-wide scientific effort towards new methods to realize a truly safe internet based on the laws of quantum mechanics. With such networks, secret eavesdropping is fundamentally impossible. However, realizing strong links in a quantum network, based on the powerful but fragile principle of quantum entanglement, is a great scientific challenge.

"Entangled particles behave as one, independent of distance. Any observation of such entangled electrons result in correlated information," Professor Ronald Hanson explains. Measuring one particle therefore instantaneously influences the other, even when they are light-years apart. Albert Einstein did not believe such a connection could exist, but a carefully designed experiment from the group of Professor Hanson in Delft in 2015 reached the world press for showing that this really is the case. They were able to succeed at this long-standing challenge by entangling quantum information over distances of over a kilometre via light particles. Scientists are now working towards ground-breaking technologies based on entanglement. Strong connections via quantum entanglement can be the basis for information sharing. 'The information exists at both places and there is no need for sensitive information to travel in between," Hanson elaborates, "we expect fundamentally safe future networks based on entanglement between quantum nodes: a quantum internet." The power of quantum entanglement is that it is invisible for third parties: the information is impossible to eavesdrop.

Entanglement distillation

The research group of Ronald Hanson at QuTech is famous for realizing networking links based on quantum entanglement. They are now building on this work to construct the first quantum internet. Ronald Hanson: "We are now taking an important step forward. Whereas we first realized entangled information between two electrons in diamonds, we now also are using one of the nuclear spins present in each diamond to temporarily store the entangled information." With the information stored safely, the scientist can entangle the electrons again. Hanson: 'Now we have two entanglement links. By combining these in a smart way, we manage to generate one strongly entangled link using two weaker entangled links, just like distilling whisky out of lower-alcoholic ingredients." In principle, this process of entanglement distillation can be repeated over and over, until high-quality entanglement is obtained."

Extending possibilities

The demonstrated method is an important step towards the quantum internet. Norbert Kalb, one of the leading authors of the paper: "To realize such a network, we need all the ingredients of the current internet: a memory, a processor and networking links. Now we have demonstrated that nuclear spins can be employed as memories that are not disturbed by regenerating entanglement between the electron spins, the processors," says Kalb.

In this publication, Hanson and his team showed that entanglement can be stored in nuclear spins while regenerating entanglement between electron spins. Hanson explains the future possibilities: "We could now entangle electrons in additional quantum nodes such that we can extend the number of networking links towards a first real quantum network. Scientifically, a whole new world opens up." This entanglement distillation is essential for the future quantum internet, which requires multiple networking links of high quality. Hanson thinks the future is within reach: "In five years we will connect four Dutch cities in a rudimentary quantum network." [20]

Study proves viability of quantum satellite communications

Researchers in Canada have taken a significant step towards enabling secure quantum communication via moving satellites, as announced by the Canadian Government in April 2017.

Their study, published today in the new journal Quantum Science and Technology, demonstrates the first quantum key distribution transmissions from a ground transmitter to a quantum payload on a moving aircraft.

To ensure the tests were a valuable proof of concept for the anticipated satellite mission, the team at the Institute for Quantum Computing (IQC) and Department of Physics and Astronomy of University of Waterloo, Ontario, designed their prototype receiver to consist of components compatible with the size and operating environment restrictions of a micro satellite.

Lead author Christopher Pugh, said: "Quantum key distribution (QKD) establishes cryptographic keys between two distant parties in a way that is cryptanalytically unbreakable. Ground based QKD systems use optical fibre links, and are limited to distances of a few hundred kilometres due to absorption losses, which get exponentially worse as the distance increases."

"Free space links have been shown to work over ground with varying distances, both in stationary and moving tests. But despite losses due to geometric effects scaling quadratically with distance, the addition of atmospheric absorption and turbulence and the need to have clear line of sight mean terrestrial free-space transmissions are also limited to a few hundred kilometres. Satellite based system expand quantum communication to a global scale."

To test their system, the team used the Twin Otter aircraft of the National Research Council to carry out 14 passes over their ground transmitting station at varying distances, achieving a quantum signal link for seven passes, and a secret key extraction for six of the seven successful passes.

Principle Investigator Professor Thomas Jennewein, said: "This is an extremely important step which took almost eight years of preparation. It finally demonstrates our technology is viable.

"We achieved optical links at similar angular rates to those of low-Earth-orbit satellites, and for some passes of the aircraft over the ground station, links were established within 10 seconds of position data transmission. We saw link times of a few minutes and received quantum bit error rates typically between three and five per cent, generating secure keys up to 868 kb in length.

"We have proved the concept, and our results provide a blueprint for future satellite missions to build upon, just in time for the announcement of a quantum satellite mission by the Canadian Government ," said Jennewein. [19]

Particle-free quantum communication is achieved in the lab

Four years ago, theoretical physicists proposed a new quantum-communication scheme with a striking feature: it did not require the transmission of any physical particles. The research raised eyebrows, but now a team of physicists in China claims it has demonstrated that the "counterfactual" scheme works. The group built an optical apparatus that it says can transfer a simple image while sending (almost) no photons in the process.

The theoretical proposal was put forward by scientists at Texas A&M University (TAMU) in the US and the King Abdulaziz City for Science and Technology (KACST) in Saudi Arabia. It is based on the phenomenon of wave–particle duality. Specifically, it uses the fact that the presence of an object blocking an arm of an interferometer can be inferred by virtue of its collapsing the wavefunction of an interrogating photon – even though it has no physical contact with the photon. The work also relies on what is known as the quantum Zeno effect, which stipulates that an ongoing series of weak measurements will stifle the quantum-mechanical evolution of a particle and almost certainly cause it to remain in its initial state.

The communication protocol is defined in terms of two characters Alice and Bob – and it is Bob who sends the message. Alice fires single photons at a chain of interferometers, created by a series of beam splitters and mirrors. At the output of the final interferometer, photons end up in one of two detectors monitored by Alice. Bob, meanwhile, can choose whether or not to switch on a measuring device in the right-hand arm of each interferometer.

Left or right

If Bob switches on his devices, he forces the photon injected by Alice to behave as a particle and therefore follow a definite path – going either left or right – through each interferometer. But since the beam splitters are highly reflective, and photons are always reflected to the left, Bob – employing the quantum Zeno effect – causes the photon to remain in the left-hand channel as it travels through the apparatus and as such triggers Alice's right-hand detector. But if Bob instead switches his devices off, the photon's wavefunction is allowed to evolve and the photon instead ends up in the left-hand detector.

Intriguingly, therefore, Alice learns of Bob's decision – whether or not to turn on the devices – even though no photon passes between them. In neither case does Bob's equipment interact with a photon. As such, Bob can send Alice a message by using the states "on" and "off" to represent the ones and zeros of a binary code, even though he sends no physical particle to Alice.

The counterfactual protocol put forward by the TAMU-KACST group, which is led by TAMU's Suhail Zubairy, was actually slightly more complicated. It involved the addition of an extra chain of interferometers in the right-hand arm of each existing interferometer. This was done to make sure that any photons that enter the communication channel between Alice and Bob are lost.

Eve the eavesdropper

That fix clearly didn't satisfy everyone. After Zubairy and colleagues had published their research in Physical Review Letters, Lev Vaidman of Tel-Aviv University in Israel sent a comment to the journal arguing that photons would not pass between Alice and Bob only when Bob switches his devices on. With the devices off, reckoned Vaidman, a weak measurement would in fact reveal photons to be present in the channel. Saying that Zubairy's group has a "naive classical approach to the past of the photons", Vaidman adds that the misconception could allow an eavesdropper (Eve) to uncover part of the message being transmitted.

Notwithstanding the debate that ensued, Jian-Wei Pan of the University of Science and Technology of China in Hefei and team set about building an experiment to put the protocol to the test. As they point out in a paper describing the work in the Proceedings of the National Academy of Sciences, a completely counterfactual scheme would require an infinite number of interferometers, which is clearly not practical. So instead they used a simplified design – employing just two interferometers (one each for the external and internal chains) and sending each photon back and forth multiple times, thanks to the use of nanosecond timing and phase stabilization.

Pan and colleagues transmitted a 100 × 100 monochrome bit map of a Chinese knot. After five hours of painstakingly transmitting each of the 10,000 bits multiple times (to overcome channel loss), the researchers were able to clearly reproduce the image, successfully transmitting the correct bit value – black or white – 87% of the time. Comparing that figure with the rate at which photons erroneously leaked through the communication channel – just 1.4% – they conclude that they had indeed sent the information counterfactually. In other words, the vast majority of the transmitted bits, they say, were not associated with the passage of any physical particle.

Imaging delicate art

Despite their positive results, the Chinese researchers say that further experiments are necessary. Among the possible tests that could be carried out, they say, are weak measurements at the output of each inner interferometer to establish whether photons are in fact leaking through the communication channel. The researchers do not explicitly discuss the possibility of developing a practical ultra-secure communication scheme on the back of their work, but they do raise the possibility of "counterfactual imaging". Involving an array of optical switches that are used to send data counterfactually to a camera, the technique, they suggest, could prove handy in imaging delicate pieces of ancient art that cannot be exposed to direct light.

As to exactly what is physically transmitting information from Bob to Alice, if not particles, that remains an open question. Hatim Salih of KACST, lead author on the theory paper, is convinced that the culprit must be the photon's wavefunction. As such, he argues, the research would help settle a decades-old debate among physicists about the reality of the wavefunction: it must be real, he says. [18]

Researchers achieve direct counterfactual quantum communication

In the non-intuitive quantum domain, the phenomenon of counterfactuality is defined as the transfer of a quantum state from one site to another without any quantum or classical particle transmitted between them. Counterfactuality requires a quantum channel between sites, which means that there exists a tiny probability that a quantum particle will cross the channel—in that event, the run of the system is discarded and a new one begins. It works because of the wave-particle duality that is fundamental to particle physics: Particles can be described by wave function alone.

Well understood as a workable scheme by physicists, theoretical aspects of counterfactual communication have appeared in journals, but until recently, there have been no practical demonstrations of the phenomenon. Now, a collaborative of Chinese scientists has designed and experimentally tested a counterfactual communication system that successfully transferred a monochrome bitmap from one location to another using a nested version of the quantum Zeno effect. They have reported their results in the Proceedings of the National Academy of Sciences.

The quantum Zeno effect occurs when an unstable quantum system is subjected to a series of weak measurements. Unstable particles can never decay while they are being measured, and the system is effectively frozen with a very high probability. This is one of the implications of the well known but highly non-intuitive principle that looking at something changes it in the quantum realm.

Using this effect, the authors of the new study achieved direct communication between sites without carrier particle transmission. In the setup they designed, two single-photon detectors were placed in the output ports of the last of an array of beam splitters. According to the quantum Zeno effect, it's possible to predict which single-photon detector will "click" when photons are allowed to pass. The system's nested interferometers served to measure the state of the system, thereby preventing it from changing.

Alice transfers a single photon to the nested interferometer; it is detected by three single photon detectors, D0, D1 and Df. If D0 or D1 click, Alice concludes a logic result of one or zero. If Df clicks, the result is considered inconclusive, and is discarded in post-processing. After the communication of all bits, the researchers were able to reassemble the image—a monochrome bitmap of a Chinese knot. Black pixels were defined as logic 0, while white pixels were defined as logic 1.

The idea came from holography technology. The authors write, "In the 1940s, a new imaging technique—holography—was developed to record not only light intensity but also the phase of light. One may then pose the question: Can the phase of light itself be used for imaging? The answer is yes." In the experiment, the phase of light itself became the carrier of information, and the intensity of the light was irrelevant to the experiment.

The authors note that besides applications in quantum communication, the technique could be used for such activities as imaging ancient artifacts that would be damaged by directly shining light. [17]

Envisioning a future quantum internet

The quantum internet, which connects particles linked together by the principle of quantum entanglement, is like the early days of the classical internet – no one can yet imagine what uses it could have, according to Professor Ronald Hanson, from Delft University of Technology, the Netherlands, whose team was the first to prove that the phenomenon behind it was real.

You are famous for proving that quantum entanglement is real, when, in 2015, you linked two particles that were 1.3 kilometres apart. But the main objective of your work has always been to connect entangled particles into a 'quantum internet.' What could such a network enable us to do?

One of the things that we could do is to generate a key to encode messages using the quantum internet. The security of that key would now be based on this property of entanglement, and this is basically the properties of the laws of physics.

You will get a means of communication whose security is guaranteed by physical laws instead of (by) assumptions that no one is able to hack your code.

That's probably the first real application, but there are many, many more applications that people are thinking about where this idea of entanglement, this invisible link at a distance, could actually be helpful. For example, people have calculated that you can increase the baseline of telescopes by using quantum entanglement. So, two telescopes quite far apart could have better precision than each of them individually would have. You could envision using this quantum internet to create entanglement between atomic clocks in different locations around the world, and this would increase the accuracy of timekeeping locally.

So the quantum internet is primarily a tool for encryption?

There is no quantum internet as of yet. And if you think back to the time when people were developing the classical internet, I don't think anybody was really thinking about the applications that we are using it for right now.

The first real users of the internet were like, "Ok there is a big computer somewhere in one place, and I'm in the other place, and I actually want to use that computer because they are very expensive, so how can I make use of that computer remotely? Well, I need an internet to connect to it."

And now we are using the internet in a totally different way. We are all part of this huge global information highway. And I think some of the same things could happen with the quantum internet. It's very hard right now to imagine what we could do (with it), and I think it is even harder than with the classical internet, because this concept of quantum entanglement is so counterintuitive that it is not easy to use your intuition to find applications for it.

How do you envisage the quantum internet? How would we use it?

The quantum internet allows you to do some extra stuff, some things that you cannot do with the normal internet that we have. But on the other hand, it is also much harder to implement and much more costly in terms of use.

I envision that, in the end, when you are using the web most of the time, you are using the classical internet, and when you need some extra feature that requires quantum entanglement, then you are using the parallel quantum infrastructure that is also on the internet to get the functionality that you want to have. So it is not going to be a replacement to the classical internet, but it will be something that is added on top of it.

Back in 2014, you announced that you connected particles three metres apart and 'teleported' information between them. In what sense was this information teleported?

Quantum teleportation is the idea that quantum states—and they contain information of course—disappear on one side and then reappear at the other side. What is interesting is that, since the information does not travel on a physical carrier, it's not encoded in a pulse of light—it does not travel between sender and receiver, so it cannot be intercepted. The information disappears on one side and reappears on the other side.

Quantum teleportation is the most fundamental operation that can be done on the quantum internet. So to get entanglement distributed over long distances, you are actually teleporting the entanglement from one node to the other.

In a classical network, you send your data package, and there is an address contained in that, and the router will read off that information and send it on to the next node. We don't want to do that with these quantum signals. We want to send these quantum signals by teleportation so they don't have to go through the (optical) fibre; they disappear on one side and reappear on the other.

Your work is based on this crazy concept of entanglement. What is your personal opinion of how entanglement works?

What I have learned is to let go of all my intuition when I talk about quantum entanglement. Any analogy you try to make with something in the world that we see around us will fail because it is a quantum concept and we don't really see quantum concepts in our daily lives. So I have given up on trying to have an intuitive explanation of what entanglement is. [16]

Towards quantum Internet: Researchers teleport particle of light six kilometers

What if you could behave like the crew on the Starship Enterprise and teleport yourself home or anywhere else in the world? As a human, you're probably not going to realize this any time soon; if you're a photon, you might want to keep reading.

Through a collaboration between the University of Calgary, The City of Calgary and researchers in the United States, a group of physicists led by Wolfgang Tittel, professor in the Department of Physics and Astronomy at the University of Calgary have successfully demonstrated teleportation of a photon (an elementary particle of light) over a straight-line distance of six kilometers using The City of Calgary's fiber optic cable infrastructure. The project began with an Urban Alliance seed grant in 2014.

This accomplishment, which set a new record for distance of transferring a quantum state by teleportation, has landed the researchers a spot in the prestigious Nature Photonics scientific journal. The finding was published back-to-back with a similar demonstration by a group of Chinese researchers.

"Such a network will enable secure communication without having to worry about eavesdropping, and allow distant quantum computers to connect," says Tittel.

Experiment draws on 'spooky action at a distance'

The experiment is based on the entanglement property of quantum mechanics, also known as "spooky action at a distance"—a property so mysterious that not even Einstein could come to terms with it.

"Being entangled means that the two photons that form an entangled pair have properties that are linked regardless of how far the two are separated," explains Tittel. "When one of the photons was sent over to City Hall, it remained entangled with the photon that stayed at the University of Calgary."

Next, the photon whose state was teleported to the university was generated in a third location in Calgary and then also travelled to City Hall where it met the photon that was part of the entangled pair.

"What happened is the instantaneous and disembodied transfer of the photon's quantum state onto the remaining photon of the entangled pair, which is the one that remained six kilometres away at the university," says Tittel.

City's accessible dark fibre makes research possible

The research could not be possible without access to the proper technology. One of the critical pieces of infrastructure that support quantum networking is accessible dark fibre. Dark fibre, so named because of its composition—a single optical cable with no electronics or network equipment on the alignment—doesn't interfere with quantum technology.

The City of Calgary is building and provisioning dark fibre to enable next-generation municipal services today and for the future.

"By opening The City's dark fibre infrastructure to the private and public sector, non-profit companies, and academia, we help enable the development of projects like quantum encryption and create opportunities for further research, innovation and economic growth in Calgary," said Tyler Andruschak, project manager with Innovation and Collaboration at The City of Calgary.

"The university receives secure access to a small portion of our fibre optic infrastructure and The City may benefit in the future by leveraging the secure encryption keys generated out of the lab's research to protect our critical infrastructure," said Andruschak. In order to deliver next-generation services to Calgarians, The City has been increasing its fibre optic footprint, connecting all City buildings, facilities and assets.

Timed to within one millionth of one millionth of a second

As if teleporting a photon wasn't challenging enough, Tittel and his team encountered a number of other roadblocks along the way.

Due to changes in the outdoor temperature, the transmission time of photons from their creation point to City Hall varied over the course of a day—the time it took the researchers to gather sufficient data to support their claim. This change meant that the two photons would not meet at City Hall.

"The challenge was to keep the photons' arrival time synchronized to within 10 pico-seconds," says Tittel. "That is one trillionth, or one millionth of one millionth of a second."

Secondly, parts of their lab had to be moved to two locations in the city, which as Tittel explains was particularly tricky for the measurement station at City Hall which included state-of-the-art superconducting single-photon detectors developed by the National Institute for Standards and Technology, and NASA's Jet Propulsion Laboratory.

"Since these detectors only work at temperatures less than one degree above absolute zero the equipment also included a compact cryostat," said Tittel.

Milestone towards a global quantum Internet

This demonstration is arguably one of the most striking manifestations of a puzzling prediction of quantum mechanics, but it also opens the path to building a future quantum internet, the long-term goal of the Tittel group.

The Urban Alliance is a strategic research partnership between The City of Calgary and University of Calgary, created in 2007 to encourage and co-ordinate the seamless transfer of cutting-edge research between the university and The City of Calgary for the benefit of all our communities. The Urban Alliance is a prime example and vehicle for one of the three foundational commitments of the University of Calgary's Eyes High vision to fully integrate the university with the community.

The City sees the Alliance as playing a key role in realizing its long-term priorities and the imagineCALGARY vision. [15]

The path to perfection: Quantum dots in electrically-controlled cavities yield bright, nearly identical photons

Optical quantum technologies are based on the interactions of atoms and photons at the single-particle level, and so require sources of single photons that are highly indistinguishable – that is, as identical as possible. Current single-photon sources using semiconductor quantum dots inserted into photonic structures produce photons that are ultrabright but have limited indistinguishability due to charge noise, which results in a fluctuating electric field. Conversely, parametric down conversion sources yield photons that while being highly indistinguishable have very low brightness. Recently, however, scientists at CNRS - Université Paris-Saclay, Marcoussis, France; Université Paris Diderot, Paris, France; University of Queensland, Brisbane, Australia; and Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France; have developed devices made of quantum dots in electrically-controlled cavities that provide large numbers of highly indistinguishable photons with strongly reduced charge noise that are 20 times brighter than any source of equal quality. The researchers state that by demonstrating efficient generation of a pure single photon with near-unity indistinguishability, their novel approach promises significant advances in optical quantum technology complexity and scalability.

Dr. Pascale Senellart and Phys.org discussed the paper, Near-optimal single-photon sources in the solid state, that she and her colleagues published in Nature Photonics, which reports the design and fabrication of the first optoelectronic devices made of quantum dots in electrically controlled cavities that provide bright source generating near-unity indistinguishability and pure single photons. "The ideal single photon source is a device that produces light pulses, each of them containing exactly one, and no more than one, photon. Moreover, all the photons should be identical in spatial shape, wavelength, polarization, and a spectrum that is the Fourier transform of its temporal profile," Senellart tells Phys.org. "As a result, to obtain near optimal single photon sources in an optoelectronic device, we had to solve many scientific and technological challenges, leading to an achievement that is the result of more than seven years of research."

While quantum dots can be considered artificial atoms that therefore emit photons one by one, she explains, due to the high refractive index of any semiconductor device, most single photons emitted by the quantum dot do not exit the semiconductor and therefore cannot be used. "We solved this problem by coupling the quantum dot to a microcavity in order to engineer the electromagnetic field around the emitter and force it to emit in a well-defined mode of the optical field," Senellart points out. "To do so, we need to position the quantum dot with nanometer-scale accuracy in the microcavity."

Senellart notes that this is the first challenge that the researchers had to address since targeting the issue of quantum dots growing with random spatial positions.

"Our team solved this issue in 20081 by proposing a new technology, in-situ lithography, which allows measuring the quantum dot position optically and drawing a pillar cavity around it. With this technique, we can position a single quantum dot with 50 nm accuracy at the center of a micron-sized pillar." In these cavities, two distributed Bragg reflectors confine the optical field in the vertical direction, and the contrast of the index of refraction between the air and the semiconductor provides the lateral confinement of the light. "Prior to this technology, the fabrication yield of quantum dot cavity devices was in the 10-4 – but today it is larger than 50%." The scientists used this technique to demonstrate the fabrication of bright single photon sources in 20132, showing that the device can generate light pulses containing a single photon with a probability of 80% – but while all photons had the same spatial shape and wavelength, they were not perfectly identical.

"Indeed, for the photons to be fully indistinguishable, the emitter should be highly isolated from any source of decoherence induced by the solid-state environment.

However, our study showed that collisions of the carriers with phonons and fluctuation of charges around the quantum dot were the main limitations." To solve this problem, the scientists added an electrical control to the device, such that the application of an electric field stabilized the charges around the quantum dot by sweeping out any free charge. This in turn removed the noise. Moreover, she adds, this electrical control allows tuning the quantum dot wavelength – a process that was previously done by increasing temperature at the expense of increasing vibration.

"I'd like to underline here that the technology described above is unique worldwide," Senellart stresses. "Our group is the only one with such full control of all of the quantum dot properties. That is, we control emission wavelength, emission lifetime and coupling to the environment, all in a fully deterministic and scalable way."

Specifically, implementing control of the charge environment for quantum dots in connected pillar cavities, and applying an electric field on a cavity structure optimally coupled to a quantum dot, required significant attention. "We had strong indications back in 2013 that the indistinguishability of our photons was limited by some charge fluctuations around the quantum dot: Even in the highest-quality semiconductors, charges bound to defects fluctuate and create a fluctuating electric field3. In the meantime, several colleagues were observing very low charge noise in structures where an electric field was applied to the quantum dot – but this was not combined with a cavity structure." The challenge, Senellart explains, was to define a metallic contact on a microcavity (which is typically a cylinder with a diameter of 2-3 microns) without covering the pillar's top surface.

"We solved this problem by proposing a new kind of cavity – that is, we showed that we can actually connect the cylinder to a bigger frame using some one-dimensional bridges without modifying too much the confinement of the optical field." This geometry, which the researchers call connected pillars, allows having the same optical confinement as an isolated pillar while defining the metallic contact far from the pillar itself. Senellart says that the connected pillars geometry was the key to both controlling the quantum wavelength of dot and efficiently collecting its emission4.

In demonstrating the efficient generation of a pure single photon with near-unity indistinguishability, Senellart continues, the researchers had one last step – combining high photon extraction efficiency and perfect indistinguishability – which they did by implementing a resonant excitation scheme of the quantum dot. "In 2013, Prof. Chao-Yang Lu's team in Hefei, China showed that one could obtain photons with 96% indistinguishability by exciting the quantum dot state in a strictly resonant way5. Their result was beautiful, but again, not combined with an efficient extraction of the photons. The experimental challenge here is to suppress the scattered light from the laser and collect only the single photons radiated by the quantum dot."

Senellart adds that while removing scattered photons when transmitting light in processed microstructures is typically complicated, in their case this step was straightforward. "Because the quantum dot is inserted in a cavity, the probability of the incident laser light to interact with the quantum dot is actually very high. It turns out that we send only a few photons – that is, less than 10 – on the device to have the quantum dot emitting one photon. This beautiful efficiency, also demonstrated in the excitation process, which we report in another paper6, made this step quite easy."

The devices reported in the paper have a number of implications for future technologies, one being the ability to achieve strongly-reduced charge noise by applying an electrical bias. "Charge noise has been extensively investigated in quantum dot structures," Senellart says, "especially by Richard Warburton's group."

Warburton and his team demonstrated that in the best quantum dot samples, the charge noise could take place on a time scale of few microseconds – which is actually very good, since the quantum dot emission lifetime is around 1 nanosecond7. However, this was no longer the case in etched structures, where a strong charge noise is always measured on very short time scale – less than 1 ns – that prevents the photon from being indistinguishable. "I think the idea we had – that this problem would be solved by applying an electric field – was an important one," Senellart notes. "The time scale of this charge noise does not only determine the degree of indistinguishability of the photons, it also determines how many indistinguishable photon one can generate with the same device. Therefore, this number will determine the complexity of any quantum computation or simulation scheme one can implement." Senellart adds that in a follow-up study7 the scientists generated long streams of photons that can contain more than 200 being indistinguishable by more than 88%.

In addressing how these de novo devices may lead to new levels of complexity and scalability in optical quantum technologies, Senellart first discusses the historical sources used develop optical quantum technologies. She makes the point that all previous implementations of optical quantum simulation or computing have been implemented using Spontaneous Parametric Down Conversion (SPDC) sources, in which pairs of photons are generated by the nonlinear interaction of a laser on a nonlinear crystal, wherein one photon of the pair is detected to announce the presence of the other photon. This so-called heralded source can present strongly indistinguishable photons, but only at the cost of extremely low brightness. "Indeed, the difficulty here is that the one pulse does not contain a single pair only, but some of the time several pairs," Senellart explains. "To reduce the probability of having several pairs generated that would degrade the fidelity of a quantum simulation, calculation or the security of a quantum communication, the sources are strongly attenuated, to the point where the probability of having one pair in a pulse is below 1%. Nevertheless, with these sources, the quantum optics community has demonstrated many beautiful proofs of concept of optical quantum technologies, including long-distance teleportation, quantum computing of simple chemical or physical systems, and quantum simulations like BosonSampling." (A BosonSampling device is a quantum machine expected to perform tasks intractable for a classical computer, yet requiring minimal non-classical resources compared to full-scale quantum computers.) "Yet, the low efficiency of these sources limits the manipulation to low photon numbers: It takes typically hundreds of hours to manipulate three photons, and the measurement time increases exponentially with the number of photons. Obviously, with the possibility to generate more many indistinguishable photons with an efficiency more than one order of magnitude greater than SPDC sources, our devices have the potential to bring optical quantum technologies to a whole new level."

Other potential applications of the newly-demonstrated devices will focus on meeting near-future challenges in optical quantum technologies, including scalability of photonic quantum computers and intermediate quantum computing tasks. "The sources presented here can be used immediately to implement quantum computing and intermediate quantum computing tasks. Actually, very recently – in the first demonstration of the superiority of our new single photon sources – our colleagues in Brisbane made use of such bright indistinguishable quantum dot-based single photon sources to demonstrate a three photon BosonSampling experiment8, where the solid-state multi-photon source was one to two orders-of-magnitude more efficient than downconversion sources, allowing to complete the experiment faster than those performed with SPDC sources. Moreover, this is a first step; we'll progressively increase the number of manipulated photons, in both quantum simulation and quantum computing tasks."

Another target area is quantum communications transfer rate. "Such bright single photon sources could also drastically change the rate of quantum communication protocols that are currently using attenuated laser sources or SPDC sources. Yet, right now, our sources operate at 930 nm when 1.3 µm or 1.55 µm sources are needed for long distance communications. Our technique can be transferred to the 1.3 µm range, a range at which single photon emission has been successfully demonstrated – in particular by the Toshiba research group – slightly changing the quantum dot material. Reaching the 1.55 µm range will be more challenging using quantum dots, as it appears that the single photon emission is difficult to obtain at this wavelength. Nevertheless, there's a very promising alternative possibility: the use of a 900 nm bright source, like the one we report here, to perform quantum frequency conversion of the single photons. Such efficient frequency conversion of single photons has recently been demonstrated, for example, in the lab of Prof. Yoshie Yamamoto at Stanford9."

Regarding future research, Senellart says "There are many things to do from this point. On the technology side, we will try to improve our devices by further increasing the source brightness. For that, a new excitation scheme will be implemented to excite the device from the side, as was done by Prof. Valia Voliotis and her colleagues on the Nanostructures and Quantum Systems team at Pierre and Marie Curie University in Paris and Prof. Glenn Solomon's group at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. Applying this technique to our cavities should allow gaining another factor of four on source brightness. In addition, operating at another wavelength would be another important feature for our devices, since as discussed above, this would allow using the source for quantum telecommunication. For example, a shorter wavelength, in the visible/near infrared range, would open new possibilities to interconnect various quantum systems, including ions or atoms through their interaction with photons, as well as applications in quantum imaging and related fields."

The researchers also want to profit from the full potential of these sources and head to high photon number manipulation in, for instance, quantum simulation schemes. "We're aiming at performing BosonSampling measurements with 20-30 photons, with the objective of testing the extended Church Turing thesis and proving the superiority of a quantum computer over a classical one." The original Church Turing thesis, based on investigations of Alonzo Church and Alan Turing into computable functions, states that, ignoring resource limitations, a function on the natural numbers is computable by a human being following an algorithm, if and only if it is computable by a Turing machine.

Another promising impact on future optical quantum technologies is the generation of entangled photon pairs. "A quantum dot can also generate entangled photon pairs, and in 2010 we demonstrated that we could use the in situ lithography to obtain the brightest source of entangled photon pairs10. That being said, photon indistinguishability needs to be combined with high pair brightness – and this is the next challenge we plan to tackle. Such a device would play an important role in developing quantum relays for long distance communication and quantum computing tasks."

Senellart tells Phys.org that other areas of research might well benefit from their findings, in that devices similar to the one the scientists developed to fabricate single photon sources could also provide nonlinearities at the low photon count scale. This capability could in turn allow the implementation of deterministic quantum gates, a new optical quantum computing paradigm in which reversible quantum logic gates – for example, Toffoli or CNOT (controlled NOT) gates– can simulate irreversible classical logic gates, thereby allowing quantum computers to perform any computation which can be performed by a classical deterministic computer. "Single photons can also be used to probe the mechanical modes of mechanical resonator and develop quantum sensing with macroscopic objects. Other applications," she concludes, "could benefit from the possibility to have very efficient single photon sources, such as an imaging system with single photon sources that could allow dramatically increased imaging sensitivity. Such technique could have applications in biology where the lower the photon flux, the better for exploring in vivo samples." [14]

Team demonstrates large-scale technique to produce quantum dots

A method to produce significant amounts of semiconducting nanoparticles for light-emitting displays, sensors, solar panels and biomedical applications has gained momentum with a demonstration by researchers at the Department of Energy's Oak Ridge National Laboratory.

While zinc sulfide nanoparticles - a type of quantum dot that is a semiconductor - have many potential applications, high cost and limited availability have been obstacles to their widespread use. That could change, however, because of a scalable ORNL technique outlined in a paper published in Applied Microbiology and Biotechnology.

Unlike conventional inorganic approaches that use expensive precursors, toxic chemicals, high temperatures and high pressures, a team led by ORNL's Ji-Won Moon used bacteria fed by inexpensive sugar at a temperature of 150 degrees Fahrenheit in 25- and 250-gallon reactors. Ultimately, the team produced about three-fourths of a pound of zinc sulfide nanoparticles - without process optimization, leaving room for even higher yields.

The ORNL biomanufacturing technique is based on a platform technology that can also produce nanometer-size semiconducting materials as well as magnetic, photovoltaic, catalytic and phosphor materials. Unlike most biological synthesis technologies that occur inside the cell, ORNL's biomanufactured quantum dot synthesis occurs outside of the cells. As a result, the nanomaterials are produced as loose particles that are easy to separate through simple washing and centrifuging.

The results are encouraging, according to Moon, who also noted that the ORNL approach reduces production costs by approximately 90 percent compared to other methods.

"Since biomanufacturing can control the quantum dot diameter, it is possible to produce a wide range of specifically tuned semiconducting nanomaterials, making them attractive for a variety of applications that include electronics, displays, solar cells, computer memory, energy storage, printed electronics and bio-imaging," Moon said.

Successful biomanufacturing of light-emitting or semiconducting nanoparticles requires the ability to control material synthesis at the nanometer scale with sufficiently high reliability, reproducibility and yield to be cost effective. With the ORNL approach, Moon said that goal has been achieved.

Researchers envision their quantum dots being used initially in buffer layers of photovoltaic cells and other thin film-based devices that can benefit from their electro-optical properties as light-emitting materials. [13]

Superfast light source made from artificial atom

All light sources work by absorbing energy – for example, from an electric current – and emit energy as light. But the energy can also be lost as heat and it is therefore important that the light sources emit the light as quickly as possible, before the energy is lost as heat. Superfast light sources can be used, for example, in laser lights, LED lights and in single-photon light sources for quantum technology. New research results from the Niels Bohr Institute show that light sources can be made much faster by using a principle that was predicted theoretically in 1954. The results are published in the scientific journal, Physical Review Letters.

Researchers at the Niels Bohr Institute are working with quantum dots, which are a kind of artificial atom that can be incorporated into optical chips. In a quantum dot, an electron can be excited (i.e. jump up), for example, by shining a light on it with a laser and the electron leaves a 'hole'. The stronger the interaction between light and matter, the faster the electron decays back into the hole and the faster the light is emitted.

But the interaction between light and matter is naturally very weak and it makes the light sources very slow to emit light and this can reduce energy efficiency.

Already in 1954, the physicist Robert Dicke predicted that the interaction between light and matter could be increased by having a number of atoms that 'share' the excited state in a quantum superposition.

Quantum speed up

Demonstrating this effect has been challinging so far because the atoms either come so close together that they bump into each other or they are so far apart that the quantum speed up does not work. Researchers at the Niels Bohr Institute have now finally demonstrated the effect experimentally, but in an entirely different physical system than Dicke had in mind. They have shown this so-called superradiance for photons emitted from a single quantum dot.

"We have developed a quantum dot so that it behaves as if it was comprised of five quantum dots, which means that the light is five times stronger. This is due to the attraction between the electron and the hole. But what is special is that the quantum dot still only emits a single photon at a time. It is an outstanding single-photon source," says Søren Stobbe, who is an associate professor in the Quantum Photonic research group at the Niels Bohr Institute at the University of Copenhagen and led the project. The experiment was carried out in collaboration with Professor David Ritchie's research group at the University of Cambridge, who have made the quantum dots.

Petru Tighineanu, a postdoc in the Quantum Photonics research group at the Niels Bohr Institute, has carried out the experiments and he explains the effect as such, that the atoms are very small and light is very 'big' because of its long wavelength, so the light almost cannot 'see' the atoms – like a lorry that is driving on a road and does not notice a small pebble. But if many pebbles become a larger stone, the lorry will be able to register it and then the interaction becomes much more dramatic. In the same way, light interacts much more strongly with the quantum dot if the quantum dot contains the special superradiant quantum state, which makes it look much bigger.

Increasing the light-matter interaction

"The increased light-matter interaction makes the quantum dots more robust in regards to the disturbances that are found in all materials, for example, acoustic oscillations. It helps to make the photons more uniform and is important for how large you can build future quantum computers," says Søren Stobbe.

He adds that it is actually the temperature, which is only a few degrees above absolute zero, that limits how fast the light emissions can remain in their current experiments. In the long term, they will study the quantum dots at even lower temperatures, where the effects could be very dramatic. [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 resonance-fluorescence-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.

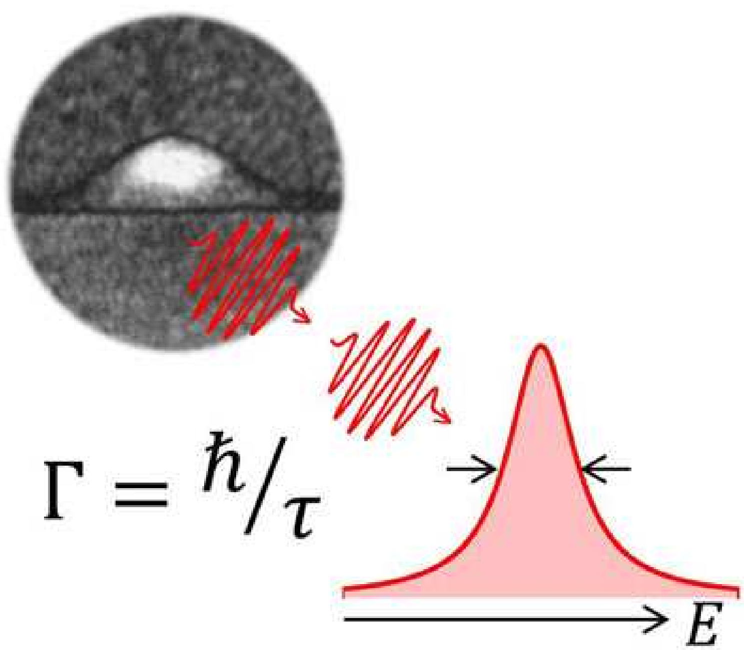
The micropillar is about 2.5 µm in diameter and about 10 µm tall, and it allowed the team to harness the "Purcell effect", whereby the rate of fluorescence is increased significantly when the emitter is placed in a resonant cavity.

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.

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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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